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A two-stage Microgrid cost optimization considering distribution network loss and voltage deviation

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Abstract

This paper proposes a novel two-stage Microgrid (MG) scheduling methodology to decide optimal location and size of MG and outputs of dispatchable and intermittent distributed generators (DGs). In the first stage, a system stability index (SSI) representing the performance of the distribution network is proposed to select the location of the MG. The size of the MG is derived by minimizing of SSI. In the second stage, the group search optimizer (GSO) algorithm is applied to further determine the outputs of each DG in the MG, including photovoltaic (PV) panels, wind turbines (WT), battery energy storage systems (BESS) and diesel generators (DIG). To validate the proposed approach, the IEEE 33-bus radial distribution systems has been applied. The simulation results show that the approach minimizes MG investment costs under the premise of considering loss and voltage deviation of the distribution network.

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Keywords: System stability index; Microgrid; Distributed generation; Group search optimizer

1. Introduction

Currently, the application of renewable energy to the grid has become an inevitable trend due to environmental pollution problems and the depletion of fossil fuels. On account of cleanliness and security, the integration of PV and wind power into grid has been intensively sought. Microgrid (MG) can be defined as the aggregation of renewable and conventional sources distributed generations (DGs), fuel cells and battery energy storage devices, utility grid. The MG not only provides uninterrupted power to local users, but also brings multiple technical benefits to distribution systems such as loss reduction, voltage profile improvement, voltage stability enhancement. However, unlike conventional macro-grids, the wide range of operating conditions and the disparity in the operational dynamics of individual sources make the MG reliable and economical operation quite challenging. Moreover,

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inappropriate allocation and size of the MG may introduce great influences to the grid, such as power loss increase, voltage stability reduction and operation cost increase.

As a result, a lot of studies on DGs integration have been reported. Hung Duong Quoc (2014) [1] proposes a new analytical expression to capture the optimal power factor of DGs for reducing energy losses and enhancing voltage stability. Teng, Jen Hao et al. (2013) [2] presents an optimal charging/discharging scheduling for battery storage systems to minimize the line loss of distribution systems such that the line loss of distribution systems interconnected with sizeable PV generation systems can be minimized. However, none of the above references consider the economic operation of the MG. If only considering reducing the network loss or improving the system stability, additional costs may be added due to energy storage and micro-combustion engines increasing. In order to overcome this shortcoming, Tan, Y. et al. (2014) [3] proposes a two-stage stochastic-programming-based optimal power flow model for the short-term operation of distribution networks with wind power. Chen, G. (2018) [4] proposes a novel iterative algorithm to solve the economic dispatch problem of modern cyber-physical. Chen, J. (2017) [5] presents a multiobjective optimization method to jointly optimize the planning and operation of an integrated MG. Although such works optimize the size of the DGs for the MG operation, the MG optimal location is not addressed.

In view of the above discussion, this paper proposes a two-stage optimization method to determine location and capacity of MG and achieve the economic operation of the MG. In the first stage, a system stability index (SSI) is proposed to choose the installation location and size of the MG. The SSI can simultaneously consider active loss, reactive loss, and voltage deviation of the distribution network. In the second stage, the GSO algorithm is used to economically dispatch the MG and the optimal outputs of various DGs in the MG are further determined.

The remainder of this paper is organized as follows. Section 2 presents the MG installation location and capacity selection and explains the objective function. Section 3 shows the simulation results. Finally, the conclusions of this paper will be presented in Section 4.

2. Two-stage microgrid

In order to fully measure the performance of the grid, a comprehensive indicator SSI including active loss, reactive loss, and voltage deviation is proposed in this section to determine the installation location of the MG. Considering the volatility of the load, the time-varying voltage-dependent load model proposed by Hung Duong Quoc (2014) [6] is adopted. The hourly solar irradiance and wind speed data are modeled by Beta and Weibull probability density functions (PDF), respectively.

