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Volume 2 Issue 1

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Contents

Solar Charge Controllers using MPPT and PWM: A Review

Tulika Majaw[1], Reeny Deka[2], Shristi Roy[3], Bikramjit Goswami[4]

[1,2,3,4]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati-781017, Assam, India
[1]tulika9majaw@gmail.com, [4]bikramjit.goswami@dbuniversity.ac.in*

Abstract: ***With the increasing demand of power and energy, energy conservation and use of renewable resources have become a crucial necessity. Solar energy will become the ultimate and prime source of energy in near future. Therefore, highly efficient and low energy consuming solar-powered equipment and applications will soon be a major requirement. In this paper, solar charge controller using Maximum Power Point Tracking (MPPT) and Pulse Width Modulation (PWM) have been analyzed and compared, which is needed in all solar powered systems that utilize batteries. Its role is to regulate the power going from the solar panel to the batteries. Most of the modern charge controllers include PWM and MPPT. These charge controllers are designed such that the solar battery gets recharged quickly and does not get over discharged, thereby ensuring the prolonged lifespan of the battery.***

Keywords: Solar energy, MPPT, PWM, Charge controller.

1. Introduction

Today's world is facing an energy shortage due to the increase in consumption of energy day by day. This led to a decrease in natural resources like oil and natural gas that are not eco-friendly. To meet this increasing demand of power, renewable energy sources are an urgent need. Hence, solar energy, which is pollution free and easily available natural resource, can be used for power generation.

The solar charge controller's primary function is to maintain the amount of charge coming from the solar PV module that flows into the battery bank in order to avoid the batteries being overcharge. It performs three basic functions:

(i) It limits and regulates the voltage from the solar panel to avoid overcharging the battery.
(ii) While dc loads are used, the controller does not allow the battery to get discharge.
(iii) Allows different dc loads to be used [1].

Modern charge controllers are pulse width modulation (PWM) and maximum power point tracking (MPPT) controllers which are mostly used now-a-days. Both technologies are widely used in the off grid solar industries and are both great options for efficiently charging the battery. MPPT charge controller major role is to extract the maximum power from the PV module. The MPPT checks the output of the PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery to get maximum current into the battery. It is also a DC to DC converter which takes DC input from the PV module then changing it to AC and converting it back to DC voltage and current of different values to match the PV module of the battery [2].PWM comes into play when battery bank is full. It is use to control high current and voltage [3].

2. PWM Charge Controller

Pulse width modulation (PWM) main purpose is to switch the solar system controller power devices by applying a constant voltage battery charging. Modern charge controllers used PWM to allow lower amount of power applied to the batteries when the batteries are almost fully charged. PWM allows the battery to be fully charged with less stress on the battery prolonging the battery life.

PWM controller works on the concept that when solar cell produces voltage, this voltage is then indicated by voltage indicator. After this measurement, voltage controller controls the voltage and thus by using this voltage solar panels batteries are charged [3].

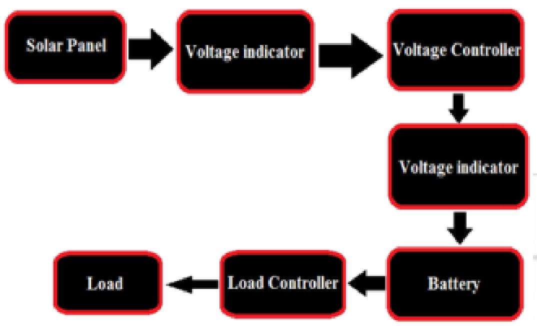

Figure 1: Flowchart of Pulse Width Modulation (PWM) charge controller [3]

PWM charge controllers use technologies similar to other modern high quality battery chargers. Some of the unique benefits of PWM pulsing [5] are:

- Ability to recognize lost battery capacity and to desulfate a battery.
- Dramatically increase the charge acceptance of the battery.
- Maximum high average battery capacities.
- Equalize drifting battery cells.
- Reduce battery heating and gassing.
- Automatically adjust for battery ageing.
- Self-regulate for voltage drops and temperature effects in solar systems.

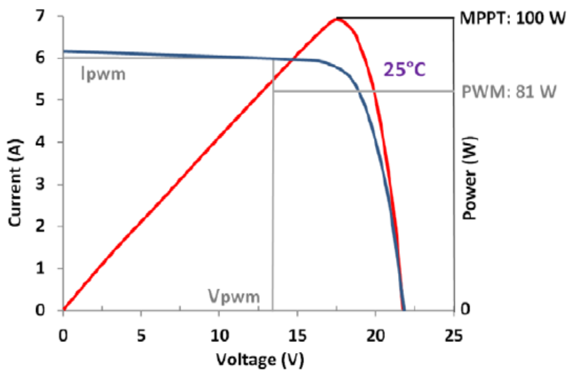

Figure 2: Current Vs Voltage curve for PWM [5]

A PWM controller is not a DC-DC transformer. It is a switch, which connects the solar panel to the battery. When the switch is close, the panel and the battery will be at nearly the same voltage. The voltage will increase with increasing state of charge of the battery [3].

3. MPPT Charge Controller

To increase the efficiency of a solar panel, use of MPPT, which is a power electronic device, comes into play. By using MPPT, the system will start operating at Maximum Power Point (MPP) and produces its maximum power output by detecting the maximum radiation on sun that falls into the PV module. Thus, it produces overall system cost [6].

Under certain conditions, MPPT charge controllers are used for extracting maximum available power from PV module so that the voltage at PV module can produce maximum power that is called 'maximum power point'. Maximum power changes with solar radiation, ambient temperature and solar cell temperature. Maximum power point tracking (MPPT) technique is used to improve efficiency of solar panel [6].

Fig. 1 shows I-V characteristics of a non-linear output efficiency of a solar cell as solar cells have a complex relationship between temperature and total resistance. Thus, the purpose of MPPT system is to sample the output PV cell and apply proper resistance to obtain maximum power for any environmental conditions. MPP is the product of MPP voltage (V_{mpp}) and MPP current (I_{mpp}) [7].

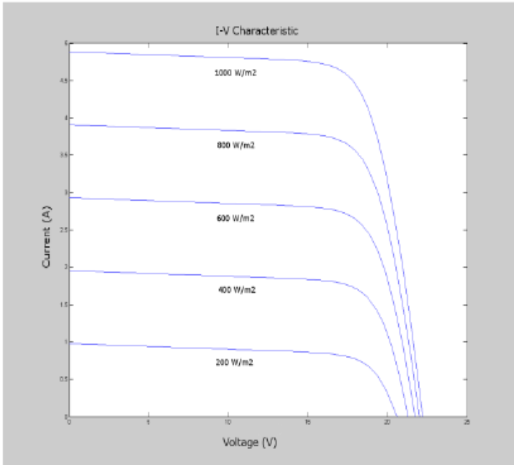

Figure 3(a): I-V characteristics of PV panel [7]

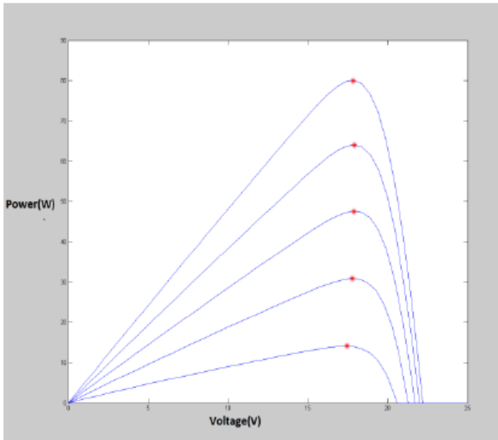

Figure 3(b): P-V characteristics corresponding to I-V characteristics (red dot shows maximum power point (MPP) [7]

The MPPT solar charge controller acts like a DC-DC transformer, which transforms power from a higher voltage to a lower voltage level. If the output voltage is lower than the input voltage, then the output current will be higher than its input current so product P=V*I remains constant. This equation implies that fluctuations in power also mean changing of voltage and current values [12].

There are three factors are to be considered when extracting maximum amount of power from a PV panel:

(i) **Irradiance:** Changes PV panel current operating point
(ii) **Temperature:** Changes PV panel voltage operating point.

(iii) **Load:** Used as a reference for the current and voltage [12].

4. Comparison Between PWM And MPPT Solar Charge Controllers

PWM helps to get the batteries charged up, extends the life of the battery, and more of the power generated by the solar panels is stored. Since the batteries store more energy on average, a smaller battery (or less battery in a battery bank) can be used reducing overall system costs [13].

MPPT solar charge controllers allow users to use PV module with a higher voltage output than operating voltage battery system. Since MPPT units are generally larger in physical size so they are more costly as compared to PWM controllers[2].

Table 1: Advantages of PWM and MPPT

PWM	MPPT
▪ PWM controllers are built on a time tested technology ▪ These controllers are inexpensive. ▪ PWM controllers are available in sizes up to 60Amps. ▪ PWM controllers are durable, most with passive heat sink style cooling. ▪ Can control high current and voltage. ▪ Longer expected lifespan [3].	▪ MPPT solar charge controllers offer an increase in efficiency up to 30%. ▪ These controllers also offer the potential ability to have an array with higher input voltage than the battery bank. ▪ Used to correct for detecting the variations in the I-V characteristics of solar cell. ▪ It forces PV module to operate at voltage close to maximum power point to draw maximum available power. ▪ Reduces complexity of system while output of system is highly efficient [2].

Table 2: Disadvantages of PWM and MPPT

PWM	MPPT
▪ The Solar input nominal voltage must match the battery bank nominal voltage if we are going to use PWM. ▪ There is no single controller sized over 60 amps DC as of yet. ▪ PWM controllers have limited capacity for system growth. ▪ Cannot be used effectively with 60A panels.	▪ MPPT controllers are more expensive. ▪ MPPT units are generally larger in physical size. ▪ Sizing an appropriate solar array can be challenging without MPPT controller manufacturer guides. ▪ Using an MPPT controller forces the solar array to be comprised of like photovoltaic modules in like strings [10].

PWM charge controller's work is to match the voltage of the panel to battery voltage and pulls down the panel output voltage in doing so. Whereas MPPT is the latest technology meant to extract maximum from solar panel. They operate according to the panel voltage and converts extra voltage of panel into current which increases the output from the solar system.

MPPT controller is at least 30% more efficient than PWM controller i.e. with MPPT we get 30% more output of the solar power system.

5. Conclusion

In this paper, a detailed review of PWM and MPPT is presented. It is understood that the major role of renewable energy like solar energy in today's world is going to play a role in the global energy sector. Renewable energy sources are cost effective, highly efficient and easy to install. With better use of charge controllers the lighting systems' efficiency will be increase. These charge controllers prevent reverse-current flow. When solar panels are not generating electricity, electricity flows backward from the batteries through solar panels. Hence, when the controller detects no energy from the solar panels, it disconnects the solar panels and hence stops the reverse current flow. The comparison between the two types of controllers shows the superiority of MPPT as compared to PWM.

References

[1] W. Thounaojam, V. Ebenezer and A. Balekundri, "Design and Development of Microcontroller Based Solar Charge Controller", *International Journal of Emerging Technology and Advanced Engineering*, Vol. 4, Issue No. 5, May 2014, pp. 510-513. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.637.8094&rep=rep1&type=pdf

[2] A. Pradhan, S. M. Ali, S. P. Mishra and S. Mishra, "Design of Solar Charge controller by the use of MPPT Tracking System", *International Journal of Advance Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 1, Issue No. 4, 2012, pp. 256-261.

[3] B. Swarnakar and A. Datta, "Design and Implementation of PWM charge controller and Solar Tracking system", *International Journal of Science and Research (IJSR)*, Vol. 5, Issue No. 5, May 2016, pp. 1214 – 1217. Retrieved from https://www.ijsr.net/archive/v5i5/v5i5.php

[4] Morningstar Corporation, "Why PWM?", *14th NREL Photovoltaic Program Review*, November 1996. Retrieved from https://www.morningstarcorp.com/wp-content/uploads/2014/02/8.-Why-PWM1.pdf

[5] A. S. Hiwale, M. V. Patil and H. Vinchurkar, "An Efficient MPPT Solar Charge Controller", *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 3, Issue No. 7, July 2014, pp. 10505-10511. Retrieved from http://www.ijareeie.com/upload/2014/july/14_AnEfficient.pdf

[6] M. R. Hamid, J. Rahimi, S. Chowdhury and T. M. M. Sunny, "Design and Development of a Maximum Power Point Tracking (MPPT) charge controller for Photo-Voltaic(PV) power generation system", *American Journal of Engineering Research (AJER)*, Vol. 5, Issue No. 5, 2016, pp-15-22. Retrieved from http://www.ajer.org/papers/v5(05)/C0505015022.pdf

[7] K. S. Awale, A. U. Kumbhar, V. A. Kole and J. B. Kamate, "Arduino Based MPPT charge controller", *Journal of Electrical & Electronic Systems*, Vol. 6, Issue No. 2, April 2017. Doi: 10.4172/2332-0796.1000221

[8] M. S. B. Talib, *Battery Monitoring System using Arduino in solar Battery Charger*, B.E. Project Report, Universiti Teknikal Malaysia, Melaka, Malaysia, 2015. Retrieved from http://eprints.utem.edu.my/id/eprint/17464

[9] S. K. Patil and D. K. Mahadik, "Design of Maximum Power Point Tracking (MPPT) Based PV charger", *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)*, Second International Conference on Emerging Trends in Engineering' 2013, Vol. 7, 2013, pp. 27-33. Retrieved from http://www.iosrjournals.org/iosr-jece/papers/sicete-volume7/82.pdf

[10] F. Sani, H. N. Yahya, M. Momoh,, I. G. Saidu and D. O. Akpootu, "Design and construction Of Microcontroller Based charger for Photo Voltaic Application", *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, Vol. 9, Issue No. 1, 2014, pp. 92-97.

[11] J. A. Agresta and N. A. Mikolajczak, *An MPPT charge Controller for solar powered portable devices*, Polytechnic Major Qualifying Project Report, Worcester Polytechnic Institute, Massachusetts, USA, April 2017. Retrieved from https://web.wpi.edu/Pubs/E-project/Available/E-project-042617-162303/unrestricted/Agresta_Mikolajczak_MQP_MPPT_Solar_Charger_1.pdf

[12] M. S. Islam, "Thin Film Solar Charge controller: A research paper for commercialization of Thin film Solar Cell," *Advances in Energy and Power*, Vol. 3, Issue No. 2, 2015, pp. 29-60.

Authors' Profiles



Tulika Majaw **Reeny Deka** **Shristi Roy**

B.Tech. VIII semester,
Department of Electrical and Electronics Engineering, School of Technology,
Assam Don Bosco University

Bikramjit Goswami is working as an Assistant Professor in the department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University, India. He is also a Ph.D. Research Scholar in Assam Don Bosco University currently. His research interests are Reconfigurable Antenna, Microwave Remote Sensing, Artificial Neural Networks, renewable Energy, Disaster Forecasting.

An approach to enhance the efficiency of the solar PV panel in partial shading condition: A Review

Shilajeet Bhattacharjee[1], Abu Ibrahim Barbhuiya[2], Akash Mazumdar[3], Papul Changmai[4], Mrinal Krishna Chowdhury[5]

[1,2,4]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati -781017, Assam, INDIA.
*[1]shilajeet72771@gmail.com, [2]abuibrahimbarbhuiya@gmail.com, [4]papul.changmai@dbuniversity.ac.in**

[3]Department of Electronics and Communications Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati -781017, Assam, INDIA.
[3]aakashmazumder95@gmail.com

[5]Assam Energy Development Agency (AEDA)
Bigyan Bhawan, ABC, Guwahati-781005
mrinal7@gmail.com

Abstract: ***Hot spot heating causes permanent destruction of the solar cell structure. Areas with high impurity contaminants and high concentration of transition metals have the most number of hot spot heating. When the operating current of the overall series string approaches the short circuit current of a bad cell then the overall current becomes limited by the bad cell. The good cell becomes forward bias, which reverse biases the bad cell. This leads to large dissipation of power in the bad cell. Enormous power is dissipated in the bad cell or hot spot that results in destructive effects like glass cracking, melting of solder or degradation of a solar cell. The solar panel works best when there is no shade on them. If there is a partial shadow in any one of the arrays, the efficiency of the solar panel drops to a great extent. The shaded cell becomes reverse biased so maximum power will be dissipated on the shaded cell. The heat developed due to the reverse biased of the shaded region adds to the dissipated power.***

Keywords: Solar PV, partial shading, maximum power extraction, solar irradiance

1. Introduction

In a series connected solar photovoltaic module, the cells are not equally connected. The shaded cells may get reverse biased which acts as a load. If the system is not fully connected, there is a chance of creation of hotspot.

2. Partial shading and bypass diode

Shade impact depends on module type, fill factor, bypass diode placement severity of shade and string configuration [1]. Typically, a crystalline silicon module will contain bypass diodes to prevent damage from reverse bias on partially shaded cells. These diodes are placed across 12 - 18 cells in a group of cells. The bypass diode allows current from non-shaded parts of the module to pass by the shaded part and limits the effect of shading to the only neighboring group of cells protected by the same bypass diode.

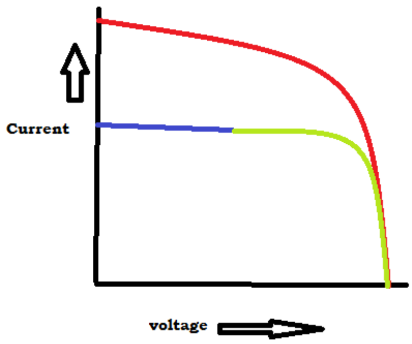

Figure 1: V-I characteristics

Here, the current will be maximum at that point where the green curve intersects the red curve. This graph depends upon the number of cells that are shaded sequentially.

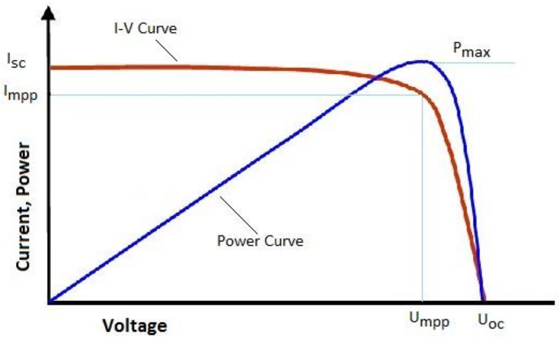

Figure 2: P-V characteristics

The P-V characteristics curve always depends upon the value of G i.e. irradiance [2]. The maximum power point is shown in the graph, which is the peak value i.e. P_{max}.

2.1 Partial shading of a single module

Bypass diodes usually reduce hotspot in solar panel. The bypass diode will ensure the operation of the module [3]. However, the number of bypass diode is limited, so the shading of one single cell will affect the cells in the module.

2.2 Partial shading in two modules

Partial shading can be done in two modules. Here the blue curve shows the p-v Characteristics of solar PV panel which are having different irradiance i.e. G.

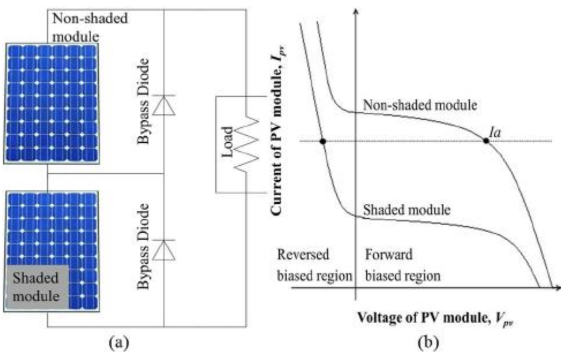

Figure 3: Partial shading in two modules

3. Hotspot in solar panel

Some cells exhibit inhomogeneity of the surface temperature resulting in localized heating [4]. These heating occur when there is one low current solar cell in a string of several high short circuit current solar cells. Hot spot heating causes permanent destruction of solar cell structure. The elemental composition of different regions of solar Cells revealed that the areas with high impurity contaminants have the most number of hot spot heating. In addition, the areas with high concentration of transition metals result in hot spot heating. When the operating current of the overall series string approaches the short circuit current of the bad cells then the overall current becomes limited by the bad cell. The good solar cells now become forward biased. The forward biased across all the cells reverse bias the bad cell. A large number of cells connected in series causes reverse bias across the shaded region, which leads to large dissipation of power in the bad cell [5]. Thus, all the generating capacity of the good cells is dissipated in the bad cell. The enormous power dissipation occurring in a small area results in overheating of the bad cell or "hot spot" which results in destructive effects like glass cracking, melting of solder or degradation of the solar cell.

4. Main causes of hotspot in solar panel

There are many causes of a hot spot. The functional causes of hot spot are-

1) Cell mismatch:- occurs when cells of varying current production are connected in series.
2) Cell damage:- occurs during the production process because the silicon cell will be subjected to many stresses during lamination, handling, and transportation.

The operation of the hot spot is related to solar park design and operation includes:-

1) Partial shading:- There is a drastic effect of shading on a solar panel. The efficiency of the solar panel decreases enormously even for a small partial shading.

2) Rooftop condition:- When cells are completely shaded this may not be sufficient to trigger the bypass diode, resulting in increased temperature which will degrade the panel.

3) Soiling:- Panels can be soiled due to dust, dirt and other contaminants during the lifetime which results in the formation of a hot spot.

In Fig. 4, two parallel-connected solar cells are shown. The green solar cell is in sunlight and the red one is shaded. The generated current from the green and red solar cell is I_1 and I_2. The total current (I_1+I_2) is flowing out from the solar panel. The V-I characteristics of the green and red cell are shown in Fig. 4.

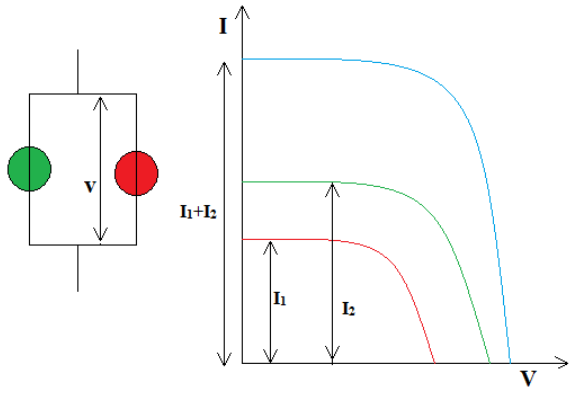

Figure 4: V-I characteristics of a good cell (in sunlight) and bad cell (shaded).

5. Conclusion

When Hotspot generates in a solar panel it permanently damages the solar panel. Because of that, a huge loss is there in the consumer end. Govt. of India (GOI) has a target to generate 100GW by 2022 from solar energy. That is why a number of solar projects are going on across the country. However, along with the solar mission of power enhancement we will have to look towards the different auxiliary problems that arise in the solar panels. Out of all auxiliary problems, hot spot generation is the most severe one. Therefore, it is our utmost requirement to do research to overcome from this problem

References

[1] B. Alsayid, S. Alsadi, J. Jallad and M. Dradi, "Partial Shading of PV System Simulation with Experimental Results", *Smart Grid and Renewable Energy*, Vol. 4, Issue No. 6, 2013, pp. 429-435. Doi: 10.4236/sgre.2013.46049

[2] A. Dev and S. B. Jeyaprabha, "Modeling and simulation of PV Module in MATLAB", *Proceedings of International Conference on Applied Mathematics and Theoretical Computer Science-2013*, Bonfring, 2013. Retrieved from http://www.conference.bonfring.org/papers/xavier_icamtcs2013/tt3_tcs_0323.pdf

[3] C. Honsberg and S. Bowden, "Bypass Diodes", *PV Education*. [Online]. Available: http://www.pveducation.org/pvcdrom/7-modules-and-arrays/bypass-diodes [Accessed: Feb. 12, 2017].

[4] H. S. Sahu, S. K. Nayak, and S. Mishra, "Maximizing the power generation of a partially shaded PV array", *IEEE Journal of Emerging and Selected Topics in Power Electronics*, Vol. 4, Issue No. 2, Jun. 2016, pp. 626–637. Doi: https://doi.org/10.1109/JESTPE.2015.2498282

[5] A. K. Chatterjee and D. Kapoor, "Identification of photo-voltaic source models", *IEEE Transactions on Energy Conversion*, Vol. 26, Issue No. 3, Sep. 2011, pp. 883–889.Doi: https://doi.org/10.1109/TEC.2011.2159268

Comparative Analysis of Different Control Schemes for DC-DC Converter: A Review

Ferrarison B. Lynser[1], Morningstar Sun[2], Maiarta Sungoh[3], Nuki Taggu[4], Pushpanjalee Konwar[5]

[1,2,3,4,5]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati-781017, Assam, India
[1]ferlynser123@gmail.com, [2]msun413@gmail.com, [3]maiaz1302@gmail.com, [4]nukitaggu.aru@gmail.com,
*[5]pushpanjalee.konwar@dbuniversity.ac.in**

Abstract: ***DC-DC converters are some power electronic circuits that convert the DC voltage from one level to another. They have a very large area of applications ranging from computing to communication. They are widely used in appliance control transportations and high-power transmission. Its increasing demand is based on its capability of electrical energy conversion. The basic topologies of DC-DC converter are Buck converter and Boost converter, other topologies are derived from these two basic topologies. Mathematical modelling of both Buck converters is done. Some of the control schemes are summarized in this paper. Current mode control (CMC), PID, Sliding Mode (SM) control including their advantages and disadvantages are highlighted in this paper.***

Keywords: DC-DC converter, PID, Sliding Mode Control and Buck converter.

