Investment Deferral of Sub-Transmission Substation Using Optimal Planning of Wind Generators and Storage Systems

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Electricity consumption increases continuously because of several reasons such as population growth. Due to consumption growth of electricity it is necessary to upgrade generation, transmission and distribution equipments. In distribution level, transformers of sub-transmission substations should be upgraded to overcome load growth. In this paper, it is recommended to use wind generators and storage devices instead of transformer upgrading of substations. This is significant because of environment pollution and investment deferral of sub-transmission substations. Hence, this paper suggests a new method to determine the optimal capacity of wind generators and energy storage system (ESS) for investment deferral of sub-transmission substations. In this method reliability and economic aspects are considered along with time varying loads. Furthermore, to peruse the uncertainty of wind generation an innovative point estimate method (PEM) has been fulfilled. The main goal of the presented method is to minimize the investment cost of the ESS units and wind generators, purchased power from upstream network and also reliability maximization. The objective function is mathematically formulated as a mixed-integer non-linear programming problem and subsequently solved by genetic algorithm (GA). The proposed method is successfully applied to a study case and obtained results show the efficiency and applicability of the proposed approach.

keywords: *Storage System; Wind Generator; Distribution Network; Asset Management; Genetic AlgorithmStorage System; Wind Generator; Distribution Network; Asset Management; Genetic Algorithm*

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1. INTRODUCTION

Recently ESS devices have converted to one of the most important solutions to minimize the operation and planning costs in modern distribution networks from system operator perspective. ESS units have various benefits for system like enhancement the reliability of network, economic benefits due to selling discharged power in peak periods, deferral upgrading of system, peak shaving as well as improvement the power quality. However, the planning storage devices required optimal and exact modeling of ESS to legitimatize its economic livability and major barricade over or under utilization. If the ESS planning problem is done optimally with considering more details about its planning, in this case it will be very beneficial and advantageous from economic and reliability points of view [1–3]. A frame of literature, which focuses on optimal sizing from economical profits [4–7], prepares necessary intentions and basic approaches to the disquisition in optimal siting of ESS a more plenary problem containing economic, assembling, operating, utilization, reliability and power quality.

By using energy storage systems in distribution systems, reliability and network security increases. Different types of ESS technologies have been introduced in [8]. Among the variety of energy storage technologies, batteries are the most popular technology [9]. The usage of battery units is investigated to manage the operational costs in various literature [10–12]. Batteries provide proper usage of energy production in the high demand by storing energy during low demand conditions. In [13] a computational method for optimum placement of DG units in radial network is proposed. The aim of this reference is minimizing power losses. In [14], for solving ESS planning issue a multi-objective algorithm which considers its operation strategy is proposed. In [15], two models were compared to specify the optimal size of battery energy storage system (BESS) and the integrated wind and diesel system dispatch with hydrogen storage. In [16] proposed a novel strategic policy for optimal management of ESS units based on hourly scheduling in the interconnected wind power company. The objective of [17] is to minimize the operation cost of thermal generator as well as ESS installation without considering ESS operating cost. The main contribution of [18] is a mixed-integer second-order cone programming (MISOCP) model for solving the optimal operation of distribution network considering energy storage device (ESDs). In [19] the inuence of different market participants on proles of distributed storage assets is investigated. In [20], optimal planning of ESS in the distribution network and the ESS are scheduled simultaneously for several objects including, peak shaving, voltage regulation and reliability enhancement is presented. In [21], the storage units are allocated in distribution network with a high penetration of wind energy system to minimize the annual cost of electricity. Energy resources are explored in [22–24], where the main aim is to cope the intermittent nature of WT and PV units as well as controllable generation. Reference [25], assumes the storage facility being operated by the wind farm operator, aiming to minimize the risk of wind power commitment. In [26], a multi period ac optimal power flow problem with battery energy storages (BESs) is formulated based on an economic criterion. In [27], a stochastic planning framework is proposed for the BESS in distribution networks with high wind power penetrations, aiming to maximize wind power utilization while minimize the investment and operation costs. According to the integration of DG, a bi-level optimization model is proposed in [28] for determining the optimal installation site and the optimal capacity of BESS in distribution network.

Also, in [29], an approach is proposed for determining the optimal location and size of ESS in a power system network integrated with uncertain wind power generation. In [30], a mixed integer second order cone programming model is presented for solving the problem of allocating energy storage devices in radial distribution networks. In [31] presents a cost-benefit analysis of energy storage for peak demand reduction in medium-voltage distribution networks.

One of the strategic goals in electrical energy section is optimal and appropriate energy efficiency. Since the electrical energy production capacity is limited to the high cost of investing in it. Therefore, increasing the productivity of existing capacity will follow a great effect on reducing the cost of investment in generation section, transmission and distribution of electrical energy. One way to achieve these goals is using load management methods such as load leveling method. The benefits of load transfer from on-peak to off-peak, in view point of demand and delaying the capacity is well known.

As it is known, electricity consumption increases continuously because of several reasons such as population growth. Due to consumption growth of electricity it is necessary to upgrade generation, transmission and distribution equipment. Consequently, it is necessary to build power plants, transmission and distribution lines, and substations. As we know, building conventional power plants has environmental concerns such as CO2 emission and climate changes on the earth. Renewable power plants are suitable replacements for conventional power plants. Among renewable power plants, wind generators are more suitable because they don't consume fuel. Beside this advantage, there is significant disadvantage of using wind generators. Uncertain generation of these generators leads to unreliable operation of power systems. To overcome to the challenge there are several techniques such as using storage devices beside wind generators. Using this technique, building new conventional power plants, transmission lines and also sub- transmission substations will be postponed. This paper is discussed about the installation of wind generators beside storage devices in HV / MV substation to overcome load growth and also investment deferral of the substations. The benefits of the storage units and DG installation in substation are derived as follows: economic benefits from improved reliability reduce the cost of active and reactive power, the benefits of delaying the substation development. Components of profit and costs associated with the project are formulated in the form of objective function. To implement this planning has been used of genetic algorithm and to demonstrate the effectiveness of the proposed method is successfully implemented to three test systems. In the first case, DG is installed only, in the second case ESS is installed and in the third case, both energy units and DG is installed in sub-transmission substation.

In this paper, the optimal sizing of ESS and DG unit in the sub-transmission substation is proposed with considering the substation upgrade deferral. The optimal ESS sizing problem is proposed which minimizes the capital cost of the ESS and maximize the benefits of ESS installation including active and reactive power supply reduction, and reliability improvement.

This paper has been organized as follows: The scheme of proposed problem is illustrated in Section 2; The proposed planning model to integrated ESS and DG is formulated in Section 3. Section 4 shows the suggested technique to handle the uncertainty of problem; Section 4 depicts the numerical simulations on a test system. Finally, the discussions and concluding of implemented approach are demonstrated in Sections 5 and 6.

2. MODEL OUTLINE

The main goal of the optimal planning ESS units is to minimize the its capital cost, the ESS expected operating cost and the benefits of ESS installation including reduction of active and reactive power supply, enhance profit of substation upgrade deferral and reliability cost.