2.1. SSI for determining optimal MG location

When there is MG access, the active power loss, reactive power loss, voltage deviation can be expressed as:

$$P_{\text{loss},t}^k = P_{\text{loss}} + \sum_{i=1}^k \frac{(P_{\text{MG},t}^k)^2 - 2P_{i,t}P_{\text{MG},t}^k}{|U_{i,t}|^2} R_i + \sum_{i=1}^k \frac{a_k^2 (P_{\text{MG},t}^k)^2 - 2Q_{i,t}a_k P_{\text{MG},t}^k}{|U_{i,t}|^2} R_i \quad (1)$$

$$Q_{\text{loss},t}^k = Q_{\text{loss}} + \sum_{i=1}^k \frac{(P_{\text{MG},t}^k)^2 - 2P_{i,t}P_{\text{MG},t}^k}{|U_{i,t}|^2} X_i + \sum_{i=1}^k \frac{a_k^2 (P_{\text{MG},t}^k)^2 - 2Q_{i,t}a_k P_{\text{MG},t}^k}{|U_{i,t}|^2} X_i \quad (2)$$

$$\begin{aligned} \text{VD}_{\text{loss},t}^k = & \text{VD}_{\text{loss}} + \sum_{i=1}^k \frac{R_i^2 \left((P_{\text{MG},t}^k)^2 - 2P_{i,t}P_{\text{MG},t}^k \right)}{|U_{i+1,t}|^2} + \sum_{i=1}^k \frac{X_i^2 \left(a_k^2 (P_{\text{MG},t}^k)^2 - 2Q_{i,t}a_k P_{\text{MG},t}^k \right)}{|U_{i+1,t}|^2} \\ & - 2 \sum_{i=1}^k \frac{R_i X_i \left(P_{i,t}a_k P_{\text{MG},t}^k + Q_{i,t}P_{\text{MG},t}^k - a_k (P_{\text{MG},t}^k)^2 \right)}{|U_{i+1,t}|^2} \end{aligned} \quad (3)$$

where, P_{loss} , Q_{loss} and VD_{loss} are the active power loss, reactive power loss, voltage deviation. P_i and Q_i are the active and reactive power flow through branch i , respectively. R_i , X_i and U_i are the resistance, impedance and voltage of branch i , respectively. n is the number of system branch. $a_k = \pm \tan(\cos^{-1}(pf_k))$, pf_k is the operating power factor of the MG unit at bus k . $P_{\text{MG},t}^k$ represents the output of MG at time t of the k th bus. Then SSI_i^k

represents the performance of the system when the MG is connected to the k th bus at period t , which is defined as:

$$SSI_t^k = m_1 \frac{P_{loss,t}^k}{P_{loss}} + m_2 \frac{Q_{loss,t}^k}{Q_{loss}} + m_3 \frac{VD_{loss,t}^k}{VD_{loss}} \quad (4)$$

where m_1, m_2, m_3 are the weighting factors and $m_1 + m_2 + m_3 = 1$. The determination of proper values for the weighting factors depend on the experience and concerns of the system planner. Referring to the experience, their value in this paper are 0.5, 0.25, 0.25. The system achieves the best performance when the SSI is at a minimum. In order to find the minimum SSI, the partial derivative of (4) with respect to $P_{MG,t}^k$ becomes zero, and the optimal $P_{MG,t}^k$ for the k th bus can also be obtained at the same time

$$\frac{\partial SSI_t^k}{\partial P_{MG,t}^k} = 0 \quad (5)$$

The relationship between the active and reactive power of a DGs at bus k is $Q_{MG,t}^k = a_k P_{MG,t}^k$. TSSI^k represents system performance during all periods T (24 h in this study), which can be calculated as follows:

$$TSSI^k = \sum_{t=1}^T SSI_t^k \quad (6)$$

Considering the MG operating conditions and technology, the power factor pf_k of the MG in this paper is 0.9. The MG location selection processes are listed as follows. Step 1, run load flow for the system without MG, and then calculate the active loss P_{loss} , reactive loss Q_{loss} and voltage deviation VD_{loss} . Step 2, calculate the MG size of the k th bus at period t using (5). Step 3, install MG with the optimal size obtained at the corresponding bus k and obtain its SSI_t^k using (4) at period t . Step 4, repeat steps 2–3 until run all periods for bus k , i.e., $t = T$. Calculate the TSSI^k using (6). Step 5, repeat steps 2–4 until $k = n$.

2.2. GSO based optimal outputs of DGs

The dynamic economic dispatch (DED) is one of the important optimization problems used in MG to obtain the optimal operation of DGs over the entire dispatch period. The model of the DED problem considers the daily cost of the MG, including the daily cost of DGs, the fuel cost and power exchange cost to the grid.

