International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 10 | Oct 2021 www.irjet.net p-ISSN: 2395-0072

An Analysis on the Effect of Demand Response Plans in the Micro-Grids Wind Resources Risk Management

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Abstract- A probabilistic method is presented in this paper to evaluate wind resources risk which is resulted from wind prediction errors. Due to fluctuations in wind resources generation, electric vehicles resources and demand responses are considered alongside the wind resources. In electricity market, the power plants are in charge of generating the power they have committed; otherwise, they must buy the fluctuations associated with their predictions from the live market or in case surplus they can sell it. In this work, prediction errors are modeled through probability distribution function. This probabilistic model indicates accuracy of predictions. In this way, the financial risk associated with wind resources in electricity market was evaluated, as well. These studies were also conducted on a sample grid.

Keywords: operational planning, wind generation resources, grid-connectable electric vehicles, consumption management solutions, risk assessment.

- Notation

1- Introduction

In traditional structure of Electric Power Industry Management, the operational planning problem mainly aims to minimize planning and operation costs, considering a certain level of reliability. In the traditional environments with centralized structure, most of the long-term operational planning models are based on optimization methods or trade-off multi-criteria risk analysis methods. These methods were useful and suitable since the planning was done centrally with lower uncertainties [1 & 2]. The only existing uncertainties were associated with fuel price, demand conditions and products of some generation resources such as hydropower plants. 1990s oil crises caused most of the countries to review theories of power industry natural monopoly [3]. Since then, the governments were faced with such an inevitable fact that power industry monopoly in state hand restricts financial resources for investment in infrastructures to be responsible for power consumption growth. Restructuring the power industry has changed goals and limitations governing on power system operation and also revolutionized operation planning [4-10] in such a way that power producers and private-section investors should make their strategies to enter competitive markets based on economic and environmental considerations, considering several uncertainties existing in economic system. In this structure, traditional planning methods were no more accountable since the actors made their investment decisions in a volatile environment [11-12].

In this paper seeks for operational planning of wind resources, grid-connectable electric vehicles and consumption management solutions in a competitive environment and energy and reservation market. Considering wind resources due to importance of environmental issues and according to uncertainties in generation of these resources as well as lack of comprehensive supportive policies, operational planning risk will be increased. For this purpose, energy storages are used, as well. Grid-connectable electric vehicles are a kind of storages which have been considerably discussed in recent studies on competitive power system and smart power grid and diverse actions have been done in this regard. In this work, effect of electric vehicles are considered, as well. Generally, grid-connectable electric vehicles are those having connectivity to the power network in certain defined points through which they can contribute in exchange of electrical power and power network. Required technical and telecommunication infrastructures should be provided for optimal operation of in question vehicles. These vehicles are able to be charged in some hours and be discharged in rest of hours. Therefore, such vehicles can be operated in a cooperative game alongside the wind resources [13-16].

Main innovations of strategic uncertainty modeling includes such actors as wind resources and storages, considering consumption management solutions in a competitive environment and energy and reservation market. Besides, wind resources own random generation which makes some problems for the corresponding companies in the power market. In addition, grid-connectable electric vehicles (as a storage) have a limited capacity relative to entire the grid and this makes them improper for base load supply. Therefore, a cooperative game model was developed so the wind resources and these vehicles look for maximizing their benefit in this game. This issue results in increased flexibility of wind resources and makes electric vehicles role more important to take part in power market. This issue is also addressed as one of the innovations of this work.

Additionally, electric vehicles are tried to work beside consumption management solutions at a cooperative game in another proposed model. In this case, the demands controllability will be improved. This issue is counted as another innovation of present work.