From the perspective of energy distribution companies, besides adding to the distribution feeder, the MV substation is also a good place to installation of distributed generation and energy storage. On the other hand, installation of energy storage units along with DG sources could be have a significant impact on peak shaving. Schematics of installation this unit is shown in Fig. 1. Installation and operation of energy storage unit and DG will have an impact on the loading of transformers and Received power from the transmission lines.

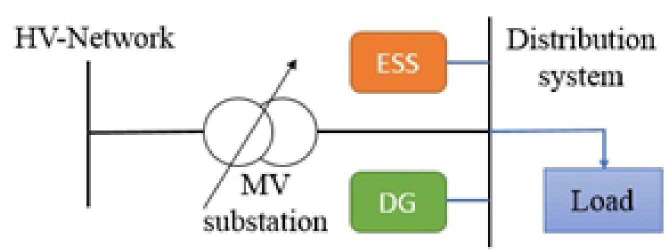

Fig. 1. Installation of energy storage and DG in HV/MV substations

The benefits and costs obtained from the installation of the energy storage unit and DG is dependent on the manner of operation of this units. Annual changes in consumption can be modeled in the form of hourly load curve.

Information relating to active and reactive load has been modeled in the form of 24-hour curve. These curves are representative of the daily loading in the whole year and for modeling annual load changes is used of 365 repetitions of this curves. In this section, economic benefits and the cost of installation energy storage system and DG is formulated and presented as mathematically. In this modeling assumes that energy storage unit and DG are owned distribution company.

A. Economic benefits related to DG along energy storage system

According to annual growth of energy consumption, the development of the distribution network is inevitable. Hence, the need to add transformers to increase the capacity of substation to be felt [17]. As shown in Figure 2, with annual growth of consumption, current peak load in substation (SD_{Max}) after M years arrives to loading limit of substation (SS_{Max}). So, transformer capacity should be increased after M years to feed network load.

While installing energy storage units and DG in substation, with the assumption of the same annual load growth rate, time of maximum loading of Transformer increases to the N years. Time delay of capacity development in substation is equivalent to:

$$\Delta T = N - M \tag{1}$$

Before installing the DG and energy storage unit, following equation is presented:

$$SD_{Max}(1+\alpha)^M = SS_{Max} \tag{2}$$

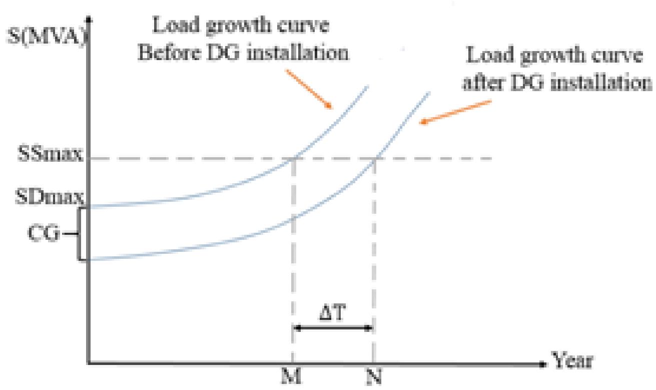

Fig. 2. Installation of energy storage and DG in HV/MV substations

And after installing DG and energy storage unit is equal to:

$$SD_{Max}(1-\gamma)(1+\alpha)^N = SS_{Max} \tag{3}$$

$$\gamma = \frac{CDG + PS}{SD_{Max}} \tag{4}$$

α, is annual consumption growth rate and γ is capacity of DG ratio and rated power of energy storage unit to current peak load in substation. CDG, is DG capacity (MVA) and PS, rated power of energy storage unit (MW). If DG is installed alone,PS is not considered and if energy storage unit is installed alone, CDG is not considered in the equation (4). By using of equations (2) and (3), the time delay in the development of substation is equal:

$$\Delta T = N - M = \frac{log(\frac{1}{1-\gamma})}{log(1-\alpha)} \tag{5}$$

N presents the years of capacity development of substation after installing energy storage and DG. The present value of the economic benefit obtained by the delay time in capacity expansion of substation from$M$ to$N$ year is equal:

$$B_1 = C_{invT}(1 - \frac{1+intfr}{1+intr})\Delta T \tag{6}$$

$$NPV(B_1) = B_1(\frac{1+intfr}{1+intr})M \tag{7}$$

where, C_{invT}, is cost of capacity expansion of substation ($). intr is the annual interest rate and infr is the annual inflation rate. NPV shows the presents value of costs and benefits.

B. Reduce the cost of active power supply

Active power received from the transmission system is consists two parts. First section is relating to distribution network load in the secondary side of the transformer in substation and on the other hand input medium voltage feeders and the second part relates to the power losses of transformer substation. Received active power is formulated as follows:

$$PT_{b,i} = PD_i + \frac{SD_i^2}{S_N^2} P_{LN} \tag{8}$$

where, PD_i, the amount of active load of system and in hours i(MW). P_{LN}, power losses of transformer in substation and in nominal loading (MW). $PT_{b.i}$, received active load from the system before installing storage and DG in hours i (MW). S_N, rated capacity of transformer (MVA). SD_i, apparent power of network load in hours i (MVA).

Thus, the annual cost of purchased active power from the transmission system for the supply of network load is equivalent to:

$$CP_b = 365 \times \sum_{i=1}^{24} [PT_{b,i} \times C_{MWhT}(PT_{b,i})] \tag{9}$$

C_{MWhT} is active power purchase price of the network. Active power prices can be varied in different hours.

As shown in Figure 3, in this paper, active power purchase cost is a function of received active power from the system. Thus, the cost of purchased power is greater at peak hours.

With the installation of DG, a part of the active power is supplied by this unit. Also, with the installation of energy storage system is showed the importance of load transfer from off-peak period to on-peak period. Hence, load transfer is the important benefit from the economic point because the cost of power purchased from the system is variable in different hours. Active power received from the system is reduced in the presence of DG. Now if in addition the DG, also energy storage is installed, active power received from the transmission lines reduced in peak hours significantly. Thus, in the presence of DG and energy storage unit, purchased power of transmission system reduced. In the following equation, the relationship of active power received from the system in the presence energy storage unit and DG is demonstrated:

$$PT_{a,i} = PD_i - PG_i - PS_i + \frac{(SD_i - SG_i - SS_i)^2}{S_N^2} \times P_{LN} \tag{10}$$

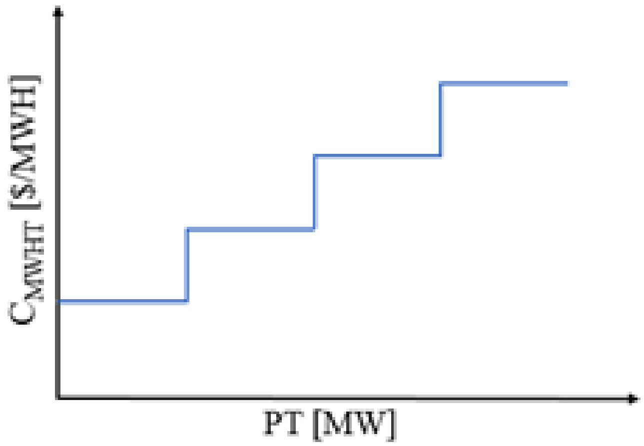

Fig. 3. The price of electricity in the transmission system as a function of the power required

where, $PT_a.i$, active load received from the system after installing storage and DG in hours i (MW). PG_i, the amount of active power produced by DG in hours i (MW). SG_i , the amount of apparent power generated by DG in hours i (MVA). PS_i, the amount of power charged or discharged by the energy storage unit. A negative value in PS_i, indicates that storage is being charged and the positive value of this parameter, indicates the storage is discharged state (MW). SS_i , the amount of apparent power generated by the energy storage system in hours i (MVA). Thus, annual cost of supplying active power from the transmission network after installing the DG and energy storage unit is equivalent to:

$$CP_a = 365 \times \sum_{i=1}^{24} [PT_{a,i} \times C_{MWhT}(PT_{a,i})] \tag{11}$$

