International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 710

AN OPTIMIZATION DISPATCH METHOD FOR MULTI-MICROGRIDS CONSIDERING RESTORING PRICE IN DISTRIBUTION NETWORKS RESTOTATION

Hongkun Wang [1,2], Shouxiang Wang [1*], Qi Liu[1]

1 Key Laboratory of Smart Grid of Ministry of Education (Tianjin University), Tianjin 300072, China

2 College of Mechanical and Electrical Engineering, Shihezi University, Shihezi 832003, China

ABSTRACT

In order to resist the frequent natural disasters, distribution networks should have the ability of rapid restoring from post-disaster. Multi-microgrids (MMG) are playing an important role in the restoration of distribution networks. Firstly, the response model of load for restoration is built. The charging and discharging models of vehicle-to-grid (V2G) in microgrid are also developed. Secondly, a bi-level multi-microgrids coordinated optimization dispatch model is presented to improve the restoration of critical loads in distribution networks. At the upper level, multi-objectives with the maximization profit of microgrid and the maximization contribution rate for restoring critical loads (CRCL) of distribution networks are proposed. At the lower level, a dichotomy optimization algorithm of restoring price (RP) is proposed to minimize the purchase cost of restoration of critical loads in distribution networks. Finally, the proposed optimization dispatch method is validated by the case study on a distribution network with multi-microgrids. The simulation results indicate that the restoration is effectively improved through the proposed optimization dispatch method.

Keywords: multi-microgrids, distribution networks, restoration enhancement, optimization dispatch, dichotomy optimization algorithm, restoring price

1. INTRODUCTION

With the change of global climate, the extremely natural disasters are occurring frequently, which bring unprecedented challenges to power systems. Statistics indicate that accidents of distribution systems account for about 90% of power systems blackouts. Therefore, enhancing the resilience of distribution networks (DNs) to extreme disasters will be of great significance.

Multi-microgrids (MMG) are playing an important role in the effective enhancement resilience and the reduction of blackout risk caused by distribution networks fault. In the literatures, research works of optimization dispatch for MMG have been carried out extensively. In [1], the MMG optimization dispatch model is proposed considering multiple uncertainties. At the same time, the resilience of microgrid island has also been studied. In [2], considering electric vehicle (EV) and microgrid (MG) island mode, the bi-level optimal dispatching model is proposed, and the impact of time-of-use (TOU) price on economic operation is analyzed. In [3], the vulnerability index of microgrid in ice and snow weather is proposed. According to the vulnerability index, a conservative optimal dispatching model is established. In [4], a consistency algorithm based a two-stage scheduling model for MMG cooperative is presented, which can effectively improve the resilience of MG island when facing the upstream power grid fault.

The existing research literatures mainly focus on improving the resilience of the connected MG island mode. However, the coordinated optimal dispatching method of MMG can be used to improve the restoration of distribution networks, which is a positive effect. But the restoring price (RP) mechanism lacks during the restoration period of DNs fault. In this paper, a bi-level model of optimal dispatching of MMG is proposed. Multi-objectives for maximum profit and contribution rate for restoration of critical loads (CRCL) of distribution networks are formulated at the upper level. At the lower level, a dichotomy optimization algorithm of restoring price (RP) is proposed to minimize the purchase cost of restoration of critical loads in distribution networks.

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).
Copyright © 2019 ICAE

2. RESPONSE MODEL OF LOADS AND VEHICLE-TO-GRID MODEL IN MICROGRID FOR RESTORATION

2.1 Response model of loads for restoration

The controllable loads are classified into interruptible loads (IL) and emergency regulation loads (ERL) in the MG. ERL is interrupted when emergency needs under islanded mode of MG. The response model of loads for restoration is expressed as Eq. (1).

$$\begin{gathered} P_t^{load,m} = P_t^{toal,m} - \omega_t^{1,m} P_t^{\mathrm{int,m}} - \omega_t^{2,m} P_t^{adj,m} \\ \omega_t^{1,m} \in [0,1], \omega_t^{2,m} \in [0,1] \end{gathered} \tag{1}$$

where, $P_t^{load,m}$ is actual loads demand, $P_t^{toal,m}$ is whole loads, $P_t^{\mathrm{int,m}}$ is IL, $P_t^{adj,m}$ is ERL, $\omega_t^{1,m}$ and $\omega_t^{2,m}$ are control variables of IL and ERL, *t* is time set, *m* is MG number set .

2.2 Charging and discharging models of vehicle-to-grid

As a special load, EV can be friendly interacted with MG. Charging and discharging model of vehicle-to-grid (V2G) can be modeled by battery capacity boundary and response time. The capacities are expressed as Eq. (2).

$$\begin{cases} e_{i,\max} = (\mathrm{SOC}_i^{\max} - \mathrm{SOC}_i^{a}) \mathrm{C}_i \\ e_{i,\exp} = \left| \mathrm{SOC}_i^{\exp} - \mathrm{SOC}_i^{a} \right| \mathrm{C}_i \\ e_{i,\min} = \left| \mathrm{SOC}_i^{a} - \mathrm{SOC}_i^{\min} \right| \mathrm{C}_i \end{cases} \tag{2}$$

where $e_{i,max}$ and $e_{i,min}$ are EV maximum and minimum capacities, $e_{i,exp}$ is the expected charging capacity, $\mathrm{SOC}_i^{\max}=0.95$, is maximum state of charge (SOC), $\mathrm{SOC}_i^{\exp}=0.95$, is expected SOC, $\mathrm{SOC}_i^{\min}=0.3$,is minimum SOC, SOC_i^{a} is initial SOC, C_i is rated capacity.

