RELIABILITY-BASED SHORT TERM SCHEDULING OF WIND POWER CONSIDERING THE IMPACTS OF ELECTRICAL VEHICLES AND FIT INCENTIVE MECHANISM

Ehsan Alishahi
Tarbiat Modares University – Iran
alishahi@modares.ac.ir

Mohsen Parsa Moghaddam
Tarbiat Modares University – Iran
parsa@modares.ac.ir

Samireh Sayyali
Ilam Electric Distribution Company – Iran
s_sayali2000@yahoo.com

ABSTRACT

Large integration of intermittent wind generation in power system has necessitated the inclusion of more innovative and sophisticated approaches in power system operation planning. In this paper, Feed-in-Tariff support scheme is used to promote wind generation firm to participate in power market. The high penetration of wind generation in power system resulting from support scheme has significant impacts on system reliability. So, determining the optimum reliability based incentive for wind generation is an important problem which is developed in this paper. In addition, a new concept of wind farm power management by high penetration of electrical vehicles (EVs) technology is investigated which is usually referred to as "vehicle-to-grid (V2G) in this study.

INTRODUCTION

The increasing concerns regarding energy security, fuel price volatility, and the environmental challenges, diversifying the resources and making use of renewable energy resources has turned to be an important issue. Among the renewable energy resources, wind power generation is holding the first rank in terms of use and importance [1,2].

The increasing bio-environmental concerns have promoted governments to support large integrations of renewable energy in power systems by introducing obligatory Renewable Portfolio Standards (RPS) or equivalent policies. The most functional mechanism used is the Feed-In-Tariff (FIT) incentive.

High penetration of wind power generation in power market which resulted from support schemes has significant impacts on system reliability. Therefore, keeping system reliability in predetermined levels is considered to be as a major challenge which regulators face with, when they are developing incentive mechanisms. Thus, incentive mechanisms which are developed for increasing the penetration of wind power, should considers reliability of power system. Furthermore, in order to serve the load more economic and reliable, generation companies have developed new operation strategies for their network inevitably. Traditional methods for serving the forecasted demand in power systems were based on using conventional power plant, using storages and Demand Side Management (DSM) programs as a reserve and interconnecting to adjacent network [3]. In this paper, a new concept of wind farm power management by high penetration of Electrical Vehicles EVs are investigated which is usually referred to as "vehicle-to-grid (V2G). As shown in [5], the backbone of smart grid emphasis on environmental protection, using variable generation, demand response, and distributed generation such as electric vehicle technology. Figure 1 depicts these factors in relation to the new emerging smart grid paradigm, and illustrates the role of renewable energy and V2G technology in the new area.

Moreover, the benefits of combining the wind power generation system with V2G concept to reduce the fluctuation of wind power and increase the wind firm benefits are discussed here. This concept makes the wind power a more reliable capacity. V2G can be assumed as storage to provide the demand of the system during off-peak and high wind power generation period and as generation devices during peak period and low wind power generation period [4].

The main contribution of this paper is scheduling of wind power generation along with EV technology while keeping system reliability in predetermined levels is considered to be as a major challenge. In this work, the impact of FIT incentive is considered for financial support of wind generation.

The rest of this paper is organized in the following order. Next section describes the proposed model of scheduling framework. After that, V2G technology is presented. Mathematical formulation of the proposed framework is provided in next section. Then, the proposed method is implemented on a test system. Finally, the last section is devoted to conclusion.

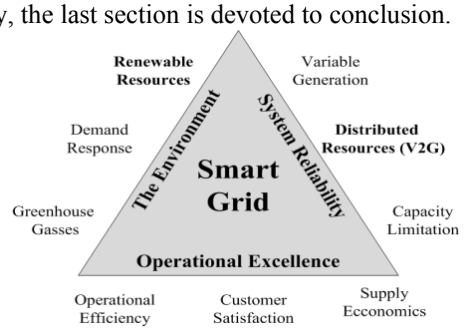

Figure 1: The role of wind and V2G in smart grid

SCHEDULING FRAMEWORK

The proposed scheduling framework of wind power generation is illustrated in figure 2 which is structured in eight blocks. The elastic demand which is considered in scheduling is illustrated in block one. The profit of the wind generation owner will be affected by fluctuation of the spot price resulting from demand elasticity.

