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Article

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Mitigating microgrid voltage fluctuation using battery energy storage system with improved particle swarm optimization

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Abstract

The variability and intermittency of light intensity, caused by cloud movement and weather conditions, can create fluctuation in the photovoltaic (PV) power generation. In a microgrid with a high PV penetration, these can affect severe microgrid voltage fluctuation problem. However, the battery energy storage system (BESS) is an equipment that can be used to smooth PV fluctuation and enhance the flexibility of the microgrid. In this paper, an improved particle swarm optimization (I-PSO) is developed to mitigate the voltage fluctuation by optimizing both BESS active and reactive power. The I-PSO is developed and implemented in MATLAB, while the time sweep load flow is calculated by using DiGSILENT PowerFactory. The proposed method is tested on the practical 22 kV Mae Sa Rieng microgrid in Thailand which has encountered from voltage fluctuation problem. The simulation results show that the I-PSO is more effective in determining the optimal BESS operation and mitigating the PV voltage fluctuation than the PV smoothing mode in the microgrid.

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Keywords: Battery energy storage system; Improved particle swarm optimization; Microgrid; Mitigating; PV smoothing; Voltage fluctuation

1. Introduction

The integration of renewable energy into a microgrid is rapidly increasing around the world. Photovoltaic (PV) is one of the highly popular renewable energy due to the eco-friendly and investment-worthy. However, Kern et al. [1] have shown that the PV power generation can be highly variable and intermittent from unpredictable weather, cloud movement, temperature, and other natural conditions which cause voltage fluctuation problem. Sasmal et al. [2] have introduced the Battery energy storage system (BESS) to deal with the voltage fluctuation problem due to the BESS has a characteristic to charge or discharge energy for smoothing PV power generation at any time. Moreover, the BESS can be the reserve power plants, providing extra energy in case of a power system interruption.

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Many researches on BESS have been proposed for mitigating voltage fluctuation, such as the efficiency of the BESS depends on the size and installation location of the BESS by Yang et al. [3]. Moreover, Shivashankar et al. [4] have proposed the important factor to mitigate the problem is BESS management system which is used to manage the BESS operation optimally. Ziadi et al. [5] have proposed the optimal power scheduling of the BESS for mitigating voltage fluctuation, but only BESS active power is discussed. In the researches mentioned, there are no comparison result with PV smoothing mode on the microgrid controller (MGC) which this mode can be used to mitigate the voltage fluctuation problem. Therefore, this paper will determine the optimal operation of the BESS and compare the results with the MGC case.

In this paper, a mitigating voltage fluctuation approach is developed by determining the optimal operation of BESS. This approach optimizes both active and reactive power of the BESS to minimize the severity of voltage fluctuation. The optimal values are calculated from an improved particle swarm optimization (I-PSO). The optimal approach is implemented by m-file script in MATLAB and DPL-scripts in DIGSILENT PowerFactory. The proposed approach is performed on a Mae Sa Riang microgrid from Provincial Electricity Authority (PEA) Thailand. The simulation results are compared with three case studies; (1) base case (2) PV smoothing (3) I-PSO.

2. Problem formulation

To determine the optimal operation of the BESS in the microgrid, the objective function in (1) is aimed to mitigate voltage fluctuation by minimizing the difference between the present voltage and the previous average voltage. Moreover, a one-day period is divided into 10 min samplings at 144 duration per day. The equality and inequality constraints of the optimization problem are shown in (2)–(12).

$$\text{Minimize } F = V_t^i - \bar{V} \tag{1}$$

$$\bar{V} = \frac{\sum_{n=1}^t V_n^i}{t} \tag{2}$$

$$E_{BESS}^{t+1} = E_{BESS}^t - (P_{BESS}^t \times \Delta t) - (Q_{BESS}^t \times \Delta t) \tag{3}$$

$$P_{Gi}^t - P_{Di}^t - \sum_{j=1}^m V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{4}$$

$$Q_{Gi}^t - Q_{Di}^t + \sum_{j=1}^m V_i V_j Y_{ij} \sin(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{5}$$