Annual economic benefit resulting from reducing the cost of buying the active power and the present value equivalent during the useful life of the energy producing units (T) respectively, equivalent to:

$$B_2 = CP_b - CP_\alpha \tag{12}$$

$$NPV(B_2) = B_2 \sum_{t=1} (\frac{1+infr}{1+intr}) \tag{13}$$

C. Reduce the cost of reactive power supply

As well as active power, in this section also has been discussed about the cost of reactive power received from upstream grid. In general, the annual cost for reactive power is calculated as follows:

$$CQ_b = 365 \times C_{MVArhT} \times \sum_{i=1}^{24} QD_i \tag{14}$$

where, $C_M VAhT$, shows the purchase price of reactive power from transmission system $(\$/MVAr - hour)$. QD_i, shows the amount of reactive load at system and in hours i(MVAr). The annual cost of reactive power supply by installing DG unit is equivalent to:

$$CQ_a = 365 \times C_{MVArhT} \times \sum_{i=1}^{24} (QD_i - QG_i) \tag{15}$$

QG_i shows the amount of reactive power produced by the DG in hours i(MVAr). The energy storage unit not affect the reactive power. Annual economic benefit resulting from reducing the cost of the reactive power and its present value equivalent during the useful life of the energy producing units (T) respectively, equivalent to:

$$B_3 = CQ_b - CQ_a \tag{16}$$

$$NPV(B_3) = B_3 \sum_{t=1}^{T} (\frac{1+infr}{1+intr}) \tag{17}$$

D. Reliability improvement

The energy storage units and DG which have been replaced in MV substation can also decrease the energy not supplied (ENS) cost during outage periods and improves reliability of disconnected customers. The ENS cost has been basically considered as the cost of not supplied loads over a time period. The ENS cost has been determined through calculate the amount of not supplied energy via equation (18). The amount of ENS and cost of the energy not supply in substation is formulated as follows:

$$CR_b = U \times SD_{Max} \times LF \times C_{MVAhns} \tag{18}$$

U , the annual duration of power outages, LF, the load factor related toHV/MV substation.C_{MVAhns}, shows cost of the energy not supply for each load ($/MVA-hour). DG and storage unit acts as a backup source in during outages. Cost of the energy not supply at the presence of DG and storage units is equivalent:

$$CR_a = U(SD_{Max} \times LF - CG - CS) \times C_{MVAhns} \tag{19}$$

The annual benefit Caused by improved reliability and its present value equivalent during the useful life of the energy producing units (T) respectively, equivalent to:

$$B_4 = CR_b - CR_a \tag{20}$$

$$NPV(B_4) = B_4 \sum_{t=1}^{T} (\frac{1+infr}{1+intr})^t \tag{21}$$

E. The cost of ESS and DG installation

The cost of installing energy storage and DG as initial investment cost according to DG capacity and the rated power related to storage is equal:

$$C_1 = NPV(C_1) = CG \times C_{MVADG} + PS \times C_{MWStor} \tag{22}$$

C_{MVADG} is represents the cost of installation DG unit /MVA) and $C_(MWStor)$ is represents the cost of installation energy storage unit according to their rated power ($/MW).

F. The operation cost of DG units

The annual cost of operation of DG units and its present value equivalent in during the useful life of the energy producing units (T) is formulated as follows:

$$C_2 = 365 \times C_{MWhDG} \times \sum_{i=1}^{24} PG_i \tag{23}$$

$$NPV(C_2) = C_2 \sum_{t=1}^{T} (\frac{1+infr}{1+intr})^t \tag{24}$$

C_MWhDG, cost of power generation by DG.

G. The cost of Maintenance

One of the other current costs is maintenance costs of production unit which consists of two parts. A fixed section that is associated with the production unit capacity and a variable part that is dependent on the operation of the generation unit.

For energy storage unit is intended annual fixed cost as maintenance cost. So, maintenance costs for the two units is expressed according to the following formula:

$$C_3 = C_{Mf} \times CG + C_{Mv} \times 365 \times \sum_{i=1}^{24} PG_i + PS \times C_{Ms} \tag{25}$$

C_{Mf}, is annual fixed cost for maintenance cost of DG unit (\$/MVA-hour). C_{Mv}, is variable cost for maintenance cost of DG (\$/MWh) and C_{Ms}, is annual fixed cost for maintenance cost of storage unit (\$/MW). so, current value equivalent related to maintenance cost for the two units in during the useful life of the energy producing units (T) is formulated as follows:

$$NPV(C_3) = C_3 \sum_{t=1}^{T} (\frac{1+infr}{1+intr})^t \tag{26}$$

3. OBJECTIVE FUNCTION

By combining mentioned the benefits and costs, the objective function is formulated as follows:

$$MaxF = \sum_{i=1}^{4} NPV(Bi) - \sum_{i=1}^{3} NPV(Ci) \tag{27}$$

Among the restrictions can be noted to limits of the maximum and minimum active and reactive power generation constraints for the DG unit. This constraint is formulated as follows:

$$PG_i \leq PD_i \qquad i = 1....24 \tag{28}$$

$$QG_i \leq QD_i \qquad i = 1....24 \tag{29}$$

$$s.t. \frac{PG_i}{PF_G} \leq CG \qquad i = 1....24 \tag{30}$$

PG_i and QG_i, are active and reactive power generated by the DG unit in each hour, respectively. PD_i and QD_i, are active and reactive power demand in each hour, respectively. PF_G, The load factor for DG. CG , is DG capacity. The amount of active and reactive power generated by the DG in each hour should not be beyond from the network load at the same hour. So, maximum active and reactive power of DG units can be limited by the constraints is noted in above. Also, DG capacity does not exceed of a certain limit (CG_{Max}). Limits the maximum capacity of DG unit is mentioned as follows:

$$CG \leq CG_{Max} \tag{31}$$

This limitation can be used in cases where for technical reasons, DG installation is not possible more than the specific capacity. Also, this constraint is important from the viewpoint of the initial budget for the implementation of the project.

To assure the operation constraints of ESS, storage units can be discharged only after the state-of-charge (SOC) achieved its own maximum level. Moreover, in each hour the SOC of ESS should be updated as below [32]:

$$SOC_{t+1} = \{SOC_t + PS_t\} \tag{32}$$

where PS_t may be has a positive or negative value. When this power is a negative value, it means that the state is discharge and if it be a positive value, means that the state is charging of storage unit. The maximum SOC of the storage units is confined to an upper bound which is less than the capacity of the storage units. SOC, must be updated every hour according to the above formula. At any given time, there are some constraints for the SOC of the energy storage system which can be expressed as

$$SOC_{min} \leq SOC_t \leq SOC_{max} \tag{33}$$

where SOC_{max} is the upper limit, and SOC_{min} is the lower limit SOC for the energy storage.

