Optimal Scheduling of Renewable Distribution Generation for Operating Power Loss Optimization

Bounthanh Banhthasit*, Chaowanan Jamroen, and Sanchai Dechanupaprittha

Abstract— *This paper presents an optimal generation scheduling method of renewable distribution generation (DG) integrated power system considering minimizing power losses. The main contribution aims at economically employing DG in a power system. In particular, maximum using the output of renewable DG is achieved by mean of power energy for stored management. In addition, minimum stored energy is represented to minimize power loss in stored energy process, and can be achieved by properly scheduling operating of energy storage system (ESS). While the minimum power loss in line can be achieved by properly scheduling dispatch of generations. Particle Swarm Optimization (PSO) algorithm is applied to search for a near global optimal solution. The optimization problem is formulated and evaluated taking into account power system operating constraints. The different operation scenarios have been used to investigate the capability and efficiency of the proposed method via DIgSILENT PowerFactory software. The proposed method is validated on IEEE 14 bus test system.*

Keywords— **Generation distribution scheduling, power losses minimization, renewable energy, particle swarm optimization.**

1. INTRODUCTION

Renewable generation distribution (DG) becomes the target of operating system for reducing power loss in system, emission of greenhouse gases and instead of fossil energy. The most important aspect of renewable power generation is less environmental impact and almost zero fuel cost. However, DG connected existing power system is raising concerns on complex combination problems for operation and control. The power flow direction through transmission line will be significantly changed causing undesired conditions of power losses in the power system.

Although DG can additionally increase energy efficiency and enhance the capability of power system, it can adversely impact on power losses due to the change of unidirectional power flow to bidirectional power flow without appropriate power management [1]. Typically, DG is operated at full capacity to meet economical investment aspect, whereas it may lead to high level of power losses and undesired voltage profiles in the power system. Consequently, generation scheduling plays a significant factor for eliminating power losses and operation complexity problems.

Scheduling generation is aimed to the optimal operation such as economic dispatch and transmission losses minimize. The generation scheduling or power management based on power losses minimization has also been focused on various methods. The power management in distribution system and operational scheduling has been presented in [2], [3] for overall benefit maximization and loss minimization based on electrical vehicles integrated system. Real-time energy management strategy was proposed in [4], [5] to considering operational constraint and power flow for micro-grid. Demand response and output of renewable energy source (RES) DG were considered for minimizing power loss using heuristic algorithm [6], [7]. Energy storage system integrated micro-grid was investigated to improve the loss minimization based on intermittent of RESs [8], [9].

Generally, the surplus of generation of DG will stored in ESS, and returned to the grid when production falls below consumption. The power stored in ESS is linked with the power loss in stored process. The electric energy storage (EES) system losses can therefore be detailed consisting of battery loss and converter loss [10]. Thus, power loss could be considered with both power loss as in stored power process and power loss in line.

This paper concentrates on optimal generation scheduling of power system considering power loss minimization. The proposed method will determine the dispatching of generation and stored power of EES in the power system. However, DG accommodation and sizing cannot be adjusted in practical. Especially, DGs are always located in specific area that is uncontrollable factor. Although maximum DGs dispatching are preferred for the producer, it can decrease surplus of generation but can increase the power losses in lines. Thus, DGs output are managed within proper range in a

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way of power will be stored in EES. The proposed method is investigated on IEEE standard 14 bus test system via DIgSILENT PowerFactory software. The simulation results are obtained from various case studies with operation scenarios in a particular day. The results of case studies are compared to evaluate the performance and effectiveness of the proposed method.

2. PROBLEM FORMULATION

The optimal generation scheduling problem for minimizing power losses in EES, and line can be formulated by (1).

$$Minimize\ f = \min(P_{Loss}^{Total}) \tag{1}$$

where f is the objective functions, P_{Loss}^{Total} is the total power losses consit of power loss in EES and power loss in line (MW).