1. Introduction

The switch mode DC-DC converters are the simplest power electronic circuit that efficiently converts an unregulated DC voltage into a regulated DC voltage. Solid state device such as transistors and diodes are used as switching power supplies. They operate as switch either in completely ON or completely OFF state. The energy storing elements such as inductor and capacitor are used for energy transfer and work as a low pass filter. The buck and boost converters are the two fundamental topologies of switch mode DC-DC converter. DC-DC converters have a wide area of applications. The drastic use of these converters in appliances control, telecommunication equipment, DC-motor drives, automotive, aircraft, etc. increases its interests in many fields.

The analysis along the control of switching converters is the main factor to be considered. Various control schemes are used to control the switch-mode DC-DC converter. There are many advantages and disadvantages related to every control methods. Preference is always given to the methods under which the best performance is obtainable. The most commonly used control technique is PWM voltage mode control, PWM current mode control, PID controller. The disadvantage of these controllers is that satisfied results are not achievable under large parameter or variation of load. Therefore the utilization of non-linear

2. Literature Review

R. Priewasser *et al.* [1] in 2010 derived a linear PID (proportional-integral-derivative) control loop, both in analog and digital domain and compared its performance to a non-linear regulation loop. A goal of this research work was to point out potential advantages and drawbacks of the different solutions. This exploration forms the starting point for the implementation of the most promising concepts in CMOS technology. Mike Wens *et al.* [2] in 2012 discussed a brief mathematical steady state model for fully-integrated boost and buck DC-DC converters, which takes all the significant resistive and dynamic power losses into account. The maximization of output power and power density parameters is the main goal of this work. K. Bhattacharyya *et al.* [3] in 2012 implemented an integral DC-DC converter to reduce the energy lost and to reduce the output voltage ripple. Apart from ripple reduction, its power efficiency is improved by reducing short-circuit currents in the switched capacitor converter. A combination of non-overlap switching phase and a dip-reducer helps to reduce short circuit current without degrading the output ripple. The converter has been used to observe the power efficiency and ripple variation at different frequency of operations. In another research work by D. Sutanto *et al.* [4] in 2010, two topologies for the buck converter are presented and the first converter consisting of two active switches and the second one derived from the parent two switch converters which consist of only one active switch. This new converter can operate a constant switching frequency using a simple PWM control.

This converter has a good efficiency, as is proved by the experimental results. The operation of the two-switch converter, derived from the new single-switch converter is presented to gain insight designing of the new converter. Yogesh V. HOTE in 2012[5], presented, using Kharitonov's theorem, an analytical technique for time domain analysis used for the transient and steady-state response of Pulse Width Modulation (PWM) push-pull DC-DC converter. Even though the transfer function model of a PWM push-pull DC-DC converter is disturbed; the complete analysis has been done on a linear transfer function model of a PWM push-pull DC-DC converter which is the main advantages of the proposed analysis. In the research work by T. B Petrovic *et al.* [6] in 1999, the design for a single operating dc/dc converter using robust controller has been investigated. Using H∞ optimization procedure with Glover-Doyle algorithm, the controller is designed. Stability and performance robustness is achieved in the presence of unstructured multiplicative (input) uncertainty using this designed controller. While maintaining robustness properties, a simple technique is used to reduce the controller order. Using computer simulation, the performance of the closed-loop system is evaluated, and the results are compared with previously designed classical PI controller and IMC controller. Xile Wei *et al.* [7] in 2009, proposed the internal model control of a conditional integrator in order to get the robust output regulation of a DC-DC buck converter. Based on the input-output linearization from the state-space averaged model of a DC-DC buck converter, the robust output regulation problems of the converter can be converted into a robust stabilization problem of a system consisting of the given buck converter and the internal model by introducing a proper internal model. In the research work done by Carlos Olalla *et al.* [8] in 2012, a new digital robust control law for dc-dc converters is analyzed and implemented in this paper which has been successfully used with analog implementation, has been adapted to the digital domain. Concretely, this paper considers the design of a power conditioning unit, which must consider the uncertainty of the converter, as the conduction mode, the load, the input voltage or the storage elements while assuring that the specifications of a well-known standard are met.

3. Background Study

3.1 Switch mode DC-DC Converter

The switch mode DC-DC converters are those which convert the unregulated DC voltage to a regulated DC voltage with high efficiency and flexibility. The various types of DC-DC converters comprise of buck converter, boost converter, buck-boost converter etc. Buck and boost converters are the two fundamental topologies of switch mode DC-DC converter whereas buck-boost converter is the combination of buck and boost converter topologies.

DC-DC converter usually operates in two modes of operation: continuous mode and discontinuous mode. In case of continuous mode, the current through the inductor never falls to zero whereas in case of discontinuous mode the current through the inductor falls to zero as the switch is turned off.

3.2 Buck Converter

The buck converter is shown in figure 1. It is the step-down converter in which a fixed high voltage is step down to a desired low voltage level. It consists of a non-dissipative switch, inductor, and capacitor. The switches will operate at the rate of PWM switching frequency. The ratio of ON time when the switch is closed to the entire switching period is known as the duty cycle and is represented as:

$$d = \frac{t_{ON}}{T}$$

and the output voltage is controlled by varying the duty cycle. During steady state, the ratio of output voltage over input voltage is d, which is given by:

$$d = \frac{V_{out}}{V_{in}}$$

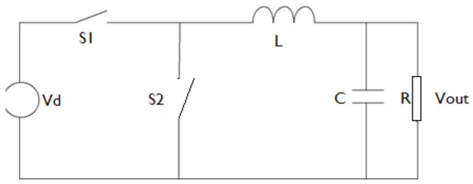

Figure 1: Basic Buck Converter

In the first sub-circuit state when the switch S1 is closed, the diode is reversed biased and the energy is transferred from the source to the inductor and the current through the inductor gradually increases during this time interval as shown in figure 2(a). In the next sub-circuit state when the switch S2 is closed, the source is disconnected from the network. The diode will be forward biased and the current will flow through the freewheeling diode. During the second time interval, the current through the circuit decreases linearly as the energy in the inductor discharges as shown in figure 2(b).

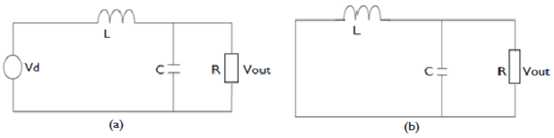

Figure 2: Buck Converter when (a) Switch is ON (b) Switch is OFF

3.3 Control techniques used in DC-DC Buck Converter

In DC-DC converter for a given input voltage, the output voltage can be controlled by controlling the ON or OFF duration of the switch. Pulse Width Modulation (PWM) is one of the methods in which the control circuit regulates the output by varying the ON time of the switch and by fixing the switching frequency.

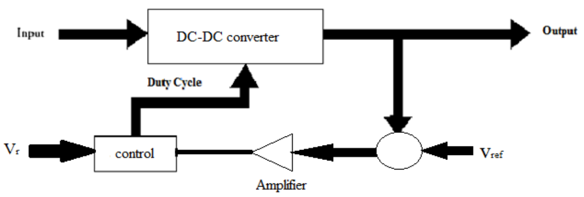

Figure 3: Elements of switching-mode regulator

3.4 Voltage Mode Control of DC-DC Converter

It is a type of single loop controller, where the output voltage is sensed and subtracted from the reference voltage in an error amplifier. The error amplifier will generate a control signal which is compared with constant amplitude saw-tooth waveform. A PWM signal is generated from the comparator is fed to the drivers of the controller switch of the converter. The duty ratio of the PWM signal depends on the value of the control voltage. The frequency of the PWM signal will remain the same as that of the control signal.

Some of the advantages of voltage mode control are its simple hardware implementation and flexibility and voltage mode provides good load regulation, that is, regulation against variation in load.

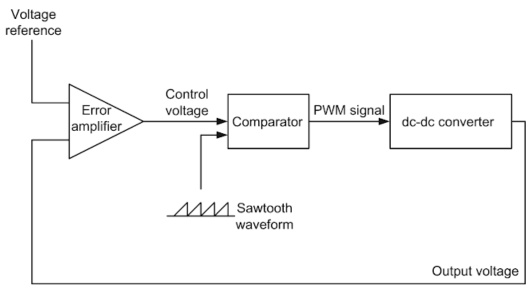

Figure 4: Control schemes for dc-dc converters: Voltage-Mode Control [13]

3.5 Current Mode Control of DC-DC Converter

Current mode control method contains dual loop including voltage and current control loop. Here an additional inner loop control loop feedbacks an inductor current signal. The current signal is converted into its voltage analog and is compared with the control voltage. The modification of replacing saw-tooth waveform voltage mode control scheme by converter current signal significantly alters the dynamic behavior of the converter.

Some of the advantages of current mode control scheme include: good and improved performance in the line regulation, self-protection opposes overload, shows improved transient response.

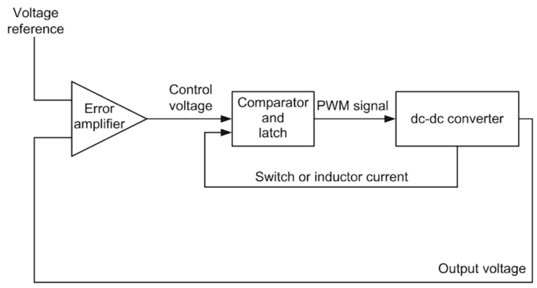

Figure 5: Control schemes for dc-dc converters: Current-mode Control [13]

3.6 Linear Control Design for dc-dc Converters

The design of the DC-DC converter using linear control method is presented. For designing a linear controller, an accurate model is essential which can be obtained using the state-space averaging technique. In the case of the buck converter, the control law is based on the small signal model.

Designing of PID and PI controllers were executed using small signal models. To achieve high loop gain, the system was compensated, wide bandwidth and sufficient phase margin. Transformation of the PID and PI controllers was possible using the backward integration method. PID and PI controllers were altered into digital controllers transform.

3.6.1 PID Controller design for Buck Converters

To design a controller using the frequency response method, phase-lead, phase-lag or lead-lag compensation is usually used. A proportional-derivative (PD) controller is phase-lead compensation. The advantage of using PD controllers is that it leads to the increase of phase margin and improvement of cross-over frequency. The transfer function of a PD controller is:

$$G_C(s) = K_P + K_D(s)$$

A proportional-integral (PI) controller is a phase-lag controller. A PI controller is used to increase the low-frequency loop gain, therefore reducing steady-state error. The transfer function of a PI controller is:

$$G_C(s) = K_p + \frac{K_I}{s} = \frac{K_p s + K_I}{s}$$

The PI controller has a pole at the origin. Both PD and PI controllers are first-order controllers.

By using a lead-lag compensator, the advantages of lead compensation and lag compensation can be combined to obtain sufficient phase margin, high loop gain, and wide control bandwidth. A proportional-integral-derivative (PID) controller is a lead-lag compensator. It is the most widely used compensator in feedback control systems. The PID controller is defined as:

$$u(t) = K_P e(t) + K_I \int_0^{\tau} e(t)dt + K_D \frac{de(t)}{dt},$$

where e(t) is the compensator input and u(t) is the compensator output.

The Laplace transform of the above equation yields the transfer function:

$$G_C(s) = \frac{U(s)}{E(s)} = K_P + \frac{K_I}{s} + K_D(s)$$

The integral term is phase-lag and the derivative term is phase-lead. The low-frequency gain is improved by the integral term, and the low-frequency components of the output voltage are accurately regulated. At high frequency, the phase margin and cross-over frequency are improved by the derivative term, which improves the system's stability and the speed of the transient response. An increase in the proportional term will increase the speed of system response; however, too much proportional gain will make the system unstable.

For operation during a startup transient and steady state, a PID and a PI controller were designed for the buck converter respectively. The derivative term in a PID controller is susceptible to noise and measurement error of the system, which could result in oscillation of the duty cycle during steady state. However, the derivative term is needed during a transient period to reduce the settling time by predicting the changes in error. Therefore, to obtain the desired response the system switches between PID and PI controllers during transient and steady-state period. The PID controller is applied during startup to obtain a fast-transient response. The PI controller is applied during steady state to reduce oscillation of the duty cycle and improve the system's stability.

3.6.2 Implementation of Digital PID and PI Controllers

Frequency response technique is used for designing the PID and PI controller, which will be based on the small signal model of the DC-DC Buck converter. These are transformed into digital controller using back integration method.

The digital PID controller can be deduced from the PID controller equation as:

$$u(t) = K_P e(t) + K_I \int_0^{\tau} e(t)dt + K_D \frac{de(t)}{dt}$$

The difference equation to calculate a new duty cycle for the digital PID controller given as:

$$u[k] = K_P e[k] + K_I T \sum_{i=0}^{k} e[i] + \frac{K_D}{T}\{e[k] - e[k-1]\}$$

The digital PID controller can be deduced from the PID controller equation as:

$$u(t) = K_P e(t) + K_I \int_0^{\tau} e(t)dt$$

The difference equation to calculate a new duty cycle for the digital PI controller given as:

$$u[k] = K_P e[k] + K_I T \sum_{i=0}^{k} e[i]$$

In the above equations, u[k] is the controller output, e[k] is the error of k^{th} sample, $\sum_{i=0}^{k} e[i]$ is the sum of the error and $\{e[k] - e[k-1]\}$ is the difference between the error of the k^{th} sample and $(k-1)^{th}$ sample.

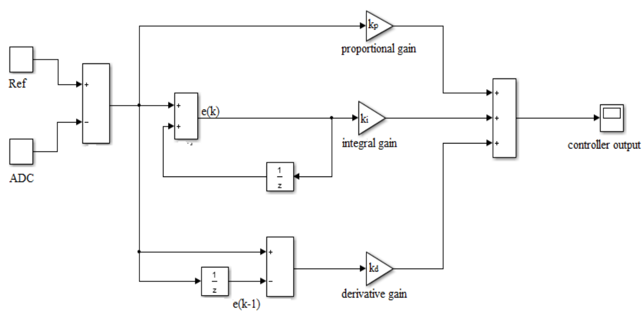

Figure 6: Block diagram of digital PID controller.

3.7 Sliding Mode Control (SMC)

Sliding mode control is the only non-linear method. Sliding mode controller is a systematic approach to solve the stability problem and consistency performance. Switch mode controller could be implemented for switch mode power supplies. Switching control action is required to drive the non-linear plants' state trajectory into a specified surface in the state space and to maintain the plants' state trajectory for subsequent time. The gain of the feedback path depends upon the position of the trajectory w.r.t surface. If the trajectory is above the surface feedback path has one gain and the gain will change as the trajectory move below the surface. The surface is known as the sliding surface. Ideally, a response is made to slide along a predefined trajectory with the help of the control algorithm. The control detects the deviation of actual trajectory from the reference trajectory and correspondingly changes the trajectory to restore the tracking.

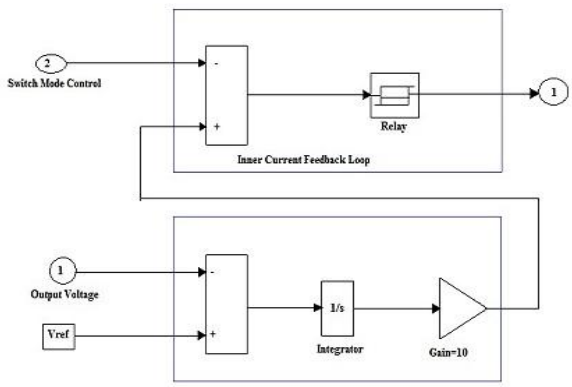

Figure 7: Block Diagram of SMC

4. Conclusion

In this review, we provided a control technique used for DC-DC converters. The basic concepts behind every adaptive control schemes have been highlighted. A comparison is made between the different control schemes. The selection of controller depends on the purpose for which it is required. The development of a more reliable and efficient control technique will be possible in the upcoming days.

References

[1] R. Priewasser, M. Agostinelli, S. Marsili, D. Straeussnigg and M. Huemer, "Comparative study of linear and non-linear integrated control schemes applied to a Buck converter for mobile applications", *e & I Elektrotechnik und Informationstechnik*, Vol. 127, Issue No. 4, April 2010, pp. 103–108. Retrieved from: https://link.springer.com/article/10.1007/s00502-010-0705-6

[2] M. Wens and M. Steyaert, *Design and Implementation of Fully-Integrated Inductive DC-DC Converters in Standard CMOS*, 2011 edition, Springer, Dordrecht, Netherlands, 2011.

[3] K. Bhattacharyya and P. Mandal, "Design and implementation of a switched capacitor-based embedded hybrid DC-DC converter", *International Journal of Electronics*, Vol. 99, Issue No. 6, 2012, pp. 823-849. Doi: http://dx.doi.org/10.1080/00207217.2011.647290

[4] B. P. Divakar IV and D. Sutanto, "Novel topologies for DC-DC converter with PWM control", *International Journal of Electronics*, Vol. 87, Issue No. 6, 2010, pp. 741-756. Doi: http://dx.doi.org/10.1080/002072100131931

[5] Y. V. HOTE, "A new approach to time domain analysis of perturbed PWM push-pull DC-DC converter", *Journal of Control Theory and Applications*, Vol. 10, Issue No. 4, November 2012, pp.465–469. Retrieved from https://link.springer.com/article/10.1007/s11768-012-0064-4

[6] T. B. Petrovic and A. T. Juloski, "Robust H∞ controller design for current mode-controlled dc/dc converters", *Electrical Engineering*, Vol. 82, Issue No. 2, November 1999, pp. 83–88. Retrieved from https://link.springer.com/article/10.1007/s002020050079

[7] X. Wei, K. M. Tsang and W. L. Chan, "DC/DC Buck Converter Using Internal Model Control", *Electric Power Components and Systems*, Vol. 37, Issue No. 3, 2009, pp. 320-330. Retrieved from https://www.tandfonline.com/doi/abs/10.1080/15325000802454500

[8] C. Olalla, C. Carrejo, R. Leyva, C. Alonso and B. Estibals, "Digital QFT robust control of DC-DC current-mode converters", *Electrical Engineering*, Vol. 95, Issue No. 1, 2012, pp. 21-31. Retrieved from https://link.springer.com/article/10.1007/s00202-012-0236-8

[9] A. B. Ponniran, *A study on optimization of circuit components in high boost dc-dc converter with hybrid-based configuration*, Ph.D. Thesis, Nagaoka University of Technology, Japan, June 2016. Retrieved from http://hdl.handle.net/10649/814

[10] H. S. Ramirez and R. S Ortigoza, *Control Design Techniques in Power Electronics Devices*, 1st Edition, Springer-Verlag, London, 2006.

[11] K. Kayisli, S. Tunner and M. Poyrax, "A Novel Power Factor Correction System Based on Sliding Mode Fuzzy Control", *Electric Power Components and Systems*, Vol. 45, Issue No. 4, February 2017, pp. 430-441. Doi: http://dx.doi.org/10.1080/15325008.2016.1266418

[12] Wang Feng-yan and Xu Jian-ping, "Modeling and Analysis of V~2C Controlled Buck Converter", *Proceedings of the Chinese Society of Electrical Engineering: CSEE 2006-02*, Vol. 2006, Issue No. 2, 2006, pp. 121. Retrieved from http://en.cnki.com.cn/Article_en/CJFDTOTAL-ZGDC200602021.htm

[13] M. H. Rashid (ed.), *Power Electronics Handbook*, 4th Edition, pp. 285, Butterworth-Heinemann, Oxford, UK, 2017.

Authors' Profile

Ferrarison B. Lynser

Morningstar Sun

Maiarta Sungoh

Nuki Taggu

B.Tech. 8th Semester, Dept. of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University

Ms. Pushpanjalee Konwar is an Assistant Professor in the department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University, Guwahati. She received her M. Tech. degree from Assam Don Bosco University in 2014 and pursuing Ph.D. from NIT Nagaland. She has authored one book chapter published by IGI Global Journals and has published many research papers in journals and conferences. Her area of research is biomedical instrumentation and power systems.

Automatic Climate Control of a Greenhouse: A Review

Nabajeet Sen[1], Shuvom Deb[2], Dabiangpura Sungoh[3], Sarbani Das[4]

[1,2,3,4]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati-781017, Assam, India
[1]nabajeetsen001@gmail.com, [2]shuvom.sd001@gmail.com, [3]dabz1996@gmail.com*

Abstract: ***Greenhouse crop production was a very significant event in the history of agriculture since it was realized that with the help of it many plants could be protected from different biotic and abiotic stress. It emerged as a system to protect crops from critical and adverse conditions affecting the growth of plants. The greenhouse is a non-linear system and controlling becomes a difficult task. The parameters affecting the plant growth are temperature, relative humidity, carbon dioxide, nutrition, availability of water and the growing media. The quality and productivity of the crop plants is highly dependent on the management of these parameters. From all the parameters, temperature and humidity are of primary importance to most growers as it is responsible for determining the reaction rates of various metabolic processes involved in the plant growth. In addition, regulating temperature has a direct influence on the relative humidity and carbon dioxide levels of the greenhouse system.***

Keywords: Greenhouse, Climate Control, Control Actuators.

1. Introduction

The popularity of computers for the management of greenhouses is increasing in those countries where the environmental conditions are not suitable for the development of plants. In The Netherlands, computers are used for different applications like the climate control, the boiler, and the irrigation control, but the best known of them is the climate control (temperature, humidity, CO_2level and artificial lighting). Automatic greenhouse climate control systems are being widely installed nowadays in Southeast Spain. As a basic requirement, climate control helps to avoid extreme conditions (high temperature or humidity levels, etc.) which can cause damage to the crop and to achieve adequate temperature integrals that can accelerate the crop development and its quality while reducing pollution and energy consumption. The crop production system is characterized by both fast and slow dynamics, the first associated with the greenhouse climate and the second with crop growth. As a first approximation, seasonal optimization can treat the physical climate as immediately realizable through the control. The main improvements in the computer -based climate control are found in data logging the determination of climate set-points, monitoring and alarm functions. Nowadays, the agro-alimentary sector is incorporating new technologies due to the large production demands and the diversity, quality, and market presentation requirements. The dynamic behaviour of the micro climate is a combination of physical processes involving energy transfer (radiation and heat) and mass balance (water vapour fluxes and CO_2 concentration). These processes depend on the outlet environmental conditions, structure of the greenhouse, type and state of the crop and on the effect of the control actuators. The main ways of controlling the greenhouse climate are by using ventilation and heating to modify inside temperature and humidity conditions, shading and artificial light to change internal radiation, CO_2 injection to influence photosynthesis and fogging/ misting for humidity. The temperature in a greenhouse is affected by the ventilation and the amount of sunshine it receives Greenhouses are designed to trap the heat from the sun. If nobody changed anything, the temperature would keep rising until the sun sets. The temperature can be controlled by opening the door or opening vents in the roof. In extreme cases, air conditioning could be used to bring the temperature down to a reasonable level. The humidity inside a greenhouse is almost always close to the maximum because of the amount of greenery. Leaves naturally perform a process called transpiration, in which they release moisture into the atmosphere from pores in their surface Controls on humidity are similar to those for heat.

The idea of synchronizing graspable real models and virtual world by interfacing sensor was published for the first time by Bruns. Many ideas, applications and prototypes based on this concept have been investigated and implemented since then. In the work done by R. Caponetto *et al.* [1], the authors proposed the modelling of greenhouse from a physical point of view, which requires a large computer effort due to the intrinsic complexity of the system and of the phenomenon involved. The synthesis of a climate control became a complicated task due to the physical dynamics involved in the greenhouse. In another work by F. Lafont *et al.* [2], the authors proposed that the greenhouse models are non-linear and are strongly disturbed often by the weather conditions that are impossible to forecast precisely. Thus, model-free control is a saviour to this problem. In the work by W. J. Roberts [3], the author proposed that controls are important part of heating and ventilating system. Capillary bulb type thermostats are the most durable for greenhouse use. Residential home type thermostats are usually more accurate but are also more subject to deterioration and malfunctioning caused by the greenhouse environment. In another work by M. Berenguel *et al.* [4], the authors proposed the development of mixed feed forward adaptive controllers for greenhouse climate control based on both simplified physical laws and online measured data and were discussed in terms of their suitability for adaptive control purposes. The schemes are tested using a highly nonlinear model of a typical Mediterranean greenhouse. The behaviour of the control scheme has been analysed during daily operation (first time scale) to compensate for changing dynamics induced by operating point changes and disturbance cycles. The authors F. Rakoczi *et al.* [5] proposed that the humidity of the atmosphere is a very important factor influencing the greenhouse intensity of the atmosphere. Greenhouse intensity is calculated as the difference between the surface temperature and the effective temperature of the atmosphere. If the water content increases by 10%, it will result in the increase of the greenhouse intensity by 1.34°C. In the case of decrease of the atmospheric water content by 10%, the greenhouse intensity will decrease by 1.6°C.