4. UNCERTAINTY MODELLING

A. Concepts and Motivations

In this paper, the planning of wind turbines and storage devices has been investigated to deferral the upgrading of subtransmission substation. Therefore, to study the impact of variations of generated power of wind turbine on the proposed model, in this section a novel approach based on point estimate method (PEM) is proposed.

B. Point Estimate Method

PEM is one of the powerful techniques to handle the uncertainty, which is well understood in power system studies. In this approach, the Probability Distribution Function (PDF) of uncertain parameter, which in this paper the wind speed is considered as uncertain parameters, should be known. Hence, according to previous literature [33] the Weibull PDF has been employed to model the wind speed in the location of installed wind turbine as shown in Fig. 4. The following formulation is shown the Weibull PDF form of wind speed and generated power by wind turbine as [34]:

$$F(v) = \frac{\zeta}{k} (\frac{v}{\zeta})^{\theta-1} \times e^{fracvk} \tag{34}$$

$$P_{WT} = \begin{cases} 0 & x < V_{ci} \qquad x > V_{co} \\ (\frac{v-v_{ci}}{v_r-v_{ci}}) \times P_{rat} & V_{ci} < x < V_r \\ P_{rat} & V_r < x < V_{co} \end{cases} \tag{35}$$

where ζ and k are the shape parameters of Weibull PDF which is set to 5 and 3 and also, v is the speed of wind [**?**]. Also, V_{ci}, V_co and V_r are the speed of cut-in, cut-out and rate for wind,

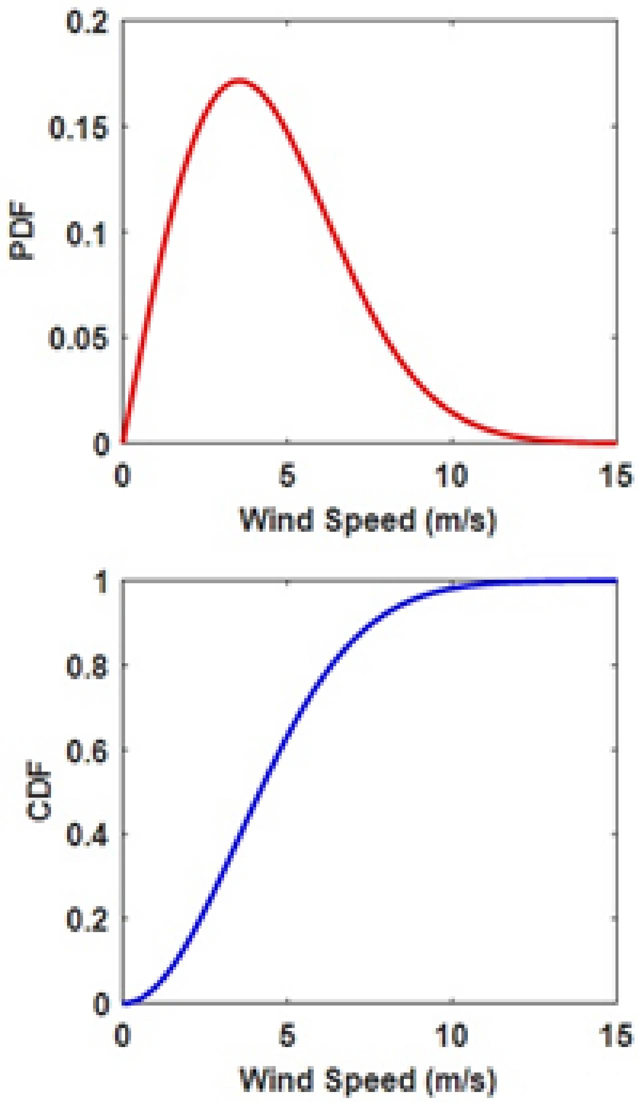

Fig. 4. PDF and CDF of Weibull to demonstrate the wind speed error

respectively. P_{WT} denotes the generated power of wind turbine and P_{rat} is rated power of wind turbine.

In PEM approach, there are central points (K) named concentrate points [35]. The main aim of this approach is to find the best concentrate point which has the maximum weight proportion to elsewhere. Therefore, by finding this point which determines from PDF curve of uncertain parameters, it considers as input parameter in optimization process as well as gives information about the nature of uncertainty associated with output random variables which can be obtained. The kth concentration $(p_{l.k}.w_{l.k})$ of a random variable $p_l canbedefinedasapaircomposedofalocation$ $p_{l.k}$ and a weight $w_{l.k}$ that the location $p_{l.k} isthekthvalueofvariable$ p_l. Therefore, in this approach unlike scenario-based method, the objective function runs only K times [36]. This is one of the most important advantages of PEM proportion to stochastic scenario based approaches. Input vector for each evaluation and $p_{l.k}$ are obtained as follows [37]:

$$(\mu_{p1}, \mu_{p2}, ..., \mu_{kk}, ..., \mu_{pm}) \tag{36}$$

$$P_{lk} = \mu_{pl} + \xi_{lk}\Theta_{pl} \tag{37}$$

where ξ is the standard location, μ and θ are the mean and standard deviation of the input random variable. Standard locations for $2m+1$ approaches and weights of random variable have been calculated as below:

$$\xi_{l,1} = \frac{\lambda_{l,3}}{2} + \sqrt{m + (\frac{\lambda_{l,3}}{2})^2} \tag{38}$$

$$\xi_{l,2} = \frac{\lambda_{l,4}}{2} + \sqrt{m + (\frac{\lambda_{l,4}}{2})^2} \tag{39}$$

$$w_{l,1} = \frac{(-1)^{-3-k}}{m} \frac{\xi_{l2}}{\xi_{l1} - \xi_{l2}} \tag{40}$$

$$w_{l,2} = \frac{(-1)^{-3-k}}{m} \frac{\xi_{l1}}{\xi_{l1} - \xi_{l2}} \tag{41}$$

$$w_{l,1} = \frac{M_j(P_j)}{(\theta_{pl})^j} \tag{42}$$

where $lambda_{l,3}$ and $lambda_{l,4}$ are the skewness and kurtosis. The probability of p_l is calculated by equation 43:

$$M_j(p_l) = \int_{-\infty}^{+\infty} (p_l - \mu_{pl})^j f_{pl} d_{pl} \tag{43}$$

Finally, by applying weighting factor, the expected values of output have been obtained as final results as [38]:

$$\mu_j = E[Z^j] = \sum_{l=1}^{m} \sum_{k=1}^{K} w_k (Z(l,k))^j \tag{44}$$

5. SOLUTION APPROACH

In this paper, a genetic algorithm (GA) is employed to solve the optimization problem. The aim of this problem, calculating the optimal capacity of wind generators and energy storage system (ESS) in sub-transmission substations. Thus, the suggested chromosome includes two sections. The first section of the chromosomes shows the generated power by wind turbines in the ith hour with lower limit equal to $ai = 0$ and upper limit equal to $bi = PF_G * CG_{Maxi}$. The second part of the chromosome also shows the charge /discharge power of battery in the ith hour with lower limit equal to $ai = -PBi$ and upper limit equal to $bi = PBi$. Negative value means the battery charge and positive value means the battery discharge in the candidate sites.

