Two-level planning for coordination of energy storage systems and wind-solar-diesel units in active distribution networks

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Abstract
The optimal operation strategy of active distribution networks is investigated by this paper. The energy storage system (ESS) and distributed generation (DG) are utilized in the proposed planning. The paper presents two-level planning including short term and long term planning. The long term planning installs ESSs and diesel DGs on the network and the short term one determines an hourly optimal operation strategy for ESSs and diesel DGs. Different types of DG including solar photovoltaic (PV), wind, and diesel are studied at the same time. The objective function of the planning is to minimize annual operation cost of distribution network subject to security constraints of the network. The uncertainty of solar-wind units is estimated by many scenarios and stochastic programming is carried out to solve the problem. The proposed problem is expressed as a nonlinear mixed integer programming and solved by modified PSO algorithm. In order to cope with the real conditions, reactive power of ESSs and diesel DGs are included in the problem. Depth of discharge is also considered as a design variable and optimized for ESSs. The planning optimizes a large number of design variables at the same time including size and location of ESSs and diesel DGs, daily operation of diesel DGs, daily charging-discharging pattern of ESSs, and optimal depth of discharge for ESSs. The results demonstrate that the proposed two-level planning can effectively reduce cost and losses as well as increase efficiency and performance of the network.

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1. Introduction

1.1. General impacts of diesel DG and ESS on the network

The distributed generation basically support both active and reactive powers in distribution networks [1]. Diesel generators (DGs) have various problems such as limitations of fossil fuels, environmental pollutions, and global warming. However, most of the renewable energy sources (especially wind and solar) are uncertain in their nature resulting in great challenges in electrical networks. The energy storage systems (ESSs) are presented to deal with this problem. The ESSs interchange both active and reactive powers with network [2] and they are effective in reduction of wind and solar uncertainties [3]. Some applications of ESSs can be stated as voltage profile improvement [4], renewable energy integration, smoothing, and time-shift [5], peak shaving [6], loss reduction [7], renewable energy capacity firming [8], emission reduction [9] and frequency control [10].

1.2. Review of previous literature

1.2.1. Optimal placement of distributed generation

In Ref. [11] a strategy for optimal operation of distributed energy storage systems is proposed to improve the load and generation hosting capability of distribution network. Where, objective function is cost and the constraints are voltage limits, voltage unbalance factor, battery power, and battery energy. It is also assumed that ESSs only can interchange active power and diesel DG is not installed on the network.

A long-term expansion planning in microgrid is presented by Ref. [5]. The planning installs new generating units, lines, and energy storage systems in the microgrid to deal with load growth. The problem is presented in two levels. One level installs optimal technologies on the network and the other level optimizes short-term operation of the installed technologies. In Ref. [5], the reactive power of generating units, loads, and energy storage systems are not considered.
In Ref. [12], a new objective function is presented for optimal distributed generation placement (ODGP) problem. The mentioned ODGP offers energy loss minimization considering network layout and its load composition. Ref. [13] examines the impact of these variations in order to verify how optimal solution should adapt to any load composition.

In the long term planning such as network expansion planning, the short term operation of DG (daily or 24-h operation) has not been adequately molded and discussed. In Ref. [14], the daily power of DG is modeled as uncertain parameter and the short term planning in competitive and uncertain power markets. Where, a stochastic mixed integer linear programming model (MILP) has been developed, combining advanced optimization techniques with Monte-Carlo method in order to deal with the uncertainty issues.

An optimization-based methodological approach is presented by Ref. [19] to address the problem of optimal power system planning in competitive and uncertain power markets. Where, a stochastic mixed integer linear programming model (MILP) has been developed, combining advanced optimization techniques with Monte-Carlo method in order to deal with the uncertainty issues.

An approach to solve optimal power flow combining stochastic wind-solar power with thermal power is presented by Ref. [20]. Weibull and lognormal probability distribution functions are used for forecasting wind-solar power. The objective function considers reserve cost for overestimation and penalty cost for optimization finds optimal siting-sizing of storage units and minimizes losses and expected energy not supplied (EENS) at the same time. The authors in Ref. [18] present a multi-objective algorithm for power-flow which is able to optimize reactive power of PV, capacity of PV, and capacity of storage systems. The algorithm includes an objective function that minimizes voltage variations and capital costs of PV and storage units as well as maximizes energy saving and peak load cutting.

