CONTROLLERS AND METHODS FOR DIFFERENT ELECTRICAL MEASUREMENTS IN SYNCHRONIZATION OF RENEWABLE ENERGY SOURCES FOR GRID CONNECTIVITY: A REVIEW

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Abstract: In this paper, different controllers used in synchronization of renewable energy sources are studied. A study regarding the use of artificial intelligence in synchronization of grid connected power converters, efficient method for phase angle detection, frequency variation detection and good performance during voltage depression etc carried out here. Importance of hybrid controllers over conventional controllers is also presented. Possibility of Z source T type inverter as an alternate solution to DC-DC converter is explored based on existing works.

Keywords: controllers; electrical measurements; renewable energy sources; grid; artificial intelligence; hybrid controller; net metering

1. Introduction:

With the increase in demand of energy, there is shift in the energy scenario towards renewable energy. There is ample number of renewable energy sources. Due to lack of proper and efficient harnessing methods, total contribution of renewable energy sources out of other energy sources is nearly about 14% [1].Synchronization of different energy sources is a common practice for efficient utilization of energy. Net metering is on trend these days. Net metering not only helps to reduce electricity bills but also attempts to create an energy hub. Synchronization of renewable energy sources supports net metering. Net metering is a process which uses a bi directional meter that records the amount of electricity which is drawn from the grid or supplied to the grid. The electricity provider pays the consumer for supplying back the additional amount of electricity produced, back to the grid. Various constraints have to be solved in order to achieve optimal power flow between grid and renewable energy sources. Improper synchronization and variability in renewable energy sources is a constraint to optimal power flow in grid connectivity and without proper optimal power flow in grid connectivity net metering is difficult to achieve [2].

It is intended to club hydro energy and wind energy at Tapesia campus of Assam Don Bosco University, to produce energy that can fulfill the energy demand of the campus. There are lots of issues when we try to synchronize renewable energy sources with that of the grid like problems due to voltage unbalance, fluctuations, frequency variations etc. In this review paper it is aimed to study different controllers that can be used in an efficient synchronizing scheme for practical use.

Different controllers which are used to monitor the system are studied in this paper. Different algorithms like proportional integral derivative, fuzzy logic, artificial neural network, genetic algorithm etc [3] have also been studied in this review paper.

2. Challenges in grid synchronization and its existing solutions:

Some of the challenges in grid synchronization are occurrence of spurious frequency transients, delay in estimation and synchronization, effects of phase angle variation and frequency variations, deterioration of performance due to voltage depression and harmonics, effects of angular frequency variations and positive and negative sequences of fundamental components of 3-ϕ signal, variability and limited predictability of renewable energy sources etc.

It is observed that, mostly in grid synchronization methods, phase angle detection and frequency detection is done in the same loop in PLL. Due to this when phase angle changes, spurious frequency transients are caused. This transient delays the process of estimation and synchronization. Hence there is a need to develop efficient method for phase angle detection, frequency variation detection and good performance during voltage depression and harmonics [4].

It is seen that dynamic response during transients is sensitive to phase angle jumps. Therefore more attention should be given to synchronization schemes which are based on grid voltage and frequency estimation. In the near future, smart grids will need an intelligent technique which will be fast and effective for synchronization of required positive/negative sequences, fundamental variables and harmonic voltage components for the controllers [4].

Power generation system under voltage unbalance and frequency variations can be taken care of by using extended Kalman Filter (EKF) based synchronization scheme which tracks the phase angle of the utility network [5].

There is a particle filter based scheme which estimates phase angle of the utility grid in the presence of voltage imbalance and frequency variations in the αβ stationary reference frame [6]. The positive and negative of the 3-ϕ input signal in the reference frame are separated by Clarke Transformation. Grid synchronization is done by customizing traditional SIR filter. Simulation results shows that this method is superior to traditional EKF – based scheme in regards to accuracy in estimation and convergence time under voltage imbalance and frequency variations [6].