2. Greenhouse Control

A lot of simulations, referring to different control techniques, can be done like standard bang-bang control technique, fuzzy controller designed on the basis of expert description, fuzzy controller optimized via GAs; and, finally distributed proportional integrative derivative (PID) controller. Soft computing methodologies are complementary and synergistic than competitive. The guiding principle of soft computing is to exploit the tolerance for imprecision, uncertainty and partial truth, and the approximation to achieve the tractability, the robustness, the low solution cost, and the better rapport with reality. When there is difference between the temperature and humidity of the measured data and the data stored in the database of natural temperature and humidity, adjust by data detector, transfer the signal information to the temperature and humidity adjusting device which control the test point temperature and humidity. The physical point of view for designing a Greenhouse requires a large computer effort. It is due to the internal complexity of the system and operation involved. The effectiveness of a Greenhouse, which is a distributed parameter system, depends on several non-linear phenomena. Radiation and convectional effects are the factors on which the heat transferred in a Greenhouse depends. Moreover, on account of many uncontrollable signals like the solar radiation, the crop transpiration, and so on, makes validation of the model even difficult.

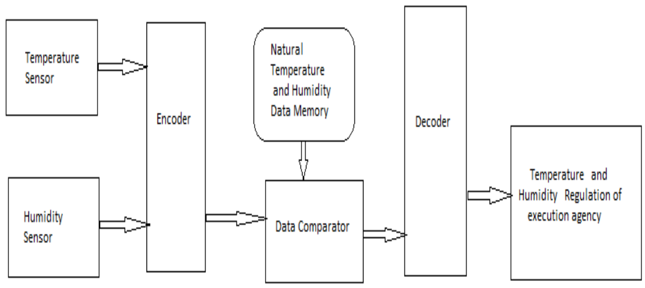

Figure 1: Schematic Diagram of simulation control system of temperature and humidity

Factors affecting the climate of the green house are temperature, humidity, CO_2, soil composition, light and soil ph. It is difficult to control the parameters of the green house using conventional techniques, the advanced technologies like fuzzy logic, genetic algorithm, PID distributed control and system modelling are widely accepted nowadays The use of fuzzy logic controllers in a greenhouse for controlling parameters like temperature humidity reduces the energy cost for heating. Climate control of greenhouse involves control and modification of day and night temperature, CO_2 and relative humidity for maximum plant growth. Extreme values of temperature as well as humidity need to be controlled for both summer and winter season. In order to make the feasible condition for the optimum plant growth, the cooling and the heating system need to be installed. The heating system is installed to exchange the energy lost from the greenhouse when the temperature outside the greenhouse remains lower than the desired temperature in the greenhouse growing area. As we know the nutrition of the crops depends upon the light, temperature, moisture and CO_2 concentration but the level of these climate parameters particularly during rainfall will vary between location and years due to the difference in its climate.

3. Summary

Automatic greenhouse climate control systems are being widely installed worldwide, using computers for different applications like the climate control and the irrigation control, climate control being one of the major concerns. As a basic requirement, climate control helps to avoid extreme conditions (high temperature or humidity levels, etc.) which can cause damage to the crop. Simulation, referring to different control techniques, can be done like standard bang-bang control technique, fuzzy controller designed on the basis of expert description.Climate control of greenhouse involves control and modification of day and night temperature, CO_2 and relative humidity for maximum plant growth.

4. Conclusion

Due to the physical dynamics involved in a greenhouse, the synthesis of a climate controller becomes a complicated task using traditional techniques of control. The temperature was controlled by regulating the water temperature within an appropriate set of pipes uniformly distributed in the greenhouse, while the humidity was controlled indirectly by the ventilation rate regulation (which affects both temperature and humidity). Thus, using these systems were quite expensive and not an efficient way of controlling. Thus, automatic control of the greenhouse became the mainstream technique which created the most desirable environment for crop growth according to the growth habits of the greenhouse crops and the needs of the market, some even get rid of the natural environment constraints. It is also suitable for large scale production.

References

[1] R. Caponetto, L. Fortuna, G. Nunnari, L. Occhipinti and M. G. Xibilia, "Soft Computing for Greenhouse Climate Control", *IEEE Transactions on Fuzzy Systems*, Vol. 8, Issue No. 6, Dec 2000, pp. 753-760. Doi: https://doi.org/10.1109/91.890333

[2] F. Lafont, N. Pessel, J. F. Balmat and Michel Fliess, "On the Model-Free Control of an Experimental Greenhouse", *Proceedings of the World Congress on Engineering and Computer Science (WCECS 2013)*, Vol. II, 23-25 October, 2013, San Francisco, USA. Retrieved from http://www.iaeng.org/publication/WCECS2013/WCECS2013_pp960-965.pdf

[3] W. J. Roberts, "Environmental control of greenhouses," Technical Report, *CCEA-Centre for Controlled Environment Agriculture, Cook College, Rutgers University*, New Jersey, U.S, 2005. Retrieved from http://horteng.envsci.rutgers.edu/factsheets/envcontrolofghs.pdf

[4] M. Berenguel, L. J. Yebra and F. Rodriguez, "Adaptive Control Strategies for Greenhouse Temperature Control", *2003 European Control Conference (ECC)*, Cambridge, UK, 1-4 Sep. 2003, pp. 2747-2752. Retrieved from https://ieeexplore.ieee.org/document/7086457/

[5] F. Rakoczi and Z. Ivanyi, "Water Vapour and Greenhouse Effect", *GEOFIZIKA*, Vol. 16-17, 1999-2000, pp. 65-72. Retrieved from http://geofizika-journal.gfz.hr/Vol_1617/geofizika_1617_1999 2000_65-72_rakoczi.pdf

[6] C. Pengzhan and L. Baifen, "Construction of Intelligent Greenhouse Control System based on CAN bus", *2010 International Conference on Computer Application and System Modeling (ICCASM 2010)*, Taiyuan, 2010, pp. V10-631-V10-634. Doi: https://doi.org/10.1109/ICCASM.2010.5622630

[7] O. Körner and H. Challa, "Process-based Humidity Control regime for greenhouse crops", *Computers and Electronics in Agriculture*, Vol. 39, Issue No. 3, 2003, pp. 173-192. Doi: https://doi.org/10.1016/S0168-1699(03)00079-6

Authors' Profiles


1


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3

[1]Nabajeet Sen
[2]Shuvom Deb
[3]Dabiangpura Sungoh
B.Tech. 8th Semester,
Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University.

Sarbani Das is working as Assistant Professor in the department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University. Her research interest includes Control Systems, Instrumentation and Controller Design.

A Review on Stability Improvement of Wind Farm using FACTS Device

Darihun Sawkmie[1], Julene Seka H. Thabah[2], Maitshaphrang Lyngdoh[3], Smriti Dey[4]

[1,2,3,4]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati-781017, Assam, India
[2]julenethabah@gmail.com, [4]smriti.dey@dbuniversity.ac.in*

Abstract: ***This paper represents a review on Stability improvement of wind farm using Flexible AC Transmission System (FACTS) device. FACTS devices are used to increase the transient stability on the presence of faults and the integration of renewable sources, like wind energy. Due to continuously varying wind speed and also due to fault the active and reactive power along with terminal voltage fluctuates continuously. By connecting Static Synchronous Compensator (STATCOM) into the grid, the active power, reactive power and terminal voltage are maintained constant and also help to improve the transient stability of the system.***

Keywords: Transient Stability, Wind farm, FACTS, STATCOM.

1. Introduction

Wind power industry is developing rapidly, more and more wind farms are being connected to the power systems to utilise the available wind energy for reducing electricity price and generating clean energy. Although there is a significant growth and great development in wind energy generation technology, the only way of generating electric power or electricity from available wind energy is to use wind turbines which converts the energy available in flowing air into electricity [2]. Due to low maintenance cost of turbines as well as high capacity electric power generation wind turbines has attracted the attentions of utilities.

The most common type of wind turbine is the fixed speed turbine with squirrel cage induction generator directly connected to the grid. These wind turbines based induction generators require reactive power for compensation. Sufficient power has to be supplied to the turbine to maintain the electromagnetic torque of the wind generator. The electromagnetic torque in case of wind generator decreases significantly if the sufficient amount of power is not supplied to the turbine. The wind generator and turbine speeds increase rapidly if the difference between mechanical and electromagnetic torques increases. As a result, the system becomes unstable due to behavior of the induction generator and that results in disconnection of induction generator from the power system. The shutdown of a large wind farm creates serious effects on operation of the power system like loss of generation, voltage and frequency variations and power imbalance. Therefore the shutdown operation has to be decreased [3].

2. General Background

The Static Synchronous Compensator (STATCOM) is a controlled reactive-power source, consists of shunt connected voltage source converter through coupling transformer with the transmission line. STATCOM can control voltage magnitude and, to a small extent, the phase angle in a very short time and therefore, has ability to improve the performance of the system [1].Due to the increased load demands as well as the economic growth and rapid increase in emission of CO_2 creates the global warming. These problems created the desire for renewable energy sources like solar energy, wind energy etc. Electricity generation using wind turbine generator has attracted more attentions [3].

Fixed speed turbine induction generator with squirrel cage type is the most common type of wind turbine generator directly connected to the grid. Reactive power compensation is required for these types of wind turbines based induction generators. If sufficient reactive power is not supplied, the system becomes unstable due to the imbalances in the torques i.e. electromagnetic and mechanical torques.

Short circuit of power systems network, equipment short circuits, loss of production capacity and tripping of transmission lines creates fault on power system. Faults on power systems are related to the transient stability of the system. Such kind of faults affects the both real and reactive power flow and also their balances. When large voltage drops occur, there will be unbalances and redistribution of real power and reactive power in the power network which may force the voltage to cross the limit of stability even though the induction generator have the suitable capacity. After that, a period of low voltage may occur and possibly be followed by a complete loss of power system and the wind farm connected nearby will be affected by this problem. If a fault strikes the transmission line and causes the voltage at point of common coupling of local wind turbines to drop, then local wind turbines will be simply disconnected from the grid and reconnected when the fault is cleared and the voltage returned to normal operating conditions. Earlier, wind power penetration was low, wind power generation by wind farms increases as the penetration of wind energy increases. Due to the imbalances between electromagnetic and mechanical torques, stability of the system gets affected for that production of wind generation is lost. Therefore a large capacity of wind farm may have to be suddenly disconnected from the systems. The system may suffer a drop in voltage or frequency and possibly followed by a complete blackout unless the remaining power plants replace the loss within a very short time. As a result, to avoid total disconnection from the grid, there might be a new generation of wind turbines that can ride through the disturbances and faults. It is important to ensure that the wind turbine can restore the normal operation in a simple way and within suitable time in order to keep system stability. Optimization of wind turbine technologies may result in adequate design so as to face the future problems. FACTS devices such as STATCOM may be used to limit these problems and support the system stability [1].

3. Wind Farm

The combination of wind turbines are called wind farm, which is used for production of electricity. A few dozen to several hundred individual wind turbines constitutes a large wind farm and cover an extended area of hundreds of square miles (square kilometres. Because of strong winds flowing over the surface of an ocean or lake the best location of a wind farm is off-shore.

4. Transient Stability

Transient stability of the power system is the ability of the system to maintain or remain synchronism or returned back to its original position after subjected to a large disturbance. Severe or large disturbances like equipment outages, abnormal conditions like faults and load changes result in large excursion of generator rotor angles. The resulting system response is influenced by the nonlinear power-angle relationship. In case of transient stability study the time frame is usually considered as 3–5 s following the disturbance. The duration may extend up to 10–20 s for a very large system with dominant inter-area swings.

The main aspects of wind farm that affect the transient stability are location of wind farm and generator technology.

High wind resources located in one particular area leading high power generation for that modified power flows is required including increased tie-line flows. Critical fault clearing times can be considerably reduced and additional lines might be required to transfer the generated power.

Transient stability margins can be improved when variable speed wind generators being equipped with low voltage ride-through capability, reactive current boosting and ideally with fast voltage control. because the reactive contribution is highly limited due to reactive losses in sub-transmission and distribution systems, the integration of wind has a negative impact on transient stability [10].

5. Introduction of grid stability and its requirements

The connection of large wind turbines to the grid has large impact on grid stability. The squirrel cage induction generator of the constant speed systems always consumes reactive power. The consumption depends on the voltage and generated active power. In most of the cases this consumption is compensated by capacitors. By adding capacitors the impact of the wind generator is reduced. However, controllable reactive power sources are needed to fulfil the requirements, such as switched capacitor banks, STATCOM and Static VAR Compensator [10].

6. Literature survey of existing work

Bouhadouza Boubekeur *et al.* [1] describe how FACTS devices are used to increase the transient stability on the presence of faults and the integration of wind energy source. Wind turbine system is modeled in this paper. For modelling of wind turbine system, two main blocks are needed that is rotor model and generator model, and then it is connected to the grid. After connecting it to the grid simulation using MATLAB is done on presence of fault. Simulation results shows that using STATCOM shows the active and reactive power at the load bus stabilized faster with less oscillation compared with the results without using STATCOM in the transient state and even after the fault. The research work done by Omar Noureldeen, Mahmoud Rihan and Barkat Hasanin [2] presents about the impact of the fault which ride through on the stability of fixed speed wind farm which connected to the grid. Effect of the location of fault and its duration time are studied for different types of fault. The application of STATCOM to support the fixed-speed wind farm connected to grid during different fault locations and different fault duration times are investigated. Another research work done by Qusay Salem and Ibrahim Altawil [3] presents the transient stability enhancement in different operating conditions. A wind farm consisting of wind turbines which are based on fixed speed induction generators connected to grid has been proposed. A Static VAR Compensator (SVC) and STATCOM have been attached at the transmission system for reactive power support. It was noticed from the simulation results that STATCOM and SVC have strongly supported the point of common coupling voltage and reactive power as well as the grid voltage and reactive power particularly when the system has subjected to severe disturbances. In addition, it was also noticed that STATCOM is more robust and faster than SVC in recovering the system back to a stable operation. M. Tarafdar Hagh, A. Roshan Milani and A. Lafzi [4] described the effects of using a local resistance (stabilizer) and STATCOM in keeping and increasing stability of wind farms by MATLAB SIMULNK software and the STATCOM application role in induction generators stability increase to grid. FACTS devices are used in wind farm in order to keep the stability and also create generated power transmission. It uses 6 turbine which is of 15 mw each and it is connected to the grid by a 400/20 kV transformer. Squirrel cage induction generators are employed in this paper. In addition, the wind farm modelling and STATCOM usage are studied to increase the upper limits of induction generators dynamic stability in various distortion conditions in grid. The work done by Vaishali Chavhan and A. A. Ghute [5] presents the fixed speed induction generator (FSIG) based wind farm connected to interconnected power system. This paper presents the impact of fault on the system stability. After modelling of wind turbine and induction generator, STATCOM is also connected in order to make the system stable. Another research work done by Vimal Patel and Ravi Kumar Paliwal [6] describes the model to maintain the stable operation of grid connected wind farm when the fault ride through the system, voltage stability is a main important function for this operation. This paper investigates voltage source static VAR compensator such as STATCOM for the voltage stability as shunt compensator for DFIG-based wind farm connected to load and a grid Flexible AC Transmission System (FACTS) devices have been used for flexible power flow control, secure loading and damping of power system oscillation. Some of those are used also to improve transient and dynamic stability of wind power generation system (WPGS). The work done by Mohamad Amiri and Mina Sheikholeslami [7] presents the transient stability improvement of wind farms based on fixed speed induction generators using STATCOM and SVC. So the use of the SVC and STATCOM are investigated for wind farm integration. The effect of fault location and its duration time is studied for different types of fault. Simulation test that is using MATLAB-Simulink are implemented on a 9 MW wind farm which exports power to 120 KV grid. The research work done by V. Suresh Kumar, Ahmed F. Zobaa, R. Dinesh Kannan and K. Kalaiselvi [8] presents Power Quality and Stability Improvement in Wind Park System Using STATCOM where wind turbine is connected to an induction generator and synchronous generator was modelled using PSCAD to analyze power quality and reliability problems. STATCOM unit was developed to inject and absorb reactive power to mitigate power quality problems and to get stable grid operation. Voltage flicker and harmonics are the main power quality issues and two approaches are used to mitigate power quality problems, they are load conditioning which ensures that equipment is made less sensitive to power disturbances, allowing the operation even under significant voltage distortion and install line conditioning system that suppresses the power disturbances. The review work done by Sandeep Gupta, Prof. R. K. Tripathi and Rishabh Dev Shukla [9], shows how FACTS controllers are used in order to improve the voltage stability. These FACTS devices are used to adjust the magnitude of voltage in power system with proper control. M. K. Deshmukh and C. Balakrishna Moorthy [10] presented the different models of generators for stable operation of electrical power systems and then analysis the effects and improvement of power system stability of grid connected wind farm. Alok Kumar Mishra *et al.* [11] presented an overall perspective of wind power plants and grid integration. Various wind turbine systems with different generators are described, and different technical features are compared. It summarized the electrical topologies with grid requirement for grid stability of wind farms summarized and gives the possible uses of grid stability with wind farms.

7. Wind farm with STATCOM

STATCOM is the method that is used for compensating the transient stability in the System. It is a shunt connected device which is used to compensate the reactive power and it is able of generating or absorbing reactive power in which the output can be varied to control the parameters of an electric power system [7].

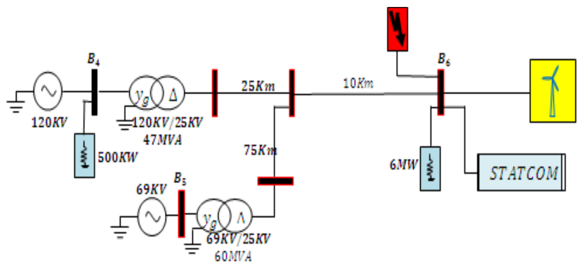

Figure 3: Modelling Wind farm with STATCOM[2]

When a fault occurs in the power system, the wind turbine mechanical power has to be reduced in order to improve stability. For fixed-speed rotor short circuited induction generators, it is not possible to control the input mechanical power, and therefore the effective approach would be the use of reactive power compensators such as Static Synchronous Compensator STATCOM or Static Var Compensator (SVC) to help the voltage recovery [2]. Compared with the SVC, the STATCOM has many advantages, such as overall superior functional characteristics, better performance, faster response, smaller size, cost reduction, and capable of providing both active and reactive power [8].

8. Conclusion

Wind power which is one of the important renewable sources is considered in order to analyze the effect of this generation on voltage operation and at the voltage stability limits. It can also be concluded that STATCOM can withstand the successive disturbances of the system more efficiently than SVC. In this system many problems occur and this problem compensated by using STATCOM. It full fill the reactive power requirement of the system at the time of fault occur in the system. Because when fault occur on system then voltage low and system get unstable so in that case STATCOM help the system. The impacts of the Static Synchronous Compensator STATCOM on the stability of the system during different fault locations and different fault duration times are studied.

References

[1] B. Boubekeur, A. Gherbi and H. Mellah, “Application of STATCOM to Increase Transient Stability of Wind Farm”, *American Journal of Electrical Power and Energy Systems*, Vol. 2, Issue No. 2, 2013, pp.50-56. Doi: 10.11648/j.epes.20130202.14

[2] O. Noureldeen, M. Rihan and B. Hasanin, “Stability improvement of fixed speed induction generator wind farm using STATCOM during different fault locations and durations”, *Ain Shams Engineering Journal*, Vol. 2, Issue No. 1, March 2011, pp. 1-10. Doi: https://doi.org/10.1016/j.asej.2011.04.002

[3] Q. Salem and I. Altawil, “Transient Stability Enhancement of Wind Farm Connected to Grid Supported with FACTS Devices”, *International Journal of Electrical Energy*, Vol. 2, Issue No. 2, June 2014, pp. 154-160. Doi: 10.12720/ijoee.2.2.154-160

[4] M. T. Hagh, A. R. Milani and A. Lafzi, “Dynamic stability improvement of a wind farm connected to grid using STATCOM”, *2008 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, Krabi, 2008, pp. 1057-1060. Doi: https://doi.org/10.1109/ECTICON.2008.4600614

[5] V. Chavhan and A. A. Ghute, “Stability Improvement of Wind Generation UsingFACTS Device”, *Technical Research Paper Competition for Students (TRPCS-2K17)*, 23 March 2017, G. H. Raisoni College of Engineering and Management, Amravati, Maharashtra, India. Retrieved from https://www.ijsr.net/conf/TRPCS2017/TRPCS2K17-15.pdf

[6] V. Patel and R. K. Paliwal, “A Study on Improvement of the Transient Stability Using STATCOM in DFIG Based Wind Farm”, *International Journal of Modern Trends in Engineering and Research*, Vol. 2, Issue No. 3, pp. 56-61. Retrieved from https://www.ijmter.com/papers/volume-2/issue-3/a-study-on-improvement-of-the-transient-stability-using-statcom-in-df.pdf

[7] M. Amiri and M. Sheikholeslami, “Transient stability improvement of grid connected wind generator using SVC and STATCOM”, *Proceedings of International conference on Innovative Engineering Technologies (ICIET’2014)*, Dec. 28-29, 2014, Bangkok (Thailand), pp. 136-140. Retrieved from http://iieng.org/images/proceedings_pdf/7452E1214025.pdf

[8] V. S. Kumar, A. F. Zobaa, R. D. Kannan and K. Kalaiselvi, “Power Quality and Stability Improvement in Wind Park System Using STATCOM”, *Jordan Journal of Mechanical*

and Industrial Engineering, Vol. 4, Issue No. 1, Jan. 2010, pp. 169-176. Retrieved from https://pdfs.semanticscholar.org/b2a3/c241e6c5cd9f3e37c9c77d61861e6e3699d0.pdf

[9] S. Gupta, R. K. Tripathi and R. D. Shukla, "Voltage Stability Improvement in Power Systems using Facts Controllers: State-of-the-Art Review", *2010 International Conference on Power, Control and Embedded Systems*, Allahabad, 2010, pp. 1-8. Doi: https://doi.org/10.1109/ICPCES.2010.5698665

[10] M. K. Deshmukh and C. B. Moorthy, "Review on Stability Analysis of grid connected Wind Power Generating System", *International Journal of Electrical and Electronics Engineering Research and Development (IJEEERD)*, Vol. 3, Issue No. 1, Jan-March 2013, pp, 1-33. Retrieved from https://www.researchgate.net/publication/267331051

[11] A. K. Mishra, L. Ramesh, S. P. Chowdhury and S. Chowdhury, "Review of Wind Turbine System and its Impact for Grid Stability", *Journal of Electrical Engineering*, Vol. 11, Issue No. 1, 2011, pp. 153-170. Retrieved from http://www.jee.ro/covers/art.php?issue=WZ1280390887W4c5136e7ac4d4

Authors' Profile

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[1]Darihun Sawkmie

[2]Julene Seka H. Thabah

[3]Maitshaphrang Lyngdoh

B.Tech. 8th semester,
Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University, Airport Road, Azara, Guwahati-781017, Assam, India

Smriti Dey is an Assistant Professor in the department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University. She is currently pursuing Ph.D. in Gauhati University, India. She completed her M.Tech. degree from NIT Silchar with specialization in Power and Energy System Engineering in 2012. She did her B.Tech. degree in Electrical Engineering in 2010 from NIT Agartala, India. Her research interests are Power Management, FACTS, Network Pricing, Power Quality.

High Voltage Boost Converters: A Review on Different Methodologies and Topologies

Saurav Bharadwaj[1], Indrajit Barman[2], Midar Riba[3], Asish Arpan Dadhara[4], Biswajit Sengupta[5]

[1,2,3,4,5]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati-781017, Assam, India
[1]sauravbharadwaj41@gmail.com, [5]biswajit.sengupta@dbuniversity.ac.in*

Abstract: ***Power converters are a fundamental element in the industries, micro-grids and households appliances providing all the necessary power regulation increasing flexibility of the voltage, current, power and phase. In this review a number of boost converters are studied, responsible for converting a low direct current voltage to a higher magnitude using a number of different methods including coupled inductors, series combination of a capacitor and two parallel inductors and an inductor discharging to two series connected capacitors in transfer of power. The converters encounter two major practical issues sudden rise in di/dt and dv/dt that drastically reduces the efficiency and increases power loss in passive elements and stress in active switches.***

Keywords: Boost Converter, DC power transfer, Zeta Converters, Dual active bridge (DAB), Miller capacitor, V2G operation.

1. Introduction

Boost converter is a fundamental component of a system dealing in changing the direct current power. It is responsible for boosting the input source voltage to a higher level following the law of conservation of power within the system and hence reducing the output current. In this study, a number of boost converter topologies are being considered from different literatures where authors introduced a number of methods including the technique of coupled inductors where two inductors are charged and transfer the power to the capacitor connected parallel across the load [2]. The method of transferring the charge to two parallel capacitors from energized inductor is a method exactly opposite to the previous method. A new topology of bidirectional control of power flow can be implemented in microgrids, renewable energy systems, automotive and other applications using the technique of switched capacitor has been proved to be an efficient method of buck/ boost in a single converter [1]. These converters provide power from source to the battery or battery back to the bus in opposite direction under the operation of buck-boosting the input voltage to a desired output under the necessary bi-directional power transfer conditions [5]. A number of di/dt and dv/dt techniques are implemented on converters to have an independent electronic control on the output terminal to a wide range for reducing the use of passive components. It is made in compact configuration of the power modulators and integrated gate drives [4].