1- Demand Response Plans

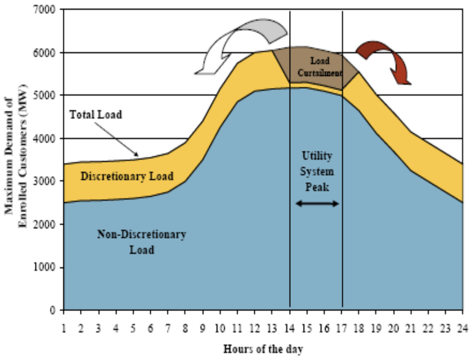
According to structural changes in power industry, International Energy Agency (IEA) presented a 5-year (2004-2009) strategic plan where traditional demand-side management methods are reviewed and 16 important Tasks are defined so that DSM plans can be implemented in power market by studying mentioned elements. These research elements are reported in the next sections. The 13th task of above mentioned projects includes Demand Response Resources [13]. Some authors consider consumption management including Energy Efficiency (EE) and Demand Response (DR) methods.

Given the definition of the US Department of Energy (DoE), the demand response includes industrial, commercial and residential subscribers' for improving consumption patterns of electrical energy during peak hours in order to achieve reasonable prices and grid reliability. The demand response can change electrical energy consumption model in such a way that the highest efficiency can be obtained within the peak hours, the demands and loads can be managed, the system peak can be decreased, the consumption can be transferred to nonpeak hours or even private Diesel Generators (DG) may be employed [14]. Figure (1-2).

Consumption management methods which are addressed as "Demand Response" in restructured system consist of:

A) Incentive-based Programs
B) Time-based Rate

Each of these categories include the following components such that a demand response contract may include one or few of these components.



Source: Federal Energy Regulatory Commission

Figure (1-2): Effect of the demand response on consumption peak

A-1) Direct Load Control

A-2) Interruptible / Curtailable Service

A-3) Demand Bidding/Buyback

A-4) Emergency Demand Response Programs

A-5) Capacity Market Programs

A-6) Ancillary Services Market Programs

B-1) Time of use

B-2) Real Time Pricing

B-3) Critical Peak Pricing

Several comprehensive studies have been conducted so far for above definitions and divisions. Therefore, additional details are not presented.

2- Computational Model

Before introduction of proposed framework, the main hypotheses are required to be pointed which are the base for modeling and studies in present work. The main hypotheses are as follows:

- The studied power market is composed of some price makers with no limitation in generation offer for the market. The competition is exclusively multilateral.
- For modeling consumption management solutions, the subscribers' demand is considered as an elastic factor.
- Locational pricing and impact of transmission network limitations are ignored.
- Like lots of operational planning studies, the time horizon is assumed 1 year (midterm planning problem). This was done to model investment cost in modeling problem, as well.
- As mentioned before, grid-connectable electric vehicles were used as energy storage in this paper. Two roles are considered for electric vehicles. In the former, these vehicles are operated along with wind resources in order to increase flexibility of wind resources. In the latter, electric vehicles are used to decrease load peak. In addition, enough incentives are assumed to be considered for drivers of these vehicles or they are supported in such a way that their presence will be reliable in power market programs.

3-1- Modeling wind resources

As mentioned earlier, the wind has a random nature and any random phenomenon can be modeled using probabilistic distribution function. The wind speed distribution can be typically described using Weibull distribution. Probability Density Function of the wind speed can be addressed using Equation (1). In this regard, the parameters c and k which respectively indicate size factor and shape factor, have a value greater than zero.

$$f_v(v)=\frac{k}{c}(\frac{v}{c})^{k-1}\exp[-(\frac{\mathrm{v}}{\mathrm{c}})^{k}] \qquad (1)$$

The wind speed information in Canada was used for numerical studies in present work. For modeling wind resources in operational planning problem, the annual information was divided into four categories depending on seasonal regime. Then, probabilistic distribution function of the wind speed was individually evaluated for each season.

