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Novel Analysis on Placement of Energy Storage Systems in Power Systems with Wind Integration

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***Abstract*: -- This paper examines the problems posed by wind integration for power system operation. For example this kind of energy source is practically flexible and unstable. The establishment of this in exhaustible source might require the grid to transmit power at full capacity and some transmission lines could wind increasing noticeably congested. Accordingly, some working conditions, wind power could be curtailed (spilled or minimized) which will drive up expenses for system administrators. One of the activities that can be taken to support the incorporation of wind is utilizing energy storage systems (ESSs). For this purpose particle swarm optimization (PSO) power flow problem with energy storage systems is implemented and sets of candidate buses for energy storage systems installation are recognized based on financial criterion to minimize the cost. Tests are performed on IEEE 14-bus and IEEE 118-bus systems to evaluate the robustness of storage location on system operation.**

***Index Terms*—Curtailed wind, Energy Storage Systems (ESSs), LMPs, Location, particle swarm optimization (PSO) Production Cost Wind Integration**

I. INTRODUCTION

ESSs can be an alternative to manage wind power irregularity, and hence provide flexibility and reliability for power systems with high wind penetration level. This technology enables electricity to be stored at times of more wind and less demand and then to be released at less wind, more demand hours. This ability to store electricity of ESSs can efficiently compensate for the irregular behaviour of wind power and provide economically optimal operation for wind generation Potential applications of ESSs for grid connected wind generation are discussed in [1] ESSs can be applied for mitigating wind power curtailment due to limited transmission capacity, which helps avoid any required transmission capacity upgrade, For optimizing the overall cost function. Presentation will give an overview of different storage technologies and how they can be used in a

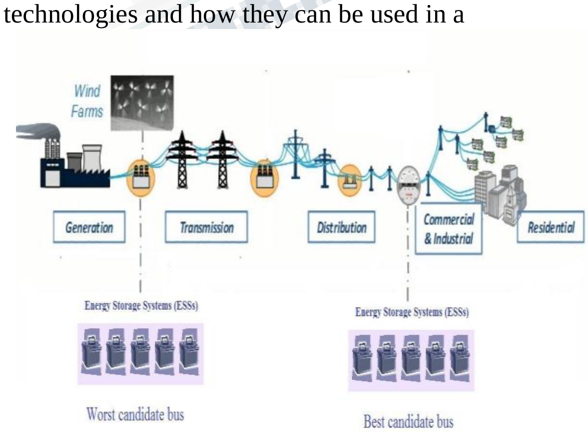

Fig. 1 Single line diagram of test system

sustainable power system [2]. ESSs are studied on optimal sizing and operation of a battery energy storage system (BESS) used for spinning reserve in a small isolated power system and Numerical simulations are performed on a load-frequency control (LFC) [4]. Further studies on other applications of ESSs such as frequency control and risk mitigation can be found in [3]–[5]. Both the operations of ESS and wind generation have very important in many studies. The optimization process is used to maximize revenue for an ESS connected to a wind power curtailment scheme [6], that paper investigates the optimal scheduling of ESS cooperating with wind farms and connected to a distribution network. In [7], presents a security constrained unit responsibility display with wind and BES and talks about the part of BES on Locational price evaluating, financial, peak-load shaving and transmission congestion administration utilizing an 8-bus system contextual investigation. An expanding enthusiasm for ideal operation techniques of ESS in power markets, where power cost is a liability, has been found in [8]-[10]. In [8] presents a stochastic programming structure on ideal offering of free storage units in the day-ahead and hour-ahead energy and reserve markets which is currently grid area in the world that has largest share of wind power in its generation profiles. Managing situation of ESS in power networks, in [11] a system is proposed to designate ESS in a dispersion system with high wind insertion. The ESS is ideally put and estimated to both wind energy and reduce generation costs. In [12] utilizes an affectability investigation strategy to discover ideal areas of ESSs for minimize transmission congestion. [13] Proposes an approach for expand storage devices and talks about the achievability what's more, financial effect of utilizing storage devices. In [14] proposed performance of energy storage applications based on genetic algorithm (GA) optimization technique. However, the approach proposed on a small size system, utilizing DC OPF model and test carried out IEEE 24-bus system. Two-point evaluation strategy to ideally place ESSs in a deregulated control system with wind integration and the optimization issue is calculated for each single period during the considered optimization[14]-[15]. Operation of ESSs into the planning problem with optimal constraints ideal control plans. The authors utilize a semi definite reclining AC OPF model to calculate the ideal position issue and perform tests on IEEE 14-bus system. In [17] a DC OPF system is proposed for capacity portfolio enhancement, including storage size, technology and area in transmission-operating power systems. The tests conducted with IEEE 14-bus system. In [18] proposes an approach utilizing a DC control stream demonstrate for deciding the ideal area and size of an ESS in a power system with uncertain wind generation.

The proposed approaches for ideal position of ESS have been exhibited with small size systems. For larger systems, particularly real size ones, computational burden (heaviness) is as yet an issue. In this manner, for the best candidate bus of ESSs, it is essential for primarily identify the most suitable area or the best candidate areas for installing the ESSs. This is performed, in the methodology proposed in this project, based on an particle swarm optimization (PSO) power flow with BESs and wind integration for time-shifting and congestion relieving applications. The principle commitment of the present work is identifying the best candidate areas for storage allocation based on financial criterion, and assessing the influence of storage location and size on production cost, amount of wind to be curtailed and Locational marginal prices (LMP) in [24] the proposed multi-period AC OPF model is performed to identify the installation of battery energy storage systems (BESs) based on economic criterion and time-shifting and congestion relieving applications in [20] to be more physical suitable approach to study operation of storage devices and good operational schedule This project the proposed model is adopted, for example, to shift wind power over time and get reduction of wind curtailment in case of transmission congestion, thus allowing an efficient utilization of transmission capacity.