$$P_{Gi}^t = P_{GRID}^t + P_{PV}^t + P_{BESS}^t \tag{6}$$

$$Q_{Gi}^t = Q_{GRID}^t + Q_{BESS}^t \tag{7}$$

$$P_{PV}^{Min} \leq P_{PV}^t \leq P_{PV}^{Max} \tag{8}$$

$$P_{BESSi}^{Min} \leq P_{BESSi}^t \leq P_{BESSi}^{Max} \tag{9}$$

$$Q_{BESSi}^{Min} \leq Q_{BESSi}^t \leq Q_{BESSi}^{Max} \tag{10}$$

$$SOC_{BESS}^{Min} \leq SOC_{BESS}^t \leq SOC_{BESS}^{Max} \tag{11}$$

$$V^{Min} \leq V^t \leq V^{Max} \tag{12}$$

where F is the objective function, V_t^i is voltage level bus i th in interval t (V), \bar{V} is average of the previous voltage level (V), t is the number of interval time (10 min per interval), E_{BESS}^t is state of charge of BESS during interval t (MWh), P_{BESS}^t is BESS active power in interval t (MW), Q_{BESS}^t is BESS reactive power in interval t (Mvar), Δt is time duration of a single interval (hour), P_{Gi}^t is active power generation at bus i th in interval t (MW), P_{Di}^t is active power of load at bus i th in interval t (MW), P_{GRID}^t is active power injected from grid in interval t (MW), P_{PV}^t is PV active power in interval t (MW), Q_{Gi}^t is reactive power generation bus i th in interval t (Mvar), Q_{Di}^t is reactive power load at bus i th in interval t (Mvar), Q_{GRID}^t is reactive power injected from grid in interval t (Mvar), $V_i \angle \delta_i$ is voltage magnitude & angle (pu., rad), $Y_{ij} \angle \theta_{ij}$ is ij th magnitude, angle in bus i th (S, rad), and SOC_{BESS}^t is soc of BESS (%).

3. Improved particle swarm optimization

Particle swarm optimization (PSO) technique is based on a group of particles which is looking for the best food. Each particle searches the corresponding location of the optimal fitness by comparing the fitness value and updating the velocity of itself. However, Gao [6] have shown that the result of PSO in complex optimization problem is local optimization and poor accuracy. Therefore, this paper has developed the original PSO to be more effective.

The key to increase the efficiency of the PSO is to increase the probability of search space. In this paper, the abandon rate in cuckoo search optimization (CSO) which has been developed by Yang and Deb [7] and reviewed by Joshi et al. [8] is introduced into the original PSO for replacing non-good solutions with the better solution and improving efficiency in solving a complex optimization. The improved particle swarm optimization (I-PSO) can avoid the local solution by a combination of the CSO, while the I-PSO still maintains the diversity of the original PSO. The flowchart of the I-PSO is shown in Fig. 1 and the processes can be explained as follows.

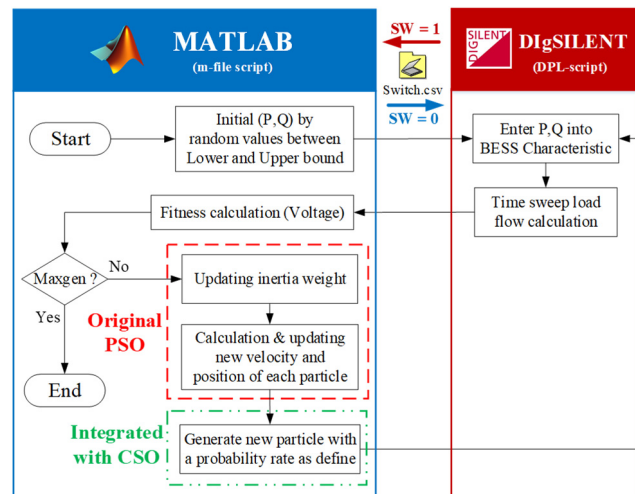


Fig. 1. Flowchart of the I-PSO.