1.2.2. Optimization algorithms
The authors in Ref. [17] propose a multi-objective optimization including islanding mode. The referred multi-objective
underestimation of intermittent renewable sources.

In Ref. [21], a new meta-heuristic technique inspired from the bubble-net hunting technique of humpback whales, namely whale optimization algorithm (WOA), has been applied to solve the optimal reactive power dispatch problem. The WOA method has been examined and confirmed on the IEEE 14-bus and IEEE 30-bus.

In Ref. [22], Teaching Learning Based Optimization (TLBO) based optimization algorithm is used for reactive power planning and applied in IEEE 30 and IEEE 57 bus system. In Ref. [23], a newly surfaced nature-inspired optimization technique called moth-flame optimization (MFO) algorithm is utilized to address the optimal reactive power dispatch (ORPD) problem.

1.2.3. Optimal planning of energy storage systems

Optimal planning of batteries in the distribution grid is presented by Ref. [2]. The optimal planning determines location, capacity, and power rating of batteries while minimizing cost subject to technical constraints. The optimal long-term planning is based on the short-term optimal power flow considering the uncertainties.

In Ref. [24], the authors address an effective sizing strategy for battery energy storage system (BESS) in the distribution networks under high photovoltaic (PV) penetration level. The main objective of the method given in Ref. [24] is to optimize size of BESS and derive the cost-benefit analysis when the BESS is applied for voltage regulation and peak load shaving.

A comparison based optimal planning of several battery technologies is represented by Ref. [25] to find the best choice in distribution grid applications. The given methodology in Ref. [25] is a novel four-layer procedure that considers the uncertainty of battery characteristics as well as load and wind power. The long-term planning layer optimizes location, capacity, and power rating of batteries. The short-term scheduling layer includes the probabilistic optimal power flow with respect to the technical constraints. The numerical results show that Zn-Br technology is the most suitable option in the deterministic studies, and the Na-S technology can be an alternative in the uncertain conditions.

In Ref. [26], DOD has not been considered and power of diesel DG is constant. Authors in Ref. [26] propose a stochastic optimization approach to cope with uncertainties associated with the problem. In Ref. [26], many scenarios are generated using Monte-Carlo simulation and problem is solved by GAMS/SCENRED. In Ref. [26], it is assumed that maximum DOD = 1 and minimum DOD = 0 and reactive power has not been studied in problem.

1.3. Contributions of current work

Considering the above literature review, the coordinated daily operation for ESSs and diesel DGs has not been adequately addressed. This paper addresses most of the shortcomings at the same time. In this paper, DOD is defined as a design variable and optimally determined for batteries. Both diesel DG and ESS can support active-reactive powers. The planning is presented in two levels including long-term and short-term. The long-term planning finds places, capacity, depth of discharge, and rated power for ESSs as well as location and rated power for diesel DGs. On the other hand, the short-term planning finds optimal daily operation of diesel DGs and optimal charging-discharging pattern of ESSs under 24-h.

This paper considers following issues at the same time in the planning:

✓ According to the conducted literature review, in the long term planning, the diesel DG operation during 24-h is often modeled by constant power. But, this operation strategy is not optimal. In this paper, a short-term planning is carried out alongside with long term planning. The long term planning optimally installs diesel DGs (determines optimal power of diesel DGs) and the short term planning determines an hourly optimal operation strategy for diesel DGs during 24-h.

✓ DGs and ESSs are usually modeled as active power sources. But this paper presents a comprehensive and practical model for DGs and ESSs including both active and reactive powers. In this paper, cost of reactive power is considered in three parts of the model including investment cost of inverter, investment cost of Diesel DG, and operational cost of Diesel DG.

✓ Depth of discharge (DOD) of BESS is often excluded from the problems or DOD is molded as a constant variable. While this paper considers DOD as a design variable and determines optimal DOD for BESS.

✓ This paper not only determines the optimal power and capacity of BESS, but also denotes the optimal charging-discharging regime of the BESS.

✓ Both wind and solar units are modeled as uncertain resources in the proposed planning.

2. Distributed generators and energy storage systems

Direction of active and reactive powers for DG and ESS is shown in Fig. 1. In this paper both diesel DG and ESSs can interchange active and reactive power with network.