The remaining of this project is arranged as follows in section II, the methodology is explained. In Section III, Tests with modified IEEE 14-bus and IEEE 118-bus systems are described and results are discussed. Finally, concludes the paper.

II. METHODOLOGY

In this section, the methodology to define the best suitable candidate locations for ESSs is described. The optimization is performed on the total generation cost which represents technical system operatives (TSO's) point of view, in other words, the goal is to improve system operation in spite of the revenues of the single companies operating wind farms. ESSs, therefore, can be installed at any bus by the TSO in order to maximize the efficiency and security of the overall system. Furthermore, the total time horizon considered (which could be either one year or a set of representative weeks of the year) is discretized and the hourly operation is enhanced considering the presence of the ESSs, particle swarm optimization approach is important to properly model the inter-temporal operating characteristic of the ESSs. The particle swarm optimization power flow explained in Sec. II.A is discuss particle swarm optimization methodology II.B gives as by product the Lagrange multipliers, which are used in II.C to formalize the best candidate locations for ESSs.

A. Particle Swarm Optimization Power Flow:

A basic variant of the PSO algorithm works by having a population (called a swarm) of candidate bus solutions (called particles). These particles are moved around in the search-space according to a few simple formulae. The movements of the particles are guided by their own best known position in the search-space as well as the entire swarm's best known position. When improved positions are being discovered these will then come to guide the movements of the swarm. The process is repeated and by doing so it is reach target position (value).

B. Particle Swarm Optimization Power Flow mathematical formulation:

PSO power flow model with ESSs integration can be formulated as follows [19]. Power system optimization, in which profit or gain is maximized, loss or expenditure is minimized. Every problem of optimization is formulated by two types

a. Objective function

b. Constraints (practical operating conditions)

a. Objective function:

Objective function (OF) to be minimized in this model is the total production cost $\mathrm{OF} = \mathrm{Min}\ \sum_{T=1}^{T}(\mathrm{PC}^{t})$ using as control variables ESS charging/ discharging power and generation output of all dispatchable generators in each period t.

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$$\mathrm{OF} = \mathrm{Min} \sum_{t=1}^{T} \sum_{i=1}^{ng} \left[C_{0_i} + C_{1_i} P_{G_i}^t + C_{2_i} (P_{G_i}^t)^2\right] + \sum_{t=1}^{T} \sum_{j=1}^{ns} \left(C_{d_j} P_{d_i}^t - C_{ch_j} P_{ch_i}^t\right) \quad (1)$$

$$\mathrm{OF} = \mathrm{Min} \sum_{t=1}^{T} (PC^t)$$

In order to take into account the variability of load and wind, possible approaches are available, to run the model on a longer time frame, e.g., one year. However, the problem is subject to the size of the system and representative of the most significant loading and wind conditions calculate the results based on the yearly energies. Therefore, the value of T depends on the time horizon adopted in the planning problem. In particular, in this project, the optimization problem is run on a daily basis, thus T = 24 hours. In equation (1), the primary term is the production cost of all generating units. The secondary term is introduced so that at the optimal solution, the ESS is not charged and discharged at the same time. Hence, C_{ch} and C_d are fictitious charging and discharging costs applied to the ESS. When charging, the ESS is treated as a load with the fictitious charging cost set equal to zero (C_d =0). To prevent simultaneous charging and discharging, the discharging cost C_d =10 $_{-2}$ is set to a very small quantity, as presented in [21].

b. Constraints:

. Equality constraints:

Power balance equations: Include equations for real and reactive power at each node i in each time period t.

$$P_i^t = P_{G_i}^t - P_{L_i}^t + P_{d_i}^t - P_{ch_i}^t$$

$$P_i^t = \sum_{i=1}^{n} V_i^t V_k^t \left[G_{ik} \cos(\theta_i^t - \theta_k^t) + B_{ik} \sin(\theta_i^t - \theta_k^t)\right] \quad (2)$$

$$Q_i^t = Q_{G_i}^t - Q_{L_i}^t + Q_{d_i}^t - Q_{ch_i}^t$$

$$Q_i^t = \sum_{I=1}^{n} v_i^t V_k^t \left[G_{ik} \mathrm{Sin}(\theta_i^t - \theta_k^t) + B_{ik} \mathrm{Cos}(\theta_i^t - \theta_k^t)\right] \quad (3)$$

ESS energy balance equations: Include energy balance equations for each ESS i In each period t, considering charging and discharging efficiencies.

$$B_i^t = B_i^{t-1} + \left(\eta_{ch_i} P_{ch_i}^t - \frac{P_{d_i}^t}{\eta_{d_i}}\right) \Delta t \quad (4)$$

.In equality constraints:

Upper and lower limits for voltage magnitudes

$$V_i^{min} \le V_i^t \le V_i^{max} \quad (5)$$

Bounds on real and reactive generation powers:

$$P_{G_i}^{min} \le P_{G_i}^t \le P_{G_i}^{max} \quad (6)$$

$$Q_{G_i}^{min} \le Q_{G_i}^t \le Q_{G_i}^{max} \quad (7)$$

Branch current limits:

$$(I_{ij}^t)^2 \le (I_{ij}^{max})^2 \quad (8)$$

$$(I_{ji}^t)^2 \le (I_{ji}^{max})^2 \quad (9)$$

ESS charging/discharging power bounds:

$$P_{d_i}^{min} \le P_{d_i}^t \le P_{d_i}^{max} \quad (10)$$

$$P_{ch_i}^{min} \le P_{ch_i}^t \le P_{ch_i}^{max} \quad (11)$$

$$Q_{d_i}^{min} \le Q_{d_i}^t \le Q_{d_i}^{max} \quad (12)$$

$$Q_{ch_i}^{min} \le Q_{ch_i}^t \le Q_{ch_i}^{max} \quad (13)$$

ESS energy limits:

$$B_i^{min} \le B_i^t \le B_i^{max} \quad (14)$$

When the ESS is discharged, constraint (10) must be fulfilled. Similarly, when it is charged, constraint (11) must be satisfied. The above optimization power flow (OPF) problem is formulated as a sparse and complete model, hence, the Lagrange multiplier λpit Connected to the real power flow equation at bus i In period t represents the variation of the total production cost with respect to the variation of real injected power at the same bus, i.e., it is the Locational Marginal Price (LMP) at bus i In period t.