3.1. Initialization

The initial solutions are generated randomly by using the uniform random equation as (13). These values are limited by the upper and lower bound from the constraints.

$$Particle = P_{BESS}^{Min} + a(P_{BESS}^{Max} - P_{BESS}^{Min}), Q_{BESS}^{Min} + a(Q_{BESS}^{Max} - Q_{BESS}^{Min}) \quad (13)$$

where *Particle* is the charging–discharging value of BESS, *Min* is the lower bound of charge–discharge of BESS, *Max* is the upper bound of charge–discharge of BESS, *a* is the uniform random number between 0 to 1.

3.2. Time sweep load flow calculation

The load flow calculation in DIGSILENT PowerFactory is normally used to evaluate the power flow in the electrical system. However, this calculation only calculates at the specified time which is not enough to analyze the all-day voltage profile. Therefore, this paper will use the time sweep load flow function in DIGSILENT PowerFactory to collect and analyze the voltage profile throughout the day.

3.3. Fitness calculation

The objective function in (1) is used as the fitness function of the I-PSO. This function evaluates the potentially better solution from particles in each iteration.

3.4. Updating inertia weight, velocity, and position

The inertia weight equation in (14) has been developed by Shi and Eberhart [9]. The inertia weight is used to play the role of balancing the global and local search which result in the better performance of the PSO. The other variables in (14) and (15) are the traditional parameters of the original PSO which are used to develop the old solution into the potentially better solution.

$$v_{id} = w \cdot v_{id} + c_1 \cdot a \cdot (p_{id} - x_{id}) + c_2 \cdot a \cdot (p_{gd} - x_{id}) \quad (14)$$

$$x_{id} = x_{id} + v_{id} \quad (15)$$

where v_{id} is the velocity of the particle, w is the inertia weight of the particle, c_1 and c_2 is the acceleration factor, a is the uniform random number between 0 to 1, p_{id} is the best position of the particle in this round, p_{gd} is the best position of the particle in all history, x_{id} is the position of the particle.

3.5. Abandoned nest

This procedure is an important condition in developing the PSO to become the I-PSO. The abandoned nest is a technique in CSO which is used to avoid the local solution and replace it with a new generated random solution. The abandoned nest is represented in (16).

$$Pa \in [0, 1] \quad (16)$$

where Pa is abandoned nest ratio from the CSO.

3.6. Termination criterion

The proposed approach will be terminated when an iteration number of both MATLAB and DIgSILENT PowerFactory programs reach the maximum generation. Otherwise, this I-PSO will continue looping.

3.7. Other details of the I-PSO

The I-PSO is implemented in MATLAB and DIgSILENT PowerFactory which have dynamic data exchange file named “Switch.csv”. The m-file script in MATLAB is used to simulate the I-PSO which includes generating data, calculation fitness, developing data from original PSO, and abandon rate from CSO. The time sweep load flow is processed by using DPL script in DIgSILENT PowerFactory. The required parameters in the I-PSO are composed of a number of particles = 100, abandon rate = 0.25, number of iterations = 150. In addition, the result from I-PSO is confirmed as the best solution by repeating it 15 times.

4. Case studies and simulation results

4.1. Case studies

The proposed approach is applied to the PEA Mae Sa Riang microgrid which is 22 kV distribution system. This microgrid has encountered two problems. The first problem is the voltage drop because of the remote distance between substations as represented in Fig. 2. The second problem is the intermittent of PV generation from the unpredictable weather as shown in Fig. 3.

The microgrid controller (MGC) is the main controller which has many modes to configure distributed generation based on the microgrid situation. Puri [10] has proposed the PV smoothing mode in MGC which usually apply to the BESS when PV is fluctuated. In this mode, the BESS will select to charge or discharge the active power for mitigating the PV fluctuation. This active power is calculated from the average PV generation. Therefore, this PV smoothing mode will be compared with the I-PSO approach as follows.

- Base case: the BESS is operated in the standby mode as the primary back up energy source. This case will be used as a base case to compare with other cases.

