Short-term Scheduling of Distribution System Along with Wind Power Generation Considering Energy Storage System

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***Abstract*— This paper proposes distribution systems operation along with wind power generation. The proposed objective function minimizes the distribution company's (DisCo's) costs in the short-term scheduling model. In this model, DisCo has been considered the battery charging/discharging decisions on total cost function and consequently its influence on load profile have been discussed. The proposed objective function is determined based on optimal power flow and with considering the technical constraints. This model is successfully applied to the 33-bus radial distribution network. The results indicate that using this method, the disco's costs as well as losses are decreasing effectively compared to without energy storage system.**

1. INTRODUCTION

Distribution companies (DisCos) attempt to supply economical and reliable electricity to customers. It is important a proper design and modeling of distribution systems by the DisCo. In the recent years, economic issues as well as technical issues has motivated DisCo to use of wind power generation (WPG) units. Development of WPG can enhance the security of energy supply, flexibility of investment, reduction of power losses and operation costs [1, 2]. In the most cases, distribution networks are expanded in a radial form. Hence the integration of WPG units into distribution network may change the power flow in distribution feeders. For instance, unidirectional power flows will change to bidirectional power flows when the penetration level of WPG becomes higher [3]. Therefore WPG may affect on the distribution system if the system be operated in an inappropriate condition. For example, power injection of the WPG units may increase the energy losses in the system [4]. On the front side, in a good operation condition, the WPG units improve voltage profile and reduce line losses [5]. Despite the advantages (or defects in some instances) of WPG units, load growth rate will cause these resources existence inadequate to reliability enhancement. A high penetration of wind power raises a problem of system instability, caused by the nature of wind uncertainty. The integration of an energy storage system (ESS) is one of the best solutions to ensure the stability and power quality of a power system with facilitating penetration of distributed wind resources.

In present paper, one of the solutions being proposed to good short-term scheduling of systems is integrate ESS into the distribution network. In some works have been investigated to the advantages of ESSs. In [6], is discussed the present status of battery energy storage technology and methods of assessing their economic viability and impact on power system operation.

In [7], different feasible electricity storage technologies are compared for their operational suitability over different time scales. The value of storage in relation to power rating and energy capacity has been investigated to facilitate appropriate sizing.

In [8], a generation curtailment scheme is set up and ESSs are sized based on the maximum curtailed generation. This study assumes that all generation curtailment will occur at night-time, and therefore a simple ESS schedule is implemented based on night-time charging, daytime discharging within each 24 hours period.

This paper proposes one solution to improve operation of distribution system along with WPG units. That is battery charging/discharging decisions by DisCo, a new model to short-term scheduling of the distribution network in the presence of WPG units. In the proposed model, the energy costs of DisCo for daily short-term period are minimized. Computation of the optimal WPG operation is formulated as a mixed integer non-linear problem which can be solved using commercial optimization packages like as GAMS software.

1.1. The main contributions of this paper are two-fold:

1) Proposing a short-term scheduling model in distribution system considering time variant load modeling,

2) Applying battery charging/discharging decisions to good operation,

The rest of this paper deals with the following subjects:

Section 2 is included time variant load model, classical objective function for the DisCo's costs and related constraints. In Section 3, the proposed model is applied on the 33-bus radial distribution system and the simulation results are given and discussed. Finally, Section 4 summarizes the findings of this work.

2. PROBLEM FORMULATION

In this section, a model for the distribution network scheduling in the presence of WPG units is presented. This model is based on optimal power flow and minimizes the energy costs of DisCo for a daily short-term period. In the proposed model for the objective function, DisCo is assumed the owner of WPG units. Therefore, planning and dispatch of these units is done by DisCo. This model is based on the variation of the daily load curve.