$$\lambda p_i^t = LMP_i^t = -\frac{\partial PC^t}{\partial P_i^t} \quad (15)$$

According to the formulation of the OPF model described above, λp_{it} includes the effects of both real losses and congestions.

B. Assessment of sensitivity:

From the data given by the Lagrange multiplier λp_{it}above, best candidate buses and worst candidate buses for installing ESSs are identified. Actually, buses with the highest Lagrange multipliers are selected as the best candidate buses, where any variation of real injected power has more influence on the generation cost than other buses. As a result, if the ESSs are installed at the best candidate buses, their operation will have greater importance on the production cost. In particular, the procedure is explained as follows:

Firstly, a base case OPF (without ESS installed) is calculated. In this way, the Lagrange multiplier is determined λp_{it} for

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each bus i at each hour t. At this step, constraints on ESSs, including equations (4) and (10)-(14) are removed From the OPF problem. Next, the following parameter df_i is computed for each bus.

$$df_i = \sum_{t=1}^{T} |\lambda p_i^t| \qquad (16)$$

This parameter is then sorted, the highest values indicate the most suitable buses for the installation of ESSs and the lowest values indicate the less sensitive candidates. The above parameter takes into account the effect of the ESSs not only for a specific hour, but considering the whole time horizon. Secondly, in view of the total number of ESSs available, they are connected to the system at the best candidate buses and the OPF problem, with all constraints included, is solved. In the following Section, a group of tests are performed to discuss both the time-shifting and congestion mitigation applications. In each test, production costs, total amount of curtailed wind power and hourly LMP variation are calculated and graphical representation shown.

III. TEST SYSTEM AND DISCUSSION

In this section, tests are performed with modified IEEE 14-bus and IEEE 118-bus systems. Wind data is taken from [24] wind farm and Load data is also relevant to the typical load of a winter day both wind and load data are suitably scaled down to fit the test systems.

A. IEEE 14-bus system:

The mathematical model described in Section II is tested on modified IEEE 14-bus system fig.1 [22]. This network has 4 conventional generators (1 synchronous generator and 3 synchronous compensators) with total capacity of 832 MW, a wind plant (at bus 2) with installed capacity of 250 MW and BESs. BESs are added to support wind generation due to its intermittent behaviour to possibly reduce wind curtailment, congestions and improve the overall economics.

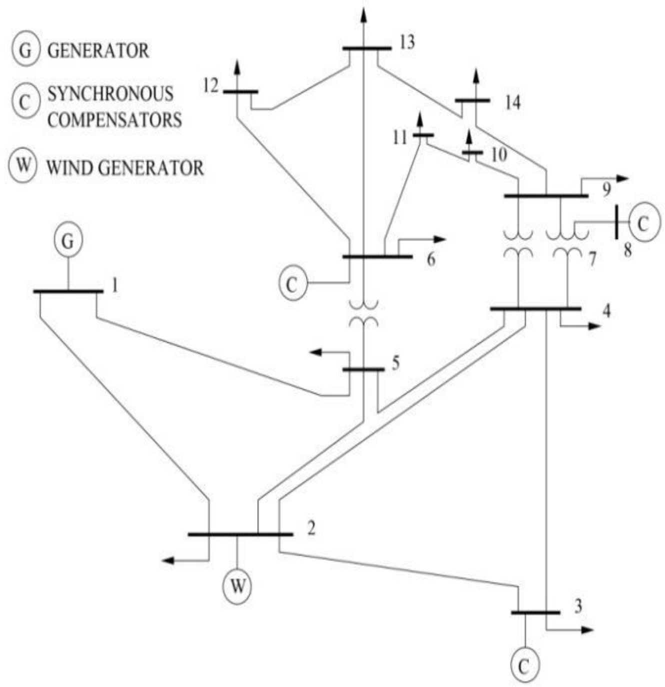

Fig. 2 IEEE 14-bus test system

Parameters for the BES are provided in table I for different tests are performed.

Table I
Parameters for BESs

P_{ch}^{max} [MW]	P_d^{max} [MW]	B^{max} [MWH]	η_{ch}	η_d
30	30	120	0.90	0.90

In this system, loads with highest value of 732 MW are supplied from both conventional and wind generation. When wind is adequate, it will be the priority source to supply loads and if there is still surplus wind power, BESs will be charged. When wind power is not sufficient, BESs will be discharged to supply loads while respecting all technical constraints. If both wind and BES stored energy are not enough for the loads, conventional generators will be dispatched subsequently. From the OPF formulation described in Section II, the Lagrange multipliers of real power at each bus in each hour are determined. The parameter dfi is then calculated for each bus , including the wind bus and load buses (Table II).

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Table II
Values of the Parameter df_i at Each Bus

Best candidate bus number	df_i [$/MWH]	Worst candidate bus Number	df_i [$/MWH]
14	1739.16	11	1615.55
10	1662.22	4	1610.09
9	1657.42	12	1605.50
13	1633.53	5	1569.58
7	1622.41	2	1485.79

From table II, the first 5 buses (14, 10, 9, 13 and 7) with highest values of Lagrange multipliers are selected as the best candidate bus to install the BESs. Similarly lowest values of LMPs are worst candidate buses (11, 4, 12, 5, 2) among this bus 2 is among the worst candidate bus. Similarly, different cases where different numbers of BES are placed in the system are considered to assess the quality of the Sensitivities computed. The tests are categorized as in table III.