Depth of discharge (DOD) is an important issue in batteries [27]. DOD describes how deeply the battery is discharged. For instance, if battery is 100% fully charged, the DOD is 0% and if battery has delivered 60% of its energy, the DOD is 60%. DOD can be treated as the energy that battery delivers. One of the most important issues on ESSs is to exponential relationship between DOD and cycle life [28].

Cycle life is the charge/discharge cycles number that the battery can experience before its nominal capacity falls below pre-determined threshold of its rated value. Cycle life is different in various charge/discharge conditions [29].

ESS with higher DOD can deliver more energy to the network, but it decreases battery life cycle and increase the investment cost.

3. Stochastic programming and scenario generation

Stochastic programming is a mathematical optimization in which some or all parameters of the optimization problem are presented by random variables. The source of random variables may be different depending on the nature of the problem. The main idea of Monte-Carlo approach is to estimate the expected value of objective function which is defined by scenarios. One of the
significant advantages of Monte-Carlo approach is that the number of samples required to achieve a specified level of accuracy is independent of the system size. Therefore, Monte-Carlo is proper to analyze large-scale systems such as power systems [26]. The uncertainties of load demand and renewable generation are often modeled by Probability Distribution Functions (PDF) [30]. It should be noted that scenarios and their related probabilities are obtained by discrete approximation of continuous PDF. Because of the stochastic nature of wind and sunlight, the generated power by wind and solar units is considered as stochastic. This paper applies the stochastic programming for scenario-generation and scenario-reduction techniques. The details of scenario-generation and scenario-reduction technique can be found in Ref. [31].

4. Problem formulation

The objective function of the proposed planning is to minimize the annual operation cost which is expressed as expected value of cost for all scenarios. Equations (1)–(9) are calculated for each scenario of performance.

The annual operation cost of active and reactive power for diesel DG is given in (1) and (2). Annual investment cost of diesel DG is expressed by (3). Energy price is defined by (4). The purchasing cost of batteries is given by (5) and its details are expressed by (6) and (7). Annual purchasing cost for inverters is expressed as (8). The final objective function of the problem is given by (9). This final objective function comprises six terms including of1 to of6. The relationship between active, reactive, and apparent power of the inverter are given by (10). The stored energy in battery is expressed by (14). The efficiency of the storage system is defined as (15).

Objective function of the problem is defined by (10).

\[
\text{Min} \quad \{OF\} \\
\text{S.T.} \\
C_{ESS} \leq C_{max} \\
S_{ESS} \leq S_{max} \\
S_{ESS}^{2} = \sqrt{P_{ESS}^{2} + Q_{ESS}^{2}} \\
E_{ch} = P_{ESS} \times T_{ch} \\
E_{disch} \leq E_{ch} \times \eta_{ESS} \\
\]

The minimum stored energy in the battery is expressed by (16). According to this equation, whatever DOD become larger, minimum stored energy in the battery becomes less and vice-versa. It is clear that if DOD is not considered (i.e., DOD = 100%), battery can be discharged completely. The stored energy in ESS is larger than minimum permitted energy as given by (17). The equilibrium of energy is defined by (18).

\[
E_{ESS}^{min} = C_{ESS} \times \left(1 - \frac{D}{100}\right) \\
E_{ESS}^{min} \leq E_{ESS}^{1} \\
E_{ESS}^{0} = E_{ESS}^{t=T} \\
\]

Apparent power of the diesel DG is restricted by (19) and relationship between active and reactive powers is defined by (20). The relationship between active, reactive, and apparent power of DG are given by (21). Active and reactive power at hour t are expressed by (22) and (23).

\[
S_{DG}^{t} \leq S_{DG}^{n} \\
S_{DG}^{n} = \sqrt{(P_{DG}^{n})^{2} + (Q_{DG}^{n})^{2}} \\
S_{DG}^{n} = \sqrt{(P_{DG}^{n})^{2} + (Q_{DG}^{n})^{2}} \\
P_{DG}^{n} = P_{DG}^{n} \times P_{DG}^{n} \\
Q_{DG}^{n} = Q_{DG}^{n} \times Q_{DG}^{n} \\
\]

Conventional power flow problem is defined through constraints (24) and (25). Voltage boundaries are given by (26), and line capacity is limited by (27).

