Optimal operation of Distributed Network embedded to wind – Battery storage system for revenue enhancement

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Abstract: ***The environmental concerns and the fuel cost uncertainties associated with the conventional energy sources consequently lead to rapid growth of renewable energy sources connected to the distribution grids. Moreover the continuous increase of power demand emphasizes more and more integration of renewable generation units to the power network to supply the required demand. This incorporation of the distributed generation into the distributed network has tremendous potential if it can be used properly. But the installation cost of these plants are very high. Thus to balance the cost incurred while installing the plant the revenue from those renewable energy producers have to be maximized and losses are to be minimized by using dynamic optimization techniques. The main aim of the project work is to find the optimal operation or condition of a distribution system when embedded to a wind-battery storage system. Hence this paper presents the operation of Particle Swarm Optimization which provides an optimal strategy to increase the revenue from the power trading to the network. Results of IEEE 14 bus system is presented.***

Keywords: Distributed Generation (DG), Distributed Network (DN), storage system (BSS), Particle Swarm Optimization (PSO), Optimal Power Flow (OPF).

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1. Introduction

Nowadays the Renewable Power Generation systems are highly preferred for clean power generation. It reduces the dependency on fossil fuels and consequently reduce all its negative impact. The Renewable energy development has expanded to a great extend, with wind power being the fastest growing technology. Many studies have been recently carried out to make the wind farms dispatchable. This can be achieved by integrating a battery storage system (BSS) with these wind farms [1]. There is a surplus power available which is used for charging the BSS during low demand and deliver power when demand is more. From the consumers' point of view, use of BSS can lower the electricity costs since it can store electricity bought at lower prices during off peak which can be used during peak periods in the place of expensive power[7].

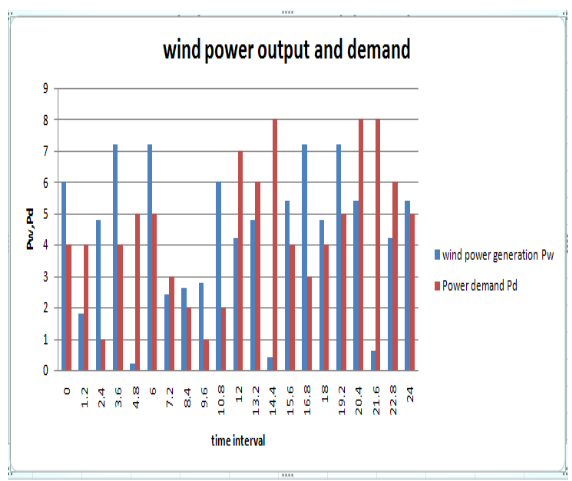

Figure.1 Wind-demand power profiles for a day

Fig. 1 schematically demonstrates the daily demand and wind Power profiles. It can be seen that, variation is observed at an interval of 1.2 hours, if demand is less than the wind power production, then the excess energy can be stored in BSS which can be used later when demand is more. Thus by optimizing the daily, weekly or yearly scheduling of the renewable generating plants it is possible to maximize the total revenue [1]. The main objective is to maximize the total income from the power trading to the DN.This process of designing the optimum system by satisfying some objective is optimization, it follows a process or methodology of making something fully perfect, functional, or effective as possible; specifically by using the mathematical procedures. In other words optimization is the process of maximizing of a desired quantity or minimizing of an undesired one [17]. The electrical power system is a network of large number of electrical components used for supplying, transferring and utilising power. Economically electricity (both power and energy) can be bought, sold and traded. The income derived from the power trading should always be more than all other costs like generation cost, operation and maintenance cost etc. which in turn will affect the electricity pricing. Thus optimization plays a great role in such condition. OPF determines the optimal solution to an objective function which is subjected to the power flow constraints and other operational constraints such as generator constraints, transmission stability constraints and voltage constraints and many more according to therequirement. But when the renewable generation units are integrated to the power network the designing of optimum model become more complex because along with the renewable source other auxiliaries will also be incorporated such as BSS, PCS etc. Hence to find the optimal operation of such integrated system there may be need of designing multiple objective functions. As a result complexities of the power system increases further.