6. NUMERICAL STUDIES

Economic evaluation using the proposed method has been implemented to illustrate the performance of the proposed method by installation DG unit and energy storage system on 63/20kv substation and with capacity of 30MVA.The profile of the active and reactive power load is shown in Fig. 5. Technical and economic data for installation DG unit and battery are shown in Table 1. In addition, the PDF of generated power by wind turbine has been shown in Fig. 6 based on Weibull form.

In this paper, the maximum loading capacity of substation (SS_{Max}) is assumed equivalent to 85

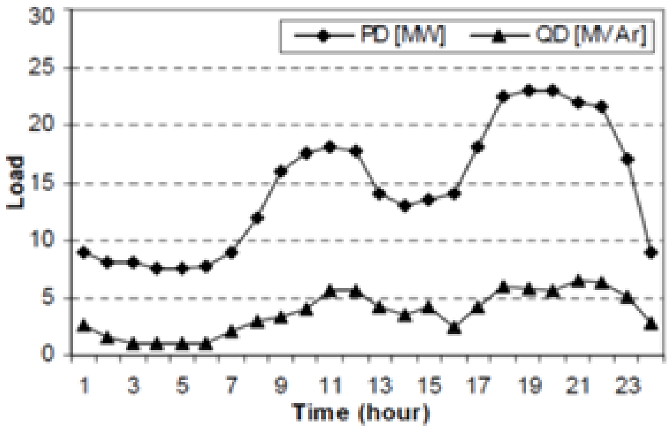

Fig. 5. Active and reactive power load curve in 24 hours

Table 1. Technical and economic data for installation dg unit and battery

Parameter	Value
Annual rate of growth of system load (cost of developing substation capacity ()	700000
maximum loading capacity in substation(MVA)	25.5
Apparent power peak in system load consumption (MVA)	23.71
Loss of transformer in rated demand (MW)	0.137
The purchase price of reactive power from transmission system ($/MVAr-hour)	1.5
cost of Lack of system power supply ($/MVA-hour)	100
cost of installing DG ($/MVA)	318000
cost of installing Battery ($/MW)	175000
cost of power generation by DG ($/MWh)	29
Fixed cost maintenance of DG ($/MVA-year)	2000
variable cost of maintenance of dg ($/MWh)	0.7
Fixed cost maintenance of battery $(/MW)$	20000
useful life of dg (year)	20
useful life of battery (year)	20
Annual inflation rate	0.09
Annual interest rate	0.14
The load factor for HV/MV substation	0.63
The load factor for operation of the DG	0.8
The annual duration of power outages in the HV/MV substation (hour/year)	30

The case studies are designed to evaluate the effectiveness of proposed method on the substation. These cases were performed in three states. In the first case is considered only installation DG unit. In the second case, only considered installation of the storage and in the third case, storage and DG have been evaluated in distribution substation. The purchase price of electricity from the transmission system at four levels is assumed as follows:

$$\begin{aligned} C_{MWhT}(PT_i) &= 20 \quad if \quad 0 \leq PT_i < 10 \\ C_{MWhT}(PT_i) &= 20 \quad if \quad 10 \leq PT_i < 15 \\ C_{MWhT}(PT_i) &= 20 \quad if \quad 15 \leq PT_i < 20 \\ C_{MWhT}(PT_i) &= 20 \quad if \quad 20 \leq PT_i < 25 \\ & \quad for \quad i = 1, 2, ..., 24 \end{aligned} \tag{45}$$

Case 1-1: In this case, generated power by the DG unit has been chosen as decision-making variable. Suggested chromosome is contains 24 genes, which represents the generated power by DG units in 24 hours. The candidate DG capacity is a multiple of 1 MVA (maximum 9 MVA) with power generation at load factor 0.8 lagging. Fig. 7 shows the optimal strategy in operation of DG unit. Also, Active power profile received from the system before and after installation of DG is shown in figures 8 and 9. According to Figure 8, obtained results of the installation DG in substation is included peak shaving and reduce active power received from upstream network during peak hours and supply part of the system load by DG. In Table 2 has been shown, profits and costs obtained of installation DG in substation such as duration of delay in the development of substation, Benefits of the reduction of active and reactive power, reliability improvement, the cost of installation and the cost of repair and maintenance of DG unit and etc.

Case 1-2: By reducing the capacity of DG to 4MVA, the results are shown in the third column of Table 2 and figures 10,11 and 12. In Table 2 compared the benefits and costs of installation two different capacity of DG unit. Generated Power by DG at peak hours, when the DG capacity is 4 MVA less than when the DG capacity is equal to 9 MVA. Thus, peak shaving in Case (1-1) is better than Case (1-2) and also duration of delay in the development of substation in Case (1-1) is more than Case (1-2).