\[
\sum_{k=1}^{n} P_{in}^{k} = \sum_{k=1}^{n} P_{out}^{k} \\
\]
\[ \sum_{k=1}^{n} Q_{in}^k = \sum_{k=1}^{n} Q_{out}^k \quad (25) \]

\[ V^\text{min}_k \leq V_k \leq V^\text{max}_k \quad (26) \]

\[ S_L \leq S_L^\text{max} \quad (27) \]

In the real conditions, the BESS performance becomes weak by passing the time, because the chemical properties of the battery are degraded. As a result, it would be proper to consider the degradation factor in the model. The degradation factor changes the ESS life-time, DOD, and efficiency. As a result, the ESS operation is worsened and the planning cost will increase due to installing more or different ESSs. However, current paper does not include the degradation factor in the model.

5. Solving the problem by Meta-heuristic optimization technique

This paper uses modified PSO technique to solve the problem. In the modified PSO, weighing factor is linearly reduced from one toward zero as well as the crossover and mutation are added to the algorithm. The problem is also solved by various optimization techniques and eventually the modified PSO technique is chosen as the final one. Moreover, the problem is solved several times to guarantee the optimal solution.

As it was stated, the paper presents two plannings as short-term and long-term. The long term planning installs ESSs and diesel DGs on the network and the short term planning determines an hourly optimal operation strategy for ESSs and diesel DGs. As a result, two PSO algorithms are simulated to solve both the planning at the same time. Population\textsubscript{1} is generated by PSO\textsubscript{1} and population\textsubscript{2} is generated by PSO\textsubscript{2}.

PSO\textsubscript{1} is related to the long-term planning and determines active and reactive power of diesel DG, active and reactive power of ESSs, capacity of, depth of discharge for batteries, location of diesel DG and batteries in network. PSO\textsubscript{2} is related to the short-term planning and determines charging-discharging state of the batteries and output power of diesel DGs at each hour over the day. Fig. 2 shows the flowchart of the proposed method.

6. Test system specifications

Fig. 3 shows a 30-bus-10MVA-11 kV radial distribution network which is considered as case study to simulate the proposed method. The network consists of wind and solar PV units that are installed on buses 8 and 23 with nominal power 100(KW) and 80(KW), respectively. Daily average generation profile of wind and solar PV units are shown in Figs. 4 and 5. Data of the network including line and loading data can be found in Ref. [32]. Candidate diesel DGs and ESSs are listed in Tables 1 and 2. Energy price is according to Table 3. The price of energy, ESS, and diesel DG in Tables 1–3 can be found in Ref. [33], respectively. Load profile in 24-h is shown in Fig. 6 [33].

There are some assumptions in this study that can be pointed out as follows: considering constant active and reactive power for diesel DGs at each time step, modeling DOD by discrete curve including four levels, modeling candidate powers of DGs and batteries by discrete curve with four levels, disregarding reactive power of wind-solar units, considering four buses as candidate locations of DGs and ESSs, modeling 24-h load profile by six steps.
In addition to the mentioned items, Table 4 describes some other assumptions of current study. It is worth mentioning that the proposed model still works under all of the assumptions, because the assumptions only change the optimal solution of the planning and they do not make impact on the feasibility of the planning. In other words, the planning excluding such assumptions provides less planning cost compared to the model including assumptions. On the other hand, solution of the planning excluding assumptions is time-consuming. This paper makes tradeoff between solution time and model simplification. The mode is simplified in order to reduce the solution time.

In this paper, the wind-solar uncertainties are modeled by scenarios [34]. Many scenarios are made and stochastic programming is adopted to solve the problem [35,36]. Some scenarios of performance are depicted in Fig. 7.

### 7. Simulation results

The proposed model is implemented in MATLAB software. The model is solved by PC including 16 GB RAM Memory and 3.4 GHz-4 Cores Processor.

#### 7.1. Comparison of deterministic and stochastic planning

The proposed stochastic planning is evaluated against a deterministic one. In the deterministic planning, power of wind and solar PV units is considered as constant and the uncertainties are not included. Both the deterministic and stochastic planning are simulated on the test system and results are listed in Tables 5 and 6.