Table III
Tests for IEEE 14-Bus System

Case 0	No BES connected to the network
Case 1	1 BES connected to bus 2 (the worst candidate bus)
Case 2	1 BES connected to bus 14 (the best candidate bus)

The optimization problem is run for a period of 24 hours. Operation of the BES for Case 2, with 1 BES connected to bus 14 (the best candidate bus), are represented in Fig.3.

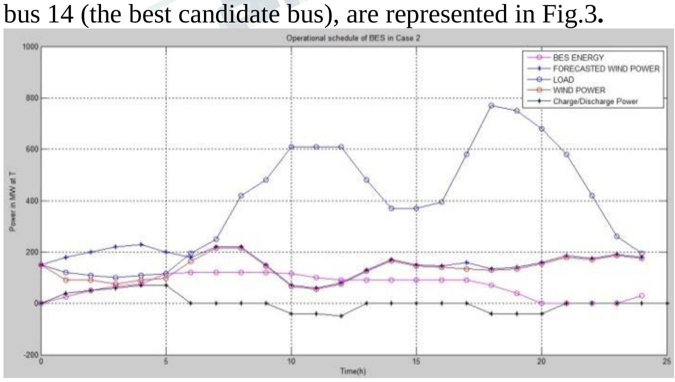

Fig. 3 Operational schedule of BES in Case 2

As appeared in the fig.3, the BES is charged when wind power more than the load and then it is discharged when wind power is inadequate to supply the load. At hours when wind is very well than the load, after the storage has been energized as far as possible, either power or energy limit, the extra wind is necessarily curtailed. To understand the operation of the BESs in each case, the resulting production costs, amounts of curtailed wind power, and LMPs of the previous cases will be compared.

a. Generation costs: Production cost is the cost for generating real power by the generating units only (not including generating cost by the storages). Generation costs of three cases are shown in Fig. 4. It can be clearly seen from this figure that the case without BESs yields very high generation cost over the other cases. Cases with only 1 BES connected to the network result in a noticeable reduction of generation cost and this minimized is higher in the case when the BES is connected to the best candidate bus (Case 1 achieves about 2.1% cost savings while Case 2 obtains approximately 2.35% cost savings compared to Case 0). The production cost is further minimized. Generally, the selection of the best candidate buses improves system operation, although the effect due to the total BES capacity looks more significant in this case. Quality of sensitivities computed can be evaluated by comparing cases 1and 2, the comparison shows that the candidate buses for BES installation are identified. Also, from the above analysis, it can be observed that higher capacity of BES added to the network can significantly improve the overall Economics of the system.

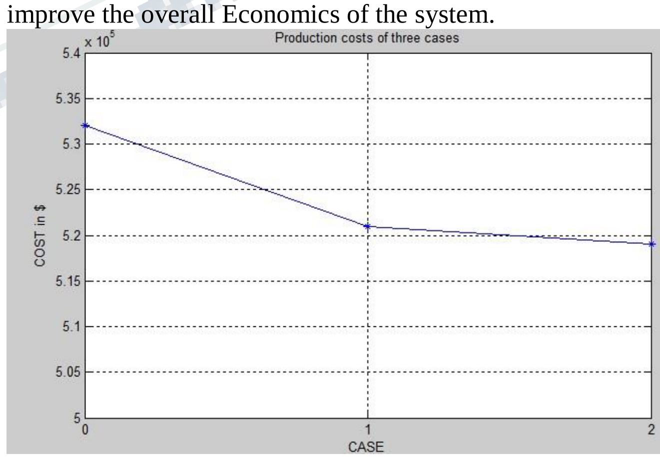

Fig. 4 Production costs of three cases 0 to 2

b. Curtailed wind energy: Wind is curtailed once there is surplus wind but BESs have already reached their capacity limit, either power or energy limit. This curtailment of wind can be viewed as an undesirable loss of “cost-free” and clean energy.

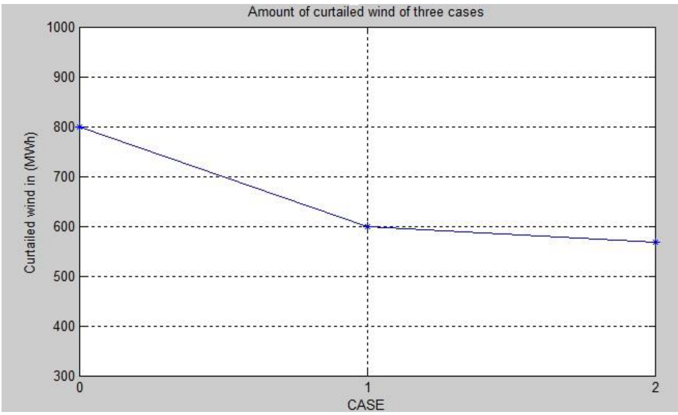

Fig. 5 Amount of curtailed wind of three cases 0 to 2

From Fig. 3, wind is possibly curtailed from hours 1 to 5, in which wind is more than load. Total amount of curtailed wind for every case can be seen in Fig. 5. Amounts of curtailed wind energy in all three cases vary similarly as the generation costs. From this fig.5 we can observe that Case 2 uses more wind power than Case 1 even BES in Case 2 is located away from the wind bus. Therefore, it is important to observe that the computed sensitivities take correctly into account also wind curtailment.

c. Locational Marginal Prices: LMP is an important price indicator inserted at each node and congestion in the transmission network [23]. It consists of marginal unit cost, congestion cost, and cost due to losses. Reference [21] demonstrates that LMPs play a very important role in driving storage operation at low levels of ESS integration. From this work, we observe how LMPs are changed due to the addition of BESs at different locations. The hourly LMP Variation of all 14 buses in Case 0 is presented in Fig. 6 during peak load hours, LMPs also reach higher values while during off-peak hours their values become much lower. This is understandable since at peak load hours, cheap wind power is not enough to supply the load and more expensive conventional generators are dispatched instead, which causes an increase in LMPs.

