REPLACING DIESEL GENERATOR WITH WIND TURBINE & LI-ION BATTERY IN VIRTUAL POWER PLANT

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ABSTRACT: *Diesel generators are the most common distributed generation (DG) units that are used in distribution networks. Depletion and increasing cost of fossil fuels is an important factor that makes us using renewable energy resources (RES) as DG. Virtual power plant (VPP) as an aggregation of some DGs with own local energy management system and some fixed and variable loads is used to solve some problems in association with controlling the connection between RES and power system. In this paper, substituting diesel generator with wind turbine (WT) as one of the most important kind of RESs and battery as an energy storage system (ESS) is evaluated by MATLAB tools and this replacing effect on economical aspect is argued.*

Key Words: Distributed Generation, Wind Turbine, Virtual Power Plant, Energy Storage System

1. INTRODUCTION

Distributed generation (DG) is gained attention because of line loss reduction, reduced environmental impacts, peak shaving, increased overall energy efficiency, relieved transmission and distribution congestion, voltage support, and deferred investments to upgrade existing generation, transmission, and distribution systems [1]. Among different types of DG, diesel generator is one of the most usable DGs.
Diesel generator's low capital costs cause that they are used a lot in off-grid locations [2]. Other advantages of diesel generators include easily availability in the market, portable, least inflammable, easy maintenance. However diesel generators are emitted pollutants such as Particulate matter, Carbon monoxide, Nitrogen oxides, Hydrocarbons, Volatile organic compounds [3]. The increasing of global warming because of these damaging greenhouse gases heightens the attempt to find substitution for diesel generators. RES units can be replaced with diesel generators. Nowadays, wind energy has become the most competitive RES [4].
Wind power can be easily captured by wind generators with higher power capacity in comparison with other RESs [5]. Wind energy has no harmful environmental effect and is considered because of the global warming, but it has intermittent nature and it causes challenges in different aspects such as grid interconnections and control, voltage and frequency regulation, stabilization of power, securing power quality, system security, reliability and stability, load management [6], [7]. These difficulties can be eliminated or minimized by using ESSs.
Major ESSs for wind turbine are battery, flywheel, pump storage and ultracapacitor. The advantages of Li-ion battery like high energy density, high efficiency, no memory effect and low self-discharge turns it to one of the best ESSs. So Li-ion battery is chosen as ESS.
DG units cannot be connected directly to electrical network. Firstly, their production is low and about RESs is random, so they cannot afford to supply necessary energy for specified load. Secondly, the penalties of the energy contracts are too heavy for some DGs [8]. So VPP is chosen for solving these problems.

VPP is a modularly designed software suite which effectively connects, coordinates and monitors decentralized power-generating sites, storage facilities and controllable loads via a common intelligent control center. In doing so, it can act within various energy markets as would a conventional power plant. The virtual power plant offers a broad variety of services to power plant operators, industrial enterprises, public services, electricity suppliers, power brokers and grid operators. VPP combines different types of DGs and ESSs to take part at electricity market as a single power plant with defined hourly output [9]. Some of VPP benefits are [10]:

- Bundling of decentralized power sources such as wind, solar or biomass and controllable loads into a high-performance network
- Real-time monitoring of all production data and load profiles
- Direct marketing of renewable energies to the electricity market: issuing of detailed schedules for optimal energy trading on the spot and intraday markets
- Making system services available such as secondary and tertiary reserve power
- Avoidance of balancing energy through regulation within the pool
- Cost effective operation with regard to grid tariffs and avoidance of load peaks
- Efficient integration of reliable solar and wind power predictions and electricity price forecasts
- Stabilization of weak grids and implementation as a master control for island systems

In this paper, we want to show the result of replacing diesel generator with WT and Li-ion battery as ESS in VPP.

The paper is organized as follows; Section 2 will introduce the distributed system model. Section 3 will present distributed generation units. Section 4 will provide introduction of ESS. Section 5 is described simulation result & discussion. Section 6 is argued the economic result and finally the conclusion is presented in section 7.