Renewable generation dispatch function

In practical aspect, DGs are always operated at the maximum rated power output ($P_{DG\ output}$). This aspect may lead undesired conditions of power losses in the power system. On the other word, the utilities cannot directly control the injected DG power output. This term focuses on renewable DG dispatch ($P_{DG\ dispatch}$) and an excessive power of DG dispatch from maximum rated power output for reducing power in ESS. The excessive power ($P_{storage}$) will be stored in ESS. The renewable DG dispatch function is given as follows:

$$P_{DG\,dispatch} = P_{DG\,output} - P_{storage} \tag{2}$$

Since the excessive power is stored in EES, which links with the power loss in EES. The EES losses can therefore be detailed consisting of battery loss and converter loss as written below:

$$P_{Loss\,EES} = P_{Loss\,battery} + P_{Loss\,converter} \tag{3}$$

$$P_{Loss\,battery} = I_{battery}^2 \times R_{battery} \tag{4}$$

$$P_{Loss\,converter} = P_{sb} + \left(k\% \times P_{storage}\right) \tag{5}$$

where $P_{Loss\ battery}$ and $P_{Loss\ converter}$ are the battery loss and converter loss, respectively. $R_{battery}$ is the internal resistance of battery. $I_{battery}$ is the charging current related to stored power ($P_{storage}$). P_{sb} is the constant standby loss accounted for the power consumed by control platform, gate drivers, display, transducers and cooling fans. $k\%$ is the percentage of semiconductors and filter losses.
However, this paper considers a direct relationship of the $I_{battery}$ and $P_{storage}$. Hence, EES loss is particularly assumed in the variable of $P_{storage}$ instead of $I_{battery}$. Therefore, the $P_{storage}$ is firstly represented in (2), which significantly effects on the power loss of ESS. Consequently, the EES loss can be assumed in stored power in EES and efficiency of EES (η) as provided follows:

$$P_{storage} = P_{DG\,output} - P_{DG\,dispatch} \tag{6}$$

$$P_{Loss\,EES} = \left(1-\eta\right) P_{storage} \tag{7}$$

Power loss in line

The power loss in line of the power system is obtained by calculation which power flow equation is employed in this paper to calculate the power losses. The power flow equation deals with steady-state analysis related with real power and reactive power [11] can be expressed as follows:

$$S_i = P_i + jQ_i \tag{8}$$

$$P_i = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \cos(\theta_i - \theta_k - \alpha_{ik}), \quad i = 1, 2, ..., \mathrm{n} \tag{9}$$

$$Q_i = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \sin(\theta_i - \theta_k - \alpha_{ik}), \quad i = 1, 2, ..., \mathrm{n} \tag{10}$$

where S_i, P_i and Q_i are the net apparent power, active power and reactive power injections to bus i, respectively. n is the total number of buses in the system. V_i and V_k are the voltage magnitudes at buses i and k, respectively. θ_i and θ_k are the voltage angles at buses i and k, respectively. Y_{ik} is the admittance magnitude between buses i and k, respectively. α_{ik} is the phase angle of admittance between buses i and k, respectively.
This paper considers merely the power loss in line with respect to active part from a branch conductance between buses i and k (g_{ik}) that can be described as follows:

$$P_{Loss\,line_{ik}} = g_{ik}\left[V_i^2 + V_k^2 - 2V_iV_k\cos(\theta_i - \theta_k)\right] \tag{11}$$

Objective function

The operation for minimum total loss is minimum excessive power which links with minimum the power loss in EES, and power loss in line. Therefore, the objective function can be expressed:

$$Min\ P_{Loss}^{Total} = \sum_{i=1}^{Nl} P_{Loss\,line,i} + \sum_{j=1}^{Nst} P_{Loss\,EES,j} \tag{12}$$

where $P_{Loss\ line,i}$ is the power loss in line i, $P_{Loss\ EES,j}$ is the EES loss at location j. Nl and Nst are the total number of lines and the total energy storage locations, respectively.