Electric power generated by the wind resources is calculated through Equation (2). In this equation, the factors A, B and C are the constants obtained based on [19].

$$Pw_i=\begin{cases}0 & 0\le \mathrm{WS_i}\le \mathrm{V_c}\\ P_r(A+B\times WS_i+C\times WS_i^2 & \mathrm{V_c}\le \mathrm{WS_i}\le \mathrm{V_r}\\ P_r & \mathrm{V_r}\le \mathrm{WS_i}\le \mathrm{V_{co}}\\ 0 & \mathrm{WS_i}\ge \mathrm{V_{co}}\end{cases} \qquad (2)$$

3-2- Modeling the uncertainties

The logical uncertainties are often associated with strategic actors' behavior. Since the decisions made by competitor actors are based on logical approaches and models which are not precisely known by an assumed actor, these uncertainties are called "logical". Therefore, every actor needs to use suitable tools to model and analyze competitor actors' behavior. Karno model was used in this paper to model this kind of uncertainty. In Karno model, the competition is only done in terms of quantity (production volume) and the product is assumed homogeneous and non-storable. In addition, no new actor will enter the match during the game and the decision is made by actors concurrently [1].

Therefore, for the game considered in present work, Nash Equilibrium includes a set of available development options$\mathrm{gex}^*=(\mathrm{gex}_*^1,\dots,\mathrm{gex}_*^N)$ where:

$$\mathrm{be^i}(\mathrm{gex_*^i},\mathrm{gex_*^{-i}})\ge \mathrm{be^i}(\mathrm{gex^i},\mathrm{gex_*^{-i}}),\forall \mathrm{gex^i}\in \mathrm{Gex^i},\mathrm{i}=1,2,\dots,\mathrm{N} \qquad (3)$$

In which, gex^{i} indicates non-Nash equilibrium options by the actor i and gex_{*}^{-i} shows Nash Equilibrium options of other actors. gex_{*}^{i} Also indicates Nash equilibrium selection by the actor i and $\mathrm{be}^{i}(\mathrm{gex}_{*}^{i}, \mathrm{gex}_{*}^{-i})$ shows the benefit made for the actor i in Nash equilibrium.

3-3- Mathematical formulation

As mentioned earlier, according to random nature of operational planning problem considering wind resources, stochastic programming method was used for optimization problem, considering wind resources.

3-3-1- Actors' benefit in operation

Operational planning problem in present work was divided into two levels of operation and planning. In this section, actors' benefit optimization problem in operation field and the way of market clearing are described. For wind resources, supportive policies are considered, as well.

Equations (4-10) indicate the optimization problem which should be resolved by each producer in an iterative process.

$$\begin{aligned} Be_s = \mathrm{E}\left[\mathrm{Be}_{\mathrm{energy,i,s}}\right] + \mathrm{E}\left[\mathrm{Be}_{reserve,\mathrm{i,s}}\right] & \\ + \mathrm{E}\left[\mathrm{Be}_{incentive,\mathrm{i,s}}\right] & \\ - \mathrm{C}_{\mathrm{annual,inv,i,s}} - \mathrm{C}_{\mathrm{var,i}} & \\ - \mathrm{C}_{\mathrm{c-tax,i}} & \end{aligned} \quad (4)$$

Subject to:

$$\sum_{a=1}^{A} P_{Ge,sl,a} + \sum_{a'=1}^{A'} P_{Gew,sl,a'} + \sum_{a''=1}^{A''} P_{Gev2g,sl,a''} \leq D_{sl} \quad (5)$$

$$\mathrm{P}_{\mathrm{Ge,min}} \leq \mathrm{P}_{\mathrm{Ge,tsl}} \leq \mathrm{P}_{\mathrm{Ge,max}} \quad (6)$$

$$\mathrm{P}_{\mathrm{Gew,min}} \leq \mathrm{P}_{\mathrm{Gew,tsl}} \leq \mathrm{P}_{\mathrm{Gew,max}} \quad (7)$$

$$P_{Gev2g,min} \leq P_{Gev2g,sl} \leq P_{Gev2g,max} \quad (8)$$

$$\Pi_{\mathrm{tsl}} \leq \mathrm{PC} \quad (9)$$

$$LOEE_{pu} \leq LOEE_0 \quad (10)$$

The indices a، a′، a″ ،n ،s and 1 respectively indicate traditional generation sources, wind resources, the grid-connectable electric vehicles, the number of scenarios intended for wind resource probabilistic modeling in midterm studies for calculation of operation benefit and the demand level.