Angular frequency estimation and estimation of positive and negative sequences of the fundamental component of an unbalanced 3-ϕ signal is given by a phase locked loop method where variables are described in fixed reference frame co-ordinates. This method delivers pure, balanced sinusoidal signal vector that represents the positive sequence of the voltage signal and a fundamental frequency estimated signal that is ripple free. This method also compensates step variations on the frequency due to the adaptation mechanism [7].

Using switched capacitor at parallel operation of inverters, voltage quality of the micro-grid and synchronization requirements can be met. One can also use synchrocheck relays for micro-grid synchronization [8].

Variability and limitations in predictability of renewable energy sources creates difficulty in integrating renewable energy sources to smart grids. Two major challenges described in this regard are: low voltage ride through (LVRT) capability and inter area oscillation.

LVRT capability of wind power plant and photo voltaic power plant is the ability of renewable energy sources to stay connected to the grid when there are voltage dips. LVRT confirms stability of the system after a fault and fast recovery of the system after the occurrence of the fault. When power system is ruled over by hydro generation photo voltaic power plant along with ultra capacitor gives better damping for intra area oscillations. When thermal generation dominates the system, battery energy storage system – Photo Voltaic power plant provides higher damping [9].

Three methods for damping inter area oscillations as described by Eltigani et.al are:
- Incorporating energy storage devices.
- Generation re dispatching.
- Power oscillation damping controller utilization [9].

Different existing methods of synchronization for grid connected converters like [4].
- **Zero crossing detector**: it is used in phase angle detection.
- **Kalman filter**: it is used for measurement of frequency.
- **Discrete Fourier Transform**: it is used for harmonic and frequency detection.
- **Non linear least square**: it is used for frequency estimation. It minimizes the square error between the modeled and measured signal.
- **Adaptive notch filter** (ANF): it provides higher immunity to noise, detects phase angle, frequency, amplitude in frequency variations, current harmonic etc.

• **Artificial intelligence** (AI): AI tools have broad application. Artificial neural network tends to mimic the human brain. It is also used to identify phase, amplitude, frequency and harmonic deviations in power system.
• **Delayed signal cancellation**: detects fundamental and harmonic components related to grid with zero steady state error and short transients. This method provides immunity to small variations in frequency.
• **Phase locked loop** (PLL): it reduces the phase error to zero and provides the output phase.
PLL is simple, effective and robust in different grid conditions. Its vast range of application is found in the field of control system, communication, instrumentation etc.

Algorithms based on ANF are gaining more attention because of its simplicity. In ANF based methods, transient response is found o be faster than PLL based method.

Active synchronization, passive synchronization, open transition transfer methods are another three approaches of synchronization.

3. Algorithms of synchronization in grid connected renewable system:

Five algorithms of synchronization which are commonly used in grid connected renewable system are [10]

Synchronous reference Frame phase locked loop (dqPLL)	It is very easy to implement. It can have an acceptable operation under the influence of low order harmonic distortion and frequency variations of the 3 phase utility grid voltages.	Under the unbalanced voltage conditions, second order harmonic in the detected phase and frequency was observed.	Drawback: high sensibility to voltage imbalances.
Positive sequence detector+ dqPLL	Helps to extract positive sequence of the three phase utility grid voltage	Under the condition of voltage imbalances, a reliable detection of positive sequence of the frequency and phase can be achieved through this structure.	Drawback: A small degradation of power factor of the inverter grid connection.
Dual second order generalized integrator phase locked loop(DSOGI-PLL)	Due to the combination of DSOGI and PLL a significant harmonic attenuation was observed in the detected frequency when the 5 th and 7 th harmonics were introduced in the utility grid.	Able to detect a phase and frequency free of the 2 nd order harmonic, when unbalance occurs in the utility voltages.	Drawback: Presence of an overshoot and certain fluctuation were observed when a step frequency was exerted.
Dual second order generalized integrator frequency locked loop(DSOGI-FLL)	An ideal frequency and phase detection is attained under the condition of frequency variations due to its frequency adaptive filter.	Under the condition of voltage unbalance, the algorithm is capable of calculating positive sequence of the utility grid voltages.	Advantage: distorted free feedback phase.
Multiple second order generalized integrator phase locked	Detects the positive sequence of three phase utility grid	Uses large number of adaptive filters for each harmonic in the	Drawback: computational burden.

loop(MSO GI-PLL)	voltage and rejects low order harmonic contamination	utility voltage.	