Operational constraints

$$I_{i-j} \le I_{i-j}^{\max} \tag{13}$$

$$P_N^{\min} \le P_N \le P_N^{\max} \tag{14}$$

$$Q_N^{\min} \le Q_N \le Q_N^{\max} \tag{15}$$

$$0 \le P_{DG,N} \le P_{DG,N}^{\max} \tag{16}$$

$$V_N^{\min} \le V_N \le V_N^{\max} \qquad N = 1, ..., n.\ \text{bus no.} \tag{17}$$

$$VD_i = V_i^{\max} - V_i^{\min} \qquad i = 1, ..., m.\ \text{scinarios no.} \tag{18}$$

where $I_{i\text{-}j}$ is the current in the line between buses i and j; $I_{i-j}^{\max}$ is the maximum current capacity of the line between buses i and j; P_N and Q_N are the active and reactive power injection at generator bus N; $P_N^{\max}$ and $Q_N^{\max}$ are the maximum active and reactive powers of the generator N; $P_N^{\min}$ and $Q_N^{\min}$ are the minimum active and reactive powers of the generator N; V_N is the bus voltage where a generator connected at bus N; $V_N^{\max}$ and $V_N^{\min}$ are the maximum and minimum operating voltage boundaries of a generator bus. $P_{DG,N}$ is the active power dispatch from DG to bus N; $P_{DG,N}^{\max}$ is the maximum rated active power of each DG at bus N; The voltage deviation (VD) is represented as the different of voltage between maximum and minimum voltage boundaries; $V_i^{\max}$ and $V_i^{\min}$ are the maximum and minimum of system voltage at i^{th} scenario, respectively.

3. PROPOSED METHOD

PSO for proposed method

This proposed method applies PSO algorithm [12] to find the optimal solutions of generation scheduling for minimizing power losses in accordance with Section 2. The PSO algorithm is initialized with the particles x to search the best position for obtaining the optimal solution with respect to the objective functions. The steps of the proposed method based on optimal generation scheduling using PSO are represented in Fig. 1. Moreover, the particles x are determined as the multi-dimension variables depending on the numbers of variables in the power system. The set of particles is associated with the conventional power generation (P_N), voltage at generation bus (V_N) and renewable distributed generation ($P_{DG\,dispatch}$) that can be presented as follows:

$$x = \left[P_N \quad V_N \quad P_{DG\,dispatch} \right]^T \tag{20}$$

Cases for comparison

The methods of two cases study for comparison were formulated to exploit the capability of the proposed method. The detail of both cases can be presented as follows:

Case 1: The generation units (conventional generation units and DG units) in the system will be searched to receive optimal power dispatches considering solely power losses minimization.

Case 2: The minimum excessive power is the main objective function of this case. The method will be explored the optimal point of conventional generations and minimizing excesive power from DG units dispatch. The search space was consistent and recalled from case 1.

However, the search space of proposed method has been determined by cases for comparison, like as lower and upper margin obtain by case 1 and case 2, respectively.