3-3-2- Market model and pricing

The following algorithm can be used to find Nash Equilibrium, as well. Energy market and reservation are also cleared together.

Upon the optimization problem solving whose modeling was done in previous section, the market price can be found by Equation (11) [12]:

$$D_{sl} = -\mathrm{A}_{\mathrm{s,l}}.\Pi_{s,l} + \mathrm{B}_{\mathrm{s,l}} \qquad (11)$$

Where demand in each season and demand level D_{s1} are addressed as a function of price. $A_{s,l}$ and $B_{s,l}$ show slope of demand function at s1in MW/$/MWh and total demand for a price of zero in MW, respectively.

Since supply (total generated power of actors) should be equal to demand in order to reach equilibrium point of the market, therefore in every iteration the price is calculated by placement of total marketable generated power instead of $D_{s,l}(\pi_{s,l})$ in Equation (11). It can be seen that the price is affected by generation of all companies and in the next iteration, the corresponding optimization problems will be associated through price. In order to find the coefficients $A_{s,l}$ and $B_{s,l}$, the Equations (12) and (13) as well as the base points $(D_{base,s,l}, \pi_{base,s,l})$ are used [12]. Solving the optimization problem by actors and clarification of the market in a process iterate until none of the actors can increase their profits by production change. In this case, the equilibrium point of the game includes production, benefit of each actor and market clearing price. $D_{base,s,l}$, $\pi_{base,s,l}$ and ε are forecasted demand at s1 in MW, competitive price of electricity at s1 in $/MWh and elasticity coefficient of demand, respectively. The base price $\pi_{base,ksl}$ which is marginal cost system is found by the problem solving through considering power plants in traditional system [12].

It is noteworthy to mention that since investment cost is considered in the initialization phase and the studies here are based on a one-year period, therefore investment cost is obtained according to the technology type lifetime and annual inflation rate as per Equation (14).

$$A_{s,l} = \varepsilon . \frac{D_{bae,s,l}}{\Pi_{base,s,l}} \qquad (12)$$

$$B_{s,l} = D_{base,s,l} .(1+\varepsilon) \qquad (13)$$

$$\mathrm{C}_{\mathrm{annual,inv,i}} = \mathrm{C}_{\mathrm{present,inv,i}} \left[\frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{n}}}{(1+\mathrm{i})^{\mathrm{n}}-1}\right] \qquad (14)$$

3-3-3- Electric Vehicles Model

This model has been studied in diverse aspects. In the first perspective, this technology has been operated along with wind resources. With increased penetration of wind resources and higher contribution of these resources to supply power system, the need for using electric vehicles for existing uncertainties compensation is felt more considerably. The differences made in market clearing prices at diverse seconds which may be resulted from increased contribution of wind resources having uncertainty are known as the main actuator and primary signal needs to use limited energy resources. Figure (1) shows the proposed algorithm for operational planning, considering the role of electric vehicles along with wind resources.

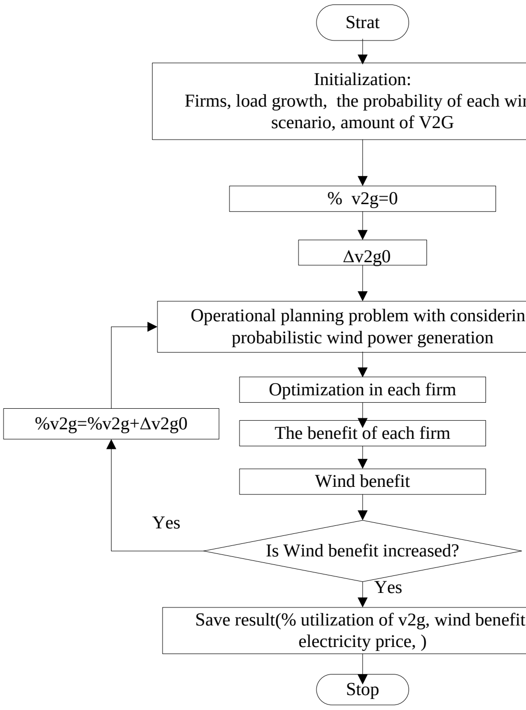


Figure 1: The proposed algorithm for operational planning problem considering the role of grid-connectable electric vehicles alongside wind resources