2. Operating Scheme Of Wind-Storage System

Energy storage is one of the efficient and effective solutions to store and use energy on demand. It provides flexibility throughout the grid and improves stability, power quality and reliability of supply. Hence Energy storage systems if embedded with the renewable energy generations provide a wide range of ways to manage power supplies and create a more stable energy infrastructure and as a result the cost of energy for utility providers and consumers get reduced as well as it lowers the operating cost of generation. However the optimal BSS capacity is closely related to the shape of load curves and parameters of all generating units in a power system. [3].Energy storage systems are comprised of three main modules:

a. The Battery storage i.e, BSS.

b. The Power Conditioning System(PCS) which help the energy the energy conversion from AC to DC or DC to AC

c. The control system that controls the operation of energy storage system

The operation of Wind-Battery stations is considered which is composed of two main substations. First, a wind farm substation which can dispatch power hourly. Second, a Battery substation in which its power and capacity are selected initially through simulation procedures for satisfying the electricity market requirements at the same time. The wind farm (WF) is designed to generate the active and reactive power. During low demand the excess power is used to charge the battery through PCS. While during high demand the power to the network is supplied by the wind farm as well as the battery.

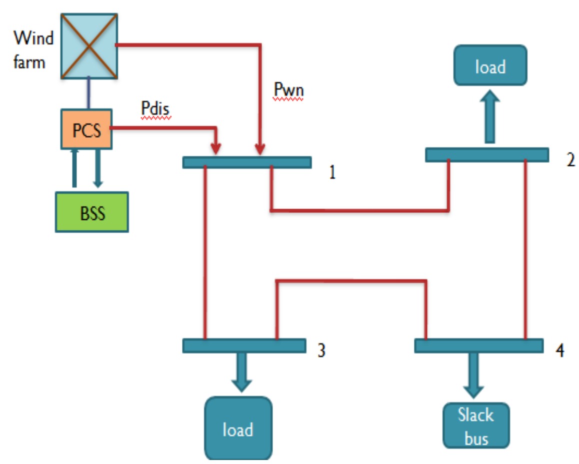

Figure.2 Model diagram of the wind storage system integrated to a bus.

P_{sell} the hourly total active power to be sold by the windfarm to the electrical power network, P_{ch} the hourly active power used for charging the battery substation and P_{dis} the hourly active power discharged to the network from the battery substation respectively. Pw is the hourly wind power generation, Pwn is the hourly active power delivered by the wind farm to the network. Where

$$Psell(k) = Pwn(k)+Pdis(k)$$

$$Pw(k) = Pwn(k) +Pch(k) \qquad \text{Where } k=1……..20$$

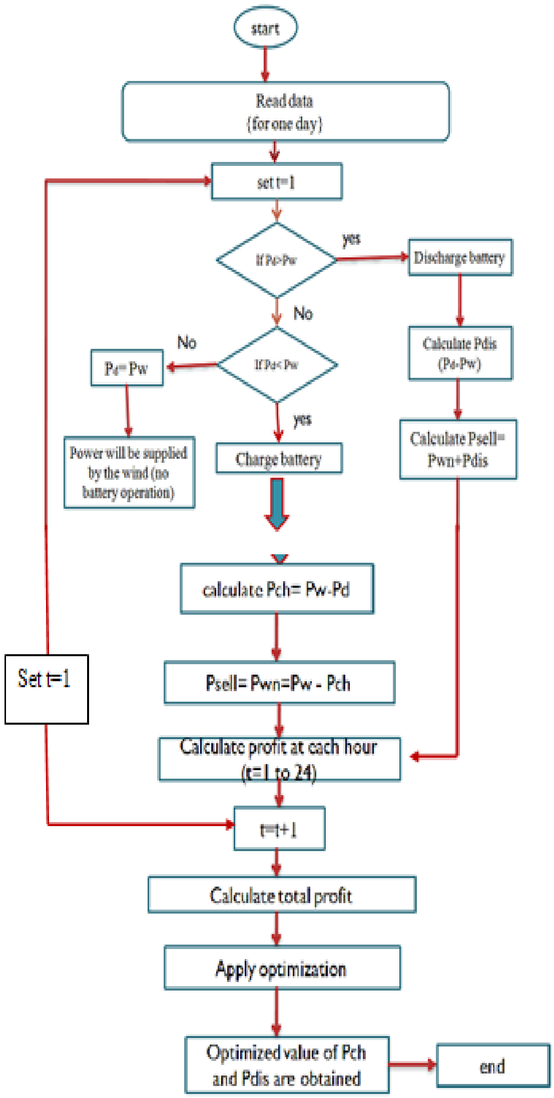

Figure.3 Flowchart showing the operation of charging discharging of the battery

3. Objective Function To Maximize the Revenue of the system

Considering the above assumptions a dynamic optimization problem is formulated to maximize the profit of a operating Wind-battery storage system integrated to the network while all the operational constraints are satisfied.