2.1. Load & electricity price model

The load variation curve is modeled by multiplication of two-parameter. The first one is base load ($S_{i,base}^{D}$) and any hours a day is defined as a load level. Then each day is divided into N_{dlf} demand levels. A demand level factor (DLF_h) is defined in order to determine a forecasted value of "load to peak load ratio" in each demand level which varies between 0 and 1. Demand level factor is shown in Fig. 1. Therefore, demand in i^{th} bus, h^{th} demand level is calculated as follows [9]:

$$P_{i,h}^{D} = P_{i,base}^{D} \times DLF_h$$
$$Q_{i,h}^{D} = Q_{i,base}^{D} \times DLF_h \quad (1)$$
$$S_{i,h}^{D} = P_{i,h}^{D} + jQ_{i,h}^{D}$$

The price of energy purchased from the main grid is not considered identical for different demand levels. Hence generally we assume that the price of electricity in h^{th} demand level can be determined as follows [9]:

$$\lambda_h = \rho \times PLF_h \quad (2)$$

where ρ is base price and PLF_h is h^{th} price level factor. For simplicity, we assume that for load levels, PLF_h curve is considered such as DLF_h curve.

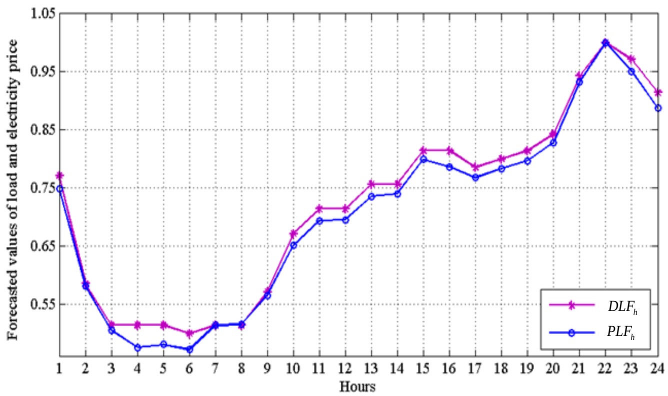

Fig 1: Demand level factor for daily short-term period

2.2. Wind power generation:

Generation scheduling the wind turbine depends largely on wind speed at the site and it is calculated by using the equation (6) [10].

$$P_{i,t,h}^{w} = \begin{cases} 0 & \text{if} \quad v < v_{in}^{cut},\ v > v_{out}^{cut} \\ \dfrac{v - v_{in}^{cut}}{v_{rated} - v_{in}^{cut}} \times P_{i,w}^{\max} & \text{if} \quad v < v_{in}^{cut},\ v > v_{out}^{cut} \\ P_{w}^{\max} & \text{if} \quad v_{rated} < v < v_{out}^{cut} \end{cases} \quad (3)$$

The wind velocity curve is considered as Figure 2 [10].

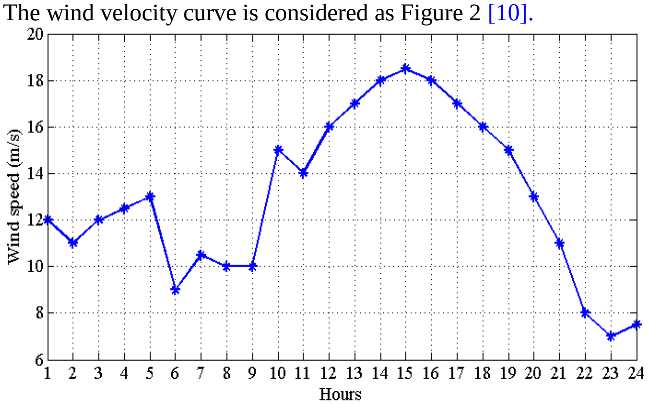

Fig 2: wind velocity curve for the daily period.

2.3. Objective function

The operation model of distribution network in the presence of WPG is optimal combination of the WPG units and other energy sources as ESS. The proposed model is also included the battery charging/discharging decisions. The ESS has several benefits and advantages in distribution system such as short term power supply, power quality improvement, ancillary service and the operation costs decrease of DisCo. The objective function minimizes the energy costs for a day. The cost function is expressed by Eq. 4.

$$CF = \sum_{t=1}^{N_h} \left\{ \begin{array}{l} \sum_{i=1}^{N_{SS}} \rho^{P} \times P_i + \sum_{i=1}^{N_{SS}} \rho^{Q} \times Q_i + \sum_{i=1}^{N_{WPG}} OC_{WPG} \times P_i^{DG} \\ + C_k^{\deg} \left(\sum_{k=1}^{N_k} \dfrac{P_{k,h}^{disc}}{\eta_k^{disc}} + \eta_k^{C} \times P_{k,h}^{c} \right) + P_{loss}^{Total} \end{array} \right\} \quad (4)$$