3- Case study

In order to assess efficiency of the models presented in previous section, they are simulated as case studies here. In this section, numerical studies and the relevant sensitivity analysis are carried out from system operator's point of view on an authoritative and standard grid.

4-1- Studied system

In this paper, an IEEE Reliability Test System (RTS) with 24-bus was used for evaluation of proposed method. The structure of this network is shown in Figure (2). The IEEE 24-bus grid includes 32 production utilities and 17 busbars. It is noteworthy to mention that the 6 production utilities in the bus 22 are water utilities which are ignored in this work. However, maximum generation capacity of grid and the load peak of grid are 3105 MW and 2850 MW, respectively. Also, in order to study impact of wide penetration of wind resources on power system performance, a wind farm with a capacity of 545 MW was considered in the bus 22 that is almost equal to 15% of the total system installation capacity. The curve associated with production unit cost that is considered as a quadratic functions, was also estimated using a piecewise-linear approximation. In proposed model and for concurrent market of energy and reservation services, the utilities are assumed to contribute in energy market and reservation services market with 3-piece and 1-piece prices, respectively.

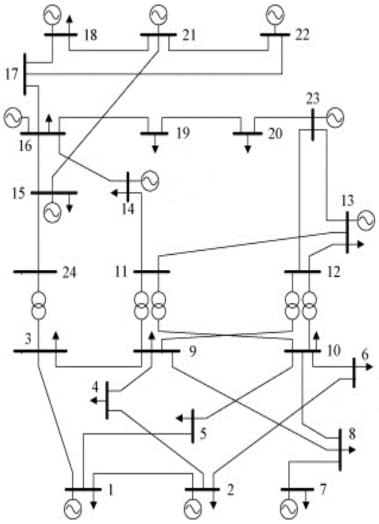


Figure 2: IEEE 24-bus system

The offered price of utilities was considered as 40% of the highest increasing cost in energy market in order to provide increasing and decreasing spinning reserve capacity.

It should be noted that the wind generator firm was considered as a non-competitive utility and all wind products were bought by system operator. Also, the emission factors (Table-1) of the utilities were also considered in present study.

Table-1: Pollution specification of the utilities

Utility No.	Technology	Emission Factor of Pollutant (kg/MWh)NOx	Emission Factor of Pollutant (kg/MWh)SO_2
1-5	Gas	2.5	1
6-9	Gas	2.8	1.1
10-13	Coal	2.1	12.7
14-16	Crude Oil	2	4.5
17-20	Coal	1.8	10.3
21-23	Crude Oil	1.9	4.3
24	Coal	1.8	10.7
25-26	Nuclear	0	0

Each busbar is assumed to have a Demand Response (DR) which collects and manages subscribers' responses and participates in increasing spinning reserve and energy markets on behalf of them. Also, DR providers are assumed to contribute in energy and reserve services markets with 3-piece and 1-piece prices, respectively.

The assumed values considered for DR resources offering are presented in Table-2. The proposed price for increasing spinning reserve capacity is assumed 6.4$ per MWh.

Table-2: Price values- Proposed values of DR providers

k	1	2	3
q_{dt}^{k}	25% of responsiveness	75% of responsiveness	100% of responsiveness
c_{dt}^{k}	12	14	16

It's noteworthy to mention that the demand is separated into three periods including low demand (12:00 a.m. to 7:00 a.m.), middle demand (8-9 a.m., 12:00 p.m. to 2:00 p.m., 5 p.m. to 7 p.m. and 10 p.m. to 11 p.m.) and peak demand (10 a.m.

to 11 a.m., 3 p.m. to 4 p.m. and 8 p.m. to 9 p.m.) and base values of standard system are relevant to the middle demand. These values are assumed to be multiplied in 0.8 and 1.2 for low demand and peak, respectively. The cost of subscribers' power outages was considered 2000$ per MWh and the cost of limiting or lack of integration was also taken 2000$ per MWh into consideration.