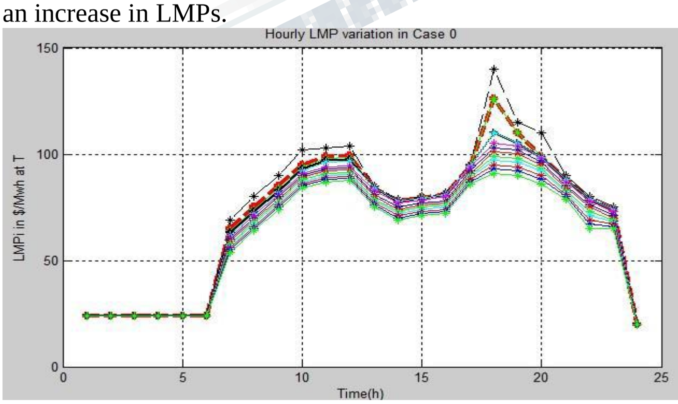

Fig. 6 Hourly LMP variation in Case 0

Fig. 7 shows LMPs of Case 1, in which a BES is connected to bus 2 (the worst candidate bus). In this case, peak prices are obviously reduced for the higher peak hours (18 to 20), from peak value of about 140 $/MWh to around 95 $/MWh. The lower peak hours (for the period of 10 to 12 hours) is also somewhat reduced (from peak value of about 105 $/MWh to 80 $/MWh).

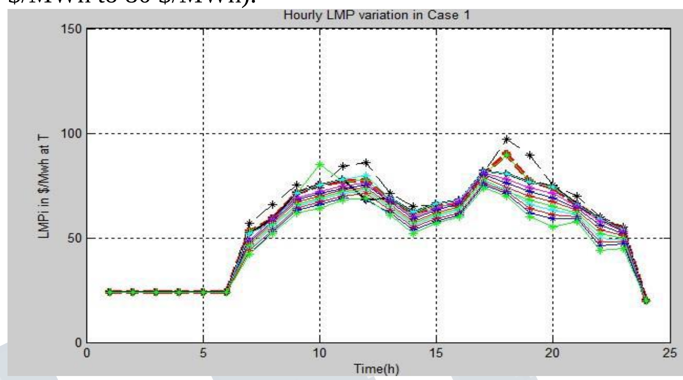

Fig. 7 Hourly LMP variation in Case 1

This shows that the addition of the BES can provide additional cheap power to loads during peak hours. The fall in LMP values in this case will affect the cost of supplying load at each bus. In Case 2, both peaks are further reduced. The second peak hours (18 to 20) is greatly reduced and becomes almost equal to the first peak (hours 10 to 12), i.e., about 80 $/MWh. This shows the addition of BESs at a bus in the best candidate buses has more significant influence on marginal prices than the addition of BESs at a bus in the worst candidate buses, which means the computation of sensitivities are accurate.

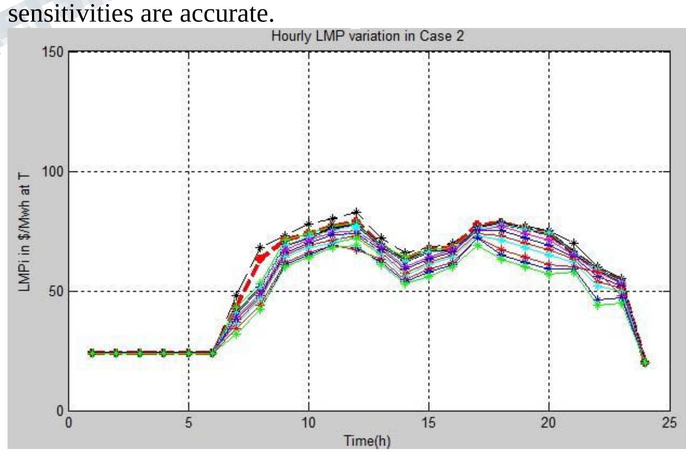

Fig. 8 Hourly LMP variation in Case 2

B. IEEE 118-bus system

To again examine the sensitivities of BES location and size in congestion relieving application in a large system, an extended set of tests is performed on modified IEEE 118-bus

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system [22]. The test system has 56 conventional generators (19 synchronous generators, 35 synchronous compensators) with a total capacity of 2500 MW, 2 large wind generators connected to buses 8 and 10 with a total installed capacity of 700 MW and 9 transformers,91 loads are connected. Load with peak value of 2189 MW is supplied from both conventional and wind generators.