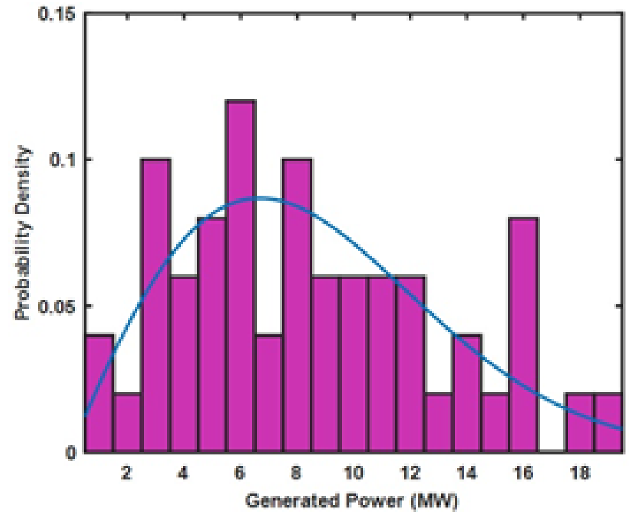

Fig. 6. PDF of generated power by wind turbine

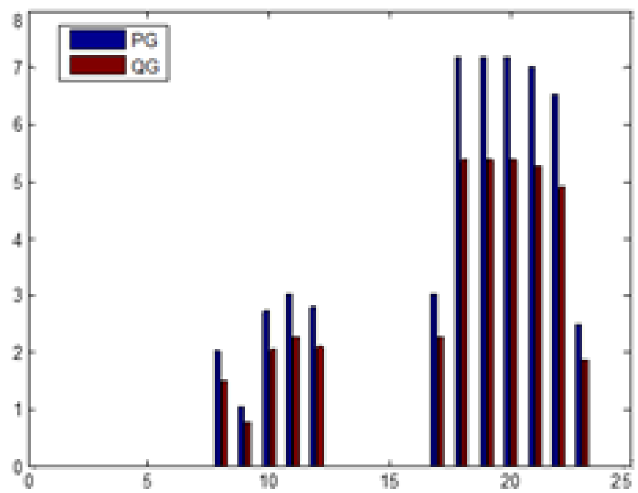

Fig. 7. The optimal strategy in operation of DG unit

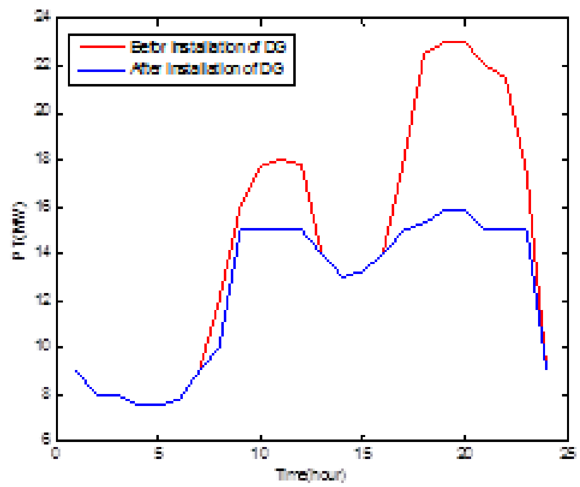

Fig. 8. Active power profile received from system before and after

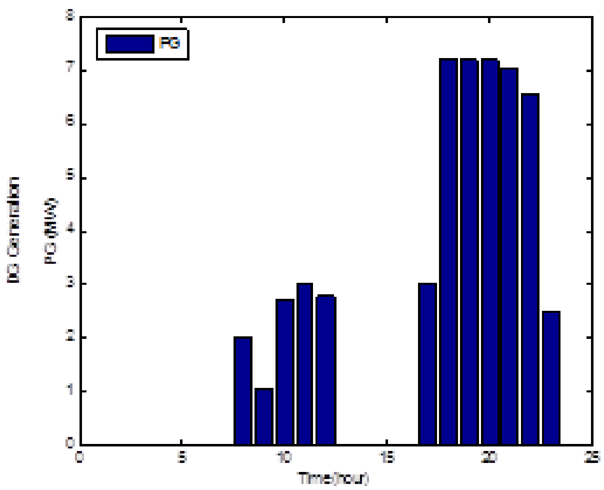

Fig. 9. Active power generated by DG

Table 2. Compare the benefits and costs of installing DG with two Different capacity

Parameters	Case1-1	Case1-2
The time delay in the development of substation	9.7841year	3.7870year
The present value of the economic benefit delay in the development of substation	2.3255e+05$	1.0227e+05$
The present value of the economic benefit of reducing the cost of active power	1.5754e+07$	1.2321e+07$
The present value of the economic benefit of reducing the cost of reactive power	2.7720e+05$	1.7558e+05$
The present value of the economic benefit of improved reliability	3.4858e+05$	1.5492e+05$
DG unit construction costs	2862000 $	1272000 $
The present value in operation cost of DG	7.1456e+06$	4.5261e+06$
The present value in maintenance cost of the DG	4.0486e+05$	2.1253e+05$
The present value of economic benefits in the project	6.2003e+06$	6.7427e+06$
DG nominal power	9MVA	4MVA
Power factor	0.8	0.8

Number of delay time in the development of substation in Case (1-2) is equivalent to3.7870 year, While in Case (1-1) is equal to9.7841 year.

Case 2: In this case, generated power by the storage system

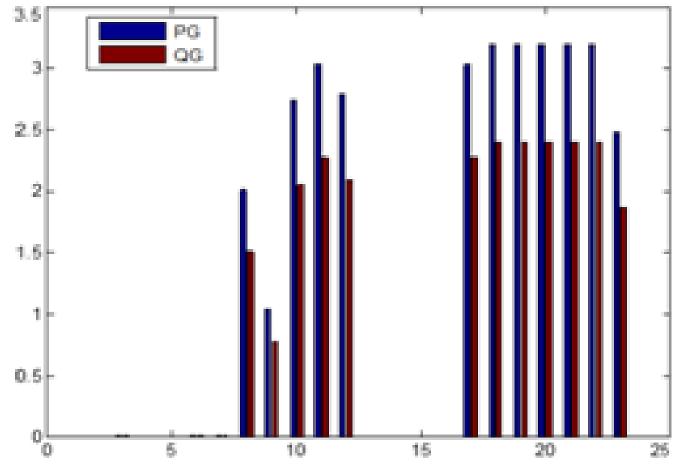

Fig. 10. The optimal strategy in operation of DG unit with capacity 4MVA

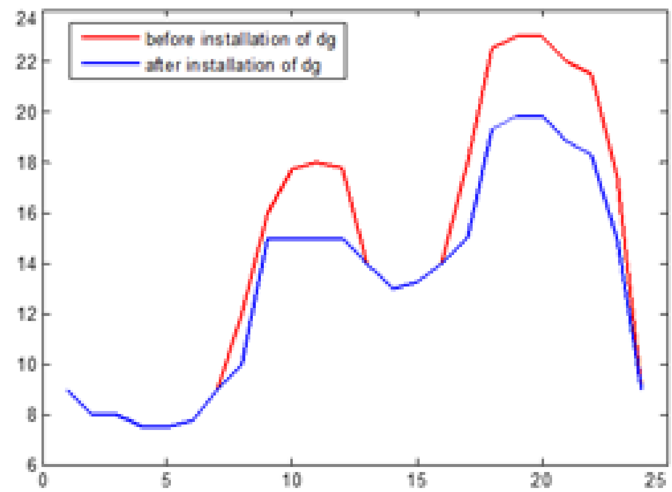

Fig. 11. Active power profile received from system before and after installation of dg with capacity 4MVA