Advances in BESS provide an opportunity to make these nondispatchable renewable sources dispatchable like conventional generators. When the output of renewable energy is insufficient, DIG generates electricity to meet the needs of the MG, thus avoiding the occurrence of power outages.

$$\min f = C_{pv} + C_{wt} + C_{bess} + C_{dig} + C_{cod} + C_{ph} \quad (7)$$

where the C_{pv} , C_{wt} , C_{bess} and C_{dig} are the daily cost of PV, WT, BESS, DIG, respectively. The daily cost mainly includes the daily operation and maintenance costs of the equipment. The C_{cod} and C_{ph} are the fuel consumption cost and power exchange cost, respectively, which can be obtained by follows.

$$C_{cod} = b_g P_{n,dig} + a_g P_{dig} \quad C_{ph} = c_{ph} \sum_{t=1}^T P_h(t) \quad (8)$$

where the b_g and a_g are the fuel consumption factors, $P_{n,dig}$ and P_{dig} are the rated output and actual output of the diesel generators. $P_h(t)$ and c_{ph} are the exchange power and the unit exchange cost. The constraints of this paper mainly includes power balance constraints, voltage constraints, power exchange constraints of MG and distribution network, energy storage constraints, and fuel machine output constraints. Due to the limitations of the length of the paper, the constraints are no longer displayed in detail. The following is the flowchart of the two-stage method proposed in this paper (see Fig. 1).

3. Case study

The proposed two-stage cost analysis method is tested on IEEE 33-bus system. This system with a normal operating voltage range is 0.95 to 1.05 p.u. and a peak load demand is 3715 kW and 2300 kVAR.

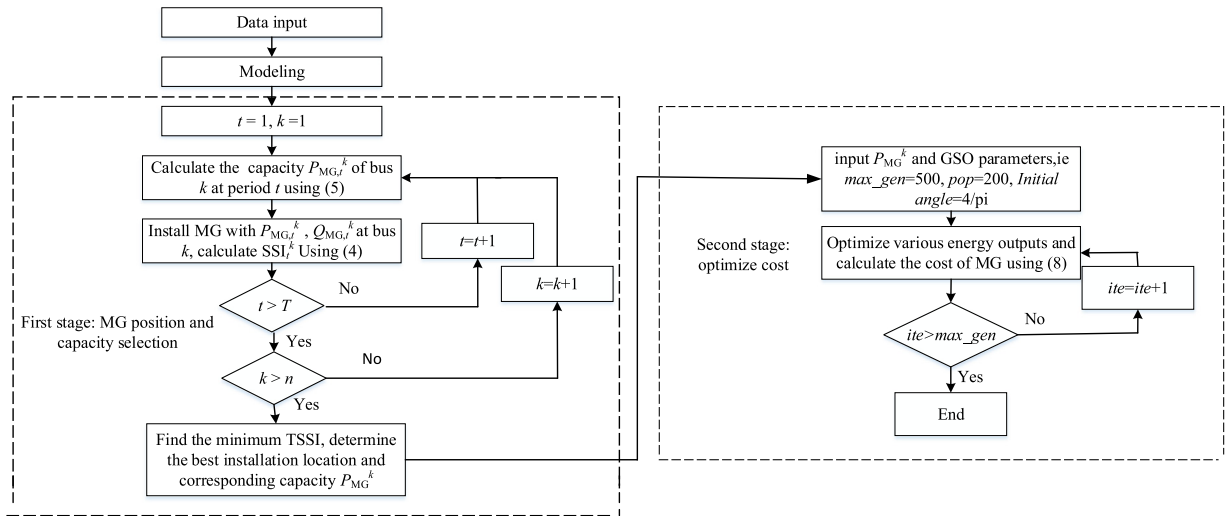


Fig. 1. The flowchart of two-stage MG model.

3.1. (First-stage) MG sizing and location selection

According to the method mentioned above, the bus with the minimum TSSI is the best installation location of the MG. It can be observed from Fig. 2(a) that the TSSI is minimum when the MG is located at bus 6, that is, the optimal installation location of the MG is bus 6 and its corresponding TSSI is 9.6. The 24-h output of the MG in bus 6 is shown in Fig. 2(b).