3.1 Objective function

The entire optimization problem is divided into six terms for simplification . Firstly to maximize thetotal yield obtained from the wind storage system and to find the optimal condition. Secondly to minimize cost due to power losses in the lines of a 14 bus system and then to find the optimal operating condition of the system while combining both the problems along with all the traditional generating units

The objective function can be formulated as:

$$F = F_1 - F_2 + F_3 + F_4 + F_5 + F_6$$

$$F_1 = \sum_{k=1}^{20} [Cpr(k)(Psell(k) - Cch(k)Pch(k) + Cdis(k)Pdis(k) - \beta\{\{(Pch(k+1) - Pch(k)\}^2 + \{Pdis(k+1) - Pdis(k)\}^2\}]$$

$$F_2 = Cpr(k) \sum_{i=1}^{N} \sum_{j}^{N} Lpij \qquad \text{for } (i \neq j)$$

The first function F_1 represents wind generation which comprises of two parts. The first part gives the total revenue from wind active power trading to the network in which the losses in the revenue due to charging of the battery are subtracted. The second summation term is formulated to minimize the differences of control variables between two successive time intervals. β is the weighting factor used to formulate a multi-objective model where the generation cost and system network loss is combined together. Function F_2 represents the total costs due to the energy losses. $L_{pij}$is the line losses of the system between the nodes i and j which is again subtracted from the total revenue. While F_3, F_4, F_5 and F_6 are revenue collected from the traditional generating units of the network.

3.2 Operational Constraints

The Optimal Power Flow model contains an objective function, equality constraints such as power balance equations, and inequality constraints such as the power flow limit, Generator power limits, Bus voltage limits etc.The operation constraints for satisfying the technical requirements of the whole system are given by inequalities

- $Psell.min(k) \leq Psell(k) \leq Psell.max(k)$
- $0 \leq Pwn(k) \leq Pw(k)$
- $0 \leq Pch(k) \leq Sr(k)$
- $0 \leq Pdis(k) \leq Sr(k)$

Where Psell. min(k) and Psell. max(k) are the minimum and maximum active power output respectively.

3.3 Inequality constraints

Bus Voltage bounds of the system is

- $V_{min}(i) < V(i,h) < V_{max}(i)$ where $i \in N$

Active power bounds at the slack bus

- $-Ps.rev.max < Ps(h) < Ps.fw.max$

Power flow bounds of the lines of the network

- $S(i, j, h) < S_{1.max}(i,j)$, where $i,j \epsilon N$ ($i \neq j$)

4. Results and Analysis

The case study is done firstly for an isolated wind Battery embedded system supplying power to a bus. Fig.2 shows the model of system of wind farm and storage system connected to a node of a power system. The main objective is to maximize the income obtained from power trading to the network, The optimization problem that is formulated is solved under the MATLAB environment, using PSO optimization technique. PSO is based on the swarm intelligence. It can be applied into both scientific research and engineering use. Real-time spot prices are available as a scenario for one day-ahead market [7].

TABLE 1. WIND POWER GENERATION AND REAL-TIME SPOT PRICES FOR ONE DAY-AHEAD (01.11.2010)

Time (hour)	Wind power (Pw) (MW)	Spot price (Euro/MWh)
0	6	41.5
1.2	1.8	40
2.4	4.8	30
3.6	7.2	32
4.8	0.2	6
6	7.2	19
7.2	2.4	26
8.4	2.6	28
9.6	2.8	46
10.8	6	50
12	4.2	50
13.2	4.8	50
14.4	.4	50
15.6	5.4	51
16.8	7.2	51
18	4.8	50
19.2	7.2	51
20.4	5.4	51
21.6	.6	51
22.8	4.2	51
24	5.4	56

TABLE 2. CASE STUDY DATA

β	$P_{sell\ min}$ (MW)	$P_{sell\ max}$ (MW)	S_r (MVA)
8	2	8	3

4.1 Result 1

The programming is done in MATLAB environment. Result 1 gives the optimized output when an isolated wind storage system is considered. The figure 4 gives the graph of the PSO convergence and it is found that the objective function increases with each iteration by using the Particle swarm optimization technique. Here the maximum iteration is considered to be 10. The program is being run twice and from the output of the PSO the best run is found for run 1 and the global best value of the variables are found i.e (Psell, Pch and Pdis). i.e. during the 1st run the objective function value is found to be maximum using the global best values of the variables. It is found to be 20000 euro and it is the best function value.