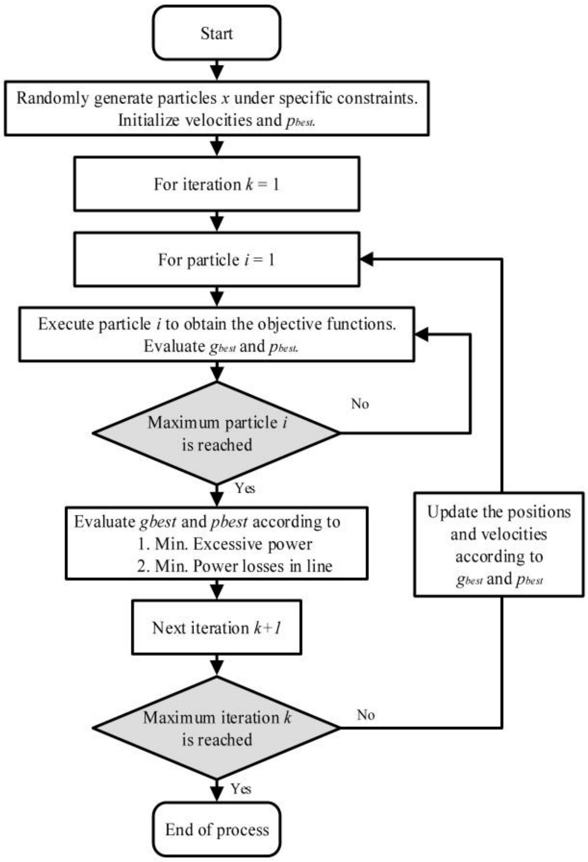


Fig. 1. Flow chart of PSO based proposed method.

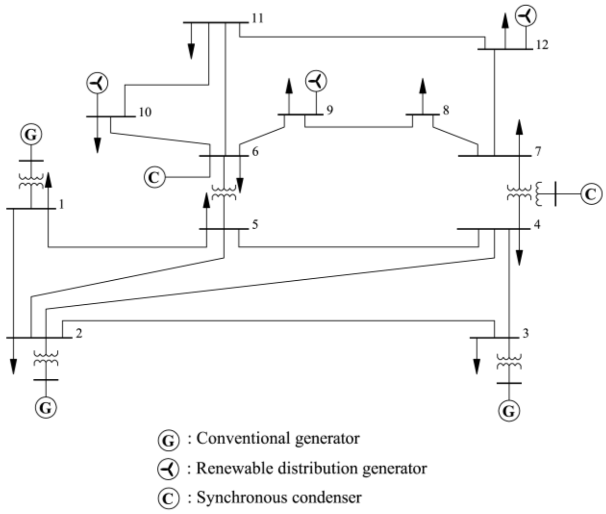
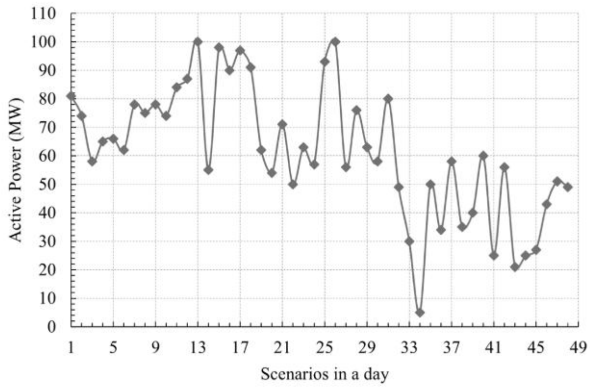


Fig. 2. Single diagram of IEEE 14-bus modified system.