The regulatory policies such as FIT incentive for wind energy and using V2G technology along with wind power for increasing the wind generation flexibility are illustrated in blocks two and three, respectively.

The support scheme will cause the high share of wind generation in power market. On the other hand, within enhancing wind power penetration, the reliability index

of power system turns to be a more crucial problem. To maintain the system reliability in an acceptable level, a criterion for EENS is defined as a constraint. This pre-specified EENS is indicated in block four. The amount of incentive in block three for wind expansion should be calculated by an optimization problem, which must satisfy the essential system reliability. This idea is considered as the main contribution of the intended study.

One of the most important impacts due to considering wind power generation is the creation of uncertainties in power production [1]. Therefore, incorporating such uncertainties in operation decisions are required which is shown in block five. Furthermore, other uncertainties about V2G which can influence on operational planning are illustrated in block six. Since the objective of wind generation owner is to maximize his/her profit, the revenue of the owner from power market must be calculated during the operation period. This requires the calculation of electricity price at each hour of operation. The way that the electricity price is evaluated is also important. For evaluating the price of electricity, the equilibrium analysis has been applied. The scheduling of wind generation and V2G technology and system reliability are outputs of the framework (blocks 7 and 8).

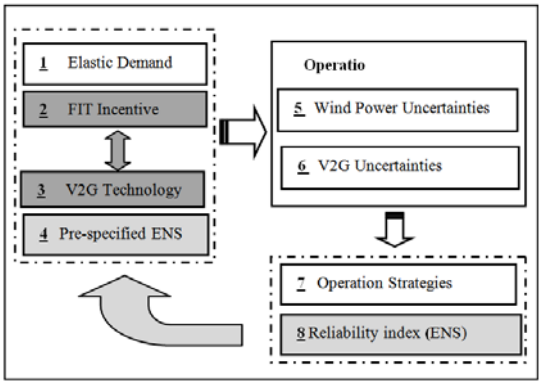

FIgure 2: The proposed framework for scheduling of wind

INTEGRATION OF VEHICLE-TO-GRID (V2G)

V2G concept applies the EVs (electric vehicles) as a resource for the support of electrical grid, where power can be absorbed or sourced by the vehicle energy storage system. However, there are many intermediary steps that have to be achieved, before this vision comes to fruition [4].

The battery of a vehicle is a very small storage capacity of energy that its impact on the grid can be neglected. The typical range for commercial EV battery storage is from 1 to 60 KWh. So, in this paper, the extensive use of aggregation (in parking lots) to overcome the small storage capability/capacity of an EV is suggested. The EV parking lot is a new player whose role is to collect the EVs by attracting and retaining them with suggest incentive for owners of EVs in order to reach high storage capacity from small battery capacity of multi EVs that can affect the grid beneficially. In this paper, the availability of the EVs is not the point of interest to study and just for the convenience it is considered as uniformly distributed numbers between 0.3 and 0.9 for each hour as it will be addressed in next section [4].

MATHEMATICAL MODELING

A mathematical formulation of the problem is presented in this section. Here, the impacts of incentive mechanism and electrical vehicle are being considered in formulation of power generation scheduling. The optimization problem is formulated in Eqs. (1)-(7). The objective function represented by Eq. (1) indicates total profits result from scheduling of power generation. Eq.(2) represents the benefits for time step t. The first and second terms in Eq. (2) represent a wind firm owner's revenues resulting from energy sales in electricity market and support of wind power. The benefit of implementing EVs. is represented by the third term, where this equation consists of the benefit resulted from sale of electricity to the network (discharging state) minus the cost caused from buying electricity from the network (charging state). The forth term illustrates the revenue or cost about trading the power by adjacent network. The operation cost and power losses cost are expressed by the fifth and sixth terms, respectively. More details about this equation (equation 2) are illustrated in Eqs. 8-11.