In the stochastic planning, the planning must cope with wind/solar uncertainties and it should satisfy all constraints under all scenarios of performance. As a result, the stochastic planning utilizes more resources and storage units to deal with such conditions. This issue increases the total planning cost of stochastic planning. The results demonstrate that active power, reactive power, and DOD of ESSs in the stochastic planning are more than the deterministic one.

According to the voltage profile shown in Fig. 11, the voltage profile is dropped from bus 17 to 27 and it needs improvement. As a result, both the stochastic and deterministic planning install ESS on buses 19 and 24. But in the stochastic planning, ESS 3 is also installed on bus 8 to mitigate wind power uncertainty at this location. The wind power is on maximum at hours 0–6 and it increases the voltage profile at bus 8 at hours 0–6. As a result, the
planning installs one ESS on bus 8 and this ESS absorbs reactive power at hours 0–6 to reduce the voltage profile below the permitted level. The operation of ESS 3 under 24-h is shown in Fig. 8 and it is clear that the ESS absorbs reactive power at hours 0–6.

Annual cost for both planning is listed in Table 7. The results show that annual cost for deterministic planning is less than stochastic planning by 15.17%. It does not mean that the deterministic planning is better, because the network under deterministic planning is not flexible against uncertainties of PV and wind units. This issue is demonstrated in Table 8. It is clear that deterministic planning is not robust against the fluctuations. As a result, the extra cost of stochastic planning can be properly justified and this cost is necessary to tackle such uncertainties.

### 7.2. Analysis of the annual cost

Annual cost of the network under different conditions is listed in Table 9. In the primary network (initial network defined in the case study), voltage profile is out of the permitted range under some scenarios and the operation is not safe. Among the other results, it is clear that the proposed network equipped with both diesel DGs and ESSs indicates better performance than the other cases.
7.3. Impacts of short term planning on the network

According to the short term planning, the generated power by diesel DG is not constant and it is optimally determined proportion to the network requirements at each hour. Fig. 9 shows both the daily active and reactive powers generated by diesel DG. It is clear that diesel DG power is zero at initial hours because of low demand. The generated power by diesel DG increases during high-peak hours. Table 10 demonstrates that the annual cost of the network without short-term planning is 60% more than the network with short-term planning. It is worth mentioning that in the network without short-term planning, the generated power of diesel DG is constant at 24-h.

7.4. Impacts of DOD and efficiency on the ESS

ESS is mainly charged during off-peak periods and discharged during on-peak hours. Fig. 10 shows the charging-discharging pattern of one of the installed ESS on the network. In this Figure, energy of battery is shown at each hour. Battery capacity and rated active power of this ESS are 250 KWh and 20 kW/h, respectively. As well, DOD of this ESS is 90%. As a result, the minimum permitted energy of this ESS is 25 KWh. The results confirm this issue and it is clear that the stored energy is 25 KWh at hour 24. It is also assumed that ESSs efficiency is 90% and according to Fig. 10, ESS is charged equal to 200 KWh, but it delivers 180 KWh to the network because of 90% efficiency.

7.5. Investigating the coordinated ESS-Diesel DG planning

Fig. 11 shows the voltage profile on all buses of the network during peak load (hours 18–20). Voltage profile is improved because all of the ESSs are discharging and diesel DG power is 93.5% (70.125 KVA). According to the results, voltage profile of the proposed network shows significant improvement. This issue is one of the advantages of the proposed planning.

7.6. Analysis of the network losses

Active and reactive power losses of the network during 24-h are

<table>
<thead>
<tr>
<th>Solar PV and wind power (%)</th>
<th>Number of violated constraints</th>
<th>Stochastic</th>
<th>Deterministic</th>
</tr>
</thead>
<tbody>
<tr>
<td>+100% +100%</td>
<td>3</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>+80% +80%</td>
<td>1</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>+60% +60%</td>
<td>0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>+40% +40%</td>
<td>0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>+30% +30%</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
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<td>0</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>-60% -60%</td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

7.7. Line flows and congestion of the network

Reducing the network losses is certainly due to lines flow reduction. Fig. 14 shows lines flow during peak load. It is clear that in the proposed network, capacity of lines is mostly un-occupied (33.85%), while in the primary network, the capacity of lines is highly congested. This issue limits the network flexibility and adequacy. In other words, the system cannot support load growth and it needs the reconfiguration or expansion.