The first term is cost of the purchased power from external network or the energy market, and its value depends on the electricity market price (ρ^P). Prediction of the market price is the out of debate. For simplicity, it is assumed that DisCO predicts the market price based the provided data by market operator. The second term is the paid amount for reactive power from the external network which is described in a pre-determined price (ρ^Q). The third terms represent operating costs for active power of the WPG units. The fourth term captures the degradation cost for battery in h^{th} hours for k^{th} battery due to charging/discharging activities [7, 8]. The last term describes the total loss of the network in each hour.

2.4. Constraints and optimal power flow equations:

The power flow equations must be satisfied in i^{th} bus, h^{th} hours as follows:

$$P_h^{ss} + P_{i,h}^{WPG} + \sum_{k=1}^{N_k} (P_{k,h}^{disc} - P_{k,h}^{c}) - P_{i,t,h}^{D}$$
$$= V_{i,h} \sum_{j} V_{j,h} (G_{ij} \cos\delta_{i,h} + B_{ij} \sin\delta_{j,h}) \quad (5)$$

$$Q_h^{ss} + Q_{i,h}^{DG} - Q_{i,h}^{D} = V_{i,h} \sum_{j} V_{j,h} (G_{ij} \cos\delta_{i,h} - B_{ij} \sin\delta_{j,h}) \quad (6)$$

where P_h^{ss} and Q_h^{ss} are active and reactive power generated (or absorbed) by substation in h^{th} hours. $V_{i,h}$ and $\delta_{i,h}$ show the magnitude and angle of voltage in i^{th} bus, h^{th} hours, respectively.

The voltage of each bus in h^{th} hours should be kept into the safe operating limits.

$$V_i^{\min} \le V_{i,h} \le V_i^{\max} \quad (7)$$

The active and reactive power limits of the substation are proportional to the one capacity as follows [11]:

$$P_{ss}^{\min} \le P_h^{ss} \le P_{ss}^{\max} \quad (8)$$

$$Q_{ss}^{\min} \le Q_h^{ss} \le Q_{ss}^{\max} \quad (9)$$

The DG units should be operated with considering the limits of their maximum installed capacity [11]:

$$P_{i,h}^{WPG} \le P_{WPG}^{\max} \quad (10)$$

The thermal constraint in the line connected to nodes i, j for all demand levels and each year should be in permissive limits.

$$S_{ij,t,h} \le S_{ij}^{\max} \tag{11}$$

Equations (12)-(15) express the ESS constraints [12]. The constraints (12), (13) capture the limits on the charging and discharging power as well as the level of energy stored in a battery unit. Here, the level of battery storage at the end of the scheduling horizon is equal to its initial energy level. Constraints (14) are imposed to ensure the battery cannot be charged and discharged simultaneously in any time slot. The energy dynamic model for battery is captured in (15).

$$0 \le P_{k,h}^{c} \le b_{k,h}^{c} P_{k,h}^{c,\max}, 0 \le P_{k,h}^{disc} \le b_{k,h}^{disc} P_{k,h}^{disc,\max} \tag{13}$$

$$E_k^{\min} \le E_{k,h} \le E_k^{\max} \tag{14}$$

$$b_{k,h}^{c} + b_{k,h}^{disc} = 1; b_{k,h}^{c}, b_{k,h}^{disc} \in \{1,0\} \tag{15}$$

$$E_{k,h+1} = E_{k,h} + (\eta_k^C \times P_{k,h}^{c} - \frac{P_{k,h}^{disc}}{\eta_k^{disc}}) \tag{16}$$

$$\sum_h P_{k,h}^{c} = \sum_h P_{k,h}^{disc} \tag{17}$$

3. Assumptions and Descriptions of Case Study

3.1. Assumption of problem

The proposed model is applied on a 12.66-kV, 33-bus distribution network. The distribution network operation will be carried out along with the two wind turbines units. WPG1 and WPG2 are installed at bus 17, 32, respectively. The operational period is 24 hours. Base price of the purchased energy from the network is assumed to be equal 80 dollars per MWh. Duration of each load level is equal to one hour. The rest of the parameters used in problem are listed in Tables 1.