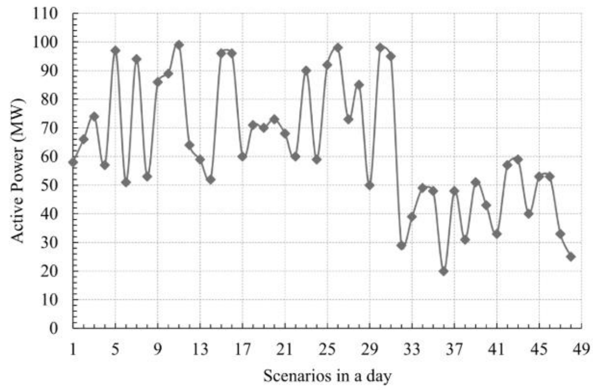
4. SIMULATION RESULTS

Description of power system for testing

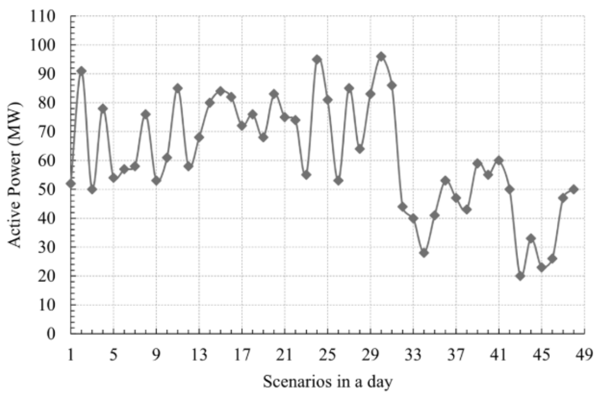
The proposed method was tested in IEEE standard 14 bus test system. The generation units consist of the conventional generation units and renewable distributed generation (DG) units. The renewable distributed generation units are refered to wind turbine generators. There are 48 scenarios DG output in period a day. The energy storage systems are installed in each location of renewable distributed generation unit to store the excessive power of DG. The available DG power output at each location is included with power energy available in DG dispatch and stored excessive power in EES. The efficiency of EES is 90% for all locations. The proposed method and cases for comparison were designed in DIgSILENT Program Language (DPL).



(a) DG unit 1



(b) DG unit 2

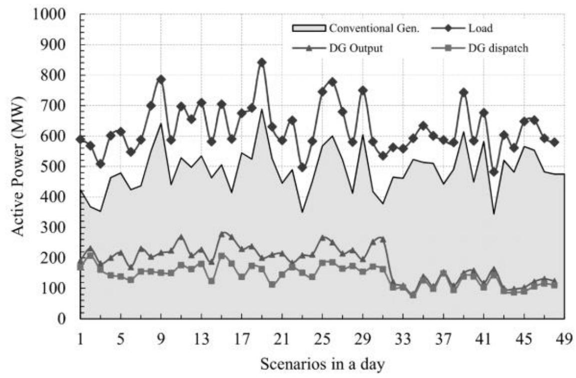


(c) DG unit 3

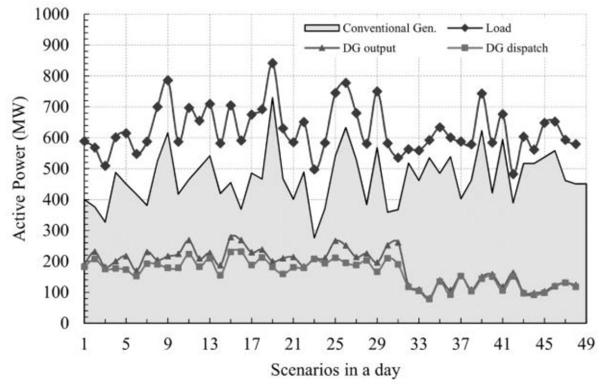
Fig. 3. Power generation of renewable distributed generation in a particular day.

Simulation results

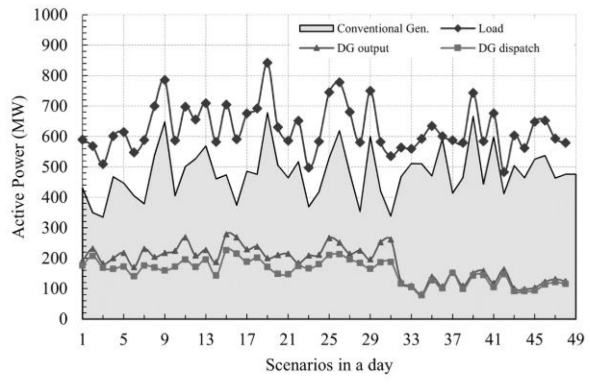
This paper considered the variation of each generated DG power output in a particular day as shown in Fig. 3. The IEEE standard 14 bus test system was determined by 48 operating conditions in accordance with half an hour. The optimal generation scheduling was obtained by proposed method and cases for comparison as illustrated in Fig. 4. Fig 4 demonstrated the load demand (MW), conventional generation (MW), maximum DG power output (MW) and DG dispatch (MW) in a particular day. The load demands were supplied by conventional generation together with DG to fulfill the mismatch power. While the stored excessive powers in EES were represented between the area of DG output curve and optimal DG dispatch. Since the stored excessive power influenced the EES loss in the system, so this area is represented to amount of EES loss.