4. Maximum power point tracking techniques in grid synchronization:

Conversion of a part of the solar irradiance into electrical energy produces photovoltaic energy. PV cells are arranged in series and parallel association and thus PV modules are formed. There is a change in the maximum power point of the PV module with the variations of solar irradiance and temperature levels. Owing to the high cost of PV modules and their low efficiency there is a need to integrate MPPT controllers [3]. For tracking down maximum power available at a particular instant MPPT techniques are used. The heart of MPPT technique is a DC-DC converter and for better performance any of the buck- boost converters are used [11].

A comprehensive comparative study of the most adopted Artificial Intelligence based MPPT techniques are:
• Proportional integral derivative
It is low cost, easy and simple to implement and offers good compromise between performance and implementation cost. Thiscontroller is recommended for non expensive application.
• Artificial neural network
It is a perfect choice for high efficiency MPPT tracking. Major drawback is additional cost of temperature and irradiance sensors. It suffers from robustness against aging of PV modules; this method is not suggested to be used in MPPT system under uniform insolation condition [3].
• Fuzzy logic based maximum power point tracking(MPPT)
It gives high performance and very good results. This method does not require exact knowledge of PV characteristics and needs only low cost sensors: voltage and current. Its implementation needs a calculator and high level programming knowledge. It is suggested for expensive application which needs a high tracking accuracy [3].
• Particle swarm optimization and genetic algorithm
Both the methods provide good MPPT and show very good performance. Genetic algorithm is more difficult than Particle swarm optimization. These controllers need several numbers of iterations to locate the MPP thus making slowness in MPP tracking [3].

The main drawback of these controllers is they cannot follow new MPP when a slight change in the MPP location is occurs. Using these techniques, when PV array is small and always receives uniform insolation is not suggested. Their use in large scale PV farms is crucial especially when a significant loss of power is caused by partial shading effect [3]. Particle swarm optimization is the best solution for MPPT application under partial shading condition [12].

Adaptive neuro fuzzy inference system(ANFIS) based MPPT can extract the maximum power in different environmental conditions. ANFIS based method takes the lowest time for the torque to settle down and also the PMDC motor rotates at maximum speed while using the ANFIS based MPPT [4]. At higher temperature and insolation levels, the fuzzy logic controllers were found to extract more power than the neural network based MPPT. At lower temperature and insolation, the neural based MPPT is able to extract more power than fuzzy logic controller [4]. The motor speed is higher for fuzzy logic controller than neural network based MPPT.

5. Role of artificial intelligence methods in grid synchronization:

Artificial intelligence in grid synchronization is less explored. More studies regarding the use of artificial intelligence in synchronization of grid connected power converters is needed.

In the near future, smart grids will need an intelligent technique which will be fast and effective for synchronization of required positive/negative sequences, fundamental variables and harmonic voltage components for the controllers [4]. In most of the research reports, effective applications of artificial intelligence in wind and solar based system are discussed. There are few research reports based on implementation of artificial intelligence approaches in other and hybrid renewable energy sources [13].
It is found that artificial immune system, artificial bee colony, artificial fish swarm algorithm have higher accuracy in parameter identification application than genetic algorithm (GA) and simulated annealing. Neural network achieves highest accuracy in sizing PV systems and MPPT [14]. Fuzzy controllers and hybrid fuzzy

controllers are widely used controllers in MPPT and inverter control. Genetic algorithm achieves the highest accuracy in sun tracking application. Neural network is most widely used algorithm for fault diagnosis [14].

6. Z source T type inverter for grid as an alternate solution to dc-dc converter:

Z source T type inverter for grid connected renewable energy system has the ability of boosting up voltage level without any additional DC-DC converter or transformer through Z impedance network. Due to the elimination of DC-DC converter or step up transformer requirement, the size of the system gets reduced [15]. T type 3 level structures is more efficient than other conventional 2 level and 3 level inverter sources for medium frequency operatio thus the use of t type 3 level structure enhances the efficiency of operation.