3.2. Descriptions of 33-bus distribution network

Simulations were carried out on 33-bus system [13]. The single line diagram of this test system is presented in Fig. 3. The hypothetical voltage level of the substation is 12.66 kV and the hypothetical capacity of the feeder is 8 MVA. Network data are given in Table 2. Peak load is occurred in 3712 kW and 2300 kVar.

TABLE 1. TECHNICAL AND ECONOMIC DATA

Parameters	Values	Parameters	Values
$V_i^{\max}$ (p.u.)	1.05	E_k^{cap} (MWh)	1
$V_i^{\min}$ (p.u.)	0.95	$E_k^{\min}$ (MWh)	0.1
ρ^P (\$/MWh)	80	$E_k^{\max}$ (MWh)	0.9
ρ^Q (\$/Mvarh)	71	$P_{k,h,s}^{c,\max}$ (MW)	0.4
$C_k^{\deg}$ (\$/MWh)	2.7	$P_{k,h,s}^{disc,\max}$ (MW)	0.4
v_{in}^{cut}	2	v_{rated}	14
v_{out}^{cut}	25	OC_{WPG} (\$/MWh)	42

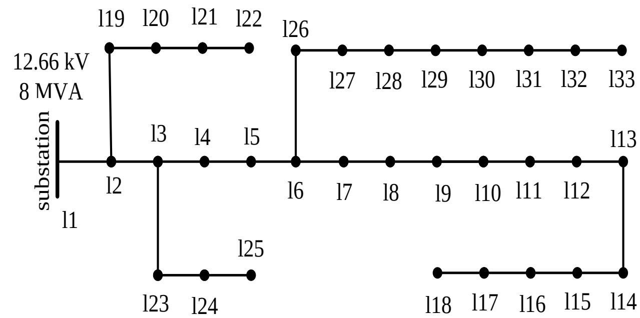

Fig 3: The single line diagram of 33-bus system

3.3. Simulation results:

Simulations carried out on 33-bus distribution network shown in Fig. 3 and the objective function result is derived. To better comparison, it is assumed that the locations of installed WPGs at both cases (without ESS and with ESS) are identical. According to the results can be concluded that the ESSs such as batteries have effective role in improving network performance. In off peak hours, batteries store additional energy of wind turbine and it is discharged in full load hours. In Table 4, a comparison between the made decisions by the DisCo for the network operation in different modes has been provided. According to the results of Table 3, by installing the WPG units in the network, the network operator costs 1440.156 dollars are saved. This value will reach to 1503.2 dollar per day with applying ESS. Optimal value for cost function is using ESS in the network. The first row of Table 3 shows that the properly installation of DG can reduce purchased energy from the grid.

The last two rows show active and reactive power losses in the network for a daily period. Loss will reduce for each both with WPG and WPG&ESS in every day. Table 4 shows the result of active power losses for three operation modes. This table is set for 24 h. the losses reduce with using distributed energy resources such as wind turbines and large scale batteries. The purpose of this work is to make the proper conditions for operation of distribution network with the WPG units. Network operation is smart, and there is a real-time control and management of the distribution network. These settings will be accordance with the voltage and reactive constraints.

Fig .4 indicates the received active power values of upstream grid. The received active power value decreases with considering wind power generation. Between the hours 9 to 20 the received active power from the network will be zero. This amount will be reduced further with batteries. Figure 5 indicates the output power of wind turbines for daily scheduling period. This power will be affected by wind speed. These values will change with considering ESS.

Figure 6 shows the hourly battery output power to decrease cost function. These values are subject to the battery charger limit at any time step. The positive/negative power output corresponds to the charging/discharging processes, respectively. In normal conditions, because the grid electricity price is cheaper in the early morning, the battery starts to store as much energy as possible. Accordingly, the batteries start to return the stored energy to the network at peak load time. Fig. 7 shows the voltage profiles for the three short term-scheduling in network. The voltage curve is shown for the peak load (hour 22). According to Fig. 7, with distance from substations in the traditional networks, they will be faced with voltage drop. The proper installation of WPG in system can improve the voltage profile. As Fig. 4, the voltage profiles will be more flat by using ESS in system. The voltage values in both nontraditional modes in peak hour have been located in permissible limits.