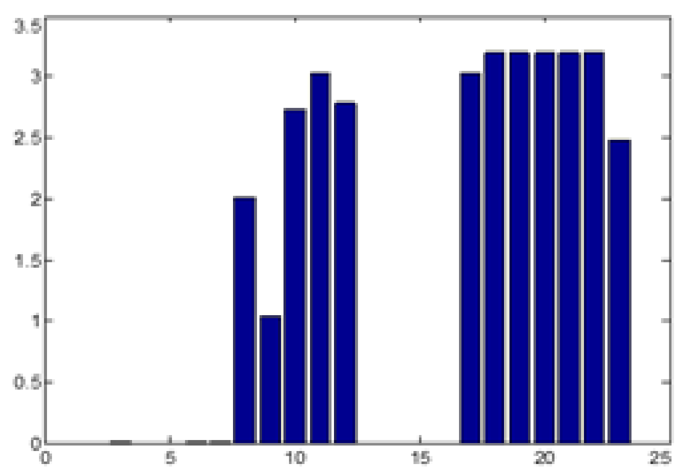

Fig. 12. Active power generated by DG

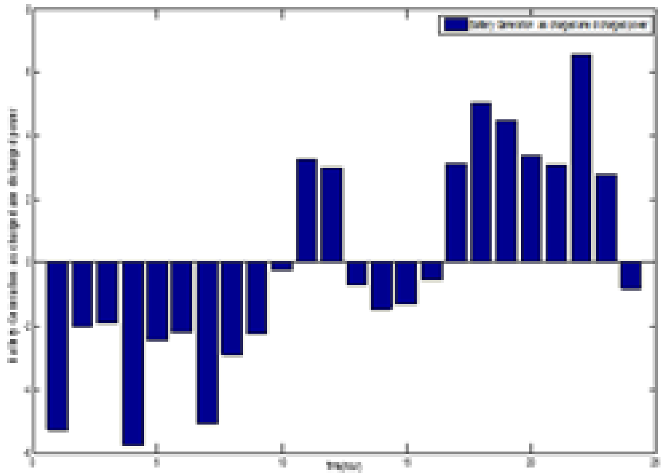

Fig. 13. Battery power charged and discharged in 24 hours

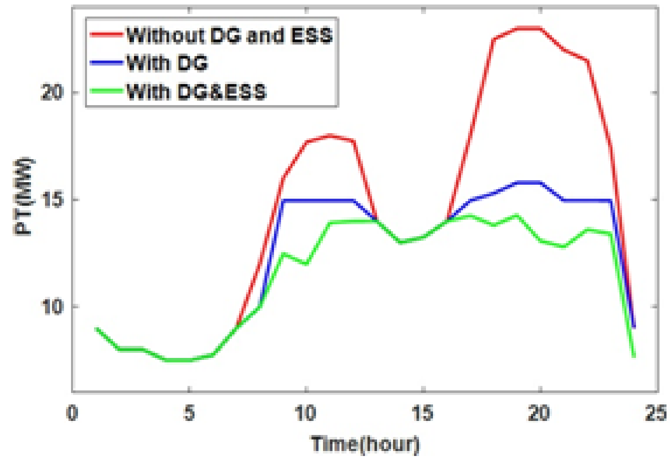

Fig. 15. Comparison between received power from upstream network in case 4 and conventional mode

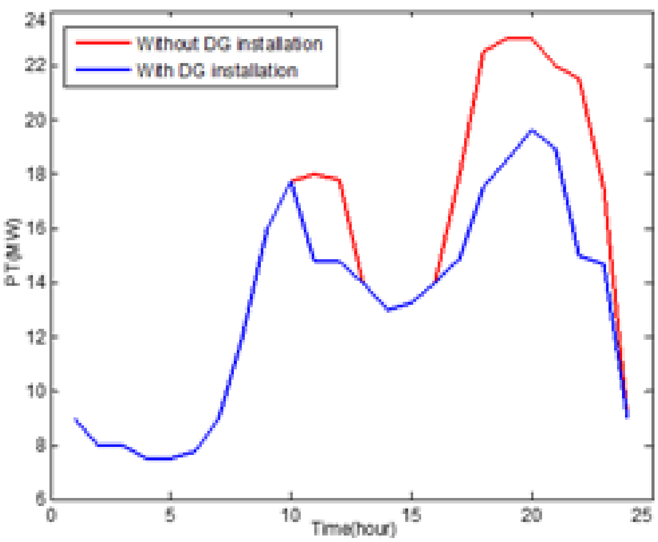

Fig. 14. Active power profile received from system before and after installation of battery

has been chosen as decision-making variable. In this case, the sizing of the battery in a HV/MV substation done in 24 hours. The power charged and discharged of ESS in 24 hours is shown in Fig.13 and active power profile received from upstream system before and after installation of battery is shown in Figure 14. When the electricity price is low, power is imported from the main grid to the substation, while at times of higher market prices storage unit inside the substation are turned onto satisfy the load. In this Case, the installed capacity of battery is 32.4466MWh and the rated power is equivalent to 9MVA and number of delay time in the development of substation is equivalent to 9.7841 year.

Case3: In this case, with the composition and installation of both these units (DG and batteries) in substation can be obtained many benefits. The most important of these benefits is upgrade deferral of substation for long-term. In this case, installation of DG unit is applied with rated power 9 MVA and the power factor 0.8 lagging. Also, installation of storage system in substation is implemented with capacity 11.1668MWh and the rated power 4MVA. According to Table III the time delay in the development of substation in Case 3 is equivalent to 16.2885year. While in Case 2, amount of delay time is equivalent to 9.7841 year. To more peruse the effects of the ESS and DG capacity of the substation upgrade deferral, the problem is minimized for a variety of ESS and DG sizes. The optimal ESS and DG planning problem is presented which minimizes the capital expenses of the ESS and DG, and expected operation and maintenance cost.

Case 4: In this case the uncertainty of generated power by wind turbine is considered associated with optimal sizing of wind turbine as well as storage device. The uncertainty is modeled via PEM approach and the expected value, which is obtained from PEM, has been used in problem. It should be noted that in this paper the wind turbine is allocated in subtransmission substation, thereby, only sizing of DG and ESS units is investigated. In this case, the optimal size of DG and ESS units are determined by GA, which have been obtained 8 MVA and 10 MVA, respectively. Fig. 15 illustrates the receiving power from main grid in this case. The obtained profit in this case is 6851745$ which is lower than case3 because in this case the uncertainty of wind generation is considered. Also, the delay time is equivalent to 12.083 year. Thereby, it is concluded that in case of the uncertainty is considered into model, the obtained profit is lower than case of the uncertainty is neglected. Note that in this paper the planning of wind turbine and ESS unit is investigated from deferral of sub-transmission substation viewpoint. Therefore, the characteristics and topology of distribution system is not indispensable.

7. DISCUSSION

ESS would increase the substation reliability by reducing load shedding and improve the substation economics by storing energy at low price hours and generating the stored energy at high price hours. It might also help defer the need for additional substation investments to meet the substation peak load. In the proposed model, the ESS and DG is installed and optimally sized to increase substation reliability and provide economic benefits including substation upgrade deferral and reduction of active and reactive power supply from the upstream network.

The present value of the economic benefit of improved reliability is equivalent to 5.035×105$. The present value of the economic benefit of reducing the cost of active power is 1.6910×107$, while the value of this benefit in case2 is 6.7647×106$. The present value of economic benefits in the project with installation of ESS and DG is equal to 6.0569×106$. The results for peak shaving during peak hours in the presence of DG unit and ESS are significant.

This work presents an optimal ESS and DG sizing that considers the storage and DG units limits and power limits. It was demonstrated that the installed ESS and DG provided positive financial-technical impact on the substation at the current year as well as the future years.

In this paper, the optimal wind and ESS sizing problem is proposed which minimizes the investment cost of the ESS and maximize the benefits of ESS installation including reduction of active and reactive power supply, enhance profit of substation upgrade deferral and reliability improvement. Determining the optimal capacity of the ESS discussed under presence of DG and time varying load. Moreover, the impact of wind uncertainty on the obtained profit of proposed model has been investigated by PEM approach.

According to Figure 16, power consumption of the network is reduced and has reached around 14MW. Also, power charged and discharged by energy storage system in 24 hours and active power generated by distributed generation is shown in Fig 17. Active power profile received from system in the presence of DG before and after installation of energy storage system is shown in these figures. As indicated in the results of case studies, the integration of energy storage system and DG unit within the sub-transmission substation could contribute to the bulk system reliability amelioration, especially when the system is heavily loaded and becomes less reliable. Active power generated by distributed generation unit and power discharged by energy storage system during peak hours will help reduce the peak load and peak shaving. Hence, system development will be delayed and the cost of investment is preserved.