2. Bi-directional Power Flow

In applications of renewable energy systems, railway transportation, automotive transportation and aerospace applications, elevators and escalators, uninterrupted power supplies, batteries, super capacitors and smart grid applications, where the use of bidirectional power flow plays an important role providing power to the bus or controlling the power balance in the system [1,5]. These converters can be efficiently designed for providing the stored power from the battery back to the grid is called as V2G operation [1]. A conventional converters having a drawback of leakage inductance and can be resolved by complex circuitry.

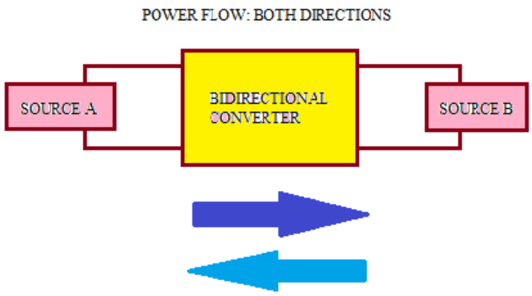

Figure 1: Power Flow in Bidirectional Converter

A general buck-boost converter can be improved into a three- level topology or a multilevel for the wider range of voltage generation and direct current voltage transfer gain. The major disadvantage in these multi-level converters is voltage capacitor balance. Zeta converters can be modified for the use in bidirectional voltage transfer techniques [1].

Dual active bridge (DAB) is a kind of isolated bidirectional dc-dc converter for high power applications. Energy transfer of the converter is controlled by adjusting the phase shift of the two ac voltages produced across the isolated transformer.

3. Power Flow Control by Switching and Semi-conductor Switches

In a distribution system, electrical transformers are existing component required for power flow control in the power system. On the other hand, use of the reactive components i.e. inductors and capacitors make the system more expensive and bulky. It may be considered that the use of series resistance is a way of absorbing power and negatively responsible for significant power loss (fig. 2 and 3). Therefore, the loads may be responsible for absorbing significant electrical power due to its inertia [9].

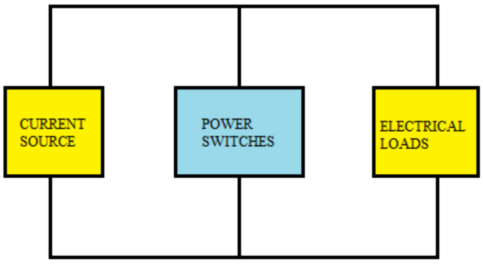

Figure 2: Parallel Configuration of Current Source, Power Switch and Electrical loads

In electrical loads, synchronous machines compensate the reactive power generated in the system. A grid is found to be efficient in adding minimum a synchronous machine to the system for absorbing or supplying reactive power.

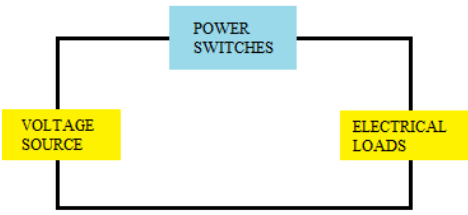

Figure 3: Series Configuration of Voltage Source, Power Switch and Electrical loads

4. Concept of Parallel Capacitor and a Inductor

A method of boosting an input voltage is done, implementing two series capacitors and an inductor. It is successfully designed and capable of increasing the efficiency to a high value of 95.03%. Parallel capacitors are charged during the time when the switch is turned off and energy stored in the capacitor is discharged to an inductor during turn on of the switch [2]. It enhances the voltage build across the inductor and boosts the input voltage.

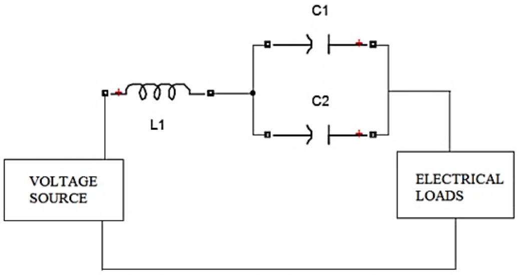

Figure 4: One Inductor Parallel Capacitor Configuration

Octavian Cornea et al. designed a boost converter for converting a voltage of 24V to a higher value of 400V for a power rating of 200W [2]. These circuits produce a very high-current transient which can be resolved by adding an inductor at the output of the parallel capacitor and resistive load circuit. An advantage of this method is reducing transient and efficient regulation of the converter together called as soft charging of switched coupled inductor.

5. Concept of Parallel Inductors and a Capacitor

A number of mutually coupled inductors are winded in a ferrite core of equal mutual inductance and resistance. A low dc voltage is switched in a periodic manner creating a fluctuating voltage across the primary inductor (fig. 5). Therefore, an induced voltage in the other inductors is induced and controlled by switching with semi-conductor switches. Energy stored in the inductors is transferred to a capacitor connected across the load in turn-off time of the switches connected in secondary inductors.

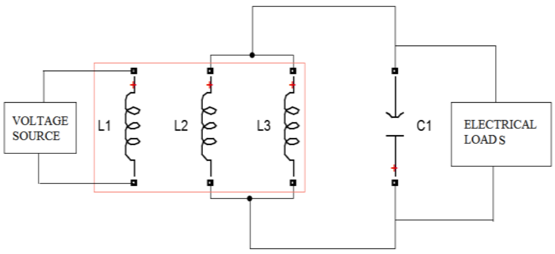

Figure 5: Parallel Inductorsand a Capacitor Configuration

A certain amount of harmonics produced in the converter can be minimized by implementing a harmonics filter. Conditions of di/dt and dv/dt, present in the output and switching characteristics can be reduced with a proper resistance-capacitance and active snubbers in the circuit [3, 5]. In absence of snubber circuit, high voltage spikes are producedacross input source and reflected in output voltage of the converter.

In designing of three single cored mutual inductors having partial resemblance with construction of a three winding transformer produces a finite magnitude of flux leakage in the core. Therefore, two methods are mentioned in testing the leakage and admittance;simulate the circuit considering finite element method (FEM) and laboratory measurements. Terminal Duality Model (TDM) analysis of the mutually coupled inductor in a single core illustrates the one-to-one relationship and terminal leakage measurement [7]. The duality model of mutually coupled inductors defines the magnetic flux distribution and leakage inductance in the inductors. Leakage flux path can geometrically be proved using the dual model of electric and magnetic circuit of the converter. Modeling of the inductor can be stated based on the steady state analysis and electromagnetic transient [8].

6. Single Switch Continuous Conduction Mode

In boost converters, a voltage spike suddenly appears as the switch is being reversed biased. A reverse biased recovery time of the continuous conduction mode creates a problem of dissipation and interference. Several voltage spikes are produced and to overcome these spikes, a number of active and passive circuits are being designed. In the literature, single switched continuous conduction mode converter is designed to reduce the reversed recovery time and switching losses. The proposed converter consists of a coupled inductor rectifier at the input and output node, connecting a rectifier between ground and common node of the coupled inductor rectifier branch. Leakage inductance of the coupled inductors is used to control the di/dt produced in the switches. It helps in both turning off the rectifier and clamping the output voltage. This does not require any extra snubber circuit from parasitic ringing. Boost switches can operate in low voltage turn-on conduction and the inductors provide parasitic capacitance to discharge before the switch is turned on [2].

7. dv/dt and di/dt control

A severe phenomenon of sudden rise of current and voltage within a very short period of time is practically observed in switching elements in converters. The technique of active gate control is used for flexible and independent control in the output current and voltage rise of insulated gate bipolar transistor (IGBT) and metal oxide semi-conductor field effect transistor (MOSFET), replacing the conventional resistance-capacitance (RC) snubber circuits. Miller effect is used to sense the collector terminal voltage and feedback to the gate terminal and reduces the dv/dt phenomenon. A number of advantages of the effect; control circuit begins as soon as drain voltage changes and collector voltage transient starts to rise without additional detection or timing circuit [4].

Controlling of the switch can be done during di/dt by changing the current gain or external impedance in the Miller capacitance. The circuit operates as there is turn on or turn off transient without any additional detection and timing circuits [4].

8. Boost Converter: Thermoelectric Energy Harvesting

Thermoelectric energy harvesting is a revolutionary technology implemented in biomedical engineering. A basic component is a low voltage and low power boost converter responsible forsupplying power to the device placed in the body. Medical and animal tracking sensors and devices are being powered with a maximum boosted voltage and power of 1V and 10uW and an input of 20mV to 250mV from the body. A major challenge is change in body temperature, as one side is placed in cold ambient air and other side in warm condition. Body temperature is affected by a number of parameter including ambient temperature, air flow and thermal insulation due to variety of clothing [6].

Discontinuous conduction mode is considered to be more effective as inductor is prevented from flowing negative and anaverage current is less the half of ripples current. In continuous conduction mode, the capacitor discharges and increases switching loss. The new modified method of synchronous rectifier described in number of literatures states that a reactive gate control uses a comparator to detect the p-type field effect transistor (pFET) becomes reversed biased and triggers a pulse to disable the switch. The two major disadvantages of the circuit; it requires a very fast comparator evaluation and gate driver for pFET. In order to overcome, a static (Complementary Metal Oxide Semi-conductor) CMOS flip-flop is implemented for the operation. The new topology improves overall efficiency of the converter by 15% than a general converter under conventional synchronous rectifier converter [6].

9. Conclusion

DC power transfer is a remarkable operation in every constant voltage system. Harmonics are being produced in the output of converters and can be reduced by filters including resistance-inductor,

inductor-capacitor and resistance-capacitance. The production of harmonics deviate the constant current or voltage output to a sinusoidal waveform results in undesired output of the circuit.

Switches are rapidly turned on or off and used to convert a dc voltage to fluctuating dc in application to mutual inductors results in voltage spike. Sudden spikes of triangular peak increase the voltage and current stress in the switches reducing the life time of elements in circuit.

In dc grid system, power is transferred in both directions using bi-directional DC-DC converter using switched capacitor technique. A number of renewable sources are cascaded including hydro, photovoltaic and wind. Boost converters using technique of energy transfer from series capacitors to an inductor can be used in the distributed system. It is also reliable to use the circuits to reduce the reverse recovery time and enhance performance of the converter and its system. A number of applications of the boost converter are motor drives and robotics in industries; automobile headlight and light emitting diode in lightning; data center and uninterruptable power supply in telecom; plasma research and particle accelerator in physics and pulsated laser and radars in military.

References

[1] M. Forouzesh, Y. P. Siwakoti, S. A. Gorji, F. Blaabjerg and B. Lehman, "Step-Up DC–DC Converters: A Comprehensive Review of Voltage-Boosting Techniques, Topologies, and Applications", *IEEE Transactions on Power Electronics*, Vol. 32, Issue No. 12, December 2017, pp. 9143-9178. Doi: https://doi.org/10.1109/TPEL.2017.2652318

[2] O. Cornea, G. D. Andreescu, N. Muntean and D. Hulea, "Bidirectional Power Flow Control in a DC Microgrid Through a Switched-Capacitor Cell Hybrid DC–DC Converter", *IEEE Transactions on Industrial Electronics*, Vol. 64, Issue No. 4, April 2017, pp. 3012-3022. Doi: https://doi.org/10.1109/TIE.2016.2631527

[3] Y. P. Hsieh, J. F. Chen, T. J. Liang and L. S. Yang, "Novel High Step-Up DC–DC Converter for Distributed Generation System", *IEEE Transactions on Industrial Electronics*, Vol. 60, Issue No. 4, April 2013, pp. 1473-1482. Doi: https://doi.org/10.1109/TIE.2011.2107721

[4] D. D. C. Lu, D. K. W. Cheng, and Y. S. Lee, "A Single-Switch Continuous-Conduction-Mode Boost Converter With Reduced Reverse-Recovery and Switching Losses", *IEEE Transactions on Industrial Electronics*, Vol. 50, Issue No. 4, August 2003, pp. 767-776. Doi: https://doi.org/10.1109/TIE.2003.814989

[5] S. Park, and T. M. Jahns, "Flexible dv/dt and di/dt Control Method for Insulated Gate Power Switches", *IEEE Transactions on Industry Applications*, Vol. 39, Issue No. 3, May-June 2003, pp. 657-664. Doi: https://doi.org/10.1109/TIA.2003.810654

[6] E. J. Carlson, K. Strunz, and B. P. Otis, Member, "A 20mV Input Boost Converter With Efficient Digital Control for Thermoelectric Energy Harvesting", *IEEE Journal of Solid-State Circuits*, Vol. 45, Issue No. 4, April 2010, pp. 741-750. Doi: https://doi.org/10.1109/JSSC.2010.2042251

[7] Casimiro Álvarez-Mariño, Francisco deLeón, and Xosé M. López-Fernández, "Equivalent Circuit for the Leakage Inductance of Multiwinding Transformers: Unification of Terminal and Duality Models", *IEEE Transactions on Power Delivery*, Vol. 27, No. 1, January 2012, pp. 353-361. Doi: https://doi.org/10.1109/TPWRD.2011.2173216

[8] F. de León and J. A. Martinez, "Dual Three-Winding Transformer Equivalent Circuit Matching Leakage Measurements", *IEEE Transactions on Power Delivery*, Vol. 24, Issue No. 1, January 2009, pp. 160-168.Doi: https://doi.org/10.1109/TPWRD.2008.2007012

[9] W. Shepherd and L. Zhang, *Power Converter Circuits*, 2004 edition, pp. 1-11, Marcel Dekker, New York, 2004.

HVDC and Green Power Corridor: A Review

Manash Jyoti Baishya[1], Satyajit Bhuyan[2]

[1,2]Assam Engineering College, Gauhati University
Jalukbari, Guwahati - 781013, Assam, INDIA.
manashiitkgp@gmail.com, satyajeetbhuyan@yahoo.co.in*

Abstract: ***High Voltage Direct Current transmission system can turn out to be the ideal power transmission system for bulk power and transferring clean power from remotely locatedhydroelectric dams to distant load centers. Therefore, the solution to the sudden increased demand for electricity can be found by evacuating remotely located bulk renewable energy and transmitting the clean power to load centers located at a significant distance away via HVDC link.***

Keywords: Bulk power transmission, Green power, HVDC, Renewable energy.

1. Introduction

With the increasing population, big cities need large amounts of electricity to function. The required power is transferred from remotely located generating stations. However, due to deteriorating environmental conditions and increased stress on clean power, the question is how to transfer power from renewable energy generation sites like hydro plants and wind grid parks to distant load centers. HVDC (high-voltage direct current) power transmission can be the solution. The major challenge of renewable energy generation is the intermittent nature of the renewable energy source. If harnessed properly, the HVDC transmission link can prove to be beneficial for bulk renewable power transmission.

2. HVDC Basics

HVDC power transmission started in the second half of the last century and provided a new way of power transmission. The initial power transmission level was very low; however with the change of technology, the power transmission level has increased significantly. Transmission of thousands of MW is being done currently via HVDC link in monopolar and bipolar mode of operation. India has also joined the HVDC membership by starting the world's first multi-terminal HVDC link from Biswanath Chariali (Assam) to Agra with Alipurduar in between. Majority of the power transmitted via the HVDC link is remotely located hydro power which is green power. HVDC links pave the way for harnessing of untapped clean and green hydro potential.

HVDC interconnections require a conversion from AC to DC and vice versa at each connection point with the AC system. This collection of equipment at each AC connection point is referred to as a converter station. The converter station requires a higher capital outlay than would be required for an AC substation; however, HVDC transmission towers are simpler and smaller than AC towers. For a monopolar HVDC link (equivalent to a single AC circuit), only one high voltage conductor is required, as opposed to three in the equivalent conventional 3-phase AC system. In some locations, electrodes can even be inserted into the earth to provide the low voltage return path. With DC transmission the DC voltage remains fixed, thus the insulation levels and the equivalent outside conductor radius required for the transmission conductor are proportional to the continuous voltage applied to the conductor.

Though ac power transmission mode is widely used, HVDC power transmission has the following advantages:

1) Bulk power transmission with reduced losses.
2) Increasing the power transmission capacity and short circuit capacity of a grid.
3) Allowing power transmission between two asynchronously connected grids.
4) Reducing the Right of Way for transmission towers.
5) Connecting a remote hydro generating plant to the load centers.
6) Reduced Corona losses.
7) Reduced conductor cost for same amount of power transmission via ac network.
8) Fast and accurate control.

2.1 Modes of HVDC Operation

The various modes of operation in HVDC are as follows [1] :

a) Monopolar operation with ground return :
In this mode of operation, only one pole is in operation and the return path for the circuit is via ground. At times, there are limitations in operating the monopole in ground return mode. The limitations may arise due to environmental impact.

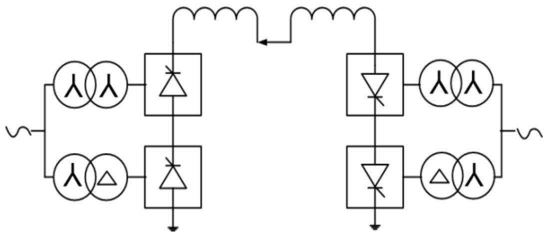

Figure 1: Monopolar HVDC with ground return

b) Monopolar operation with metallic return :
In this mode of operation, only one pole is in operation and the return path is via the conductor of the other pole or via dedicated metallic return path. Upcoming HVDC projects shall have only Dedicated Metallic Return path and the ground return mode shall not be utilized. Provision of electrode station for ground return shall be replaced by dedicated metallic return path.

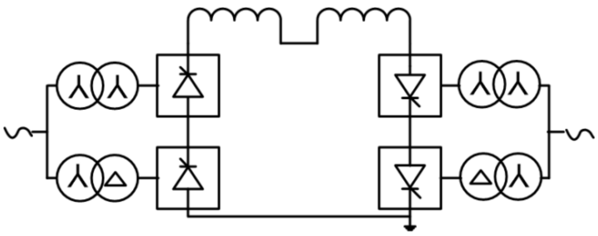

Figure 2: Monopolar HVDC with metallic return

c) Bipolar operation :
In this mode of operation, both the poles of a station are in operation. The circuit is completed via the conductor of both the poles. In case of any unbalance, the unbalance current is grounded in the electrode station.

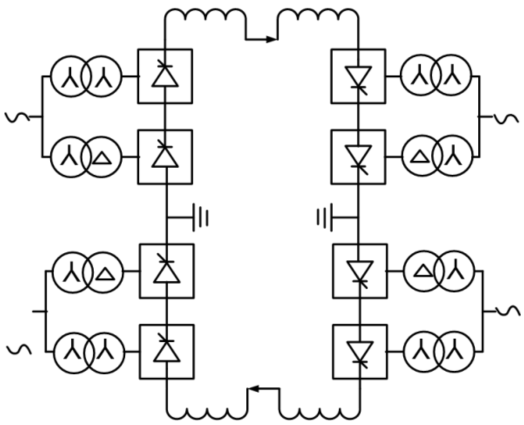

Figure 3: Bipolar HVDC system

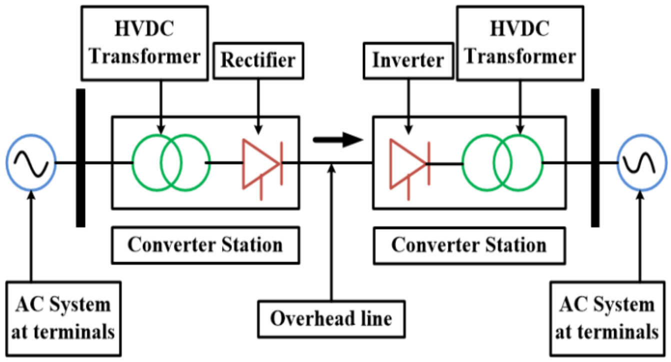

Figure 4: Typical layout of a HVDC link

3. CSC and VSC based HVDC

3.1 CSC (Current Source Converter) mode

CSC uses thyristor valves as switching devices. The thyristors can be turned off only when the current flowing through it falls to zero. The thyristors help in building stable high dc voltage. CSC-HVDC is suitable for high voltage bulk power and long distance transmission projects. CSC based stations can be used for reverse power flow by changing the polarity of the thyristor valves. The current direct direction shall remain unchanged[2].

3.2 VSC (Voltage Source Converter) mode

Insulated Gate Bipolar Transistor (IGBT) is used in VSC-HVDC projects. A new VSC topology, Modular Multilevel Converter (MMC) is bearing used for effective dc voltage build up in VSC based HVDC stations. Being a forced-commutated voltage source converter, it does not need the ac voltage support from grid side for commutation. The major advantage of VSC based HVDC stations is that these stations can be utilized as first station to charge during black start in case of grid failure.

4. HVDC and Green Power Corridor

The utility of HVDC can be seen in the case of integrating with renewable energy sources which are intermittent in nature. Due to the non-sinusoidal input to the grid by the renewable energy sources at times, the renewable energy can bring in harmonics to the grid. However, if it is integrated to the HVDC link, the AC filters will eliminate the harmonics and allow only sinusoidal voltage to enter the HVDC system. Thus, HVDC will prevent harmonics from entering the grid.

Wind generation –particularly in the coastal areas and in the seas where the wind is strong can be an ideal energy source[3].The renewable energy sources can be intermittent in nature and because of this unwanted oscillation in the availability of power, it might be a very good idea to combine renewable energy sources directly with HVDC stations. The controllers and power oscillation dampers will eliminate any harmonics in the incoming ac power from renewable energy sources before it enters the HVDC valves. Thus, the ac grid is prevented from unwanted oscillations and harmonics by the HVDC station. The incoming ac power can be cleaned of any harmonics and sent to distant load centers by converting it to dc. ABB has recently constructed a 400-MW transmission link using HVDC Light technology for a wind park 130 kilometers off the German coast. HVDC Light is also attractive for its simple-to-handle cable design and modularized, factory-assembled voltage converter, which means the network links essential to receiving power from offshore wind parks can be quickly installed and commissioned. HVDC VSC is the technology preferred for connecting renewable energy sources, such as offshore wind farms, to the power system [4].

India's first green energy corridor project links Pugalur in Karur district in western Tamil Nadu with Raigarh in Chhattisgarh which will enable the southern State to transmit excess wind energy generated to central India. This link shall play the role of a key element of integrating renewable energy with the main grid. It will link thermal and wind energy from Tamil Nadu for transmission of power to load centers located far away, The Raigarh Pugalur project is owned by Power Grid Corporation of India (POWERGRID) and is being executed by ABB along with BHEL. This HVDC transmission line will support investments in wind energy in the state. The maximum power transmission capacity will be of 6,000 MW, and it will integrate thermal and wind energy transmission to high consumption centers. When wind energy generation in Tamil Nadu is in excess it will be transmitted to central India, and when electricity demand is high in Tamil Nadu, thermal energy can be transmitted from central India to the south [5].

In normal ac transmission systems, the losses during transmission are two to three times higher when compared to HVDC. This means that HVDC system will keep around 700,000 tons of CO_2 per year out of the atmosphere. In October 2011, HVDC facilities were certified as green technology by the United Nations Framework Convention on Climate Change (UNFCCC) [6].

5. Sources of clean power in India

There are many renewable energy sources that are presently being harnessed by the power generation companies with an eye to meet the clean power requirements [7]. However, the few renewable energy resources that are being directly connected to HVDC transmission lines for transmitting the clean power to distant load centers are as follows:

I. Hydro Power: India is a significant producer of hydroelectric power in the world. Many rivers and tributaries are found in the North Eastern part of the India. The North East India is high in hydro potential. This aspect has been aptly identified and the hydro power will be sent via HVDC link to power deficit regions in the Northern part of India. India's hydroelectric power potential is increasing significantly and it is estimated at 84,000 MW at 60% load factor [8].

II. Wind Power: The progress of wind power in India began in the 1990s, and has escalated in the last few years. As of 2017 the installed capacity of wind power in India was 29151.29 MW. Though wind is easily available but the particular wind speed required to drive a turbine and convert it into electrical energy is not found easily. Adequate wind speed which can be harnessed successfully is found in coastal areas and sea shore areas. Wind power accounts for 14% of India's total installed power capacity.

III. Solar Power: Solar power can be harnessed anywhere where the level of solar insolation is adequate. In India, most of the states receive sufficient solar insolation level and thus solar power can be utilised easily. In rural areas, one of the first applications of solar power has been for water pumping, to begin replacing diesel powered water pumps. Desert areas can be used to harness the solar power significantly. Some large projects have been proposed in the Thar Desert, which has been set aside for solar power projects, sufficient to generate bulk power.