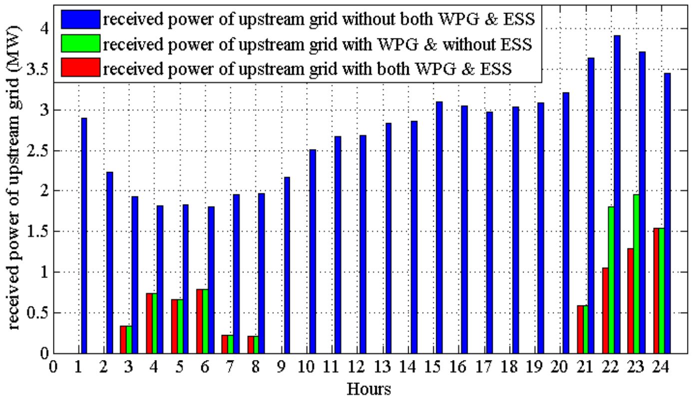

Fig 4: The received active power of upstream grid in three operation modes

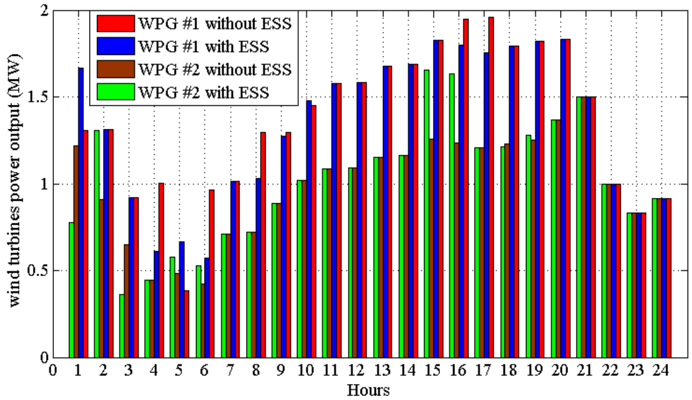

Fig 5: Wind turbines output power for daily scheduling period

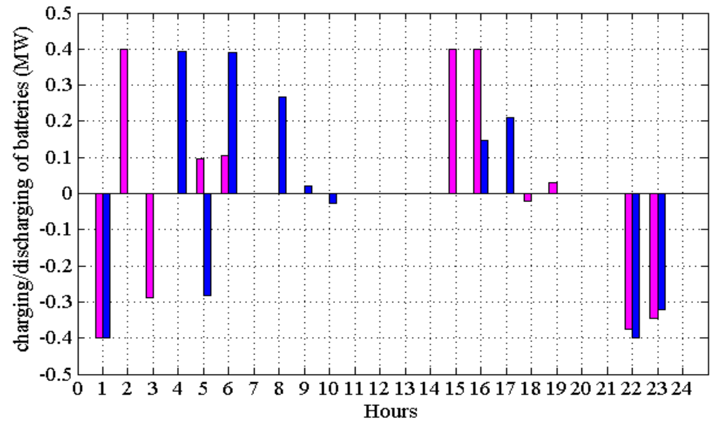

Fig 6: Hourly battery output power

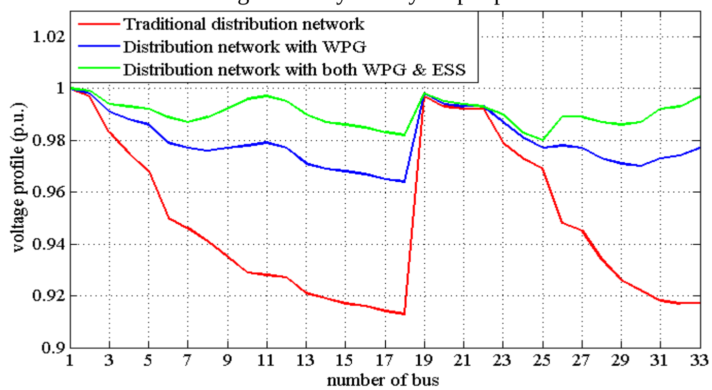

Fig 7: Voltage profile for the different operation modes in peak hour

TABLE 2. NETWORK DATA OF 33-BUS NETWORK (DLF=1)

