Micro-grid voltage control strategies considering uncertain PV generation with analysis method

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Abstract. PV is one of intermittent renewable sources, which are complicated to forecast its influence on the voltage of micro-grid system. The strategies of maintaining voltage stability of micro-grid with uncertain PV are studied in this paper. Randomize values based on real PV output and loads are used. The effects of both quantity and content of traditional or new micro-grid device on voltage stability are analysed. Other factors which can improve the performance like various algorithms and parameters are discussed in this paper. Energy saving issue is also included in the paper.

1. Introduction
Photovoltaic (PV) power system has been widely installed due to its better efficiency and stability. However, the high penetration of PV power systems in the network will have negative effects on the power system. Overvoltage, which is caused by the reverse power flow, is the main issue that reduces the efficiency of the power system [1]. The voltage along the distribution feeders usually should be kept within five percent of its nominal value.

There are two main methods for voltage control for the PV power system: active and reactive power control. As the R/X ratio in low-voltage distribution network is high so that the voltage profile in such a network is sensitive to changes of active power [1]. Appropriate reactive power control can adjust the voltage profile by injecting or absorbing reactive power, [2]. In this paper, a multi-objective strategy is proposed to control the system voltage while considering the uncertain PV generation. Two factors (i.e. voltage deviation and power loss) are considered in the proposed model. This paper mainly focuses on studying several strategies with capacitors, STATCOMs and intelligent inverters to optimize the system.

2. Micro-Grid structure modelling
Active power (MW) of loads is collected in Sydney, and adopted in IEEE 33-bus radial distribution system for modelling. According to the limitation of active power (3.715MW) and reactive power (2.3MVAR) in IEEE 33-bus system [3], the peak hour load of each bus has been collected and geometrically decreased.
2.1. Structure of Solar PV
The system discussed in this paper is highly affected by DG penetration planning. To be specific, the penetration of PV is considered to be the main factor that will fluctuate the voltage profile and affect the system operation. According to [4], the PV penetration for a time-varying load model and a mixed model is suitable for being regarded as 34.18% and 31.33% respectively. Thus, the PV penetration is assumed to be around 30% of the maximum load demand, which would be set on ten different buses in the system.

2.2. Randomized PV data
Stochastic PV outputs which are set based on raw data could lead to a more comprehensive situation and better optimization result, therefore, The Monte Carlo random value will be launched in the system and produce the stochastic PV outputs which are also time varying.

These random values which are based on real data make all possible conditions of PV output be represented by a time node. If a large number of random conditions of every PV bus can be satisfied, it is proved that this strategy can meet the stability of the system under different PV outputs.

Since the random numbers need to be limited and they are still based on the real values. Each real value is analysed to obtain a relatively appropriate standard deviations, which contributes to ensure the entire system output is more realistic and suitable for real production.

A fitness function which comprises of voltage and power loss is proposed for optimization. Voltage stability under uncertain PV is the only objects that being focused in this paper. Therefore, one of the objectives in the function should be voltage (0.95~1.05 per unit). Besides, efficient operation of the system also needs to be considered, which means reducing the loss must also be taken into account.

Based on the original data, the voltage in each bus terminal can be calculated. From 33 buses system, voltage values of 21 buses are below 0.95 in peak hour (5PM-7PM). Among them, each end of the branch would be affected severely, which is around 0.87.

Since the random number strategy has been used, only the moment with peak solar and power load needs to be selected as the reference time for this optimization. Meanwhile, the inverter, which is used for transferring the solar PV panel output from DC to AC, has been set the power factor as 0.98 and would provide reactive power in system. For simulation, DGs with 0.01MVA (pf: 0.8 lagging) capacity are taken into consideration in system. The structure of the integrated system is shown in Figure 1 and original voltage on each bus can be shown in Figure 2.

Figure 1. Initial structure of the integrated system.
3. Strategic Analysis

3.1. Strategy: Add capacity bank to the system

3.1.1. The optimization of the initial test situation. In this scenario, different numbers of capacity banks are connected to each end of branch. The fitness function here is set as: Fitness function = total voltage deviation / test times × voltage deviation weight + total loss / test times × loss weight. After test and optimization, the voltage deviation weight value is selected as 500 and loss weight is selected as 15. The fitness function value under this condition is 601.3356 and can be optimized in following steps. In following optimization, with a smaller fitness function value, the system voltage act more stable and the energy saving effect is better.

Particle Swarm Optimization (PSO) solves the aimed function by continually optimizing a set of random initial numbers and each potential solution will be assigned to a random speed. Through the optimization, the number of capacitor banks with capacity of 300KVar would be applied in bus 16, 17, 18 are 5, 2 and 4 respectively. Voltage stability is apparently improved. After the optimization, all voltages are within the tolerance, and both the lowest point and the highest point are not over 3% of the tolerance. Comparative analysis can be shown in Figure 3. Through testing the system for several time, the fitness function value reduces from 601.3356 to 114.2995 and the average voltage is around 0.998276. By using Genetic Algorithm (GA), the number of capacity bank adding to these three buses, should be 4, 1 and 8. The requirement of voltage can also be met and the average voltage is 1.003579. Compared with PSO, the average voltage is unstable which is because of the randomized PV data. The voltage can be optimized within the required range in these two scenarios.