6. Conclusion

The availability of electric power at all times is the paramount requirement from an electrical utility. However, with the growing adverse impact on the environment and climate, the power evacuation technique needs to keep an eye for reduced impact on the climate. The aspect of sustainability is gradually gaining in importance in view of such challenges as the global climate protection and economical use of power resources. With the advent of newer technology for harnessing renewable energy resources, the electrical transmission utilities in all parts of the world should be ready to transmit the clean and green power available to distant load centers. HVDC transmission lines shall pave the way for transmitting bulk power from remotely located renewable energy sources to the required load centers located far away from the point of generation. In the growing competitive market, all electrical utilities should pay significant attention for harnessing the untapped potential of renewable energy and deliver green power to the load centers. Proper measures should be taken by all the utilities so as to prevent undue stress to the global climate by reducing the dependency on fossil fuels, reducing the expulsion of CO_2 gas and also reducing the damage on the global climate. HVDC transmission lines along with FACTS technology can reduce a lot of stress on global environment by providing a proper channel for long distance green power transmission to the required load centers. A sustainable green power transmission will be required in the near future to cater to the increasing demand for green power which can be aptly provided by HVDC power transmission technology.

References

[1] Alstom Grid, "HVDC for beginners and beyond", Booklet, *Alstom Grid UK PES*, 2010. Retrieved from http://cigre.ru/research_commitets/ik_rus/b4_rus/library/ALSTOM_HVDC_for_Beginners_and_Beyond.pdf

[2] F. Wang, L. Bertling, T. Le, A. Mannikoff and A. Bergman, "An overview introduction of VSC-HVDC: State-of-art and potential applications in electric power systems." *Proceedings of Cigre International Symposium*, Bologna, Italy, Sept. 2011. Retrieved from http://publications.lib.chalmers.se/records/fulltext/179408/local_179408.pdf

[3] "Connecting renewable energy to the grid", *ABB*. [Online]. Available: http://www.abb.com/cawp/seitp326/377dbeff7a3a6aedc12577c20033dbf5.aspx [Accessed: August 20, 2017]

[4] M. Claus, D. Retzmann, D. Sörangr and K. Uecker, "Solutions for Smart and Super Grids with HVDC and FACTS", *Proceedings of 17th Conference on Electric Power Supply Industry (CEPSI 2008)*, Macau, 27-31 Oct. 2008. Retrieved from http://m.energy.siemens.com/br/pool/br/transmissao-de-energia/facts/Solutions-for-Smart-and-Super-Grids-using-FACTS-&-HVDC.pdf

[5] M. S. Preetha, "Two-way corridor to transmit thermal, wind power between T.N. and other states", *The Hindu*, May 26, 2017. [Online]. Available: http://www.thehindu.com/news/cities/chennai/two-way-corridor-to-transmit-thermalwind-power-between-tn-and-other states/article18579457.ece [Accessed: August 20, 2017]

[6] A. Rohr, "Power Transmission: HVDC in India", *Siemens*, Oct. 1, 2014. [Online]. Available: https://www.siemens.com/innovation/en/home/pictures-of-the-future/energy-and-efficiency/power-transmission-hvdc-in-india.html [Accessed: May 1, 2018]

[7] "Renewable energy in India", *Wikipedia*. [Online]. Available: https://en.wikipedia.org/wiki/Renewable_energy_in_India [Accessed: Sept. 2, 2017]

[8] "Hydroelectric power in India", *Wikipedia*. [Online]. Available: https://en.wikipedia.org/wiki/Hydroelectric_power_in_India [Accessed: Sept. 2, 2017]

Authors' Profiles

Manash Jyoti Baishya is a Research Scholar in Gauhati University, India. He completed his Master Degree from IIT Kharagpur with specialization in Power and Energy Systems in 2013. He did his B.E Degree in Electrical Engineering in 2011 from Assam Engineering College, India. He has published research papers in the field of high voltage engineering.

Dr. Satyajit Bhuyan is an Associate Professor in the department of Electrical Engineering, Assam Engineering College, Gauhati University, India. He completed his Ph.D. at Jadavpur University, India. His area of interest is power systems. He has published a number of research papers in the field of power systems and high voltage engineering.

Potential of Archimedes Screw Turbine in Rural India Electrification: A Review

Pallav Gogoi[1], Mousam Handique[2], Subrendu Purkayastha[3], Khemraj Newar[4]

[1,2,3,4] Department of Mechanical Engineering,School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati -781017, Assam, INDIA
*[1]pallav.gogoi@dbuniversity.ac.in, [2]mousam222@gmail.com**

Abstract: ***With the growing population of India, the demand for energy consumption is increasing. For an overall development of a region, especially remote areas, electricity is of prime importance. Production of electricity in large scale can further lead to various effects like environmental pollution, climate change and it is also costly. Thus the need of a socio-economic energy conversion to electricity is of prime importance for a sustainable development. India have a huge potential in the Hydro to generate 2,50,000 MW. An Archimedes Screw Turbine that was earlier used as pump can give a very good solution in harnessing water potential. It rotates as water flows through it, rotating the generator's prime mover connected to it. Archimedes Screw turbines operate at low head of 0.8m to 10 m and relatively lower flow rate than the other turbines and more cost effective and are highly efficient. The AST is quite a new form of electricity generation practice which has been implemented in different countries along with India. Thus the electrification scenario in rural areas can be improved specially where there is a continuous flow of a river or canal by the installation of the low cost socio economic AST.***

Keywords: Archimedes Screw Turbine (AST), Archimedes Screw Generator (ASG), Sustainable Development, Small Hydro Power, Rural Electrification.

1. Introduction

Renewable energy is a beautiful gift from the nature. The proper harnessing of these renewable resources into a useful form of energy is of prime importance. But during this continuous conversion of energy, various natural hazards may occur. Thus a proper form of energy conversion should take place to meet the energy demands in an optimal way. Electricity the foremost important form of energy can be harnessed through hydro power where moving water is used to rotate the prime mover of the generator where electricity is produced through electromagnetic induction. India is blessed with massive amounts of hydro-electric potential and ranks 6th in terms of utilizable hydro potential with 2,50,000 MW.Currently India has a total potential of 15,000 MW in Small Hydro Plants out of which only 2000 MW is installed [20]. A major portion of the rural India is still under darkness with no electricity. For electrifying the rural and remote parts in India, various schemes formed by Govt. Of India, RGVVY (Rajiv Gandhi Vidyutikar Vikash Yojana), DDUGJY (Deendayal Upadhyaya Gram Jyoti Yojana (Launched in Dec, 2014) being some of them, led to the increase of the number of rural household electrified from 44% to 67%. For Ministry of New and Renewable Energy, Govt. of India, Small hydro power programme is one of the thrust area of generating power from renewable resource [1].

Basically, the power that is generated from a hydro power plant is given by,

$$P = \eta \rho g H Q \text{ (kW)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where η is the hydraulic efficiency of the turbine, P is the mechanical power of the shaft, g is the acceleration due to gravity, ρ is the density of water, H is the effective , Q is the mass flow rate. [2]. Hence, more the head or the more the flow rate, higher is the power generated. To get very high power energy, the head should be increased upto a substantial height by making a dam .but such a task is difficult to achieve takes longer time and a lot of money is to be invested. Thus, the Hydro Power plants should be reservoir-less or of very low head. This could be achieved by the proper selection of the turbine depending on the site located. The Archimedes Screw Turbine(AST) can be used in such low head sites.

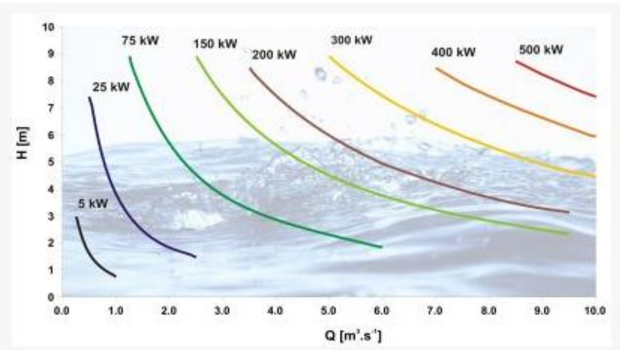

Figure 1: Power (kW) developed at different head and flow rate.

2. Rural India Electrification

The electricity situation in India, specially in the rural and remote areas is under groom with around 3,17,56,227 households unelectrified as on 10-Oct-2017 [7]. Electricity is either present or there are lot of interruptions in the power supply. Therefore, a proper way of conversion of energy into electrical energy that can be easily produced and distributed for that specific site, has to be chosen. For a developing country, these energy demands need to be satisfied. Electricity is one of the prime factors that can measure the development level of a country in terms of energy resource. It helps to increase productivity in agriculture and labour, gives access to communications (TV, RADIO), improved health conditions, improved lightning condition.For a rural and a remote a small hydro power plant is basically preferable as the installation cost and duration process is less. Small Hydro Power Plants can produce a net power of around 1-100 MW.

3. Archimedes Screw Turbine (AST)

Archimedes Screw generators have been started to be used widely specially at low head sites in Europe. In earlier days, the Archimedes Screws were used as a pump to lift water from a certain level to a higher level, specially in sewage treatment plants. These turbines are generally suitable in low head sites due to their high efficiency, low natural (environmental) impact, less cost and require less maintenance. These turbines can work under the head difference of as low as 1m upto 10m. An Archimedes screw consists of the cylindrical shaft along with some impinged helical surfaces called flights to form a screw like structure. The water enters the screw from the top and flows along the consecutive flights to rotate the shaft which in turn rotates the rotor of the generator. The maximum flow rate through the AST can be determined from the screw diameter. It can be installed in places with river or stream flowing in inclined way, an existing dam or weir, a dysfunctional hydropower plant, sites with variable flow.

3.1 Construction of AST

The main parts of a AST are the lower bearing, top bearing, gearbox, pump trough, floodgate, coarse screen and the Archimedes screw Turbine itself. The actual screw is below the upper bearing and the helical flights are formed from rolled flat steel plate, which is then welded to the central core. Majority of the screw turbines have three flights or helices welded around the cylindrical shaft [3].

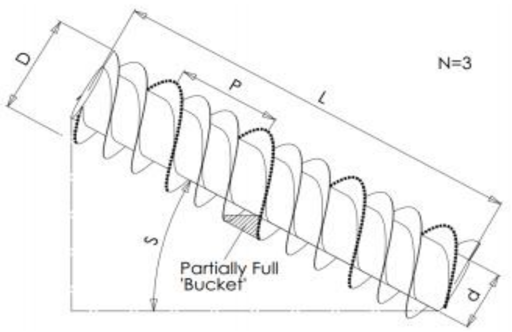

Figure 2: Example of ASG with 3 flights and geometric variables- Screw Turbine parameters [4]

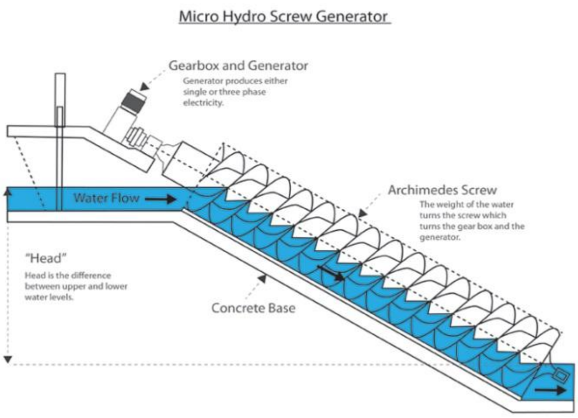

Figure 3: Basic model of Archimedes Screw Turbine [16]

Archimedes Screw is generally aligned 22 degrees from the horizontal, which is the most cost effective installation as per the experimental studies [10]. The mechanical power available at the turbine shaft is given by

$$P = \omega T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where ω is the speed of turbine m/s and T is the torque in Nm.

3.2 Efficiency

Efficiency of a turbine is its ability to transform the power and energy from the hydro power.

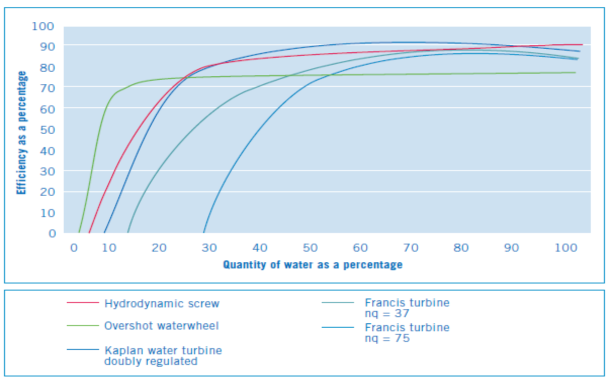

Figure 4: Efficiency comparison of different turbine types [15]

The efficiency is determined by the generator's efficiency and the various hydraulic losses. These losses include frictional loss due to fluid viscosity, leakage. So, these losses have to be minimum in order to obtain a higher efficiency.

Mathematically,

$$\eta = P_{mec} / P_{hyd} \quad (3)$$

$$P_{mec} = T\,\omega \quad (4)$$

Where, T is the torque provided by screw in Nm and ω = rotational speed of screw in rad/s.

$$P_{hyd} = \rho\, g\, Q\, H \text{ (in KW)} \quad (5)$$

Here P_{hyd} is hydro power, ρ is the density of water (kg/m^3), Q the flow rate in m^3/s, g = 9.81 m/s = the gravitational constant, H the head in meters [12].

C. Zafirah Rosly *et al.* in 2016 [13] conducted a study that identified various potential parameters of the turbine that can increase the power efficiency. They found that the combination of 3 blades with 3 helix enhances the overall efficiency. However a high efficiency of 81% was obtained when the turbine was designed with 2 blades and 3 helix turns. Through this study, it was found that the efficiency in AST is a function of the number of helix turns. Also in another research study by A. Nurul Suraya, N. M. M. Ammar and J. Ummu Kulthum in 2015 [14], it was found that lower inclination angle resulted in a higher efficiency.

4. Advantages of AST

(a) Environment Friendly: ASTs are one of the most environment friendly turbines. Being reservoir or damless there is no chance of flash floods near the site. Thus, the installation of an AST will not affect the surrounding. As a result, nearby people need not have to displace from the native part. Also as there is no chance of flash floods the natural vegetation nearby is not affected, so there will be no decomposition of this natural vegetation that might lead to the formation of the greenhouse gas methane which is primarily responsible for the climate changes hence reducing the CO_2 level.

(b) Fish friendliness of Archimedes Screw Generator (ASG): The safe passage of different aquatic animals specially fishes and debris makes the ASG even more versatile. An experimental test was conducted in the ASG present at the Dart River in Devon,UK and concluded that fish passes safely throughout the operation. Furthermore, it was found that the fishes less than 1 kg can safely pass through the blades if the blade tip velocity is upto 4.5 m/s without any protection on the leading edge of blade. A study by M. Lyons and W. D. Lubitz [4] showed that 98% of the fishes were able to pass through the turbine.

(c) Easy Set-up: It can be easily set up in small canals, ponds and rivers, etc. as the head requirement is not much (1m-10m). It also requires less maintenance and operational cost and it is easy to install as not much parts are there, thus reducing the civil work.

(d) Longer durability: The durability of an AST is more.A good quality AST has a design life of 30 years and further this can be extended with a major overhaul that includes re-tipping the screw flights. The wear and tear of the turbine is also less.

(e) Due to the low rotational speed of the turbine and more passage area, the debris can easily pass through the turbine and thus not affects the fertility of the soil towards the discharge basin.

(f) The maximum turbine efficiency of an ASG is upto 92% with a flow rate of 0.2-0.8 m^3/s with head from 0.8 m to 10 m.

The speed of the shaft is regulated with the help of the gearbox according to the current flow rate.

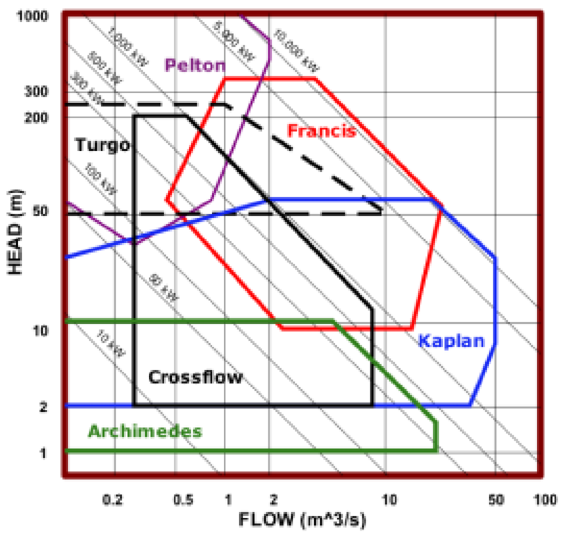

Figure 5: Classification of hydropower turbines for head V/s flow rate [14]

5. How can AST's solve rural electrification problem?

The unique, simple, environment friendly AST's being very cost effective and its specialty in low heads can be set up to electrify some of the rural and remote parts in the presence of a stream of river or continuous flowing water. If the requirement of power is high, then as per the requirement a different AST can be planned in a nearby place to meet the demands. ASTs if build as windmills in river, has the ability to generate upto few Megawatt's to electrify several households. As big dams are a major problem in various parts, ASTs can be planned in such regions to meet the energy demands.

6. Potential of AST in North East India

North East India, the Gateway to the South East Asia is gifted with vast bio-diversified energy resources and is considered as the future power house of India. Among the natural resources present, hydro energy has a huge potential in this region. According to the Ministry of New and Renewable Energy, these four states (Assam, Arunachal Pradesh and Meghalaya and Sikkim) together have utilized only 165 MW of capacity till date, though they are capable of generating 1,900 MW, a figure that is nowhere close to the real potential of these states. The Central Electricity Authority (CEA) has identified 63,238 MW in the Brahmaputra river basin. Also, the North Eastern region occupies around 34% of the country's total water wealth [11]. Archimedes Screws, since do not require much higher heads, can be properly planned in this region to electrify the darker regions.

Table 1: Hydro power scenario in North-East India as on 31.3.2017 [19]

State	Potential (MW)	Installed Capacity (MW)	Capacity Under Construction (MW)
Arunachal Pradesh	50328	405	2854
Assam	680	375	0
Manipur	1784	105	0
Meghalaya	2394	282	40
Mizoram	2196	0	60
Nagaland	1574	75	0
Sikkim	4286	1965	1326
Tripura	15	0	0
Total	**58971**	**3207**	**4380**

Note:- In addition, a total of 4785.60 MW of PSS are in operation and 1080 MW of PSS are under construction in all over India

7. Costs and economics

Investment and revenue streams are necessary for any financial analysis. The three main points that should be taken into account when doing the cost/benefit evaluation for the Archimedean Screw are -**(a)** the installation costs, **(b)** the annual operational costs and **(c)** the annual income from the electricity produced [3,4,17].

According to results of study conducted by Sachin Mishra, S. K. Singal and D. K. Khatod in 2012 [17], the total investment required for the Archimedean Screw can be divided into two main cost components – (i) The Electro-mechanical costs, and (ii) Civil Engineering Grid Connection and Installation/Commissioning Costs. The electro-mechanical costs consist of the main machine components of the scheme. Apart from the screw itself it should also include the trough, generator, gearbox, screen and inlet sluice gate. As for the civil engineering costs these should cover project management and site supervision through to materials (for screw supporting structure) and plant (shuttering, swing shovel etc.). The electricity generated will be sold to an energy company under a power purchase agreement.

The parameters on which the civil and electromechanical costs depend are the installed capacity, water head and year of commissioning [17].

$$C_{(a,b,c)} = a \times P^{b} \times H^{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Above eqn. is the basic cost equation for a small hydro project, where a, b and c are coefficients, C= Cost in rupees (Rs.), P = Installed capacity in kilo Watt (kW), and H = Head in meter (m). With rigorous experimental observations [17], the coefficients have been found giving the final cost equation as:

$$C = 6.882 \times P^{0.6369} \times H^{-0.0782} \quad \ldots\ldots\ldots\ldots (7)$$

where, C = Cost per kW in Indian Rupees, P = Capacity in kW, H = Head in m. A maximum deviation of ±10% has been observed and the cost prediction can be done in the initial stage. A lower head requirement for ASG thus lowers the cost of building a hydro power plant.

The AST with compared to the other types of turbine can be very cost effective. Use of AST requires less maintenance work and also less installation period (2-3 months), thus decreasing the overall cost. Since AST's work at low heads, not much has to be spent in building high reservoirs. Also, the setup of an AST does not require many parts [3].

8. Conclusion

ASGs are a proven hydropower technology appropriate for low head sites. Specifically, ASGs provide a unique opportunity for the private sector, small dam operators, and individual landowners to utilize existing hydropower renewable energy, adding a new source of renewable power into the region's energy mix. ASGs can be developed without many of the environmental impacts that accompany large-scale hydropower developments since many of the needed dams already exist. Furthermore, retrofitting already existing dams with ASG units would help improve dam safety, helping to safeguard property, individuals, and the environment from negative impacts of dam failure. ASTs are now widely used turbines especially in Europe and have been started to install in the U.S.A also. The rural India's electrical scenario can be thus improved by the installation of these turbines by locating the specific sites. Remote sensing and GIS can be used to determine the various parameters of a region like terrain surface, slope etc. [8]. AST is an eco-friendly, marine animals friendly, and the most important of all is that it is human friendly. It is 'Human Friendly' in a sense that since there is no need of construction of dam, therefore there will be no floods which will ultimately save people's life. Moreover, it is cost effective as it requires less labour, low maintenance and construction costs. It is more reliable compared to other turbines like Kaplan turbine, Pelton turbine, Francis turbine, etc. and also it requires less civil work. The uniqueness of AST is that at same discharge head condition, power output and speed vary as well as head efficiency. AST in relation with rural area development is that it can fulfil the need of electricity requirement and it can light up the darkest corners of India. Rural areas can easily have access to power with the help of a only a small stream and this generated electricity can be used for domestic purpose and they can also do small business using machineries that requires less power consumption. For larger demands the AST's can be setup as windmills in river.Thus AST's have the full potential to electrify and develop India sustainably.

References

[1] "The Administrative Approval for the year 2014-15 and remaining period of 12th Plan for Small Hydro Power Programme (upto 25 MW Capacity)", Letter No. 14(03)2014-SHP, dated July 2, 2014, *Small Hydro Power Division, Ministry of New and Renewable Energy*, Govt. of India, New Delhi. Retrieved from https://mnre.gov.in/sites/default/files/uploads/SHP-Scheme.pdf

[2] U. Kumar, P. Singh and A. C. Tiwari, "Suitability of Archimedes Screws for Micro Hydro Power Generation in India", *International Journal of Thermal Technologies*, Vol. 6, Issue No. 3, Sept. 2016, pp. 273-278. Retrieved from http://inpressco.com/wp-content/uploads/2016/10/Paper12273-278.pdf

[3] Renewable First, "Archimedian Screw Hydro Turbine". [Online]. Available: http://renewablesfirst.co.uk/hydropower/hydropower-learning-centre/archimedean-screw-hydro-turbine [Accessed: 25 Nov, 2017]

[4] M. Lyons and W. D. Lubitz, "Archimedes Screws for Micro hydro Power Generation", *Proceedings of the ASME 2013 7th International Conference on Energy Sustainability & 11th Fuel Cell Science, Engineering and Technology Conference (ESFuelCell2013)*, Paper ID: ES-FuelCell2013-18067, July 14-19, 2013, Minneapolis, MN, USA. Retrieved from http://www.soe.uoguelph.ca/webfiles/wlubitz/ES-FuelCell2013-18067%20Lyons%20Lubitz%20Archimedes%20screws%20for%20power%20generation.pdf

[5] M. W. K. Lyons, *Lab Testing and Modeling of Archimedes Screw Turbines*, Master's Thesis, University of Guelph, Ontario, Canada, December 2014. Retrieved from http://hdl.handle.net/10214/8647

[6] O. Paish, "Small hydro power: technology and current status", *Renewable and Sustainable Energy Reviews*", Vol. 6, Issue No. 6, Dec. 2002, pp. 537-556.Doi: https://doi.org/10.1016/S1364-0321(02)00006-0

[7] "Rural Household Electrification Status", *Saubhagya – Pradhan Mantri Sahaj Bijli Har Ghar Yojana*, Ministry of Power, Govt. of India. [Online]. Available: http://saubhagya.gov.in [Accessed: Nov 25, 2017]

[8] P. A Barik, M. Mazumdar and M. K. Dutta, "A study on Hydroelectric and Irrigation potential of Dikhow river, Assam", *ADBU-Journal of Engineering Technology*, Vol. 6, Issue No. 2, July, 2017, 00602623 (6PP). Retrieved from http://journals.dbuniversity.ac.in/ojs/index.php/AJET/article/view/351

[9] Erinofiardi, A. Nuramal, P. Bismantolo, A. Date, A. Akbarzadeh, A. K. Mainil and A. F. Suryono, "Experimental Study of Screw Turbine Performance based on Different Angle of Inclination", *Energy Procedia*, Vol. 110, 2017, pp. 8-13. Doi: https://doi.org/10.1016/j.egypro.2017.03.094

[10] D. R. Nath, "Small Hydro Power and its Potentiality in Assam", *International Journal of Engineering Trends and Technology (IJETT)*, Vol. 23, Issue No. 8, May 2015, pp.