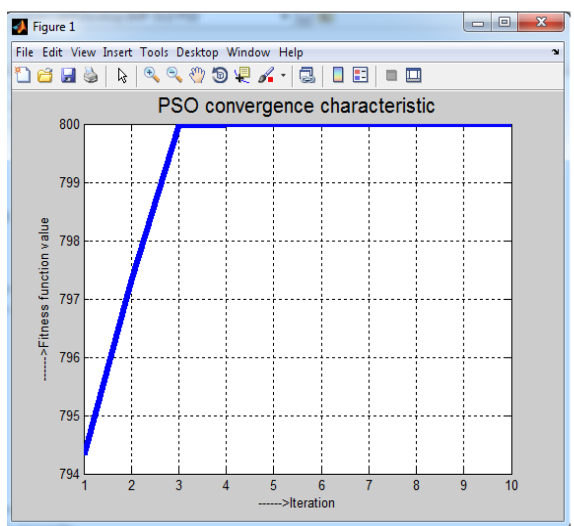

Figure. 4 Graph showing the PSO convergence of wind-storage isolated system

4.2 Result 2

In the second case the objective function is designed for wind –storage system, integrated to a Network along with the traditional generating unit. The main objective is to maximize the function using PSO. This is formulated for wind-storage system along with the line losses of DN of IEEE 14 bus system. The line losses for the system is calculated using the Newton Raphson Method. Figure 5 Shows the PSO convergence for the entire system.

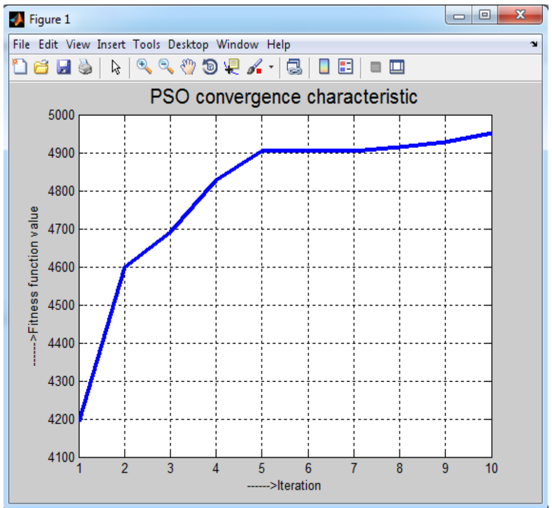

Figure 5. Graph showing the optimal output with PSO convergence characteristics of combine system

The program is being run twice and from the output of the PSO the best run is found for run 1. i.e. during the 2nd run the objective function value is found to be maximum using the global best value of the variables i.e (Psell, Pch ,Pdis and loss). The best objective function increases for each iteration. And it is found to be increasing with the iterations. The best objective function value is found to be which is the income of the system 7.8 X 10^6 euro. Thus by selling the wind power at lower price compared to the traditional power,thetotal optimized income for a systemcan be increased to a greater value.

5. Conclusion

Many power related issues influence the operation of the distributed network (DN). When Wind- Battery system is embedded with DN the system become more complex to carry out the optimal operation of the network. Thus lots of studies are done or still going on to find the most acceptable and feasible optimization technique that could be implemented to the power system for deriving the optimal operation. It can be concluded that Energy Storage facilitates lots of advantages for optimal operation of the power network and have great impact on revenue maximization specially when the generation is unpredictable. Moreover the choice of suitable optimization method totally depends on the type of optimization problem formulated. As the input parameters of the network are variable, a flexible and adaptive optimized operation strategy of storage systems can control the power flow and reduce the power losses, thereby enhancing the derived revenue from the power trading to the network. But there are very limited number of studies done related to the storage systems in grids such as design, dimension, location, operation planning and control of BSSs [10]. There lies the immense opportunities and potential of BSS yet to be explored in the field of optimal power flow which if explored will be promising in the future energy networks.

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