2. DISTRIBUTED SYSTEM MODEL

The distribution study network in level of 11 kV is shown in figure 1. The system data is given in Table 1 completely.
Three DG units are considered for supplying these three different dynamic loads. As one of the reasons that DG units are used is decrease transmission loss, the best place for DG units including diesel generator and WT is in 10, 22 and 30 buses.

TABLE 1
SYSTEM DATA AND LOAD FIXED DATA

From	To	Length km	R Ω/km	X Ω/km	Load MW
1	3	1.15	0.195	0.080	0.414
3	6	1.55	0.195	0.083	0.828
3	16	1.00	0.299	0.090	0.414
6	22	3.20	0.524	0.083	0.760
6	7	0.60	0.299	0.090	0
7	10	1.40	0.524	0.090	0.832
7	30	0.90	0.524	0.090	0.405
10	12	0.45	0.524	0.090	0.661
10	34	1.20	0.524	0.090	0.410
22	27	1.95	0.299	0.083	0.968
Total		13.40			5.691

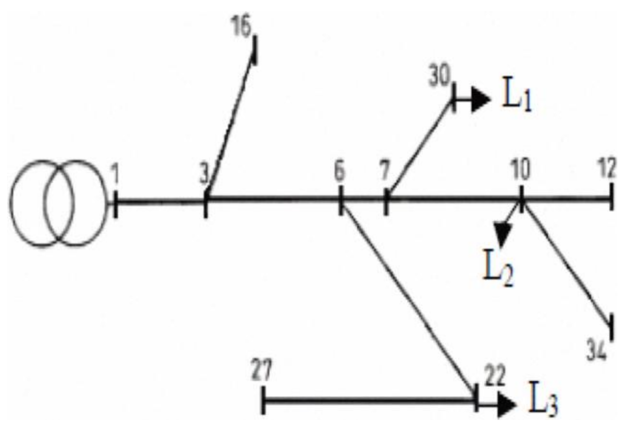

Figure 1 Distribution study network

3. DISTRIBUTED GENERATION UNITS

Different types of DG units such as diesel generator, photovoltaic, WT and fuel cell are available. They have various efficiency, energy density, capital cost, maintenance cost, operating life. Among them, we choose diesel generator and WT that they are the most common types of DG.

3.1. Diesel generator

Three diesel generator units are considered to be connected to the distribution network, which are represented by synchronous generators with nominal power of 2.5 MVA, 60Hz, 480V phase-to-phase terminal voltage and 0.9 lag power factors. Step-up transformers 0.48/1l kV, 60Hz, connect the DG units to the distribution system nodes. The capital cost of diesel generator is between 400-1200 $/kW.

3.2. Wind turbine

As it is mentioned in introduction section, wind energy is the most common RES. Considering all benefits of wind energy as RES, its random nature limits the use of this RES. But using ESS can solve this problem. For having the same situation, we select wind turbine with similar rating power 2 MW. Vestas V-90 2MW is picked up and the power curve of this WT is depicted on figure 3.

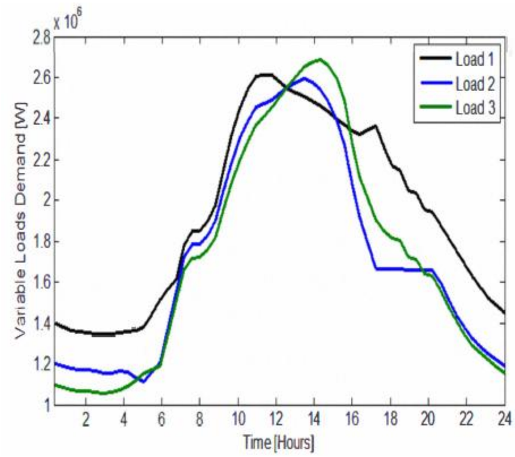

Figure 2 Dynamic load curve [11]