![Figure 2. Each bus voltage in original condition.](image-url)
3.1.2. The optimization of DGs. In the scenario of DGs being set on bus 6, 16, although two bus voltages cannot be within the 3% tolerance, the fitness function value reduces from 129.5964 to 114.2995 (total voltage deviation reduces). In the scenarios of DGs not being connected to the system, the fitness function value reduces from 134.2915 to 129.5964 with more unstable voltage of each bus.

3.1.3. The optimization of Capacity bank (CB) location. In this scenario, three buses which have the minimum voltage are selected (bus 11, 18, 33). During this process, with less capacitor banks, the fitness function value has reduced apparently, from 114.2995 to 62.0126, and the average voltage changes from 0.998276 to 0.998961. In order to find the different influence of the CB location, one of the CBs is located on the bus 11. In this condition, the fitness function has been further optimized and it reaches 56.7199. Meanwhile, the average voltage has been improved to 0.99863. Through the previous analysis, adding more CB locations can lead a better optimization performance.

In order to further analyse the impact of CB location for the system, this variable can be adjusted to six (bus 5, 11, 18, 22, 26, 33). Even if the fitness function value changed apparently after adding a CB location, setting more CB locations could not directly improve the voltage performance further, and some optimal solutions would be zero. In a nutshell, choosing an appropriate location of CB is more important than deciding its number.

3.1.4. The optimization of PV quantity. Install eight solar PV panels in eight locations that have been optimized [4], and they are Bus 8, 10, 17, 24, 26, 30, 31, 33. The fitness function can increase to 90.6989 and the average voltage reduces to 0.995082. In the case of a certain penetration of solar panels, the voltage optimization capacity declines by setting less PV panels. This is because the PV panel can provide a small reactive power and then enable the capacitor bank to improve the voltage stability flexibly.

3.2. Strategy: Add STATCOM to the system
In this scenario, the capacity banks (bus 18, 22, 33) added in previous strategy can be replaced by STATCOM with the capacity of 5Mvar. Compared with the capacity bank, STATCOM can consume and supply reactive power. After the optimization, STATCOM supplies 26.547%, 31.148% and 31.096% of its capacity, and the fitness function value decreases to 132.55 and the average voltage is now 0.999212. The bus voltage values of each bus after the optimization are shown in figure 4.

![Figure 3. Comparative analysis (PSO vs. original value).](image-url)
3.3. Strategy: Intelligent inverter in each PV bus

In the modern power grid, especially micro-scale power grid, the use of intelligent device enables the system optimization to have more possibilities. In the micro-grid, the intelligent inverter is connected to each PV panel, so the inverter can provide the system with a range of reactive power compensation and improve the voltage stability of the system with CBs.

Considering intelligent inverter can be a further optimization of system voltage, the optimized number of capacitor banks and inverters calculating factor (the power factor is 0.98) can be shown in table 1. By using the intelligent inverter, the fitness function value can be further decreased. Compared with the initial condition, the value decreases from 601.3 to 56.2. By using this method, the voltage value is effectively optimized (the voltage deviation is less than 2%). This strategy demonstrates how the new type of intelligent devices can play an important role in improving the system stability.

| Bus | 11 | 18 | 22 | 33 |
|-----|----|----|----|----|
| Capacitor bank number | 5  | 1  | 1  | 1  |
| PV inverter on bus | 8  | 13 | 16 | 17 | 20 |
| calculating factor | 0.46 | 0.60 | 0.98 | 0 |
| PV inverter on bus | 24 | 25 | 27 | 31 | 33 |
| calculating factor | 0 | 0.47 | 0.72 | 0 | 0.99 |

3.4. Program: Multi-objective Analysis

The energy conservation becomes increasingly important while dealing with the problem of the system voltage stability. Multi-objective genetic algorithm, which can optimize the voltage deviation and the system loss, will not be influenced by a relatively unsuitable weight selection. By using the gamultiobj function, there are five set noninferior solutions for the capacitor bank number, and they are shown in table 2 (Values without rounding).

| Bus | 11 | 18 | 22 | 33 |
|-----|----|----|----|----|
| Solution 1 | 5.74 | 0.93 | 0.50 | 2.57 |
| Solution 2 | 2.3 | 0.02 | 0.23 | 2.42 |
| Solution 3 | 5.43 | 0.74 | 0.87 | 2.61 |
| Solution 4 | 2.37 | 0.62 | 0.72 | 2.44 |
| Solution 5 | 4.26 | 0.77 | 0.91 | 2.63 |

Among these Pareto solutions, through some practical methods, the optimal solution would be found. Such as the fuzzy solution [6]. By using the fuzzy calculation formula, the 5th solution is the optimal value. Compared with the single objective (PSO algorithm), the average voltage drops from
0.99863 to 0.991463636. However, the power loss performance enhances apparently from 0.1901 to 0.1243. This algorithm can calculate a relative balance point for optimizing the micro-grid issue, which means the system can operate more effectively.

4. Conclusion
This paper proposed several multiple strategic combinations and different computing schemes to realize voltage control and energy saving in the power system with high PV penetration. In addition, through further research on the system, such as changing the position of each compensation, utilizing intelligent power electrical devices or separate the parameters of the simulation method, the micro-grid will operate more efficiently and smoothly with stochastic PV generation.

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