391-395.Doi: 10.14445/22315381/IJETT-V23P274

[11] K. Handique and A. Dutta, “Power and North East: The Hydro Power Scenario of North East”, *International Journal of Science and Research (IJSR)*, Vol. 3, Issue No. 12, December 2014, Paper ID: SUB14403, pp. 602-609. Retrieved from https://www.ijsr.net/archive/v3i12/U1VCMTQ0MDM=.pdf

[12] G. Dellinger, P. A. Garambois, M. Dufresne, A. Terfous, J. Vazquez and A. Ghenaim, “Numerical and experimental study of an Archimedean Screw Generator”, *IOP Conference Series: Earth and Environmental Science*, Vol. 49, Issue No. 10, Nov. 2016, 102002. Doi: https://doi.org/10.1088/1755-1315/49/10/102002

[13] C. Z. Rosly, U. K. Jamaludin, N. S. Azahari, A. N. Oumer and N. T. Rao, “Parametric Study on Efficiency of Archimedes Screw Turbine”, *ARPN Journal of Engineering and Applied Sciences*, Vol. 11, Issue No. 18, Sept. 2016, pp. 10904-10908. Retrieved from http://www.arpnjournals.org/jeas/research_papers/rp_2016/jeas_0916_5007.pdf

[14] A. N. Suraya, N. M. M. Ammar and J. U. Kulthum, “The effect of substantive parameters on the efficiency of Archimedes screw microhydro power: a review”, *IOP Conference Series: Materials Science and Engineering*, Vol. 100, Conference 1, 2015, 012030. Doi: https://doi.org/10.1088/1757-899X/100/1/012030

[15] “Screw Turbine Generating System”, *IEA Hydropower, The International Energy Agency Technology Collaboration Programme on Hydropower*. [Online]. Available: https://www.ieahydro.org/annex-ii-small-scale-hydropower/innovative-technologies/311-5-screw-turbine-generating-system [Accessed: 25 Nov. 2017]

[16] “Grid Tied Screw Generators”, *Greenbug Energy Inc.* [Online]. Available: http://greenbugenergy.com/shop-hydro/shop-hydro-products-services/grid-tied-screw-generators [Accessed: Nov. 25, 2017]

[17] S. Mishra, S. K. Singal, and D. K. Khatod, “Costing of a Small Hydropower Projects”, *IACSIT International Journal of Engineering and Technology*, Vol. 4, Issue No. 3, June 2012, pp. 239-242. Retrieved from http://www.ijetch.org/papers/357-P013.pdf

[18] P. K. Das, “North-East, ‘The Power House of India’: Prospects and Problems”, *IOSR Journal Of Humanities And Social Science (IOSR-JHSS)*, Vol. 18, Issue No. 3, Nov. - Dec. 2013, pp. 36-48. Retrieved from http://www.iosrjournals.org/iosr-jhss/papers/Vol18-issue3/E01833648.pdf

[19] “REVIEW OF PERFORMANCE OF HYDRO POWER STATIONS 2016-17”, Report,*Hydro Project Planning & Investigation Division, Central Electricity Authority*, Ministry of Power, Govt. of India, March 2018, New Delhi, pp. 11. http://www.cea.nic.in/reports/annual/hydroreview/hydro_review-2016.pdf

[20] “Small Hydro Power Programme”, *Ministry of New and Renewable Energy*, Govt. of India, New Delhi. [Online]. Available: https://mnre.gov.in/small-hydro [Accessed: Nov 25, 2017]

[21] “Annex II: Small-Scale Hydropower”, *IEA Hydropower, The International Energy Agency Technology Collaboration Programme on Hydropower*. [Online]. Available: https://www.ieahydro.org/annex-ii-small-scale-hydropower [Accessed: 25 Nov. 2017]

Authors’ Profiles

Pallav Gogoi is working as an Assistant Professor in the department of Mechanical Engineering, School of Technology, Assam Don Bosco University, India. He received his M.E. degree in Mechanical Engineering from Assam Engineering College (India) in 2014. His research interests are Thermal Engineering and Thermodynamics, Fluid dynamics and its application, Materials science and composite materials.

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[1]Mousam Handique,

[2]Subrendu Purkayastha,

[3]Khemraj Newar

B.Tech, Sixth Semester
Department of Mechanical Engineering, School of Technology, Assam Don Bosco University

Design of Micro Wind Turbine for Low Wind Speed Areas: A Review

Deibanehbok Nongdhar[1], Bikramjit Goswami[2]

[1,2]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati -781017, Assam, INDIA
*[1]deibaneh001@gmail.com**

Abstract: ***With the increase in fossil fuel prices and the increase in demand for renewable energy sources, wind turbines play an important role in becoming the alternative technology in the generation of electricity. Since wind is clean and unbounded, wind energy is one of the best renewable sources of energy for generation of electricity. This paper presents the ideas of designing a small-sized wind turbine or micro wind turbine for low wind speed areas which can be used in many applications like homes, villages, and so on to produce electricity. A small-sized wind turbine or micro wind turbine is a type of turbine that converts the kinetic energy of wind into electrical energy and it is used to generate power for small power needs. Additionally, this type of micro wind turbine can be used in rural areas, requiring a very low cost for installation.***

Keywords: Renewable Energy, Micro Wind Turbine, HAWT, VAWT.

1. Introduction

In recent years, the importance of renewable sources of energy in power generation has been growing day by day around the world. Also, due to the lack of fossil fuel resources, utilization of renewable sources of energy has become even more important. Large wind farms, either in the countryside, offshore, mountains or at the seaside have already been invested by many countries around the world. Since wind speed and direction are well known and there are only a few factors that will influence them, the energy gathered from these wind farms can easily be predicted and calculated. However, in a city environment, wind speed and wind direction cannot be predicted because they are easily led in different ways or influenced by all kind of obstacles such as skyscrapers, apartment blocks, etc. As a result, large size wind turbines cannot work effectively and efficiently. So, to overcome these problems, micro wind turbines are used [1,2].

Apart from all the renewable energy resources, cleaner energy systems such as micro wind turbines played a key role in the renewable electricity generation. A micro wind turbine is used to produce or generate power of low DC voltage. In wind turbines, some mechanical and electrical aspects of the turbines are necessary to study in details so that the turbine can achieve its electrical output efficiency [1,2].

Micro wind turbines can also be used as alternative sources of energy in locomotives, especially in passenger trains in which it can generate enough power to support the hotel load requirements including light, fan and AC and so on. Since, it is very cheap, affordable reliable and almost maintenance free it gives more benefits than the large wind turbines [3,4].

For large wind turbines, people used mostly VAWTs (Vertical Axis Wind Turbines) over HAWTs (Horizontal Axis Wind Turbines) for low wind speed areas, especially in buildup areas. VAWTS have lower wind startup as compared to HAWTS. However, for micro wind turbines, people used either micro VAWTS or micro HAWTS for power generation in low wind speed areas. Since in rural areas, electricity crisis is the main problems, they are used mainly in rural and remote applications or areas where wind speed is low [4,6].

Moreover, research on the design and development of the turbine blades has been studied so that it becomes beneficial to use in areas where wind speed is low. However, studies also show that in a low wind speed areas, a practical wind booster can also be used so that it can generate power satisfactorily [9,10].

In case of variable wind speed conditions, a controller is designed to maximize the energy output and this modified turbine controller is also used to examine the provision of frequency support from wind turbines under changing wind conditions [12,15].

Figure 1: Vertical Axis Wind Turbine- Savonius type [1]

Figure 2: Vertical Axis Wind Turbine- Darrieus type [1]

Figure 3: Horizontal Axis Wind Turbine [5]

Implementation of variable wind speed turbines also has been done enables the turbines to get maximum efficiency as the wind varies. Similarly, under varying wind conditions, control strategies are obtained for operating a variable wind speed turbine and the determination of the increase in energy can be achieved using these strategies [13].

Micro wind turbines can be designed using PVC blades as it can give better power capacity and less costly. It can be used in areas where the velocity of wind is low, that is, as low as 2 m/s, like a plateau or hilly region or in places where large wind turbine does not give a good result. Because of low cost and being of economical, it can be installed in residential areas over the houses for power generation. Moreover, utilization of small wind turbines for the household would result in fewer burdens on the grid and also plays a vital role in reducing utilization of conventional energy and mobility to utilize the power [17].

These micro wind turbines can be used where wind velocity is low like hilly regions or especially rooftops of building and they are less costly, easier to install and can power electrical devices like the LED sign, Cell phones, lighting a lamp, etc. [20].

2. Micro Wind Turbines versus Large Wind Turbines

A Micro wind turbine is set up in the location where wind power has to be consumed. It is not necessary that the design of micro wind turbine will depend on the location where the wind power is the best. Micro wind turbines help to provide energy in the locations where unavailable of other sources of electric energy are not available. Micro wind turbines are designed to operate with low wind speed even in places where the wind speed is as low as 2 m/s. Moreover, micro wind turbines do not require large areas of land. Due to their small size and modular construction, a micro wind turbine can be installed in smaller places like apartment balconies, building-terraces,the rooftop of a building and of course in small farmhouses. Based on the available space and the power output required, the size of micro wind turbines can be adapted. The design is very simple, the components required to set up the installation are easily available and maintenance is very easy. Consequently, simple designs lead to low manufacturing cost. Similarly, because of their light weight, small size, and flexible configuration they can be installed in both urban and rural environments, for individual or corporate use. Some applications, like charging the batteries on sailboats and recreational vehicles, micro wind turbines with very low capacities can be used and implemented. Such micro wind turbines with output lesser than 100W are practically used and can be utilized for charging batteries with minimum cost and minimum complexity. Such types of micro wind turbines can be used to charge automobile batteries and power security lighting systems in remote locations or urban areas [6,21].

Common types of large wind turbines require large areas of land because they are designed for a large amount of electricity production. Largely sized wind turbines are used for commercial energy production and they are very costly. They are usually connected to a power grid and installed in locations where wind speed and direction are suitable for wind turbines. These large wind turbines cannot operate in low wind speed areas or places where the wind speed is below 10 m/s. Regular wind turbines can only operate at wind speed between 10 m/s and 25 m/s [6,21].

3. Design Parameters of a Micro Wind Turbine

Following are the key parameters required to be considered while designing micro wind turbines:

1) Wind speed -It is very important for the productivity of a windmill.The output of micro wind turbine mostly depends on the wind. Therefore, the more is the wind speed, the greater is the amount of power the wind turbine generates. Different regions have different wind speeds. As a result, determination of the value of the wind speed for a particular region is necessary.Whether to design a Vertical Axis Wind Turbine (VAWT) or Horizontal Axis Wind Turbine (HAWT) is determined based on wind speed.

2) Sites Selection (Location) - By determining the direction of the wind in the selected areas, the site is considered suitable. It can be observed during wind storms, that is, by looking at the trees near the site. To determine a good indication of prevailing wind speed and direction, it can be done by identifying the trees that are all leaning in the same direction and that have branches mostly on one side of the trunk. This information can sometimes be provided by the local airports and weather stations also.

3) Height - Due to various atmospheric factors, places or region of higher altitudes experience more wind because there is less obstruction from the surrounding hills, trees and building in places of higher altitudes. As a result, a micro wind turbine should be placed at least 30 feet above the ground without any disturbances within 300 feet in any direction. Use of short towers will reduce power output, and cause physical stresses on the turbine and tower.

4) No. of Blades and Blade Length – A micro wind turbine performance can be affected by the number of blades that make up a rotor and the total area they cover. Blade length depends on the design of the power output. The space between blades should be great enough to avoid turbulence so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it. Therefore, because of this requirement, most micro wind turbines have only two or three blades on their rotors.

5) Tip Speed Ratio - The tip-speed ratio is the ratio of the rotational speed of the blade to the wind speed. This ratio is directly proportional to the rotation of the micro wind turbine rotor, that is, larger is the ratio, the faster is the rotation of the micro wind turbine rotor at a given wind speed. High rotational speed is required for electricity generation.

6) Generators - The generator converts the mechanical energy of the turbine or the turning motion of a microwind turbine's blades to electrical energy (electricity). There are different generator designs which can produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The rating or size of a generator is dependent on the length of the wind turbine's blades because longer blades capture more energy. Therefore, it is important to select the right type of generator for intended use. Most home and office appliances operate with 50 cycles AC. Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can be run on DC. Storage systems using batteries store DC and usually operate at voltages of between 12 volts and 120 volts.

7) Towers - The tower is a structure where the micro wind turbine is mounted and the turbine is mounted on a tower because wind speeds increase with height. Consequently, the higher the tower, the more power the micro wind turbine can produce. However it is not just a support structure, but it plays a very important role in raising the micro wind turbine so that its blades safely clear the ground and at higher elevations, the turbine can reach stronger winds. The height of the tower can be determined based on the cost involved versus the value of the increase in energy production resulting from their use. The towers that will be installed should be strong enough to support the wind turbine and to sustain vibration, wind loading and the overall weather elements for the lifetime of the micro wind turbine**.**

4. Energy Output Calculations of a Micro Wind Turbine

Kinetic energy in (Joules) is given by,

$$K.E = \frac{1}{2}.m.V^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where,
m = mass (kg)
V = velocity (m/s)

Since, Energy = Power × Time

And to express the mass of flowing, air density is a more convenient way to consider; the kinetic energy equation can be converted into a flow equation.

Power in the area swept by the micro wind turbine rotor is given by,

$$P = \frac{1}{2}.\rho.A\,V^3 \text{ ……………………… (2)}$$

where,

P = power in watts (746 watts = 1 hp and 1000 watts =1 kilowatt),
ρ= air density (about 1.225 kg/m^3 at sea level, less higher up),
A = rotor swept area (m^2),
V = wind speed in m/s.

Micro Wind Turbine Power is calculated [17]as–

$$P = \frac{1}{2}.\rho.A.C_p.V^3.N_G.N_B \text{ ……….. (3)}$$

where,

P = power in watts (746 watts = 1 hp and 1000 watts = 1 kilowatt),
ρ = air density (about 1.225 kg/m^3 at sea level, less higher up),
A = rotor swept area (m^2),
C_p = Coefficient of performance (0.59 {Betz limit} is the maximum, 0.35 for a good design)
V = wind speed in m/s,
N_G = generator efficiency (50% for car alternator, 80% or more for a permanent magnet generator or grid-connected induction generator),
N_B = gearbox or bearings efficiency (if good it could be as high as 95%).

Tip Speed ratio for a micro wind turbine is also defined as the ratio between the tangential speed of the tip of a blade and the actual velocity of the wind.

$$\lambda = \frac{r.\omega}{v} \text{ …………………..……….. (4)}$$

where,

λ = Tip speed ratio
r = Radius of a rotor
v = wind velocity

Wind velocity at different places can be measured by anemometer and Turbine velocity with the help of Non-contact type Tachometer [17].

5. Vertical Axis Wind Turbine versus Horizontal Axis Wind Turbine

Wind turbines are designed both as Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbine (HAWT), depending on the wind speed, power output required and efficiency.

Vertical Axis Wind Turbine (VAWT):

Generally, there are two kinds of VAWTs, namely, the Savonius and the Darrieus. The functions of Savonius are similar to a water wheel whereas the Darrieus makes use of blades similar to the blades used on HAWTS. VAWTs commonly function closer or nearer to the ground level and not in the nacelle, and has the benefit of enabling placement of heavy equipment, such as the gearbox and generator. However, near ground level the winds are lower; hence a less amount of power is generated. Similarly, among the vertical axis wind turbines, the Darrieus rotor is the more efficient than the Savonius rotor, but the main limitation of the Darrieus rotor is that it cannot be self-start. The efficiency of the Savonius rotor is much less as compared to the Darrieus rotor even though its rotor is simple and cheap. VAWTs give many advantages when compared to horizontal axis wind turbines (HAWTs). They are much more compact and can be placed on building rooftops and other urban locations whereas, the tall tower and long blades of HAWTs work well only in wide-open spaces. Similarly, they do not need much wind in order to produce power and hence allowing them to be nearer to the ground where the speed of the wind is lower. Since they are closer to the ground, they can be easily controlled and implemented on tall structures [22].

Horizontal Axis Wind Turbine (HAWT):

Since a nacelle is installed perpendicular to the turbine tower and horizontal in terms of the ground, hence, they are called as the horizontal axis wind turbine. These Horizontal Axis Wind Turbines should always be pointed in the right direction, that is, into the wind, or away from the wind, based on the type so that they can achieve maximum efficiency. Currently, because of their good aerodynamic efficiency, high-speed propeller wind turbines are commonly used as horizontal axis turbines. The core components of a horizontal wind turbine consist of the main rotor shaft, the electrical generator, the gearbox to increase the rotation speed of the blades and the Turbine blades.

HAWTS has also some of its advantages. They use the variable pitch of blades to collect the maximum amount of energy from the wind. HAWTs have higher efficiency as it has blades in perpendicular to the direction of the wind. Similarly, the designs of HAWTs allow easy installation as well as easy maintenance [22].

6. Conclusion

This paper presents an exclusive review of the design of micro wind turbines for low wind speed areas. Small or micro wind turbines are more suitable in regions where wind speed is low and also in urban areas. The energy output calculations are included for the benefit of designers. Also, a comparison between Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) has been done, with regard to their efficiency. This will enable the designers to select a particular design and a type for low wind speed areas.

References

[1] D. M. Bui and W. J. C. Melis, "Micro wind Turbine for Energy Gathering in buildup areas", *International Journal of Sustainable Energy Development (IJSED)*, Vol. 2, Issue No. 2, December 2013, pp. 105-114. Retrieved from http://infonomics-society.org/wp-content/uploads/ijsed/published-papers/volume-2-2013/Micro-Wind-Turbines-for-Energy-Gathering-in-Build-Up-Areas.pdf

[2] Z. Li, F. Boyle and A. Reynolds, "Domestic Application of Micro wind Turbines in Ireland: Investigation of their economic viability", *Renewable Energy*, Vol. 41, May 2012, pp. 64-74.Doi: https://doi.org/10.1016/j.renene.2011.10.001

[3] J. K. Sahu and M. Sahu, "Micro Wind Turbine Technology: To Enhance Self Generative System in Passenger Train", *International Research Journal of Engineering and Technology (IRJET)*, Vol. 3, Issue No. 11, November 2016, pp. 629-634. Retrieved from https://www.irjet.net/archives/V3/i11/IRJET-V3I11110.pdf

[4] A. R. Sengupta, A. Biswas and R. Gupta, "Vertical Axis Wind Turbines in the Built Environment: A Review", *ISESCO Journal of Science and Technology*, Vol. 12, Issue No. 22, pp. 11-16. Retrieved from https://www.researchgate.net/publication/313740546

[5] A. Deo, J. N. Goundar, S. Narayan and N. Chettiar, "Design and Performance Analysis of Micro Wind Turbines for Fiji", *International Journal of Information and Electronics Engineering*, Vol. 6, Issue No. 1, January 2016, pp. 37-40. Retrieved from http://www.ijiee.org/vol6/590-SE307.pdf

[6] N. N. Sorte and S. M. Shiekh, "Design and Development of Micro Vertical Axis wind turbine for Rural Application", *International Journal of Engineering and Computer Science*, Vol. 3, Issue No. 7, July 2014.

[7] J. Zhang, Z. Zhou and Y. Lei, "Design and research of high-performance low-speed wind turbines blades", *2009 World Non-Grid-Connected Wind Power and Energy Conference (WNWEC 2009)*, Nanjing, 24-26 Sept., 2009, pp. 1-5.Doi: https://doi.org/10.1109/WNWEC.2009.5335818

[8] M. Mohammadi, A. Mohammadi, M. Mohammadi and H. N. Minaei, "Optimization of small-scale wind turbine blades for low-speed conditions", *Journal of Clean Energy Technologies*, Vol. 4, Issue No. 2, March 2016, pp. 140-143.Doi: 10.7763/JOCET.2016.V4.268

[9] N. Prasad E., Janakiram S., Prabu T. and Sivasubramaniam S., "Design and development of Horizontal small turbine blade for low wind speed", *International Journal of Engineering Science & Advanced Technology (IJESAT)*, Vol. 4, Issue No. 1, 2014, pp. 75-84. Retrieved from http://ijesat.org/Volumes/2014_Vol_04_Iss_01/IJESAT_2014_01_01_14.pdf

[10] N. Korprasertsak and T. Leephakpreeda, "Analysis and optimal design of wind boosters for Vertical Axis Wind Turbines (VAWTs) at low wind speed", *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 159, Dec. 2016, pp. 9-18.Doi: https://doi.org/10.1016/j.jweia.2016.10.007

[11] Y. Vidal, L. Acho, N. Luo, M. Zapateiro and F. Pozo, "Power control design for variable speed wind turbines", *Energies*, Vol. 5, Issue No. 8, Aug. 2012, pp.3033-3050.Doi: http://dx.doi.org/10.3390/en5083033

[12] S. Rajendran and D. Jena, "Control of variable speed variable pitch wind turbine at

above and below-rated wind speed", *Journal of Wind Energy*, Vol. 2014, Oct. 2014, Article ID 709128. Retrieved from http://downloads.hindawi.com/journals/jwe/2014/709128.pdf

[13] A. Mclver, D. G. Holmes and P. Freeze, "Optimal control of Variable speed wind turbine under dynamic wind conditions", *Proceedings of Industry Applications Conference, 1996. Thirty-First IAS Annual Meeting, IAS '96., Conference Record of the 1996 IEEE*, San Diego, CA, Vol. 3, 6-7 Oct. 1996, pp. 1692-1698. Doi: https://doi.org/10.1109/IAS.1996.559297

[14] M. Izadbakhsh, A. Rezvani, M. Gandomkar and S. Mirsaeidi, "Dynamic analysis of PMSG wind turbine under variable wind speeds and load conditions in the grid-connected mode", *Indian Journal of Science and Technology*, Vol. 8, Issue No. 14, July 2015. Doi: 10.17485/ijst/2015/v8i14/51864

[15] L. Wu and D. Enfield, "Investigation on the interaction between inertial response and droop control from variable speed wind turbines under changing wind conditions", *Proceedings of 2012 47th International Universities Power Engineering Conference (UPEC)*, London, 4-7 Sept. 2012, pp. 1-6. Doi: https://doi.org/10.1109/UPEC.2012.6398429

[16] Abubakkar A., T. Ravisankar and M. Makeshkumar, "Design and fabrication of micro wind turbine", *International Journal of Science, Engineering and Technology Research (IJSETR)*, Vol. 5, Issue No. 5, May 2016, pp. 1785-1787. Retrieved from http://ijsetr.org/wp-content/uploads/2016/05/IJSETR-VOL-5-ISSUE-5-1785-1787.pdf

[17] V. K. Rathod and S. Y. Kamdi, "Design and Fabrication of PVC bladed inexpensive wind turbine", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, Vol. 11, Issue No. 4, Ver. II, Aug. 2014. pp. 114-119.

[18] A. Dhote and V.Bankar, "Design, analysis, and fabrication of Savonius Vertical axis wind turbine", *International Research Journal of Engineering and Technology (IRJET)*, Vol. 2, Issue No. 3, June 2015. pp. 2048-2054.

[19] M. Kumari and H. K. Singh, "Small Scale Wind Turbines: As alternative Energy system", *International Journal of Science and Research (IJSR)*, Vol. 3, Issue No. 6, June 2014, pp. 1607-1609.

[20] D. P. Drumheller, G. C. D'Antonio, B. A. Chapman, C. P. Allison and O.Pierrakos, "Design of a micro wind turbine for implementation in low wind speed environment", *Proceedings of 2015 Systems and Information Engineering Design Symposium*, Charlottesville, VA, 24 April 2015, pp. 125-130.Doi: https://doi.org/10.1109/SIEDS.2015.7116959

[21] A. Suresh and S. Rajakumar, "Design and experimental investigation of a micro wind turbine", *International Journal of Advances in Engineering Research (IJAER)*, Vol. 10, Issue No. VI, December 2015, pp. 216-224. Retrieved from http://www.irapub.com/images/short_pdf/1454220602_A_Suresh_22.pdf

[22] M. M. M. Saad and N.Asmuin, "Comparison of Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines", *IOSR Journal of Engineering (IOSRJEN)*, Vol. 4, Issue No. 8, V2, August 2014. pp. 27-30. Retrieved from http://www.iosrjen.org/Papers/vol4_issue8%20(part-2)/E04822730.pdf

Authors' Profiles

Deibanehbok Nongdhar is a student of M.Tech. 4th semester in the department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University.

Bikramjit Goswami is working as an Assistant Professor in the department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University, India. He is also a Ph.D. Research Scholar in Assam Don Bosco University currently. His research interests are Reconfigurable Antenna, Microwave Remote Sensing, Artificial Neural Networks, renewable Energy, Disaster Forecasting.

Potential Use of DC Microgrid for Solar and Wind Power Integration in Rural Areas in India: A Review

Risalin Lyngdoh Mairang[1], Bikramjit Goswami[2]

[1,2]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati -781017, Assam, INDIA
*[1]risavecca@gmail.com**

Abstract: ***This paper describes the possibilities of the application of DC microgrids to solve the rural areas, energy problem in the country (India). DC Microgrids open a gateway for integration of solar and wind energies which together are efficient and cleaner way of renewable energy generation, which can be integrated into the power distribution network. They have several other advantages, which include - reduction in transmission losses, improvement in power quality & reliability, reduction in emissions and even they are cost effective. The most important characteristic is that it provides a possibility for electrification of remote villages, which are far from the reach of the conventional grid. This paper presents a detailed discussion on the possibility of application of DC microgrids for rural areas in India.***

Keywords: DC microgrid, solar, wind, BESS, supercapacitor, HOMER, State of Charge (SoC).