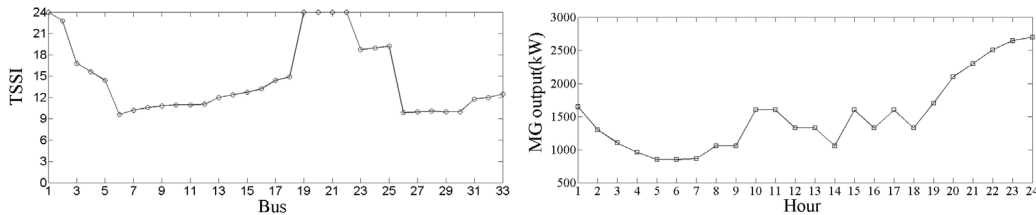


Fig. 2. (a) The TSSI at various locations; (b) The 24-h output of the MG at bus 6.

3.2. (Second-stage) Cost optimization

The maximum value of power delivered from the upper power grid to the MG is 200 kW and the maximum power delivered by the microgrid to the upper grid is 150 kW. The BESS charge efficiency and discharge efficiency are both set as 0.75, the maximum charge and discharge power are both 150 kW, the initial energy state is 0.5, and the energy state limits are set to be 0.2, 0.8, respectively. The fuel consumption cost factor are taken as $b_g = 0.0815$, $a_g = 0.2461$. The unit power exchange cost between MG and superior grid is set to be 0.0119 \$/kWh.

Fig. 3 shows the power transfer of the MG to the superior grid. When the MG transfers energy to the superior grid, P_h is negative. On the contrary, the MG obtains the energy from the superior grid P_h to be positive. In 1–4, 6–10 h, the outputs of PV and WT are greater than the demand of MG and the maximum charging power of BESS, so the excess power is sold to the upper grid. Conversely, when the PV, WT and BESS cannot meet the MG demand, the MG buys electricity from the grid at hours 12, 13, 15, 20–24. Table 1 shows the outputs of various DGs. It can be seen that WT accounts for a large proportion of the MG output, and PV is relatively small. Because the PV power generation cost is relatively high, and there is no illumination input during the 0–5, 20–24 time period.

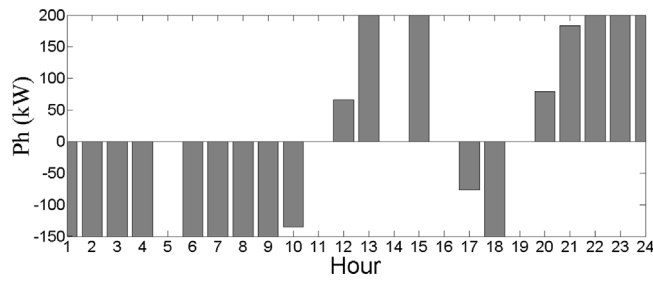


Fig. 3. The exchanged power between MG and distribution network.

Table 1. The outputs of various DGs.

Hour	Output (kW)				Hour	Output (kW)			
	PV	WT	BESS	DIG		PV	WT	BESS	DIG
1	0	2398.00	150.00	0.60	13	665.30	287.86	-150.00	23.88
2	0	1991.00	150.00	0.60	14	644.93	383.81	-28.10	0.60
3	0	1679.16	150.00	0.60	15	577.04	647.68	-150.00	25.12
4	0	1367.32	150.00	0.60	16	509.16	935.53	117.65	0.60
5	0	1031.48	132.67	0.60	17	386.96	1439.28	150.00	0.60
6	67.88	1103.45	150.00	0.60	18	237.61	1799.10	150.00	0.60
7	257.97	1367.32	150.00	0.60	19	67.89	1487.26	-145.73	0.60
8	441.27	1439.28	150.00	0.60	20	0	1871.06	-150.00	0.60
9	543.10	1559.22	150.00	0.60	21	0	1967.02	-150.00	0.60
10	610.99	1199.40	75.33	0.60	22	0	2134.93	-150.00	25.12
11	658.51	839.58	-101.76	0.60	23	0	2278.86	-150.00	21.49
12	678.88	431.78	-150.00	0.60	24	0	2350.82	-150.00	0.60

Due to the high start and stop costs, the DIG only available when the PV, WT, BESS outputs are insufficient and maintain minimum output at other periods.

4. Conclusion

In this study, a two-stage optimization method has proposed to determine the installation location and operating costs of the MG. To show the impact of the MG allocation on the distribution network, a system stability index including voltage deviation, active power loss, reactive power loss is defined. This index is then adapted to find the optimal installation and size for MG in the first stage. After the optimal position and size are determined, the outputs of the various DGs in the MG is optimized to achieve economic operation of the MG.

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