(a) case 1



(b) case 2



(c) Proposed method

Fig. 4. Optimal generation scheduling and load demand for all case studies.

In case 1, the simulation results were demonstrated at

Fig. 4 (a). Some scenarios in a particular day were focused. The load demand at scenario 5 was 614.057 MW. The case study was taken an accounted where conventional generations and DGs were optimally generated at 478.678 MW and 139.219 MW, respectively. The total excessive powers were stored 77.780 MW as illustrated in Fig. 5. The total power losses were 11.008 MW as illustrated in Fig. 6. For scenario 25, the load demand was 744.880 MW, whereas the conventional generations and DGs were optimally generated at 567.691MW and 182.571 MW, respectively. The total excessive powers were stored 83.4294 MW in EES resulting the total power losses 13.116 MW as illustrated in Fig. 5 and 6, respectively.

In case 2, the scenarios in a particular day were recalled from the previous case. The optimal conventional generations were totally generated at 450.806 MW, and DGs were optimally dispatched at 172.661 MW as illustrated in Fig. 4(b). The total excessive powers were stored 44.338 MW in the ESS. The total power losses were 13.239 MW in scenario 5 as illustrated in Fig. 5. In scenario 25, DGs were generated at 540.515 MW and the conventional generations were generated at 211.262 MW to meet the optimal solutions as illustrated in Fig. 4(b). The excessive powers were stored 54.738 MW leading the total power losses 11.693 MW as illustrated in Fig. 5 and 6.

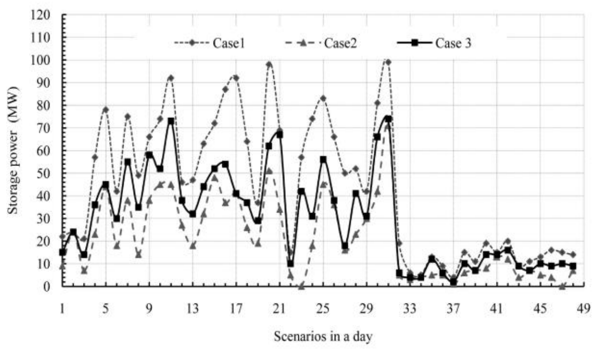


Fig. 5. The stored excessive power in EES.

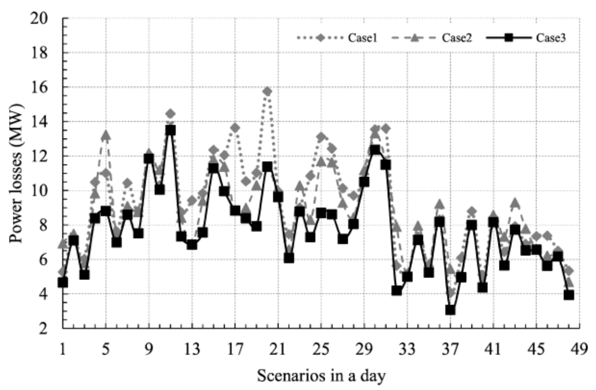
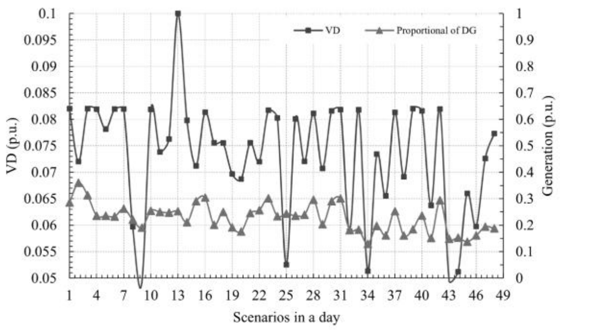
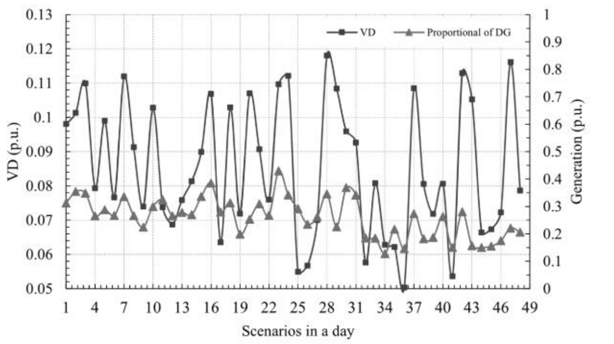