1. Introduction

Renewable energy plays an important role in the global energy sector. The wind and solar energy sectors particularly have experienced tremendous investment and growth in the last decade and the trend still continues [1]. The global society has not only become increasingly more energy dependent, but has also become more aware of environmental effects. Once the renewable energy technologies become more dominant, then energy would be produced anywhere without polluting the environment.

Ministry of Non-Conventional Energy Sources (MNES) in India has been supporting research and development efforts to upgrade the existing technologies of renewable energy generation[2]. The R&D work mainly focuses on power generation, system design and optimization. The energy systems designed using renewable sources primarily seek to address issues related to electric and transportation sectors. The ideas presented in this paper mainly focus on electrical energy generation and also to analyze usefulness of designing DC microgrids for remote locations in the developing world. A key advantage of DC microgrids is that the low risk of dangerous electric shocks from low voltage DC makes plug-and-play grids a possibility [3]. DC microgrid is one of the new approach to generate and use power in our buildings and also link how to make and distribute power at the national electrical grid level—the "macro grid". The use of microgrids is partly motivated by the increasing concern for the strain on and vulnerability of electrical macro grid system.

The operational controls are designed using different methods in order to support the integration of wind and solar power within microgrids. Reported works in literatures also describe that the engineers design multilevel energy storage systems comprising of Battery Energy Storage System (BESS) and Supercapacitors. Energy can be stored in batteries when it is generated by both wind turbine and the PV array. Later, during peak time the stored energy can be used. Hence DC microgrid with multiple sources can benefit the poor by providing efficient and cost effective energy storage technologies.

2. Basic Structure of a DC Microgrid

Depending on its operational frequency, microgrids are classified into three types, viz., AC microgrid, DC microgrid and hybrid AC/DC microgrid. Compared to the others, DC microgrids have shown more advantages and they are being studied by many researchers these days for different applications. Researchers believed bygrowing number of proponents that "smart" dc microgrids can make better use of the energy generated, stored, and used at a local level. Whether are new on-site energy generation (e.g., solar installations) or adding smart devices to monitor energy use or intelligently connecting power to electric vehicles and battery storage, such approaches added control of energy use at the building level, thus making buildings better "partners" with the nation's smart grid efforts[4]. It also provide a way to buy centrally generated energy at times of the day when it is more abundant, temporarily store it, and then use it during peak demand periods.

A Hybrid energy storage system (HESS) consisting of batteries and supercapacitors, used to meet the highly fluctuating power demands [5]. The main purpose of supercapacitor is that it can take care of high frequency power component in contrast to the batteries which can take care of average power component only. Therefore a hybrid energy system improves system efficiency and reduces the battery cost. It is very important to study the steady state characteristics of the DC microgrid as mentioned by Dong Chen and Lie Xu [6], in order to gain a deep understanding of its effect on the system. Itrequires local and supervisory detection units at the constant power loads (CPLs) to detect the fault.

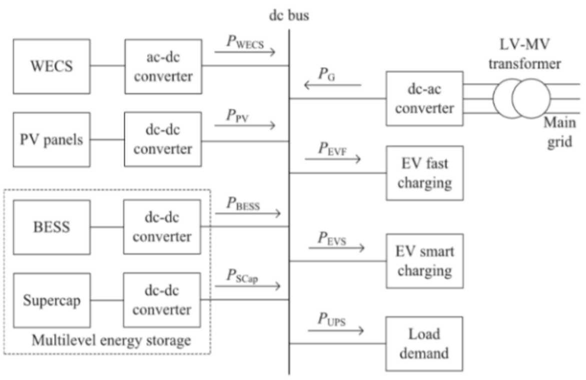

Figure 1: Layout of DC Microgrid [3]

Figure 1, shows the schematic diagram of a typical DC microgrid with conventions employed for power transmission. The primary requirement of DC microgrid is to maintain the DC bus within an acceptable range of voltage. Wind energy conversion system (WECS) connects to dc bus generally through ac to dc converter and PV panel connects to dc bus through dc to dc converter.A multilevel energy storage comprising of Battery Energy Storage System (BESS) and Supercapacitors also connects to dc bus through dc to dc converters. The capacitor has much less energy capacity than the battery, but has the capacity of charging and discharging much faster than a battery. Also dc bus can be connected to Electric Vehicle (EV) charging points through EV charging station and grid interface.

A typical DC microgrid system has four kinds of terminals: generation, load, Energy Storage System (ESS), and grid-connected voltage-source converter (G-VSC). In research works by Dong Chen, Lie Xu and Liangzhong Ya [7] and in another by Xiu Yao [8], these terminals have been classifiedinto two types: power terminal and slack terminal. Power terminals usually operate on their own merits and do not actively contribute to system control. Typical power terminals are variable generations such as wind and photovoltaic systems, which normally operate at maximum power point tracking (MPPT) according to weather conditions, and variable load. On the other hand, slack terminals are controlled to accommodate the power variation coming from the power terminals and maintain a stable system operation with limited DC voltage variation. A DC microgrid should have at least one slack terminal to satisfy the operation. The generation within a DC grid can come from wind, photovoltaic units, diesel generator, etc.

The DC Grids can be cost effective and present a minimal technical risk while addressing energy scarcity in many parts of the world [9].

3. Energy Requirement of Rural Area

Many of India's villages are still un-electrified. Most of the houses in rural areas use kerosene lamp for lighting and fire wood for cooking. Houses are built with local materials such as clay, wood, bamboo etc. Requirement of energy in most of the rural houses are also minimal.

Figure 2 shows a DC village-microgrid [7] with the goal of meeting the dynamic electricity needs of households within a 2 km radius which will integrate the following features:

(a) Line transmission losses will be minimized by using 380V DC and converted to safer 12VDC at the households.
(b) A droop voltage power-sharing scheme is implemented, wherein the microgrid voltage droops in response to low-supply/high-demand.

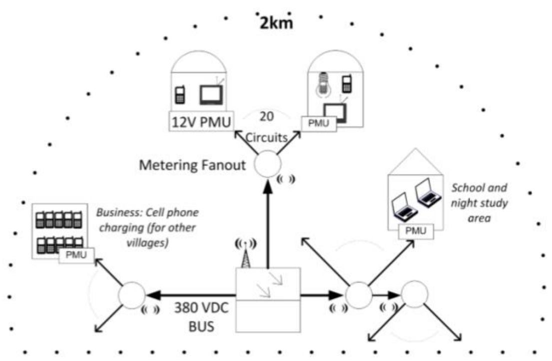

Figure 2: Architectural overview of a DC village-microgrid with a 380VDC transmission bus that is converted to 12VDC for household usage [7]

(c) The household power management units (PMUs) integrate scalable distributed storage that are owned by individual households.
(d) PMU will have good efficient DC-DC converters that provide power to efficient DC appliances.

A technique of prediction of PV inverter current is presented in research work by P. Achintya Madduri *et al.* in 2013[11] when the current exceeds its rated value, due to any grid faults. The objective of this work was to prevent the loss of PV based renewable generation due to fault. The grid code required the DG inverter to stay connected and provide Low Voltage Ride Through (LVRT) capability during fault scenario. The proposed methodology was based on the evaluation of slope and magnitudes of the PV inverter current for short circuit current detection. The photovoltaics (PV) require an automation surveying over large geographical areas [12]. It is very important to have a good knowledge of roof top characteristics in order to identify where the problems arise in the National Grid and where mitigation measures may be necessary. The research describes that how the required roof characteristics may be obtained together with expected percentage error.

4. Loss Optimization and Cost Effectiveness

The goal of microgrid is to coordinate operation with the large power grid and also to provide an effective complement to the power grid. With large scales of microgrid connected in the distribution grid, the interaction between the DC microgrid and the power grid cannot be ignored [13]. The main backbone of microgrid is DC where DC equipment connect microgrid directly.

A loss optimized cost effective droop control schemein some research works [14,15] described a remotely located DC microgrid connected to a weak radial distribution feeder. It provides a loss optimized and cost effective droop control law for the battery energy storage converter (BESC) and bidirectional interfacing converter (BIC). The BIC controller ensures that the drop/rise in distribution grid voltage at the point of common coupling (PCC) due to the active power exchange between DC microgrid and utility grid is as per the Indian voltage regulation standards set by the Central Electricity Authority (CEA).

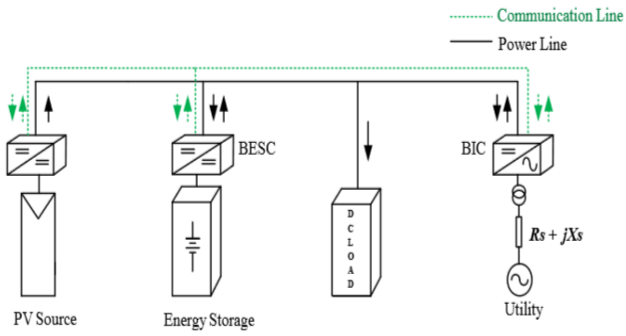

Figure 3: Single line diagram of a DC microgrid connected to the utility grid [14]

The total system losses in dc microgrid are compared with the losses of ac microgrid. The less power conversion stages due to the very nature of the distributed sources, storages, and loads make DC microgrid more attractive than the AC microgrid. The DC microgrid is also preferred over AC microgrid because (i) quality of power supply is high, (ii) has more reliability and higher uninterruptible supply, (iii) the losses are less due to the absence of reactive power, and (iv) has higher efficiency [16].

Microgrids are key elements to integrate renewable and distributed energy resources as well as distributed energy storage systems. The new electrical grid named as Smart-grid (SG) will deliver electricity from suppliers to consumers by using digital technology to control appliances at consumer's homes to save energy, reducing cost and increase reliability and transparency [17,18]. Use of transformer can be eliminated on load side converter by using proper dc voltage of the microgrid (±750V in some study) [19].

Thus a dc microgrid leads to minimization of cost of improvement in efficiency at the same time.

5. Charging and Discharging Status Monitoring of The Battery Bank

The condition of the smart grid to work safely depends on maximum **State of Charge (SoC)** and the lifetime of the battery bank guaranteed by minimum state of charge. In order to maintain the state of charge (SoC) of the storage system within its nominal limits, a storage converter voltage control loop is used, with a correction of the reference voltage as a linear function of the deviation between the desired SoC and the actual one [20]:

$$V_{dc-ref} = V_{dc}^{*} - k.(Q_{storage\ -ref} - Q_{storage\ -meas})$$

where,
V_{dc}^{*} = dc reference voltage of the interface converter
$Q_{storage\ -ref}$ = target state of charge
$Q_{storage\ -meas}$ = measured state of charge
k = proportionality constant

The proportionality constant of the SoC controller is set according to the desired range excursion of the storage system SoC. In this way an automatic self-regulating control of SoC is implemented which guarantees that SoC is brought back to its target value in steady-state conditions.

Also flow of energy from the wind turbine and the battery bank should be done for charge acceptance and discharge rate of batteries [21]. Limitations of state of charge (SoC) depend on the characteristics of battery charging regulator.

Use of voltage regulator also is one of the main tasks to take care of the fluctuating conditions to make the system efficient. To follow all the power fluctuations on the dc bus, the closed-loop bandwidth set for the storage converter is kept as high as possible.In another type of work,green energy storage monitoring system was designed to monitor the lithium iron phosphate battery charging and discharging status for a long time [22]. It is basically used manage diverse power sources from power plants, solar panelsand wind turbines and to coordinate the difference between the peak and average power availability, and also to maintain the consistency of the power quality in the user side. The core of the overall solution for these issues is the use of the energy storage systems efficiently.

6. Tri-Loop Dynamic Error-Driven PI Controller

Research works carried out by O. M. Longe, K. Ouahada, H. C. Ferreira and S. Chinnappen in 2014 [23] and by T. Aboul-Seoud and A. M. Sharaf in 2009 [24,25], present a design of tri-loop dynamic error-driven PI controller. The design is to improve the power quality in the distribution systems that are interfaced with distributed generation (DG), a novel PWM switched DVR and MPFC driven by a Tri-loop Dynamic Error Driven PI Controller are developed.

1) DVR: The tri-loop dynamic error-driven PI controller is the summation of the three basic loops: **(i)** The voltage stabilization loop functions tracking the error of load voltage if there is any fluctuation in the wind speed and regulating it to near unity, **(ii)** The second loop is the load bus current dynamic error tracking loop, which compensate when there is any current change, **(iii)** The Current Harmonic Tracking Loop is the supplementary used for reducing the harmonic ripple content in the distribution system.

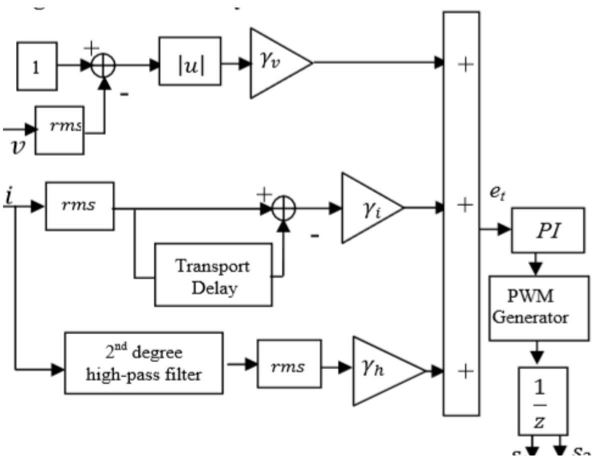

Figure 4: The Tri-loop dynamic error driven controlled PWM layout [23]

2) MPFC: The MPFC tri-loop dynamic error-driven PI controller corrects the global error. It is the summation of the three basic loops for voltage, current, and current harmonic ripple with different assigned loop weights. The scheme introduces significance to the network power factor while decreasing the supply current, and the losses in the distribution feeders. It also decreases the total harmonic distortion in the current. The scheme is cheap and robust.

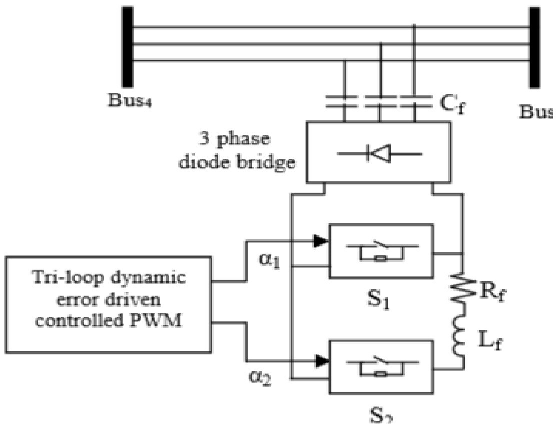

Figure 5: The MPFC layout [24]

7. Hybrid Optimization Model for Electric Renewables (HOMER)

The renewable energy in India has got very high potential, but the total contribution of renewable power as compared to electricity generation is very low. Hence, it is necessary to utilize these resources in optimum manner. One of the excellent solutions for the energy problems in rural areas is the hybrid energy system where grid extension is difficult and not feasible. It is a combination of two or more different types of energy systems which come together to give the optimum output by utilizing the available natural resources in India. The task to design such system is very difficult; hence good planning of such system is important before its construction.

The HOMER software is used to determine the optimal sizing and operational for a hybrid renewable energy system, using the solar radiation data, wind speed data, and load data, based on the three principal steps viz., Simulation, Optimization and Sensitivity analysis [26,27,28]. HOMER simulates the system based on estimation of installing cost, replacement cost, operation and maintenance cost, fuel and interest.

SIMULATION: HOMER performs the energy balance calculations, which determines the best feasible system configuration which can adequately serve the electric demand. HOMER simulates the system based on estimation of installing cost, replacement cost, operation and maintenance cost, fuel and interest.

OPTIMIZATION: Optimization is done after simulation of different combination of hybrid renewable energy system configurations. It is based on Total Net Present Cost (TNPC) to find out number of system configurations.

SENSITIVITY ANALYSIS: The HOMER software repeats the optimization process for every selection of sensitivity variables for the hybrid renewable energy system. The sensitivity variables are the global solar irradiation, wind speed and the price of diesel fuel. The various configurations of hybrid renewable energy are tabulated from the lowest to the highest TNPC. The optimal solution of hybrid renewable energy system is referring to the lowest TNPC.

Hence HOMER software is designed which is used for the simulation and optimization analysis because it limits the input complexity, performs fast enough computation [29].

The work done by Vlado Ostovic in 2014 [10], shows the Harmonic Fields (HF) Generator which is a new electric machine topology for wind. The Harmonic Fields (HF) Generator is perfectly suited for wind applications. A wind turbine drive built around an HF generator has a higher energy yield than a turbine with conventional generator and frequency converter. It is cheaper to build and requires less maintenance.

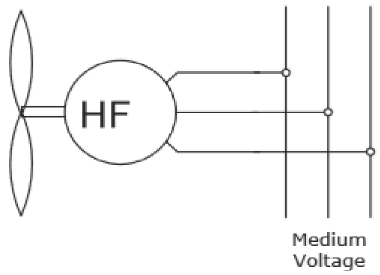

Figure 6: HF generator schematics

Besides low maintenance costs, the wind turbine with HF generators are characterized by low investment cost because they do not requirepermanent magnet, frequency converter, gearbox, transformer and slip rings to generate electric energy from wind.

8. Conclusion

A detailed review of the scope and advantages in using DC microgrid from rural areas has been done. The DC grid shows marked advantages over AC grids in terms of their efficiency and cost effectiveness. The latest trend in controlling the voltages and used of HOMER software in simulation, optimization and sensitivity analysis are also discussed. Overall, the DC microgrid is a viable option for distributing power in both rural and urban households, utilizing solar and wind power available freely.

References

[1] N. Aspinall, L. Mills, D. Strahan, R. Boyle, V. Cuming, K. Stopforth, S. Heckler and L. Becker, “Global Trends in Renewable Energy Investment 2014: Key Findings”, Global Trends Reports, *UNEP Collaborating Centre for Climate & Sustainable Energy Finance, Frankfurt School of Finance & Management*, Germany, April 2014. Retrieved from http://fs-unep-centre.org/publications/gtr-2014

[2] D. P. Kothari, “Renewable Energy Scenario in India”, *Conference Proceedings of 2000 IEEE Power Engineering Society Winter Meeting*, (Cat. No.00CH37077), Vol.1, Jan 23-27, 2000, pp. 634-636. Doi: https://doi.org/10.1109/PESW.2000.850112

[3] K. Strunz, E. Abbasi and D. N. Huu, “DC Microgrid for Wind and Solar Power Integration”, *IEEE Journal of Emerging and Selected Topics in Power Electronics*, Vol. 2, Issue No. 1, March 2014, pp. 115−126. Retrieved from https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6681907

[4] B. T. Patterson, “DC, Come Home: DC Microgrids and the Birth of the “Enernet” ”, *IEEE Power and Energy Magazine*, Vol. 10, Issue No. 6, Nov.-Dec. 2012, pp. 60-69. Doi: 10.1109/MPE.2012.2212610

[5] S. K. Kollimalla, M. K. Mishra, A. Ukil and H. B. Gooi, “DC Grid Voltage Regulation Using New HESS Control Strategy”, *IEEE Transactions on Sustainable Energy*, Vol. 8, Issue No. 2, April 2017, pp. 772-781. Doi: 10.1109/TSTE.2016.2619759

[6] D. Chen and L. Xu, “Autonomous DC Voltage Control of a DC Microgrid with Multiple Slack Terminals”, *IEEE Transactions on Power Systems*, Vol. 27, Issue No. 4, November 2012, pp. 1897-1905. Doi: 10.1109/TPWRS.2012.2189441

[7] D. Chen, L. Xu and L. Ya, “DC Voltage Variation Based Autonomous Control of DC Microgrid”, *IEEE Transaction on Power Delivery*, Vol. 28, Issue No. 2, April 2013, pp. 637-648. Doi: 10.1109/TPWRD.2013.2241083

[8] X. Yao, “Study on DC arc faults in ring-bus DC microgrids with constant power loads”, *Proceedings of 2016 IEEE Energy Conversion Congress and Exposition (ECCE)*, Milwaukee, WI, Sept. 18-22, 2016, pp. 1-5. Doi: 10.1109/ECCE.2016.7855474

[9] F. Sharp, D. Symanski and M. S. Dudzinski, “Scalable DC Micro Grids provide cost effective electricity in regions without electric infrastructure”, *Proceedings of IEEE Global Humanitarian Technology Conference (GHTC 2014)*, San Jose, CA, Oct. 10-13, 2014, pp. 18-24. Doi: 10.1109/GHTC.2014.6970255

[10] V. Ostovic, “Harmonie fields machine-The low cost, high efficiency alternative to a conventional generator with frequency converter for wind energy applications”, *Proceedings of 2014 International Conference on Renewable Energy Research and Application (ICRERA)*, Milwaukee, WI, 19-22 Oct. 2014, pp. 48-54. Doi: 10.1109/ICRERA.2014.7016453

[11] P. A. Madduri, J. Rosa, S. R. Sanders, E. A. Brewer and M. Podolsky, “Design and Verification of Smart and Scalable DC Microgrids for Emerging Regions”, *Proceedings of 2013 IEEE Energy Conversion Congress and Exposition*, Denver, CO, Sept. 15-19, 2013, pp. 73-79. Doi: 10.1109/ECCE.2013.6646683

[12] R. K. Varma, S. A. Rahman, V. Atodaria, S. Mohan and T. Vanderheide, “Technique for Fast Detection of Short Circuit Current in PV Distributed Generator”, *IEEE Power and Energy Technology Systems Journal*, Vol. 3, Issue No. 4, Dec. 2016, pp. 155-165. Doi: 10.1109/JPETS.2016.2592465

[13] J. M. Guerrero, M. Chandorkar, T. L. Lee and P. C. Loh, “Advanced Control Architectures for Intelligent Microgrids-Part I: Decentralized and Hierarchical Control”, *IEEE Transactions on Industrial Electronics*, Vol. 60, Issue No. 4, April 2013, pp. 1254-1262. Doi: 10.1109/TIE.2012.2194969

[14] J. M. Guerrero, P. C. Loh, T. L. Lee and M. Chandorkar, “Advanced Control Architectures for Intelligent Microgrids—Part II: Power Quality, Energy Storage, and AC/DC Microgrids”, *IEEE Transactions on Industrial Electronics*, Vol. 60, Issue No. 4, April 2013, pp. 1263-1270. Doi: 10.1109/TIE.2012.2196889

[15] D. Palmer, I. Cole, T. Betts and R. Gottschalg, “Assessment of potential for photovoltaic roof installations by extraction of roof tilt from light detection and ranging data and aggregation to census geography”, *IET Renewable Power Generation*, Vol. 10, Issue No. 4, April 2016, pp. 467-473. Doi: 10.1049/iet-rpg.2015.0388

[16] G. Melath, D. Kapse and V. Agarwal, “A Loss Optimized and Cost Effective Droop Control Scheme for a DC Microgrid Integrated with a Weak Rural Distribution Grid”, *Proceedings of 2016 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, Trivandrum, 14-17 Dec. 2016, pp. 1-6. Doi: https://doi.org/10.1109/PEDES.2016.7914272

[17] H. Kakigano, M. Nomura and T. Ise, “Loss evaluation of DC distribution for residential houses compared with AC system”, *Proceedings of The 2010 International Power Electronics Conference - ECCE ASIA*, Sapporo, 21-24 June 2010, pp. 480-486. Doi: https://doi.org/10.1109/IPEC.2010.5543501

[18] L. Zhang, T. Wu, Y. Xing, K. Sun and J. M. Gurrero, “Power Control of DC Microgrid Using DC Bus Signaling”, *Proceedings of IEEE Applied Power Electronics 26th Annual Conference and Exposition (APEC)*, Fort Worth, TX, April 2011, pp. 1926-1932.