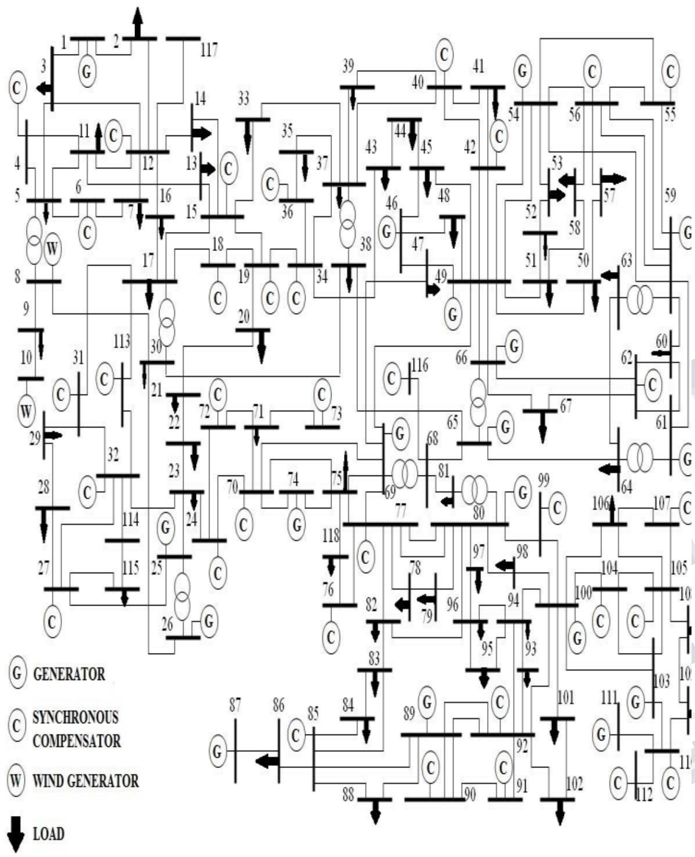

Fig. 9 IEEE 118 bus test system

Generation from the wind generation is likely to cause congestion through this medium from wind to loads, which might result in wind curtailment. In this case, BES are installed to charge this alternatively curtailed wind amount for later releasing and allow an efficient utilization of transmission lines. For this test, congestion is observed during peak hours on lines 8-5, from wind generators to loads. The Parameters for the BES are the same as in the previous test system. The calculated parameter df_i, high the best candidate and worst candidate buses for installing BES are selected as shown in Table IV.

Table IV
The Selected Best and Worst Candidate Buses

Best candidate bus number	df_i [$/MWH]	Worst candidate bus Number	df_i [$/MWH]
5	658.28	37	581.38
3	654.75	114	581.21
7	650.06	115	581.18
2	649.77	23	576.83
11	648.80	38	575.17
117	647.73	17	574.39
13	637.95	30	552.03
14	631.46	8	491.10
109	624.09	9	486.10
16	623.80	10	480.64

From this table, known data for the best candidate buses include buses 5, 3, 7, 2, 11, 117, 13, 14, 109 and 16 while the worst candidate buses include buses 37, 114, 115, 23, 38, 17, 30, 8, 9 and 10. From this values observing that wind buses (8 and 10) are not in the best candidate set as the optimization is performed from a system point of view. The tests performed are explained in Table v.

TABLE V
Tests for IEEE 118-Bus System

Case 0	No BES connected to the network
Case 1	1 BES connected to bus 8 (the worst candidate bus)
Case 2	1 BES connected to bus 5 (the best candidate bus)

***a. production costs**:* In Fig. 10, explain production costs of the system in three cases is provided. Case 0 provides the maximum prices compared to the others. From cases 1 to 2, the price is continuously reduced.

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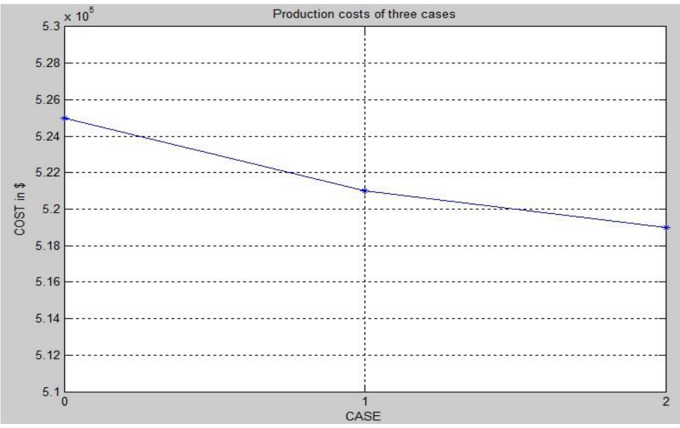

Fig. 10 Production costs of three cases 0 to 2

This demonstrates that of BES installed return more economical operation of the system. The effectiveness of a best selection of candidate buses by the sensitivities computation is clear by looking at cases 1 and 2, Case 2 results is higher saving as compared to Case 1. From this analysis, it can be conclude that in such a congested system, storage devices placed at the best candidate buses can provide far more economical operation than those placed at the worst candidate buses. Thus, it is important to identify the best candidate locations for the planning of storage devices. Additionally, in this case, a large BES connected to a bus in the best candidate buses can operate as efficiently as several BESs distributed among the best candidate buses.

***b. Curtailed wind energy**:* Amounts of curtailed wind energy in 3 cases are characterized in Fig. 11. taking into consideration Case 1 and Case 2, for instance, the conclusion is that the difference in total cost price (Fig. 10) is not due to wind curtailment, like for the 14 bus test system above, but due to congestions, the optimal placing of BES allows, in this case, to best relieve the congestions due to wind power. In this case, the amount of wind energy to be curtailed is not affected by centralized or decentralized placement of the storage devices

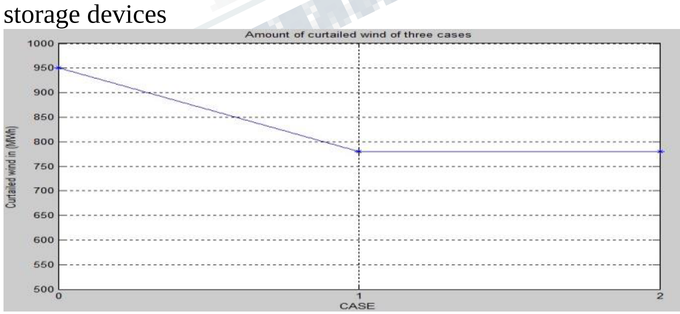

Fig. 11 Amounts of curtailed wind of three cases 0 to 2

c. Locational marginal prices: hourly LMP variation of all buses for each case is also shown to discuss the impacts of BES location and size on LMPs. Hourly LMP variation of Case 0 is shown in fig. 12 in this figure, curves with the maximum peak values belong to load buses on the receiving side of congested lines and curves with the minimum prices belong to wind buses. During off-peak hours, LMPs are about the same for all buses since there is no congestion