Due to the use of PR controller, steady state error is eliminated. Simulation studies suggest that exportation of DC energy to the grid while its voltage level is lower than the peak value of the grid voltage without any additional converter or transformer is possible.

Synchronization between the inverter output current and grid phase and frequency can be achieved. A value of total harmonic distortion level of the inverter output current up to 2.41% can be attained [15].

7. Advantages of hybrid methods over conventional methods:

Hybrid methods have better convergence time and better dynamic response [16]. Hybrid methods give better total harmonic distortion level at inverter output. These methods reduce the cost of the inverter and complexity in control algorithms [17]. Ensures accurate convergence of global maximum point under complicated shading patterns [18,19]. Provides good efficiency, faster convergence speed, less oscillations around MPP under steady state condition, low power consumption and no divergence from the MPP during varying weather conditions[20,21]. Combination of different methods not only reduces steady state oscillation to zero once the maximum power point is located but also tracks MPP for extreme environmental condition [22]. Hybrid structures provide a low cost method that predicts the global MPP region at any environmental condition and finds global MPP within the classified region [23,12]. Ensures solar irradiance measurement which may in turn be used to maximize efficiency directly [24] and provides smaller response time [25].

8. Conclusion:

In this paper, different controllers used in synchronization of renewable energy sources are studied. Challenges regarding grid connectivity are studied here and few existing solution along with few future recommendation are also mentioned.

Fuzzy logic-genetic algorithm controllers found to be the most efficient under standard conditions and under the conditions of changing irradiance. Similarly for better THD Fuzzy logic controller and to reduce steady state oscillation and for tracking global peak point particle swarm algorithm controllers are used.

In this paper it is attempted to explore artificial intelligence methods that can be used for grid connectivity. Methods that are helpful for parameter identification, accurate in sizing PV systems, useful in sun tracking application etc are discussed.

Contribution of hybrid controllers is found to be more effective and efficient than that of the conventional controllers. Most of the hybrid structures are made of Fuzzy logic controllers and particle swarm optimization methods. As a future recommendation hybrid structures combining other controllers may prove useful in general.

Again, controllers or methods that can follow new maximum peak point when there is slight change in the MPP location can be studied.

A detailed study on the use of Z source T type inverters to replace dc-dc converter owing to its various benefits can prove useful.

Works on synchronization of solar and wind energy are mostly available. Less work and literature is available considering other renewable energy sources.

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References:

[1].Goldemberg, J. "World Energy Assessment (2000): *Energy and the Challenge of Sustainability*." (2001).
[2].Reddy, S. Surender, and P. R. Bijwe. "Day-Ahead and real time optimal power flow considering renewable energy resources." *International Journal of Electrical Power & Energy Systems* 82 (2016): 400-408.
[3].Kermadi, Mostefa, and El Madjid Berkouk. "Artificial intelligence-based maximum power point tracking controllers for Photovoltaic systems: Comparative study." *Renewable and Sustainable Energy Reviews* 69 (2017): 369-386.
[4].Jaalam, N., et al. "A comprehensive review of synchronization methods for grid-connected converters of renewable energy source." *Renewable and Sustainable Energy Reviews* 59 (2016): 1471-1481.
[5].Sun, Ming, and Zafer Sahinoglu. "Extended Kalman filter based grid synchronization in the presence of voltage unbalance for smart grid." *Innovative Smart Grid Technologies* (ISGT), 2011 IEEE PES. IEEE, 2011.
[6].Zhu, Jiangcai, et al. "Particle filter based grid synchronization with voltage unbalance and frequency variation in smart grid." *Wireless Communications & Signal Processing* (*WCSP)*, 2013 *International Conference on. IEEE*, 2013.
[7].Escobar, Gerardo, et al. "Fixed-reference-frame phase-locked loop for grid synchronization under unbalanced operation." *IEEE Transactions on Industrial Electronics* 58.5 (2011): 1943-1951.
[8].Lidula, N. W. A., and A. D. Rajapakse. "Voltage balancing and synchronization of microgrids with highly unbalanced loads." *Renewable and Sustainable Energy Reviews* 31 (2014): 907-920.
[9].Eltigani, Dalia, and Syafrudin Masri. "Challenges of integrating renewable energy sources to smart grids: a review." *Renewable and Sustainable Energy Reviews* 52 (2015): 770-780.
[10].Guerrero-Rodríguez, N. F., et al. "Synchronization algorithms for grid-connected renewable systems: Overview, tests and comparative analysis." *Renewable and Sustainable Energy Reviews* 75 (2017): 629-643.
[11].Vinay, P., and Manju Ann Mathews. "Modelling and analysis of artificial intelligence based MPPT techniques for PV applications." *Advances in Green Energy (ICAGE)*, 2014 *International Conference on. IEEE*, 2014.
[12].Kermadi, Mostefa, and El Madjid Berkouk. "A maximum power point tracker based on particle swarm optimization for pv-battery energy system under partial shading conditions." *Control, Engineering & Information Technology (CEIT)*, 2015 *3rd International Conference on. IEEE*, 2015.
[13].Jha, Sunil Kr, et al. "Renewable energy: Present research and future scope of Artificial Intelligence." *Renewable and Sustainable Energy Reviews* 77 (2017): 297-317.
[14].Mellit, A., et al. "Artificial intelligence techniques for sizing photovoltaic systems: A review." *Renewable and Sustainable Energy Reviews* 13.2 (2009): 406-419.
[15].Ozdemir, Saban. "Z-source T-type inverter for renewable energy systems with proportional resonant controller." *International Journal of Hydrogen Energy* 41.29 (2016): 12591-12602.
[16].Lian, K. L., J. H. Jhang, and I. S. Tian. "A maximum power point tracking method based on perturb-and-observe combined with particle swarm optimization." *IEEE journal of photovoltaics* 4.2 (2014): 626-633.
[17].Thambi, G., et al. "Fuzzy-Logic-Controller-Based SEPIC Converter for MPPT in Standalone PV systems." *International Research Journal of Engineering and Technology* 2.02 (2015).
[18].Boukenoui, R., et al. "A new intelligent MPPT method for stand-alone photovoltaic systems operating under fast transient variations of shading patterns." *Solar Energy* 124 (2016): 124-142.
[19].Eltamaly, Ali M. "Performance of smart maximum power point tracker under partial shading conditions of photovoltaic systems." *Journal of Renewable and Sustainable Energy* 7.4 (2015): 043141.
[20].Chekired, F., et al. "Intelligent maximum power point trackers for photovoltaic applications using FPGA chip: A comparative study." *Solar Energy* 101 (2014): 83-99.
[21].Larbes, C., et al. "Genetic algorithms optimized fuzzy logic control for the maximum power point tracking in photovoltaic system." *Renewable Energy* 34.10 (2009): 2093-2100.
[22].Ishaque, Kashif, et al. "An improved particle swarm optimization (PSO)–based MPPT for PV with reduced steady-state oscillation." *IEEE transactions on Power Electronics* 27.8 (2012): 3627-3638.
[23].Jiang, Lian Lian, Douglas L. Maskell, and Jagdish C. Patra. "A novel ant colony optimization-based maximum power point tracking for photovoltaic systems under partially shaded conditions." *Energy and Buildings* 58 (2013): 227-236.

[24].Mancilla-David, Fernando, et al. "A neural network-based low-cost solar irradiance sensor." *IEEE Transactions on Instrumentation and Measurement* 63.3 (2014): 583-59.
[25].Kulaksiz, Ahmet Afsin, and Ramazan Akkaya. "A genetic algorithm optimized ANN-based MPPT algorithm for a stand-alone PV system with induction motor drive." *Solar Energy* 86.9 (2012): 2366-2375.
[26].Seyedmahmoudian, Mehdi, et al. "Efficient photovoltaic system maximum power point tracking using a new technique." *Energies* 9.3 (2016): 147.