[19] M. Kumar, S. N. Singh and S. C. Srivastava, “Design and Control of Smart DC Microgrid for Integration of Renewable Energy Sources”, *Proceedings of 2012 IEEE Power and Energy Society General Meeting*, San Diego, CA, 22-26 July 2012, pp. 1-7. Doi: https://doi.org/10.1109/PESGM.2012.6345018

[20] J. M. Andújar, F. Segura and T. Domínguez, “Study of a Renewable Energy Sources-based Smart Grid. Requirements, Targets and Solutions”, *Proceedings of 3rd IEEE*

Conference on Power Engineering and Renewable Energy (ICPERE), Yogyakarta, Indonesia, 29-30 Nov. 2016, pp. 45-50. Doi: https://doi.org/10.1109/ICPERE.2016.7904849

[21] M. Narayana, "Demand and Supply Analysis of Community Type Wind power System at Gurugoda Village in Sri Lanka", *Proceedings of 2007 International Conference on Industrial and Information Systems*, Penadeniya, 9-11 August 2007, pp. 117-121. Doi: https://doi.org/10.1109/ICIINFS.2007.4579159

[22] C. B. Tzeng and C. H. Tzeng, "Green Energy Storage Monitor System: Electricity storage", *Proceedings of 2017 2nd International Conference Sustainable and Renewable Energy Engineering (ICSREE)*, Hiroshima, 10-12 May 2017, pp. 67-72. Doi: https://doi.org/10.1109/ICSREE.2017.7951513

[23] O. M. Longe, K. Ouahada, H. C. Ferreira and S. Chinnappen, "Renewable Energy Sources Microgrid Design for Rural Area in South Africa", *Proceedings of 2014 IEEE PES Innovative Smart Grid Technologies Conference (ISGT 2014)*, Washington, DC, 19-22 Feb. 2014, pp. 1-5. Doi: https://doi.org/10.1109/ISGT.2014.6816378

[24] T. Aboul-Seoudand A. M. Sharaf, "A Novel Dynamic Voltage Regulator Compensation Scheme for a Standalone Village Electricity Wind Energy Conversion System", *Proceedings of IEEE Canadian Conference on Electrical and Computer Engineering (CCECE'09)*, NL, Canada, 3-6 May 2009, pp. 117-121. Doi: https://doi.org/10.1109/CCECE.2009.5090103

[25] T. Aboul-Seoud and A. M. Sharaf, "A Novel Modulated Power Filter Compensator Scheme for Standalone Wind Energy Utilization Systems", *Proceedings of IEEE Canadian Conference on Electrical and Computer Engineering (CCECE'09)*, NL, Canada, 3-6 May 2009, pp. 390-393. Doi: https://doi.org/10.1109/CCECE.2009.5090160

[26] A. M. Sharaf, A. S. Aljankawey and I. H. Altas, "Dynamic Voltage Stabilization of Stand-Alone Wind Energy Schemes", *Proceedings of 2007 IEEE Canada Electrical Power Conference*, Montreal, Que.,Oct. 25-26, 2007, pp. 14-19. Doi: https://doi.org/10.1109/EPC.2007.4520299

[27] J. B. Fulzele and M. B. Daigavan, "Optimization of PV-Wind Hybrid Renewable Energy system for Rural Electrification", *Proceedings of 2015 7th International Conference on Emerging Trends in Engineering & Technology (ICETET)*, Kobe, Japan, Nov. 18-20, 2015, pp. 101-105. Doi: https://doi.org/10.1109/ICETET.2015.47

[28] R. Huang, S. Low, U. Topcu and K. Chandy, "Optimal design of hybrid energy system with PV/Wind Turbine/ Storage: A Case study", *Proceedings of 2011 IEEE International Conference on Smart Grid Communications (SmartGridComm)*, Brussels,17-20 Oct. 2011, pp. 511-516. Doi: https://doi.org/10.1109/SmartGridComm.2011.6102376

[29] N. Razak and M. Othman, "Optimal sizing and operational strategy of hybrid renewable energy system using HOMER", *Proceedings of 2010 4th International Power Engineering and Optimization Conference (PEOCO)*, Shah Alam, 23-24 June 2010, pp. 495 – 501. Doi: https://doi.org/10.1109/PEOCO.2010.5559240

Authors' Profiles

Risalin Lyngdoh Mairang is a student of M.Tech. 4th semester in the department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University.

Bikramjit Goswami is working as an Assistant Professor in the department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University, India. He is also a Ph.D. Research Scholar in Assam Don Bosco University currently. His research interests are Reconfigurable Antenna, Microwave Remote Sensing, Artificial Neural Networks, renewable Energy, Disaster Forecasting.

Centralized Air Pollution Detection and Monitoring: A Review

Udit Ranjan Kalita[1], Heniel Kashyap[2], Amir Chetri[3], Jesif Ahmed[4]

[1] Department of Electronics and Communications Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati -781017, Assam, INDIA
*ratisacat@gmail.com**

[2,3,4]Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati -781017, Assam, INDIA
[2]henielkashayp@gmail.com, [3]chetriamir@gmail.com

Abstract: ***Air pollution has become a major concern over the last quarter century and therefore mitigation of poor air quality for health and environmental reasons has been a primary focus for local governments. Industrialization and increasing number of vehicles are the primary source of pollution. There is ever rising need for continuous monitoring of air quality. A lot of technologies have introduced for measuring the air pollution. This paper presents a comparative study of the available technologies. Comparisons have been done based on measured pollutants, sensitivity, range, implementation cost, level of complexity etc., which are provided in tabular form for easy comparison. Paper also includes a proposed model which is an idea to implement the same as a real time project for air pollution detection and monitoring using microcontroller and Wi-Fi module.***

Keywords: Centralized Air pollution, particulate matter (PM), Sensor, Wi-Fi module, Arduino Microcontroller.

1. Introduction

In recent epoch, air pollution is an important problem in society that harms the human health and environment. This is a great problem faced in the urban area. Air pollution contributes to the greenhouse gases, which causes the greenhouse effects, whose side effects are well known to all of us. In recent time, there is a tremendous increase in pollution by the private vehicles. The main component of pollution from vehicles is oxide of carbon, which can be easily sense by the semiconductor gas sensors. These pollutants impact on the human health affecting lungs & respiratory system. These pollutants also deposit on soil plants, water etc. Various sensors can do the sensing of emitted gas. This paper suggests an idea, which is expected to help in reducing the pollution in air. Paper also includes a proposed model idea to implement the same as a real time project for air pollution detection and monitoring.

2. Literature Review

A literature study was done to compare the different methods for detecting and monitoring of air pollution, specially detecting toxic gases like CO, CH_4, particulate matter etc. The survey reveals various advantages and disadvantages of those methods. The methods are illustrates in the below section. In a factsheet by World Health Organization [1], WHO has mentioned that the air pollution is a major environmental risk to health, and by reducing the air pollution level one country can reduce the burden of heart diseases, lung cancer and both chronic and acute respiratory diseases including asthma. This factsheet suggests number of policies and investment supporting cleaner transport, cleaner municipal waste management etc. WHO's factsheet also presents a study of how much of the pollutant like SO_2, particulate matter (PM), NO_2 is acceptable in the air and their effects in the human health if they increase. The authors L. C. Amorim and J. P. Carneiro and Z. L. Cardeal [2] described Solid-phase microextraction (SPME) as a sampling technique for determining benzene in exhaled air by GC-MS. A system was developed to generate a gaseous benzene standard by a permeation method to accomplish the breath analyses. Authors also optimized the condition and analyses of real samples on two groups i.e., exposed and not exposed to benzene. Authors also mention that this method has good resolution, repeatability and sensitivity. In another literature, the authors Wei Ying Yi, Kin Ming Lo, Terrence Mak, Kwong Sak Leung, Yee Leung and Mei Ling Meng [8] have described the different technique of detecting the pollutant in the air and also explained the working of those techniques. The authors also performed a comparative study on the techniques based on their performance and cost effectiveness. The authors D. Hasenfratz and O. Saukh and S. Sturzenegger and L. Thiele [7] have described about the different types of wireless nodes like community sensor node and static sensor node; and the author explained that community sensor node the sensor nodes are typically carried by the users. By utilizing the low-cost portable ambient sensors and the ubiquitous smart phones, users are able to acquire, analyze and share the local air pollution information. Similarly, in static sensor node the sensor nodes are typically mounted on the streetlight or traffic light poles, or walls. Due to the low-cost ambient sensors, the number of sensor nodes in SSN systems is much higher than that in the conventional monitoring systems. Again the authors P. Doraiswamy, W. T. Davis, T. L. Miller, J. S. Fu and Y. F. Lam [10] have performed experiments on trucks to detect its pollutant level. The authors used MQ-2 gas sensor along with an Arduino Uno board to detect the quality of the smoke produced by the exhaust pipe of the truck and after that they transmit the data through ESP8266 wireless transmitter to the predefined server and also design a mobile app to access the data. Similarly, in case of detecting the CH_4 in the air, the authors mentioned about the use of the sensor MQ-9 electrochemical sensor along with an Arduino Uno board.Authors F. Tsow, E. Forzani, A. Rai, R. Wang, R. Tsui, S. Mastroianni, C. Knobbe, A. J. Gandolfi and N. J. Tao [12] discussed about the MQTT protocol, in which the authors stated that it is a very low cost and low code footprint messaging system. Authors also established a connection between MQTT publisher and subscriber by using ESP8266 Wi-Fi module.

3. Different Pollution Monitoring methods existing

(i) Electrochemical Gas Sensing Method

The main principle of electrochemical gas sensing method is the electro chemical reaction specifically oxidation-reduction reactions in the sensor. An electrical signal proportional to the concentration of the gas molecule is generated by the reaction between the sensor and the gas molecules. This sensor is consist of three basic electrode these are Working Electrode (WE) and a Counter Electrode (CE) and Reference Electrode (RE) which is used to provide an external driving voltage. These three electrodes are separately deployed into the electrolyte within the sensor. For detecting and improving the selectivity to a specific kind of gas, different types of membranes, electrolyte and working electrodes are used. As soon as the gas reaches the working electrode, the oxidation-reduction reaction occurs. The electrode which is specifically developed for a specific gas catalyzes these reactions. By calculating the current between the Working Electrode (WE) and the Counter Electrode (CE) the concentration of the target gas is found. The Reference Electrode (RE) is responsible for controlling the oxidation and reduction reactions and reduces the potential drift on working electrode due to deterioration. It is to be noted that, most of the electrochemical ambient gas sensors require a small amount of oxygen and humidity to function properly. In addition, wind velocity also influences the chemical equilibrium on the sensor’s surface and thereby influences the sensor’s readings [7,8].

(ii) Tapered Element Oscillating Micro-Balance (TEOM) Method

In conventional air pollution monitoring system, this method is widely used. The main principle of this method is that oscillation frequency of the tapered glass tube is proportional to the mass of the tube. The mass and the oscillation frequency of the tube will be changed by the PM deposited onto the tube. By calculating the change in oscillation frequency of the tube and volume of the air sampled, researchers are able to deduce the mass concentration of PM in ambient air. The air is sampled through a size selective inlet [8].

(iii) β-Attenuation Method (BAM)

The β-Attenuation Method or β-Attenuation Monitors (BAM) are the most widely used particulate matter (PM) measurement equipment in the conventional air pollution monitoring systems. With the help of a size selective inlet (PM10 or PM2.5) the air is first sampled either with heater or without heater that minimizes the water contained in the air. After that air is passed through a paper filter which catches the PM and later on this paper filter is subjected to the β-attenuation source. By measuring the radiation intensity of the filter and the interval, one can calculate the mass of the PM on the filter [8].

(iv) Black Smoke Method

The black smoke technique collects the particulate matter (PM) on a paper filter over 24 hour period though a size selective inlet. A reflectometer is used to measure the darkness of the paper filter which is converted to the PM’s mass concentration. This type of monitoring instrument is cost-efficent, simple and robust. After that, the mass concentration is obtained by measuring the darkness of the filter paper and this varies in different locations. This means the darkness-to-mass coefficient changes with time and locations. [8].

(v) Light Scatting Method

The main component of this method is a high energy laser which is used as a light source. Whenever a particle passes through the detection chamber that only allows single particle sampling, the laser light is scattered by the particle; and by using a photo detector, the scattering light is detected. By analyzing the intensity of the scatting light, one can deduce the size of the particle. Also, the number of particle counts can be found by counting the number of detecting light on the photo detector. A single analyzer can detect particles with different diameters simultaneously (i.e., PM2.5, PM5 and PM10), this is one of the advantage of this method. Once particle count is counted, it is converted to mass concentration by calculation (depends on the particle counts, particle types and particle shapes), but this will introduce errors that further affect the precision and accuracy of the analyzers which put a limitation to this method [8].

(vi) Direct Imaging Method

In this analyzer, the particle is illuminated with a beam of halogen light and the shadow generated due to the illumination of each particle is projected to a high definition, high magnification and high resolution camera. This camera records the passing particle and after that the video is analyzed by using computer software to measure the PM's attributes. By using this method both count and size of the PMs in the ambient air is obtained [8].

(vii) Light Obscuration Method (Nephelo meter method)

In this method, a particular category of optical analyzers uses the fastest particle concentration measurement method with high precision and low detection limited. A nephelo meter is an instrument that measures the size and mass concentration of PM in the ambient air. In a nephelo meter, one silicon detector and a near infrared LED are used. The LED is used as a light source and the silicon detector is used to measure the total light scatted by the particulate matter. Mass concentration and size distribution are determined by analyzing the intensities of light scattered by the PMs the shape of the scattering pattern. The TEOMs and BAMs are used in conventional monitoring systems due to their large size, heavy weight, high cost and high data resolution and accuracy. The light obstruction and the light scatting optical analyzer results have low resolution and accuracy and it varies with time and also with the location, yet these two type of sensor are widely used in hand-held monitoring devices and The Next Generation Air Pollution Monitoring Systems (TNGAPMS) due to their low cost, light weight, small size and simultaneously measuring ability [8].

(viii) WSN Based Air Pollution Monitoring Systems

In recent times, air pollution in the urban area has attracted extensive attention throughout the world due to its impact on human lives at anytime and anywhere. To mitigate these impacts, a network of monitoring stations using traditional measuring instrument have been deployed. Acquired data can be used to generate pollution maps and models, which can be used for predicting the environmental situation. Quality of service and limitation in spatio-temporal resolution plays a vital role in these systems. These limitations result in issues and problems of the conventional air pollution monitoring systems, like non-scalability of system, limited data availability on personal exposure, and out-of-the-fact warnings on acute exposure [8].

(ix) Static Sensor Network (SSN)

In SSN systems, the sensor nodes are typically mounted on the streetlight or traffic light poles, or walls. Due to the use of low cost sensor module in SSN system, the number of sensor in SSN system is much larger, in comparison to the conventional monitoring system. The pollution information that can be achieved with the SSN system has high spatio-temporal resolution. By the use of Webpages, Mobile app, etc., the air pollution data is available to the public [8].

(x) Community Sensor Network (CSN)

In CSN (or Participatory Sensing) systems, the sensor nodes are typically carried by the users. By utilizing the low-cost portable ambient sensors and the ubiquitous smart phones, one can acquire, analyze and share the local air pollution information. Air pollution data is available to the public through the Webpages, mobile app etc. [8,9].

Table 1 shows the comparison among various pollution monitoring methods.

Table 1: Comparison of different Pollution Monitoring methods

Method	**Cost**	**Implementation**	**Sensitivity**	**Detectable Pollutant**
Electrochemical Gas Sensing	Less	Easy to implement	Moderate	CO, CO_2, NO_2, CH_4, Propane, Butane etc.
Tapered Element Oscillating Micro-Balance (TEOM) Method	High	Equipment are large but it can be implemented	High	CO, CO_2, NO_2, CH_4, SO_2, etc.
β-Attenuation Method	High	Equipment are large but it can be Implemented	High	CO, CO_2, NO_2, CH_4, SO_2, etc.
Black Smoke Method	Cost-efficient	Simple to implement	Less	CO, CO_2, NO_2, CH_4, SO_2, etc.
Optical Method	Cost-efficient	Easy to implement	Moderate	CO, CO_2, Particulate Matter
WSN Based Air Pollution Monitoring Systems	Moderate	Simple to implement	Very High	--------
Static Sensor Network (SSN)	Low	Simple to implement	Very High	--------
Community Sensor Network (CSN)	Low	Simple to implement	Moderate	--------

4. Proposed model

The block diagram of a proposed model for Centralized Air Pollution Detection and Monitoring based on sensors, one microcontroller unit, and one Wi-Fi module, is shown below.

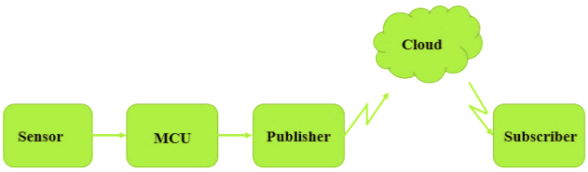

Figure 1: Block Diagram of proposed model

In this proposed model, a number of sensor nodes are being used and these sensor nodes will sense the various pollutants in the air. In the sensor node, the basic components are different types of sensors based on the requirement, one microcontroller unit, and one Wi-Fi module. The sensors are responsible for sensing the pollutant in the air and then it will generate some analog signal based on the concentration of pollutant in the air and this analog signal will feed to the analog pins of microcontroller unit and according to the incoming signal the board will process the signal and send it to the Wi-Fi module. The Wi-Fi module will publish the data to the cloud server. The cloud server is responsible for storing the sensor data and it also process the data to present in an interpretable way. The people who want to see those sensor data in the cloud server they can subscribe to the server and get those data. The Wi-Fi module is also used here to provide the location of the sensor, through geo-location. After getting those data and location of the sensor the server provides a complete scenario of the city pollution.

4.1 Components of the model

A brief working with specifications is given for the components that are used in the system.

(i) MQ2 Gas sensor

This sensor is simple to use which is used to sense the concentration of carbon monoxide in air. The MQ2 can detect CO gas in air between 20 to 2000ppm. This sensor gives quick response and is very sensitive to CO. The sensor gives output in analog form. To drive the sensor we have to apply 5V to the heater coil of sensor. This sensor has wide detection range; also it gives stable performance after it gets stable in the environment after some time. Its cost is low as compared to others. It is applicable for detecting domestic gas leakage, industrial co detection and portable gas detector. To calibrate this sensor we have to keep heating its heater coil for 48hours continuously. After this, the load resistance R_L needs to be adjusted until we get a single value, which is a response to a certain CO concentration and point of 90s. Then adjustment is required for the other load resistance R_L until we get a single value which responses to a CO concentration at the end point of 60s. After completing this task, the sensor is ready to use.

(ii) MQ4 gas sensor

This sensor is simple to use which is used to sense the concentration of methane gas (CH_4) in air. The

MQ4 can detect co gas in air between 200 to 10000ppm. This sensor gives quick response and is very sensitive to CH_4. The sensor gives output in analog form. To drive the sensor we have to apply 5V to the heater coil of sensor. This sensor has wide detection range; also, it gives stable performance after it gets stable in the environment after some time. Its cost is low as compared to others. It is applicable for detecting domestic gas leakage, industrial combustible gas detection, in car, etc. which uses methane as fuel and can be used in houses also. To calibrate this sensor we have to keep heating its heater coil for 48hours continuously. After this, the load resistance R_L needs to be adjusted until we get a single value, which is a response to a certain CH_4 concentration and point of 90s. Then adjustment is required for the other load resistance R_L until we get a single value which responses to a CH_4 concentration at the end point of 60s. Once this is over the sensor is ready for use.

(iii) Micro controller (Arduino Uno)

It is to be used for receiving data from the sensors and it stores one of the sensor values in the EEPROM. This receives analog value from the sensor and then it processes the analog value to convert it into parts per million. After converting this values both analog and ppm values will be displayed on the Liquid crystal display. The command will be given by the control to display these values on LCD.

(iv) Liquid Crystal Display (LCD)

This is the element that is used to display the concentration of gases present in the around atmosphere. This is a 16*2 display it has 16 characters to display in one line and it has total 2 line i.e. it can display total 32 characters. In this system, we have displayed the values of all the gases in analog and its corresponding value in ppm. At a time, the value of one gas is displayed in the first line analog value is displayed and in the second line concentration of gas is shown in ppm.

(v) Wi-Fi Module (ESP8266)

The ESP8266 module is a low-cost Wi-Fi microchip with full TCP/IP stack and microcontroller capability. It was introduced by Ai-Thinker in August 2014. This module establishes connection in between microcontroller and the Wi-Fi network by following TCP/IP connections.

4.2 Working Principle of proposed model

The working starts with the sensing of the sensor. In this system, there are two sensors that are MQ2 and MQ4. They sense carbon monoxide, methane respectively. They give analog output as per the concentration of gas present in the air produces analog signal at the output of sensor. This output is taken as analog input to the Arduino and then according to the programming, it processes the data and converts the analog value into its corresponding value in volts and parts per million (ppm). Equations given below are used to convert the analog value from the sensor.

(*i*) To convert analog to volts:

Volts = (5 × analog value from the sensor) / 1023

(*ii*) To convert analog value to ppm:

$$\text{ppm} = x \times \text{analog value}$$

where"x" is the multiplying factor calculated as per the sensor by calibrating it in user's own environment.

After collecting the sensor data, the data is sent through the ESP8266 module by using MQTT protocol to the MQTT broker.

5. Conclusion

One of the major issues that we are facing today is Air pollution. Pollutions in earlier days were negligible. But nowadays pollution is increasing day by day because of so many reasons like industrial growth, development of automobile industries, chemical industries etc. So in order to reduce the pollutions from such type of sources and to protect the environment from toxic gasses, it is possible to take help of some of the semiconductor sensors such as MQ9, MQ7, etc. that helps in detection, monitoring, and also self-test of vehicles with the help of Microcontrollers.

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References

[1] "Ambient (Outdoor) Air Quality and Health", Factsheet, *World Health Organization*. [Online]. Available: http://www.who.int/mediacentre/factsheets/fs313/en/ [Accessed: 20 August 2017].

[2] L. C. A. Amorim, J. P. Carneiro and Z. L. Cardeal, "An optimized method for determination of benzene in exhaled air by gas chromatography-mass spectrometry using solid phase micro extraction as a sampling technique", *Journal of Chromatography B*, Vol. 865, Issues 1–2,

April 2008, pp. 141-146. Doi: https://doi.org/10.1016/j.jchromb.2008.02.023

[3] "Air Quality Health Index (AQHI)", *Environmental Protection Department, Govt. of Hong Kong*. [Online]. Available: http://www.aqhi.gov.hk/en.html [Accessed: 22 August 2017].

[4] "Beijing Environmental Statement 2013", *Beijing Municipal Environmental Protection Bureau*. Retrieved from: http://www.bjepb.gov.cn/bjepb/resource/cms/2014/06/2014061911140819230.pdf

[5] "Air", *Department of Environmental Conservation, New York State*, U.S.A. [Online]. Available: http://www.dec.ny.gov/chemical/281.html [Accessed: 22 August 2017].

[6] "Pollution Episodes", *London Air*, London Air Quality Network (LAQN): Monitoring Site, King's College London. [Online]. Available: http://www.londonair.org.uk/london/asp/PublicEpisodes.asp [Accessed: 22 August 2015].

[7] D. Hasenfratz, O. Saukh, S. Sturzenegger and L. Thiele, "Participatory Air Pollution Monitoring Using Smartphones", *Proceedings of 2^{nd} International Workshop on Mobile Sensing*, April 16–20, 2012, Beijing, China. Retrieved from https://pdfs.semanticscholar.org/3f4f/00024beda5436dce4d677f27fe4209c3790f.pdf

[8] W. Y. Yi, K. M. Lo, T. Mak, K. S. Leung, Y. Leung and M. L. Meng, "A Survey of Wireless Sensor Network Based Air Pollution Monitoring Systems", *Sensors*, Volume 15, Issue No. 12, Dec. 2015, pp. 31392-31427. Doi: http://dx.doi.org/10.3390/s151229859

[9] W. Y. Chung and S. J. Oh, "Remote monitoring system with wireless sensors module for room environment", *Sensors and Actuators B: Chemical*, Vol. 113, Issue No. 1, January 2006, pp. 64-70.Doi:10.1016/j.snb.2005.02.023

[10] P. Doraiswamy, W. T. Davis, T. L. Miller, J. S. Fu and Y. F. Lam, "Measuring Air Pollution Inside And Outside of Diesel Truck Cabs", *Report Prepared for the U.S. Environmental Protection Agency by University of Tennessee*, Knoxville, November 4, 2005. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.401.6452&rep=rep1&type=pdf

[11] "SmartWay", *EPA, United States Environmental Protection Agency*. [Online]. Available: https://www.epa.gov/smartway

[12] F. Tsow, E. Forzani, A. Rai, R. Wang, R. Tsui, S. Mastroianni, C. Knobbe, A. J. Gandolfi and N. J. Tao, "A Wearable and Wireless Sensor System for Real-Time Monitoring of Toxic Environmental Volatile Organic Compounds", *IEEE Sensors Journal*, Vol. 9, Issue No. 12, Dec. 2009, pp. 1734-1740. Doi: 10.1109/JSEN.2009.2030747

[13] "How To - Build a Website", *w3schools.com*. [Online]. Available: https://www.w3schools.com/howto/howto_website.asp [Accessed: 23 Aug. 2017].

[14] S. Choi, N. Kim, H. Cha, and R. Ha, "Micro Sensor Node for Air Pollutant Monitoring: Hardware and Software Issues", *Sensors*, 2009, Vol. 9, Issue No. 10, pp. 7970-7987. Doi: https://doi.org/10.3390/s91007970

Authors' Profiles

Udit Ranjan Kalita
B.Tech. 8^{th} Semester,
Department of Electronics and Communications Engineering, School of Technology, Assam Don Bosco University.

Heniel Kashyap
B.Tech. 8^{th} Semester,
Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University.

Amir Chetri
B.Tech. 8^{th} Semester,
Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University.

Jesif Ahmed is working as an Assistant Professor in the Department of Electrical and Electronics Engineering, School Of Technology, Assam Don Bosco University, Guwahati, Assam, India. He is pursuing his Ph.D. from Gauhati University, Assam, India. His research interest includes study of electricity market, Power system optimization and transmission congestion management.

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ASSAM DON BOSCO UNIVERSITY

Azara Campus, Airport Road, Guwahati - 781017
+91-9435545754, 0361-2139291/92
www.dbuniversity.ac.in