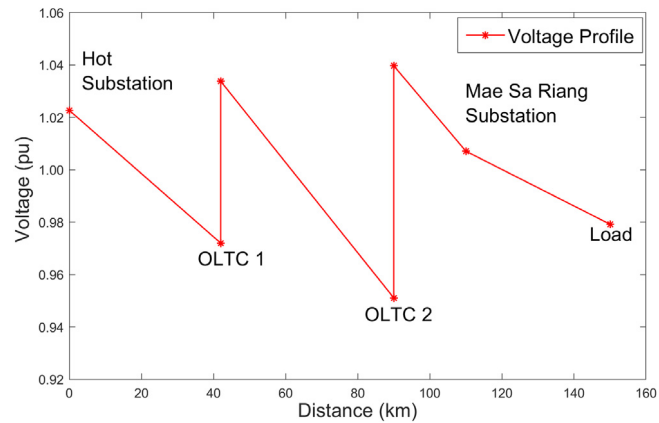


Fig. 2. Voltage profile of the Mae Sa Rieng microgrid.

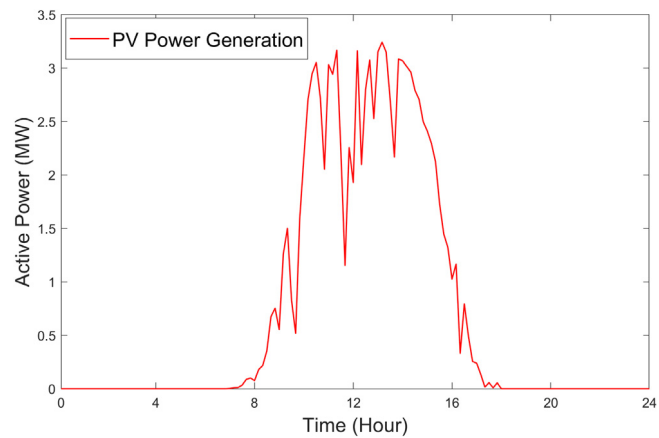


Fig. 3. PV 4 MW power generation at Mae Sa Rieng microgrid.

- PV smoothing: the BESS is operated in the PV smoothing mode. The five hundred previous PV generation values are set for BESS active power output.
- I-PSO: the I-PSO approach is implemented with the BESS for determining the optimal active–reactive power and selecting BESS to charge or discharge. The BESS power output is represented in Fig. 4 which propose to mitigate the voltage fluctuation with the objective function in (1). The convergence characteristic of the I-PSO fitness function is shown as Fig. 5 and one sampling results from the I-PSO are shown as Table 1.

Table 1. The one sampling results from the I-PSO.

Voltage level (pu)			Standard deviation (SD)	Elapsed time (min)
Max	Min	Average		
1.015	1.011	1.01166	0.00092	587

4.2. Simulation results

The simulation results from the three case studies are represented in Fig. 6 and Table 2. The results show that the base case has the most voltage fluctuation from PV intermittency due to the BESS is not operated. Therefore, the PV power generation directly affects the voltage fluctuation in the microgrid.

Next, the PV smoothing mode in MGC is applied to the BESS. The simulation results show that this mode can partly mitigate the microgrid voltage fluctuation due to the MGC controls the BESS to charge or discharge only

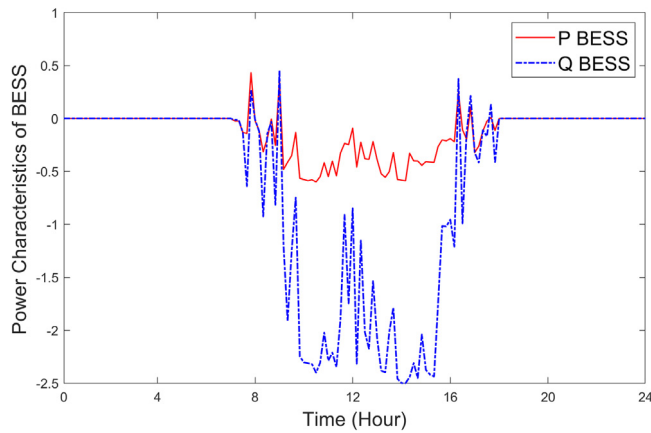


Fig. 4. The BESS output power in I-PSO approach.