The sum of wind power generation, EV power generation and the power traded with adjacent network must be equal to total demand plus power losses as shown in Eq. (3). The distribution feeder constraint is illustrated by Eq. (4) which must be satisfied. Constraints (5) and (6) are the bounds upon the decision variables which indicate the power boundary for the wind generation and energy storage capacity of the EV batteries. Finally, Eq. (7) represents the price cap constraint to prevent increasing the price of electricity.

$$\Psi_0 = \mathrm{Max}\,[\sum_{b=1}^{nlb}[B_t(P_{Gw,t}, D_t, P_{EV,t}, \pi_t)]] \quad (1)$$

$$B_t = B_{energy,t} + B_{FIT,t} + B_{EV,t} + B_{trade,t} - C_{var,t} - C_{loss,t} \quad (2)$$

$$P_{trade,t} + \sum_{b=1}^{nlb} P_{Gw,b,t} + \sum_{v=1}^{V} P_{EV,v,t} = D_t + \sum_{ij \in feeder} P_{loss,ij,t} \quad (3)$$

$$P_{ij} \le P_{ij}^{Max} \quad (4)$$

$$P_{Gw,min} \le P_{Gw,t} \le P_{Gw,max} \quad (5)$$

$$P_{EV,min} \le P_{EV,t} \le P_{EV,max} \quad (6)$$

(7)

(8)

(9)

(10)

(11)

In competitive power market, if the wind power generation's revenue is similar to other generators, the risk of revenues would be high, especially in low wind period. In this paper, the impacts of FIT mechanism on wind power scheduling are being investigated. Eq. (12) represents this revenue of wind firms.

(12)

Moreover, the high penetration of wind power resulting from support schemes has a great impact on power system reliability [6]. Therefore, identification of an incentive mechanism which leads to maintain the reliability in a predetermined level, seem to be quite crucial. This paper takes an approach to fulfill such an objective. The reliability constraint is presented in (13). In this paper, EENS is used; which is defined in terms of the ratio between the load energy curtailed resulting from deficiencies of available generating capacity and the total load energy required by the system. An analytical method is used to combine the hourly power output of the existing generation (such as wind and V2G) considering with the chronological load model to obtain the EENS.

(13)

NUMERICAL STUDIES

The Swift Current wind data are used for numerical studies in this paper [1]. A case study system consists of wind farm, EVs parking lot in order to smooth out the intermittent power of the wind farm and adjacent network as shown in figure 3. The output of wind power generations in 24 hours are illustrated in figures 6-8(dashed line). The peak load of the distribution system is 42.591 MW. The Power purchased through the existing substation and the power generated from the new wind and EV sources should meet the forecast peak demand and satisfy the system losses. Data about test system are from [4]. The results of wind generation scheduling are illustrated in the following. Two case studies are considered in the study as below:

Case study1

In this study, there is no electric vehicle, but the impact of FIT as a regulatory intervention has been considered for wind generation. The amount of incentive for wind power generation in three buses is illustrated in figure 4. The results show that the amount of incentive is high when the wind production is low and vice versa. Without using of V2G technologies, the predefined reliability index isn't satisfied. In this case, the EENS is equal to 0.003. By using of V2G technology as a flexible load in case 2 which can smooth the wind power generation, may improve the system reliability.

Case study2

In this case, the impacts of using V2G technologies are considered to increase the flexibility of wind and satisfy the reliability constraint of distribution system. The objective of scheduling wind and V2G generation is maximizing the revenue where the reliability constrained should be satisfied. In this study, the amount of FIT incentive mechanisms is differs to case 1, because the V2G help wind firms to have a fixed output in each year and the ratio of FIT incentive is devoted to encourage V2G drivers to cooperate in electricity market.

The results of this case study are shown in figures 5–7. These figures show the different storage time, and the output power of wind generator with and without integration of V2G. As it is shown in these figures, connection of V2Gs can smooth the output power of wind farm. The significant characteristic of using this method is its flexibility in using different numbers of EVs for providing an optimum amount of storage capacity. From the behavior of the system, the equivalent storage capacities are 1070, 830, 1300 KWh. Therefore, the number of required V2Gs is 35, 28, and 43 vehicles, respectively. The optimum amount of FIT incentive for wind firms in compare to case study 1 are illustrated in figures 8-10, respectively.