Fig. 6. Total power losses at the optimal schedule condition.

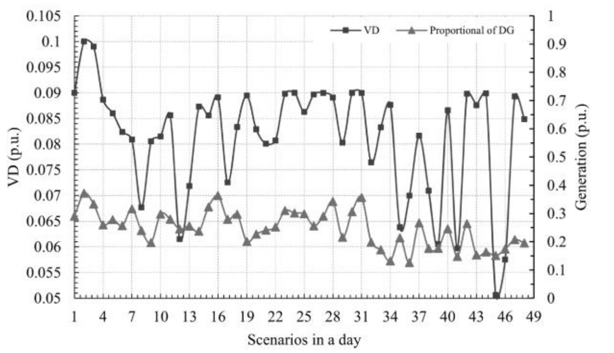
In proposed method, minimum excessive power and minimum power loss were to be the objective functions in this case. The conventional generations and DGs were optimally generated at 446.723 MW and 172.318 MW to supply 614.057 MW of load demand in scenario 5 as illustrated in Fig. 4(c). The total excessive powers were stored 44.681 MW and the total power losses were 8.8106 MW as illustrated in Fig. 5 and 6. While, the conventional generation and DG were optimally generated at 529.986 MW and 210.093 MW in scenario 25 to supply the load demand 744.880 MW as illustrated in Fig. 4(c). The total excessive powers were stored 55.907 MW resulting the total power losses 8.703 MW as illustrated in Fig. 5 and 6, respectively.



(a) case 1



(b) case 2



(c) Proposed Method

Fig. 7. DG generations and voltage deviations.

The voltage profiles were extensively investigated by voltage deviation (*VD*). Fig. 7 illustrated the level of *VD* depending on the proportion of DG in system for all case studies. The worst case was obviously indicated in case 2, which the objective function of this case was maximum renewable energy harvesting.

Consequently, the proposed method could control the *VD* within 0.1 p.u. during maximum renewable energy harvesting was considered. This means that, all buses in the system could still maintained within the marginal constraints where the minimum voltage will not be reached below 0.95 p.u.

The rest of this simulation study aimed at the convergence rate of the proposed method. The convergence curve of proposed method was depicted in Fig. 8. The power losses were minimized to 6 MW in scenario 46, which was approximately identified at iteration 6. However, traditional PSO was applied to search solution, that it is not consistent with case 1 and case 2. The results shown that at 6 MW of total power losses, the traditinal PSO was approximately converged to the minimum power loss after 95 iterations as illustrated in Fig. 9.

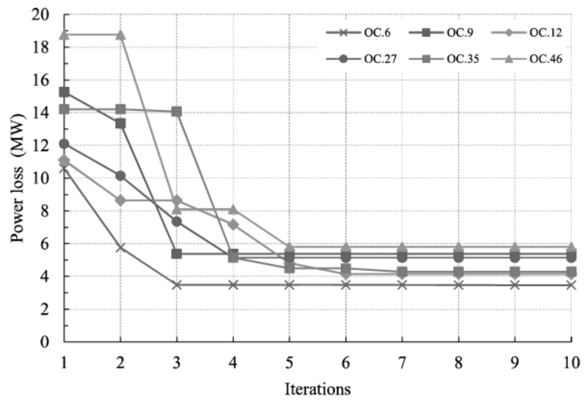


Fig. 8. The PSO convergence rate of proposed Method for 14 bus simulation result.