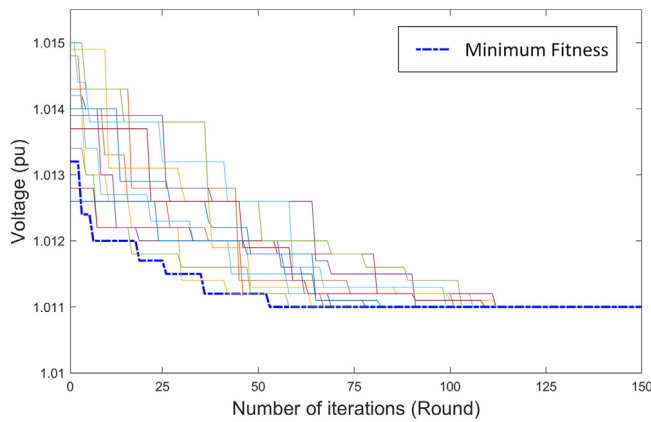


Fig. 5. The convergence characteristic of the I-PSO.

Table 2. The voltage results from the compared case studies.

Case study	Voltage level (pu)			Standard deviation (SD)
	Max	Min	Average	
Base case	1.0901	1.0038	1.02843	0.02462
PV smoothing	1.0651	1.0038	1.02322	0.01655
I-PSO	1.0402	1.0038	1.01799	0.00896

the active power to the microgrid. Moreover, the BESS output power is calculated from the PV average values which normally use for smoothing the PV power output in the microgrid. Therefore, these calculation values are not appropriate for mitigating the voltage fluctuation in the microgrid.

In the I-PSO approach, the I-PSO can handle the optimal BESS active and reactive power to the microgrid. The optimal BESS power is calculated from the objective function. The status of the BESS (charging or discharging) is also considered as a parameter for maximum efficiency. From Fig. 6, the simulation result from the I-PSO has the most efficiency in mitigating the microgrid voltage fluctuation. Moreover, the maximum, average voltage, and the standard deviation (SD) in Table 2 are lower than the other two case studies. This significant reduction shows the effectiveness of the I-PSO approach

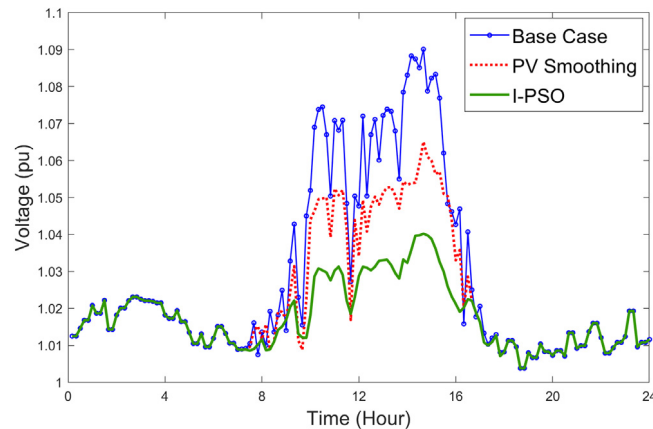


Fig. 6. The simulated voltage profile from the compared case studies.

5. Conclusion

In this paper, the optimal BESS operation is proposed with the I-PSO approach to mitigate the microgrid voltage fluctuation from PV. The comparison result shows that both the PV smoothing mode in the MGC and the I-PSO approach can mitigate the voltage fluctuation caused by PV intermittency. However, the I-PSO approach has better performance than the PV smoothing mode. Because the PV smoothing mode uses the mitigation technique based on the PV average calculation and this mode considers only the BESS active power. Moreover, the status of the BESS (charging or discharging) is considered according to the status of the PV fluctuation. On the other hand, the I-PSO approach uses the optimization technique which based on a combination of the PSO and the CSO. Furthermore, this approach can analyze the best solution which includes the active and reactive power of the BESS, the status of the BESS. Therefore, the best solution from the I-PSO approach can mitigate the voltage level effectively. As a result, it can be concluded that using the BESS with the I-PSO is effective in mitigating the microgrid voltage fluctuation.

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