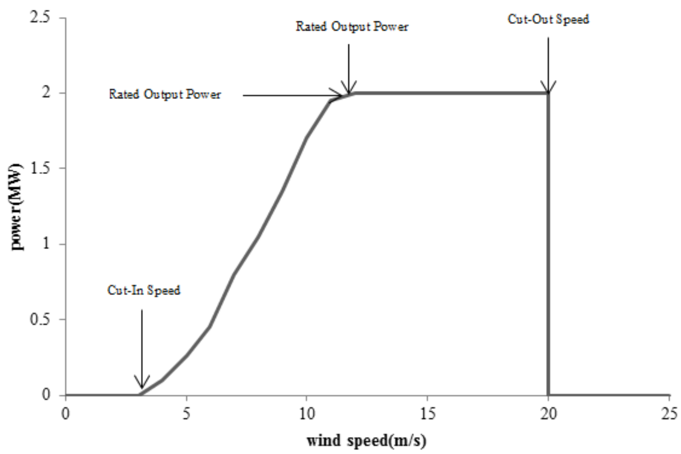

Figure 3 WT p-v curve [12]

As it is shown on figure 3, cut-in, cut-out and rated output wind speed are equal to 4, 15 and 25 m/s. In this study, we need the hourly supply profile of WT in one day. For achieving this goal, we should have the hourly wind speed. The most accurate way for measuring wind speed is anemometer. Tabriz hourly wind speed profile is shown on figure 4 [13].
According to this profile, we can calculate the hourly supply profile of WT by using p-v curve and figure 5 shows this profile.
The capital cost of wind turbine is between 1000-5000 $/kW. Three wind turbines with this supply power profile

are assumed to connect to distribution network in 10, 22 and 30 buses.

4. ENERGY STORAGE SYSTEM

ESS is the best solution for solving the problem of random wind power profile. As it is mentioned in section I, the wind energy difficulties can be eliminated or minimized by using ESS. Different types of ESS including pump storage, flywheel, ultracapacitor and battery are used for wind energy. The comparison between different types of ESS is shown on table 2.

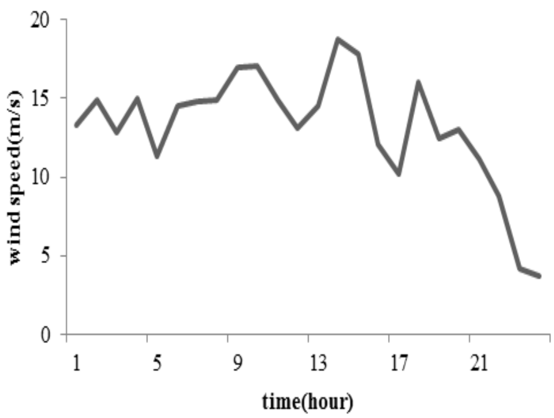

Figure 4 Wind speed profile

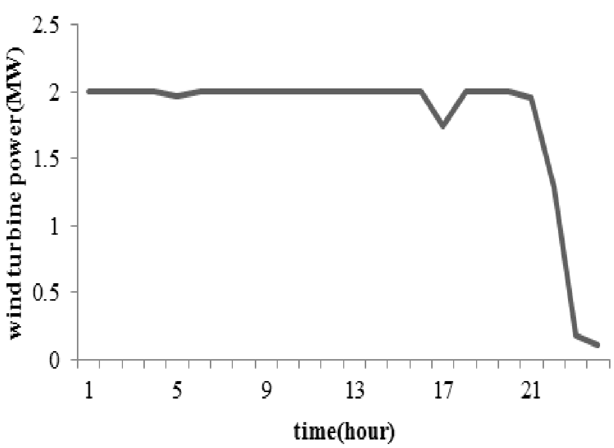

Figure 5 WT supply profile

Among various kinds of battery, Li-ion battery, according to table 3, is totally suitable for this study because of its high energy density and its efficiency. The Li-ion battery price is 500 $/kWh [14].