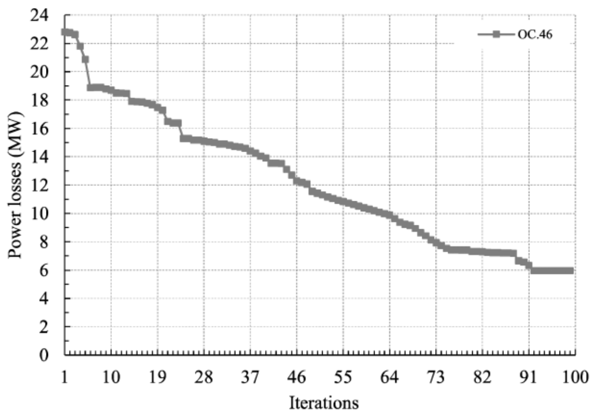


Fig. 9. The PSO convergence rate of scenario 46 with changing search space for 14 bus simulation result.

5. DISCUSSION

The power delivered from the generation units to the consumer points is always accompanied with power losses. The variations of generations can directly result the power losses in the system. The trend of power losses do not depend on only the changing condition of conventional generation, but available of renewable DG may also increase power losses in the system and rise the complexity of power management. Hence, power losses should be dealt with the combination of generation types in the power system.

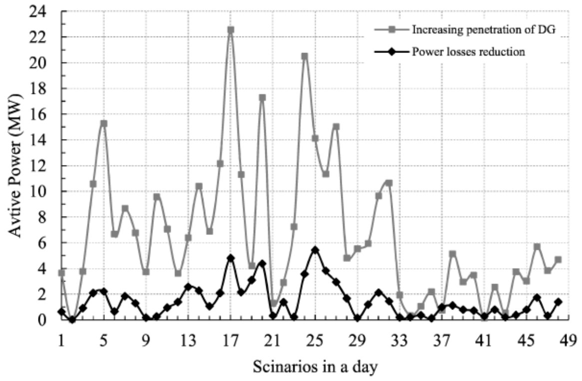


Fig. 10. Different results of cases for comparison and proposed Method.

The simulation results of three case studies show different combination of power losses at the same operating scenarios. Although the ESS losses are obviously observed to be minimal reduced in case 2. However, this reduction must be still included power losses in lines because the reduction of stored excessive power can result the power losses in lines especially long-distant transmission lines.

The Fig. 10 is presented the different results of proposed method and cases for comparison. The bold line is represented the value of power losses reduction from cases for comparison to proposed method. Power losses reduction is resulted of minimum excessive power or reducing power loss in ESS and decreasing power loss in line. This method allows the higher the ESS loss than case 2 and leads to reducing power losses in lines. That is approach in a way of optimal generation scheduling dispatch.

6. CONCLUSION

This paper, an optimal generation scheduling has been investigated in the power system. The proposed method was executed considering minimum stored excessive power and minimizing power line loss. The optimal solutions of the proposed method were identified and obtained using PSO algorithm. The two case studies for comparison were performed to exploit the capability and efficiency of the proposed method. The proposed method and cases for comparison were designed in DIgSILENT Program Language. The simulation results demonstrated the effectiveness and performance of the proposed method to achieve the optimal solutions for generation scheduling especially with minimum stored excessive power and minimizing power losses. The power losses were evidently decreased related with optimal stored power and minimizing line losses under highest DG penetration.

ACKNOWLEDGEMENTS

The authors would like to thank the Princess Sirindhorn International Center for Research, Development and

Technology Transfer, and the Kasetsart University scholarships for financial supports.

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