Due to low capacity of electric vehicles, the concept electric vehicle parking or electric vehicles collector entity are used in power system studies. The electric vehicles are assumed here to be widely spread across the country and to be charged and discharged. As mentioned earlier, 60% of the cars inside the parking are assumed to be charged and the rest is assumed to be discharged or to inject power to the grid. Also, the proposed price of parkings for contribution in energy market is shown in Table-3 as a factor of market clearing price.

Tables-3. The information about the types of electric vehicle parking

Parking Type	1	2	3	4	5
Vehicle capacity	3000	1500	1000	2000	600
Charge/Discharge Level (KW)	16.6	16.6	16.6	16.6	16.6
Maximum charge/discharge level (MW)	49.8	24.9	16.6	33.2	9.96
Proposed Price ($/MWh)	1.2*18	0.8*18	1*18	0.9*18	1.1*18

4-2- Numerical studies

In this section, the numerical studies on the studied system are presented in two modes including with/without consideration of electric vehicles.

4-2-1- The results in absence of electric vehicles

It should be noted that the system reliability will be decreased with increased penetration level of wind resources which is associated with uncertainty of wind resources in such a way that the subscribers will suffer more power outages. Considerable decrease of pollutant emission is another impact of using wind resources which is shown in Table-4. In order to assess role of demand response resources, impact of using these resources was evaluated in market energy and increasing spinning reserve. Using demand response resources will lead to decrease operational costs, improve reliability and decrease pollutant emission.

Table-3: Impact of wind resources penetration on the system performance

Penetration level of wind resources (%)	Contribution level of demand response resources (%)	Operation cost ($)	Reliability index (MWh)	Pollutant emission (Ton)	
				NO_x	SO_2
0	0	767720	0	77.42	372.275
	5	697590	0	65.7	339.78
5	0	751260	0	74.66	364.42
	5	709560	0	63.121	333.275
10	0	717520	0	71.072	351.66
	5	689640	0	59.735	320.66
15	0	798910	54.512	67.475	336.76
	5	691650	14.35	56.48	306.835
20	0	1216700	285.497	63.622	335.076
	5	803880	116.362	52.2	290.444

One of the advantages of planning with random criterion is that the planning and scheduling will be done in case of occurrence of each scenario and as an instance, Figure-3 shows the results of system operational costs in diverse scenarios into two individual modes with/without demand response resources along with the corresponding probabilities.

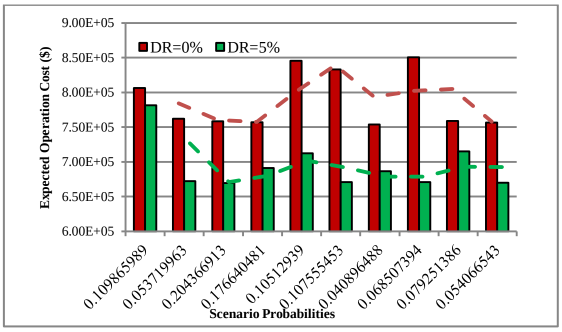


Figure 3- System operation cost along with diverse scenarios

It should also be noted that with increased penetration of wind resources, the system operator should provide more spinning reserve to cover uncertainties relevant to the wind productions and prevent consumers' power outages. The value of scheduled spinning reserve is compared in penetration levels of 10, 15 and 20% (Figure-4). In this study, demand response resources of the wind were not considered.