TABLE 2
COMPARISON OF ESSS [5]

	Energy density (Wh/kg)	Power (W/Kg)	Charge-Discharge efficiency	Self discharge (%/month)	Durability Cycle	Time Durability (Yrs)
Battery	30-200	150-3000	65-100%	3-30%	500-1K	2-10
Flywheel	100-130	1000	90%	-	>20K	>20
PHS	0.3	-	75%	Negligible	-	>75
SMES	30	Very High	95%	Negligible	-	-
CAES	10-30	-	50%	Negligible	-	>40
Super capacitor	Low	Very High	93%	Negligible	10K-100K	-

TABLE 3
COMPARISON OF BATTERIES [15]

Battery type	energy density(Wh/kg)	Efficiency(%)
Pb-acid	35-50	50-90
NiCd	75	70-90
NaS	150-240	70-92
NaNiCl	125	70
Li-ion	150-200	80-90

5. SIMULATION RESULT AND DISCUSSION

According to the assumption as mentioned on section II, the DG units (diesel generators and WTs) are located in 10, 22 and 30 buses that the dynamic loads are connected. For comparing between diesel generators and WTs the supply profile of DGs will be defined. The comparison between this supply profile and load profile indicates the benefits of substituting diesel generator with WT and Li-ion battery as ESS.

Firstly, it is assumed that each DG supplies its dedicated dynamic load and if the load is more that the supply, it is fed by electrical network. The maximum power of diesel generator is 2 MW. We should consider the point that diesel generators can consume fuel, up to 40% of the nominal consumption, even when they are unloaded [15]. According to load profile, the unloaded situation is not appeared. The supply profile of diesel generators and the load profile are indicated in figure 6.

If the generation of diesel generator is more than their loads, this difference between generation and load is injected to electrical network for compensating the grid shortfall and if the loads are more that the generation, this shortage is supplied by electrical network.

Figure 6 shows that shortages occur at peak time and it is too destructive. Supplying the electrical energy at peak time is one of the difficulties of electrical network. Although using diesel generators in this situation decreases the electrical energy that is kept from electrical network, it makes some problems for electrical network too.