Bus no	From	To	R(ohm)	X(ohm)	P_L (kW)	Q_L (kVar)
1	0	1	0.0922	0.0470	100	60
2	1	2	0.4930	0.2511	90	40
3	2	3	0.3660	0.0186	120	80
4	3	4	0.3811	0.1941	60	30
5	4	5	0.8190	0.7070	60	20
6	5	6	0.1872	0.6188	200	100
7	6	7	0.7114	0.2351	200	100
8	7	8	1.0300	0.7400	60	20
9	8	9	1.0440	0.7400	60	20
10	9	10	0.1966	0.0650	45	30
11	10	11	0.3744	0.1238	60	35
12	11	12	1.4680	1.1550	60	35
13	12	13	0.5416	0.7129	120	80
14	13	14	0.5910	0.5260	60	10
15	14	15	0.7463	0.5450	60	20
16	15	16	1.2890	1.7210	60	20
17	16	17	0.7320	0.5740	90	40
18	1	18	0.1640	0.1565	90	40
19	18	19	1.5042	1.3554	90	40
20	19	20	0.4095	0.4784	90	40
21	20	21	0.7089	0.9373	90	40
22	2	22	0.4512	0.3083	90	50
23	22	23	0.8980	0.7091	420	200
24	23	24	0.8960	0.7011	420	200
25	5	23	0.2030	0.1034	60	25
26	25	26	0.2842	0.1447	60	25
27	26	27	1.0590	0.9337	60	20
28	27	28	0.8042	0.7006	120	70
29	28	29	0.5075	0.2585	200	600
30	29	30	0.9744	0.9630	150	70
31	30	31	0.3105	0.3619	210	100
32	31	32	0.5032	0.5302	60	40

TABLE 3. THE RESULTS NETWORK OPERATION FOR 29 BUS SYSTEM

	System without WPG & ESS	System with WPG	System with WPG & ESS
Cost of grid purchased active and reactive power ($/day)	6692.566	2777.645	2654.711
Total cost ($/day)	**6692.566**	**5252.410**	**5189.366**
P_{loss} (kwh)	2463	1863	1887
Q_{loss} (kwh)	1663	1385	1408

TABLE 4. THE RESULT OF ACTIVE LOSSES (KW) IN THREE OPERATION MODES AT EACH DAY

Hour	System without WPG & ESS	System with WPG	System with WPG & ESS	Hour	System without WPG & ESS	System with WPG	System with WPG & ESS
1	0.110	0.100	0.100	13	0.106	0.096	0.096
2	0.065	0.060	0.060	14	0.107	0.097	0.097
3	0.049	0.032	0.032	15	0.126	0.114	0.114
4	0.043	0.021	0.021	16	0.122	0.110	0.110
5	0.044	0.022	0.022	17	0.116	0.105	0.105
6	0.042	0.020	0.020	18	0.121	0.109	0.109
7	0.050	0.037	0.037	19	0.125	0.113	0.113
8	0.051	0.038	0.038	20	0.136	0.123	0.123
9	0.061	0.056	0.056	21	0.175	0.116	0.116
10	0.082	0.075	0.075	22	0.203	0.092	0.110
11	0.094	0.085	0.085	23	0.183	0.084	0.090
12	0.094	0.086	0.086	24	0.157	0.072	0.072

4. CONCLUSION

In this paper, active network management (ANM) has been presented to the distribution network operation along with the DG units which results maximum penetration of the DG and minimum cost of losses for DNOs. From studied results, it has been derived that voltage profile and loss of the network are intensely depends on management method of network. It has been shown that appropriate condition of operation has great effects on the DNO costs. Using active management has several benefits in comparison to passive management which cannot be neglected. These beneficial effects include reducing the active power loss. The ANM method also reduce the received power from the upstream network

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