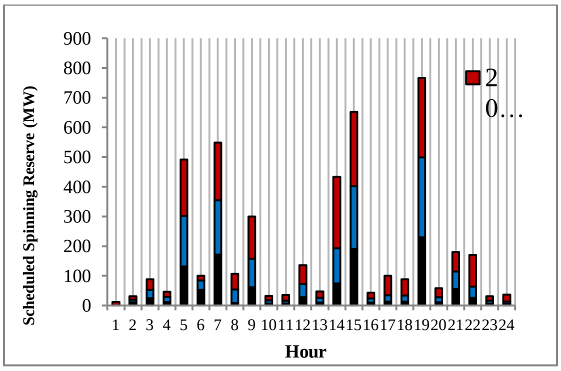


Figure 4: Scheduled Spinning Reverse (MW) in diverse penetration levels of wind resources

One of the most important specifications of demand response resources is high response rate of these resources in such a way that they can be employed in a very short time. Therefore, it can be argued that if the system operator concurrently schedules these resources along with power plant units, the system flexibility will be suitably increased. As a result, scheduled spinning reverse will be decreased in this case. This issue is shown in Figure-5 in a wind resources penetration level of 15%.

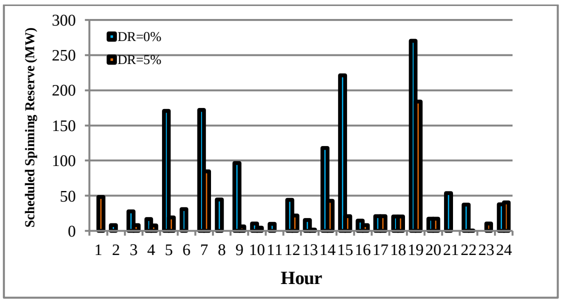


Figure 5: Comparison of scheduled spinning reverse (MW) considering demand response resources

4-2-2- The results in presence of electric vehicles

In this section, according to price offers of electric vehicles, scheduling of every parking was calculated for power supply (Figure-6).

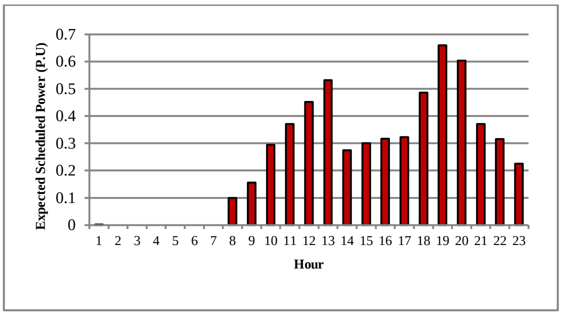


Figure 6: Expected scheduled power (P.U) of electric vehicles entire the grid

In Figure-7, total scheduled power through electric vehicles was compared to the scheduled power through typical power plants in order to meet supply. Clearly, system operator uses electric vehicles for supply only in necessary cases in particular peak hours.

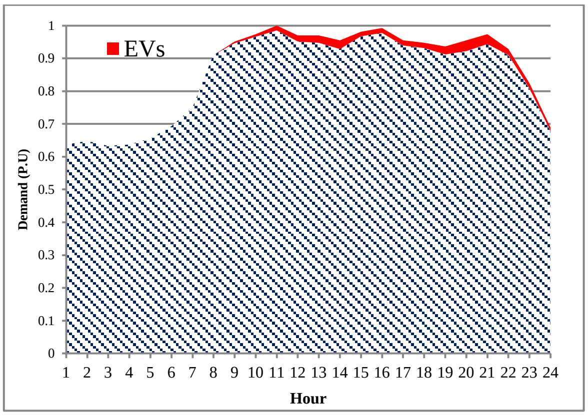


Figure 7: Comparison of expected scheduled power for demand supply

5- Conclusion

In this paper, energy planning and concurrent storage of power plant units, demand response resources and electric vehicles in a power system with wide penetration of wind resources were analyzed on IEEE-RTS grid. The results were assessed from economic, reliability and environmental aspects and the role of consumption resources in operation cost reduction, reliability level improvement and pollution reduction were evaluated.

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