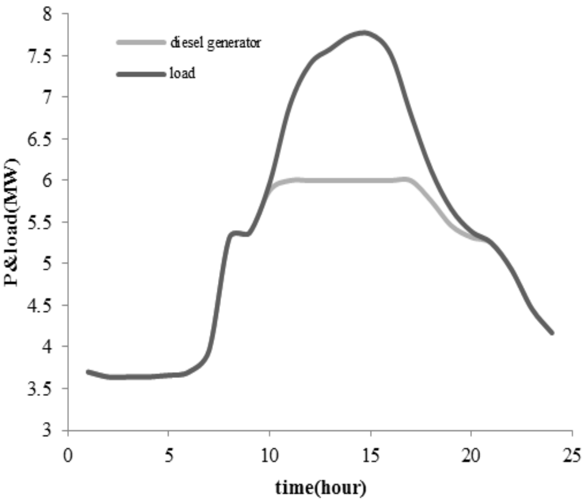

Figure 6 Supply diesel generator and load profile

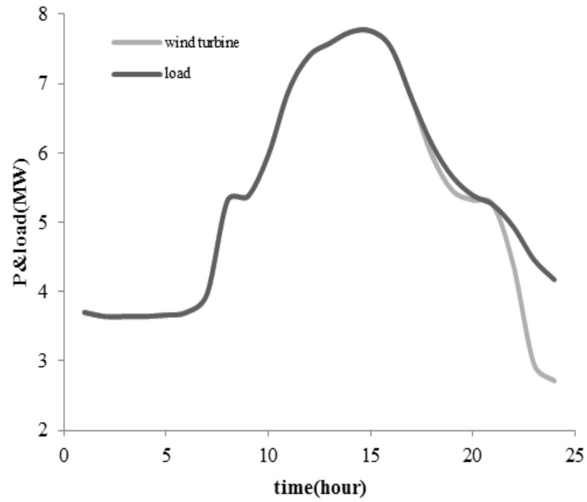

Figure 7 Supply WT and load profile

For having the same situation, 2 MW diesel generators are replaced with 2 MW WTs. The supply profile of these WTs is shown on figure 5. The necessity of using ESS is exactly argued in section IV. The selective Li-ion battery efficiency is equal to 90% and its energy density is 200 Wh/kg. It is assumed that the weight of Li-ion battery is not limited and we can totally store the difference between generation and load. So we use one Li-ion battery as ESS for each WT unit and it is because of the high energy density that should be stored in ESS.

The load and supply WTs profile is depicted on figure 7. The condition is same with diesel generator case. If the shortages occur, it will be fed by electrical network. But the difference is that the excess energy is stored at ESSs and it is used when the generation is less that loads.

As it can be seen on figure 7, we do not have any shortages at peak time. However the shortages exist in the case of replacing diesel generator with WT, it is less that using diesel generator situation. The remarkable advantage of this substitution is eliminating the shortages at peak time and it helps the electrical network too much.

So this substitution according to load profile and the geographical conditions of this state in addition to compensating some problems of using diesel generator (shortages at peak time), because of using renewable energies affect the amount of pollution.

6. ECONOMIC RESULT

Considering all benefits of RESs, one of the limitations of using these units is capital cost. They have high capital cost in comparison with diesel generators and also we should consider the necessity of adding ESSs to these units. ESSs have a wide range of price and its price depends on their energy density and efficiency. As it is mentioned in previous III and IV sections the capital cost of DG units is equal to 400-1200 \$/kW for diesel generator and 1000-5000 \$/kW for WT and the price of Li-ion battery is 500 \$/kWh. Since this study is done hourly, we assume that Li-ion battery costs 500 \$/kW. So we consider the integration of wind turbine with Li-ion battery as one set, its price is equal to 5500 \$/kW.

It is noted that the upper limit is assumed as the capital cost. The cost of this WT is obtained 11000000 \$. This cost is not considered the maintenance cost. To achieve the capital cost of diesel generator various aspects including the fuel consumption of diesel generator and the price of fuel should be noted. The price of fuel is variable and averagely it is equal to 4 \$/gallon [16]. The fuel cost of this 2 MW diesel generator is approximated to 0.29 \$/kWh for this fuel price [17]. If we assume the upper limit of capital cost for diesel generator cost, its capital cost will be equal to 2400000 \$.

The comparison between capital costs shows the reason of trend toward diesel generators as DG. But another important factor is fuel cost. If we have full load in day, the fuel cost will be obtained 13920 \$. According to this load profile, full load is approximately existed at 8 hours and this cost is reduced to half and it will be equal to 6960 \$. Considering the fuel cost does not get superiority to WT because of the vast difference in capital cost of WT and diesel generator.

The important factor is depleting fossil fuels and it causes that the fuel cost increases in future. This problem will be limited the use of fossil fuels.

7. CONCLUSION

Replacing diesel generator with WT is investigated in this paper. It is evaluated two different aspects including electrical and economical point of view. According to the load profile, the supply profile is obtained. Diesel generator supply profile has some shortages at peak time and it causes difficulties for electrical network.

This substitution improves the supply profile. Integrating Li-ion battery into the WT is improved the supply profile. The difference between load and generation at first hours of day is stored in Li-ion battery and it is discharged at the peak time. So the limitation of using diesel generator as DG is eliminated. From another point of view, the electrical effect of this substitution is studied and it shows in section VI that integration of WT with Li-ion battery capital cost is more than diesel generator and this obvious difference shows the reason of trend to choose diesel generator as DG. Although this problem is too effective in choosing DG units, the necessity of approach to WT as RES for the mentioned reasons such as depleting fossil fuels and global warming cannot be neglected.

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