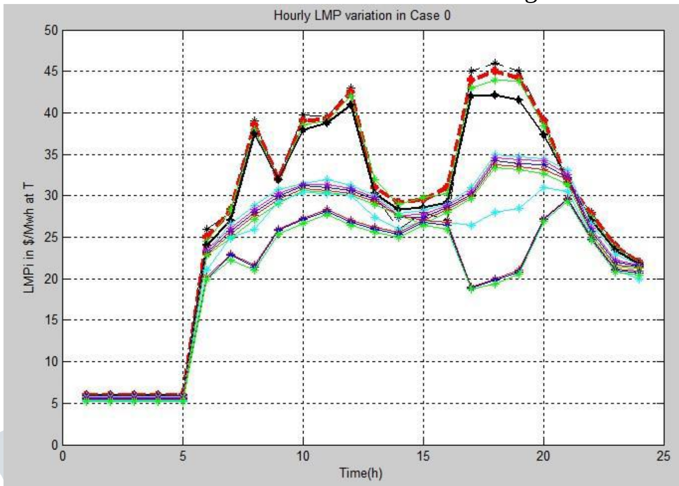

Fig. 12 Hourly LMP variation of Case 0

Hourly LMP variation in Case 1, when there is 1 BES connected to bus 8 (one of the worst candidate buses), peak prices are obviously reduced for the higher peak hours (17 to 20), from peak value of about 45 $/MWh to around 36 $/MWh. The lower peak hours (for the period of 10 to 12 hours) is also somewhat reduced (from peak value of about 43 $/MWh to 30 $/MWh) as shown in fig.13. This shows that the addition of the BES can provide additional cheap power to loads during peak hours. The fall in LMP values in this case will affect the cost of supplying load at each bus.

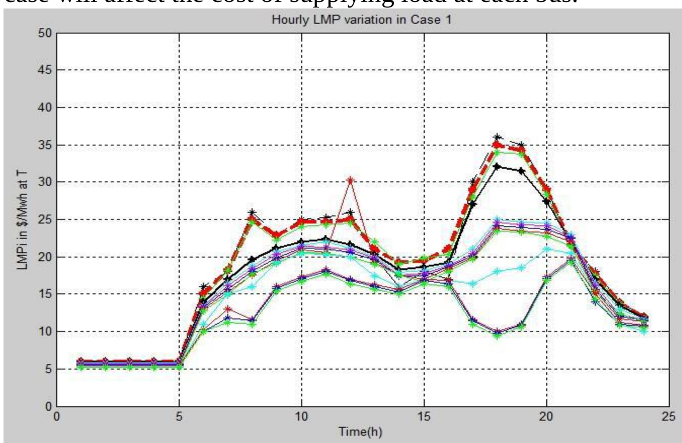

Fig. 13 Hourly LMP variation of Case 1

In Case 2, with 1 BES connected at bus 5 (the best candidate bus), the maximum prices during the first peak hours are again reduced from peak value of about 45 $/MWh to around 30 $/MWh and those during the second peak hours The

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maximum prices are not minimized at hours 18 and 19 of the second peak period because the limited capacity of the BES is not enough to supply the maximum load during these hours as shown in fig.14. For these maximum prices to get minimized, maximum capacity of the BES is required.

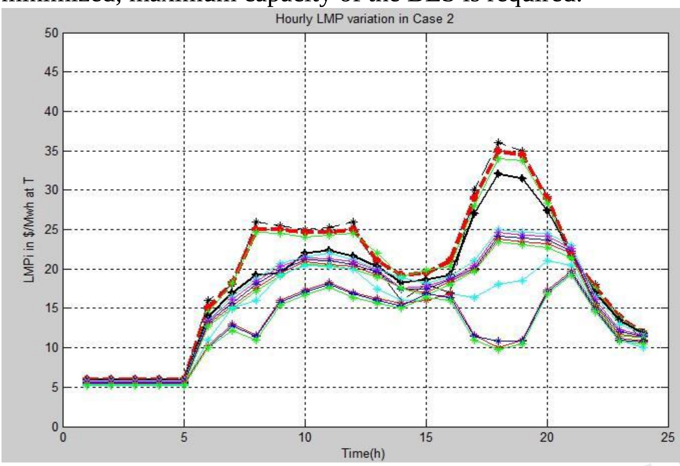

Fig. 14 Hourly LMP variation of Case 2

In this case, to avoid transmission congestion, the BES is charged by wind power during low load hours, when there are no congestions, and then discharged to supply the cheap energy to loads during congestion hours, hence it can help to reduce the marginal cost during peak hours of these load buses. This operation of the BES has effectively supported wind generation and efficiently makes use of the available transmission capacity. Now Fig.15 showing the operation of the BES connected to bus 5 (the best candidate bus) to completely examine how it shifts wind to avoid transmission constraint.