The comprehensive comparison between all applied cases has been illustrated in Fig. 18. According to this figure, it is clear that by applying uncertainty in proposed model, the obtained profit as well as investment deferral time have been decreased. Moreover, it can be seen that when both ESS unit and wind turbine are employed, the benefit of proposed approach has been significantly increased compared with when the planning of storage and wind units have performed individually. This reflects the fact that applying DG units in sub-transmission substations is a privileged and distinguished solution to postpone reinforcement and upgrading of upstream systems. It should be mentioned that the proposed model for optimal planning of DG units has been executed to postpone the upgrade of upstream network as well as reinforcement of sub-transmission substation. Therefore, the topology of downstream network has no effect on the proposed model.

Furthermore, in order to justify the optimality and efficiency of proposed GA-based algorithm in solving the proposed model, for given the same iteration number as well as size of initial population, the convergence curves of proposed algorithm and other conventional algorithms such as Particle Swarm Optimization (PSO), Imperialist Competitive Algorithm (ICA) and also Harmony Search (HS) has been illustrated in Fig. 18. Owing to this figure, it is obvious that for the proposed problem, the GA gives the more optimal solution compared with other algorithms. In addition, it is clear that from running time point of view, the proposed algorithm is better than other algorithms. Therefore, for this problem which is a MINLP model, the GA is more suitable than other optimization algorithms.

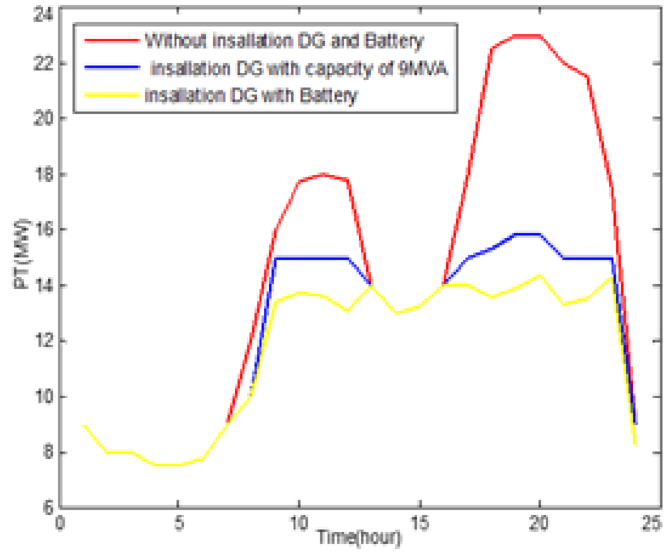

Fig. 16. Active power profile received from system in the presence of DG before and after installation of battery

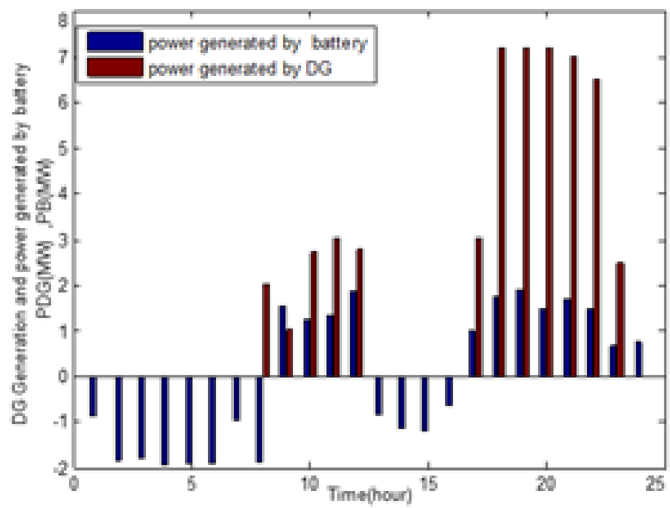

Fig. 17. Battery power charged and discharged in 24 hours and Active power generated by DG

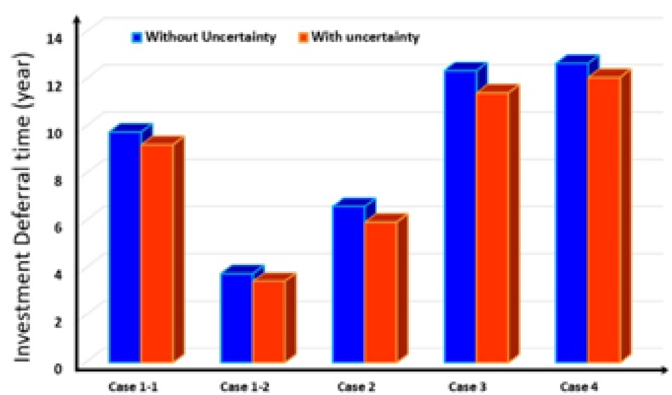

Fig. 18. Comparison of obtained profit in various cases

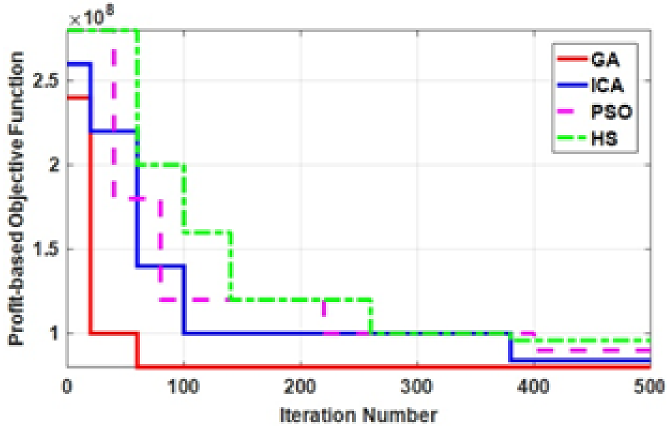

Fig. 19. Comparing the convergence curve of proposed algorithm and other conventional algorithms

8. CONCLUSION

With increasing demand electricity, the generation, transmission and distribution facilities should be upgraded continuously. Due to environmental concerns of conventional power plants, it is necessary to use renewable power sources such as wind generators. Because of uncertain production of these generators, storage systems could be used to overcome harmful effects of production uncertainty. Using this technique will postpone investment on conventional power plants, transmission lines and also sub-transmission substations. In this paper, an accurate model for calculating the optimal wind generators and ESS size in the sub-transmission substation was proposed. The approach utilized an expansion planning problem, where the ESS investment cost and the benefits of ESS installation including reduction of active and reactive power supply enhance profit of substation upgrade deferral and reliability improvement were taken into account. So, in this paper, determining the optimal size of the ESS discussed under presence of DG and time varying load. The reliability index of the system was calculated to ensure reliable operation of the substation by satisfying reliability criterion. The objective function is mathematically formulated as a mixed-integer nonlinear programming (MINLP) and solved by genetic algorithm (GA). In addition, to investigate the impact of sharp fluctuation and uncertainty of wind generation on the proposed model, an innovative possibility technique based on PEM approach has been accomplished. With respect to obtained results, it is obvious that with taking the uncertainty of wind generation into account, the obtained profit decrease proportion to case of that the uncertainty has been neglected. Although numerical studies revealed that optimal sizing of ESS unit and wind turbine with and without considering uncertainty provides large economical, technical and reliability benefits.

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