7.8. Sensitivity analysis

A sensitivity analysis is carried out on the load of network and load is increased by 20%. Fig. 15 shows the result. It is clear that the proposed planning satisfies all constraints, while the primary network cannot tackle such uncertainty and some constraints are violated.
7.9. Network simulation under various loading profiles

In the proposed model, the steps of generation and loading profiles are limited in order to decrease the simulation time. It should be noted that the proposed two-level optimization problem includes many design variables and it takes many hours to be solved. As a result, considering short term variations in the generation and loading profiles would significantly increase the simulation time. However, the proposed model is a general model which can successfully consider any generation and loading profiles. In order to demonstrate this issue, two load profiles with 22 and 12 steps are considered as shown in Figs. 16 and 17 and their results are listed in Tables 11–14. It is clear that the proposed planning can successfully solve the problem under the profiles with short term variations. However, solving the problem under 12-step loading profile increases the simulation time by about 100% and considering 22-step loading profile rises the simulation time by nearly 300%.

8. Conclusions

This paper presents a strategy to improve the operation of active distribution networks by optimal coordination of energy storage systems and renewable distributed generations. The paper includes
two planning as short-term and long-term planning. The long-term planning installs ESSs and diesel DGs on the network and the short-term planning determines an hourly optimal operation strategy for ESSs and diesel DGs. Results show that short-term planning is necessary because this planning reduces the annual cost by 60%. Furthermore, short-term planning enhances voltage of buses. The impacts of DOD and efficiency on ESS are also investigated by the proposed planning. The results confirm that DOD and efficiency make significant impacts of the ESS operation and it is inevitable to consider such issues in the planning. Results indicate that the proposed planning reduces active and reactive power losses of the network by 35.86% and 34.88%, respectively. As well, the congestion

![Fig. 15. Voltage profile during peak load following 20% increasing load.](image1)

![Fig. 16. Load profile with 22 steps at 24-h.](image2)

![Fig. 17. Load profile with 12 steps at 24-h.](image3)

### Table 11
ESSs installed by stochastic and deterministic planning for load profile with 22 steps.

<table>
<thead>
<tr>
<th>ESS</th>
<th>Bus no.</th>
<th>Capacity (KWh)</th>
<th>P_rate (KW/h)</th>
<th>Q_rate (Kvar/h)</th>
<th>DOD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESS_1</td>
<td>21</td>
<td>18</td>
<td>400</td>
<td>300</td>
<td>30</td>
</tr>
<tr>
<td>ESS_2</td>
<td>19</td>
<td>22</td>
<td>450</td>
<td>400</td>
<td>20</td>
</tr>
<tr>
<td>ESS_3</td>
<td>6</td>
<td>24</td>
<td>300</td>
<td>250</td>
<td>40</td>
</tr>
</tbody>
</table>
also demonstrate that following 20% increasing load, the proposed load profile with stochastic and deterministic planning for load profile with 22 steps.

**Table 12**

<table>
<thead>
<tr>
<th>Bus no.</th>
<th>Stochastic</th>
<th>Deterministic</th>
<th>P_{nominal}(KW)</th>
<th>Q_{nominal}(Kvar)</th>
<th>Stochastic</th>
<th>Deterministic</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>21</td>
<td>100</td>
<td>25</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

**Table 13**

<table>
<thead>
<tr>
<th>ESS</th>
<th>Bus no.</th>
<th>Capacity (KWh)</th>
<th>P_{rate}(KW/h)</th>
<th>Q_{rate}(Kvar/h)</th>
<th>DOD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESS_1</td>
<td>17</td>
<td>19</td>
<td>300</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>ESS_2</td>
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<td>16</td>
<td>300</td>
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<tr>
<td>ESS_3</td>
<td>10</td>
<td>20</td>
<td>400</td>
<td>250</td>
<td>40</td>
</tr>
</tbody>
</table>

of the lines during on-peak hours is relieved by 33.85%. The result also demonstrate that following 20% increasing load, the proposed planning satisfies all constraints, while the primary network cannot tackle such uncertainty and some constraints are violated.

Further to the current work, the following are suggested as future works; considering three phase network instead of single-line network, taking into consideration hybrid ESS, considering kind of BESS technology, modeling the degradation of BESS, considering short term variations and loading ramping, and investigating the impacts of on-load tap-changer on the network.

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