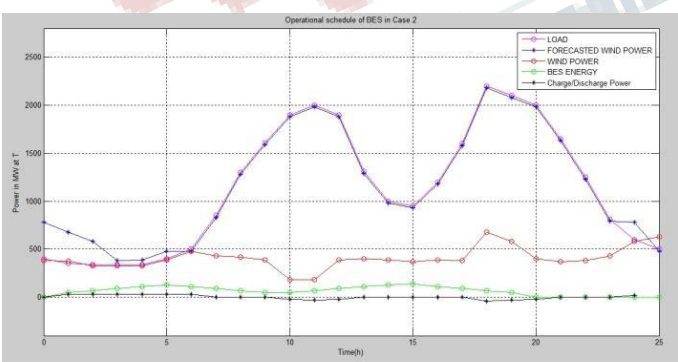

Fig. 15 Operation of the BES in Case 2

From this fig.15, the BES is charged during off-peak hours (hours 1 to 5 and hours 14 to 16), which are also hours without transmission congestion, and then discharged during peak hours (hours 10 to 12 and hours 17 to 20) when congestion occurs. From this, the BES has thoroughly shifted wind power from wind side to load side to supply loads when wind power can't be transferred from wind generators to loads due to limited transmission capacity.

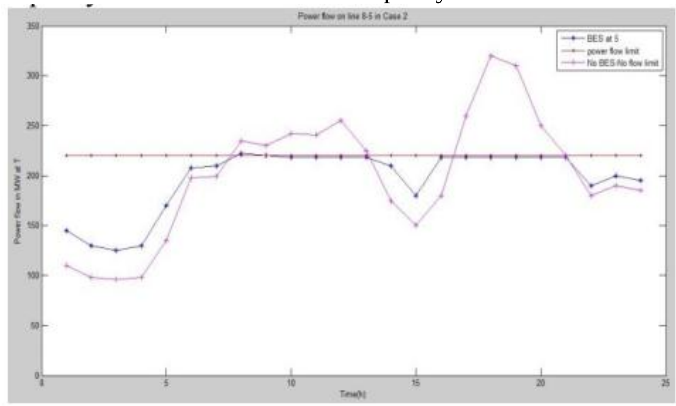

Fig. 16 Power flow on line 8-5 in Case 2

Also, in Fig.16 is a layout of power flows on line 8-5, connecting wind generators and loads. The pink line with pluses in the plot corresponds to the unconstrained case without BES, the power flow limit red line with filled circle is not enforced by the optimization procedure and this would cause the real-time curtailment of excess wind power. This figure clearly illustrates the alternative path that the BES provides for wind power to alleviate the congestion, i.e., the full blue line with circles. In this way, power flow on line 8-5 during low load hours (hours 1 to 5 and 14 to 16) are increased. But still lower than the flow limit. Such flow increase is due to the wind power flow used to charge the BES at load bus. This Stored energy is released to supply loads during peak hours, when congestion occurs. Accordingly, wind power can still be supplied to loads while ensuring the flow limit.

IV. CONCLUSION

In this paper, the problem of selecting the best location for ESSs installation is solved. The sensitivities are computed by using Particle swarm optimization power flow to identify the buses that, in case of installation of ESSs, allow the maximum benefit for power systems from several points of view: the minimum overall cost, the minimum curtailment of wind power, the maximum reduction of congestion the maximum benefit, in terms of energy process. The sensitivities are computed as a particle swarm optimization power flow, thus taking into account not only a single hour but the overall time horizon and possible time shifts of generated wind power, as well as issues related to congestions reduction and minimization of losses. The

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proposed methodology has performed test on two test systems using realistic data, and the sensitivities have been determined, showing a very informative content. Moreover, the system benefits have been proved with reference to Locational marginal prices, used here as an index of the social benefit. The results indicate that the method can be easily applied to large systems where many different scenarios can be taken into account, such has the variability of both wind power and load. Also can be applied for solar power, further extension of BES units based on availability of wind energy is possible.

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NOMENCLATURE

T	Time horizon 0 to 24 hours
n	Number of busses
ng	Number of generators
ns	Number of ESSs connected
nbr	Number of branches
$C_{0_i}, C_{1_i}, C_{2_i}$	Cost functions generating units at bus *i*
$C_{d_j}, \mathrm{C}_{\mathrm{ch_j}}$	Charging and discharging energy costs of ESSs at bus j
P_i^t	Real power at bus *i* in hour t
$P_{G_i}^t$	Generating real power at bus *i* in hour t
$P_{L_i}^t$	Active Load at bus *i* in hour t
$P_{d_i}^t$	Discharging power in ESSs at bus *i* in hour t
$\mathrm{P}_{\mathrm{ch_i}}^{\mathrm{t}}$	Charging power in ESSs at bus *i* in hour t
Q_i^t	Reactive power at bus *i* in hour t
$Q_{G_i}^t$	Generating reactive power at bus *i* in hour t
$Q_{L_i}^t$	Reactive load at bus *i* in hour t
$Q_{d_i}^t$	Discharging reactive power at bus *i* in hour t
$\mathrm{Q}_{\mathrm{ch_i}}^{\mathrm{t}}$	Charging reactive power at bus *i* in hour t
V_i^t	Voltage magnitude of bus *i* in hour t
V_k^t	Voltage magnitude of bus k in hour t
I_{ji}^t	Magnitude of the current flowing from bus j to *i* in hour t
I_{ij}^t	Magnitude of the current flowing from bus *i* to j in hour t
θ_i^t	Voltage angle of bus *i* in hour t
θ_k^t	Voltage angle of bus k in hour t
G_{ik}	Line susceptance of branch *ik*
B_{ik}	Line conductance of branch *ik*
B_i^t	Energy of ESS at bus *i* in hour t
B_i^{t-1}	Energy of ESS at bus *i* in hour t-1
$\eta_{\mathrm{ch_i}}$	Charging efficiency of ESS at bus *i*
η_{d_i}	discharging efficiency of ESS at bus *i*
Δt	Change in time (hours)
$_i^{min}$	Lower limit of that quantity
$_i^{max}$	Upper limit of that quantity

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