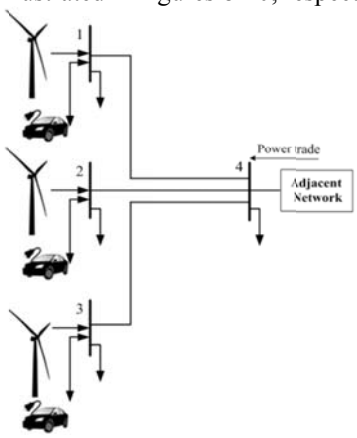

Figure 3: Test system with wind farm & EV

CONCLUSION

This paper presents a novel framework to make the wind power a more flexible source by using V2G technology. Furthermore, the impact of incentive mechanism is considered for wind energy. The high penetration of wind power has a great impact on power

system reliability. So, scheduling wind and V2G generation and identification an incentive which leads to wind power expansion and maintaining the reliability in a predetermined level is quite crucial. Two case studies are investigated, one without V2G and the other with V2G. The result show that the amount of incentive for wind power decreased in case of using V2G. This happens because some ratio of this incentive will be devoted to the promotion paid to V2Gs drivers. This procedure will decrease the uncertainty of V2Gs. Drivers and encourage them to participate in electricity market. Therefore V2G can smooth the output of wind generation in intervals of one hour, and this will result in flexibility of wind generation to participate in electricity market. A more precise modelling of V2G can be proposed for the future work of this study.

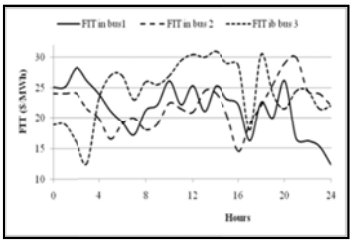

Figure 4: Obtained FIT for three wind farms

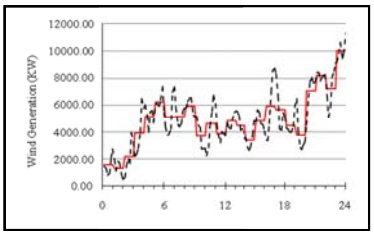

Figure 5: EV implementation in bus 1

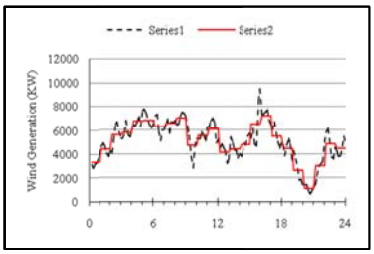

Figure 6: EV implementation in bus 2

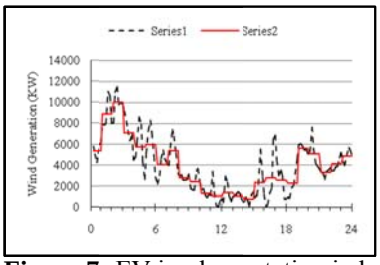

Figure 7: EV implementation in bus 3

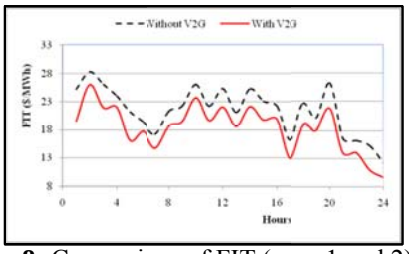

Figure 8: Comparison of FIT (case 1 and 2) in bus 1

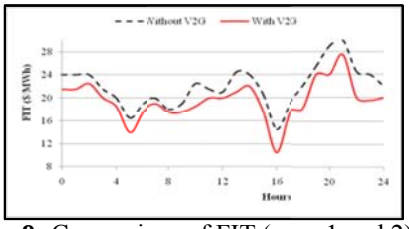

Figure 9: Comparison of FIT (case 1 and 2) in bus 2

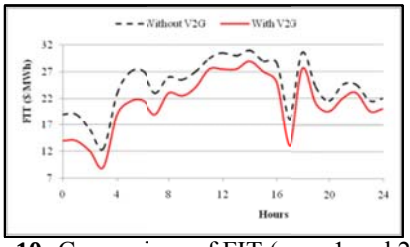

Figure 10: Comparison of FIT (case 1 and 2) in bus 3

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