The charging model of V2G is expressed as Eq. (3).

$$P_t^{ev,c,i} = \begin{cases} 0, \quad t < t_{ia}, t > t_{id} \\ P_t^{i,c} \eta_c, t_{ia} \le t \le t_{ia} + t_{icr}^{\max}, t_{icr}^{\max} = \dfrac{e_{i,\exp} - e_{i,or}}{P_{i,c}^{\max}} \\ P_{i,c}^{\max} \eta_c, t_{ia} + t_{icr}^{\max} \le t \le t_{id} \end{cases} \tag{3}$$

where $P_t^{ev,c,i}$ and $P_{i,c}^{\max}$ are charging and maximum charging power, t_{ia} and t_{id} are arrival and departure time, $t_{icr,\max}$ is maximum time of charging, $\eta_c=0.95$, is charging efficiency.

The discharging model of V2G is expressed as Eq. (4).

$$P_t^{ev,d,i} = \begin{cases} 0, \quad t < t_{ia}, t > t_{id} \\ P_t^{i,d} \eta_d, t_{ia} \le t \le t_{ia} + t_{idr}^{\max}, t_{idr}^{\max} = \dfrac{e_{i,\exp} - e_{i,\min}}{P_{i,d}^{\max}} \\ P_{i,d}^{\max} \eta_d, t_{ia} + t_{idr}^{\max} \le t \le t_{id} \end{cases} \tag{4}$$

where $P_t^{ev,d,i}$ and $P_{i,d}^{\max}$ are discharging and maximum discharging power, $t_{idr}^{\max}$ is maximum time of discharging, $\eta_d=0.95$, is discharging efficiency.

3. OPTIMIZATION DISPATCH METHOD FOR MULTI-MICROGRIDS CONSIDERING RESTORING PRICE

When a fault occurs at the DNs with MG, the non-fault area of distribution networks is regarded as a temporary MG. A MMG system is constituted via MGs and temporary MG.

3.1 Optimization dispatch model of a single microgrid

3.1.1 Objective function at the upper level

The single MG consists of WT, PV, energy storage system (ESS), EV, micro gas turbine (MT), and loads. Considering maximum benefit of MG and CRCL of DNs, the objective functions are formulated. The benefits of a MG contain the sell electricity income, IL cost, ERL cost, fuel cost of MT, and the cost of V2G. Considering that the fault time of distribution networks is relatively short, the operation maintenance costs, including PV, WT, MT, and ESS, are neglected. The objective functions are expressed as Eq. (5) - (11).

$$F = \max(C_{mg}^m, R_{con}^m) \tag{5}$$

$$C_{mg}^m = C_1^m - C_2^m - C_3^m \tag{6}$$

$$R_{con}^m = \frac{\sum_{t=T_0}^{T_d} P_t^{net,m}}{\sum_{t=T_0}^{T_d} P_t^{\exp}} \tag{7}$$

$$\begin{aligned} C_1^m = & \sum_{t=T_0}^{T_d} (p_1^t P_t^{load,m} + p_t^{phl} P_t^{net,m} + \\ & \sum_{i=1}^{N_{ev,m}} p_1^t (\alpha_t^{ev,i,m} P_t^{ev,c,i,m} - \beta_t^{ev,i,m} P_t^{ev,d,i,m})) \end{aligned} \tag{8}$$

$$C_2^m = \sum_{t=T_0}^{T_d} (p_2^t \omega_1^t P_t^{\mathrm{int,m}} + p_3^t \omega_2^t P_t^{adj,m}) \tag{9}$$

$$\alpha_t^{ev,i,m} + \beta_t^{ev,i,m} \le 1 \quad (\alpha_t^{ev,i,m}, \beta_t^{ev,i,m}) \in \{0,1\} \tag{10}$$

$$\begin{aligned} C_3^m = & \rho_{gas} \sum_{t=T_0}^{T_d} \frac{P_t^{mt,m} \Delta t}{H_{gas} \eta_{gas}} \\ & + \max\{0, \alpha_t^{mt,m} - \alpha_{t-1}^{mt,m}\} \mathrm{C}_{mt}^m \end{aligned} \tag{11}$$

where C_{mg}^m is the benefit of MG *m*, R_{con}^m is the CRCL, C_1^m is the electricity sale income, C_2^m is the compensation cost, p_1^t is the TOU price, p_2^t is the contract price of IL, p_3^t is the compensation price of ERL, p_t^{phl} is the RP, $P_t^{net,m}$ is the net injection power, $P_t^{\exp}$ is the expected power of DN, T_0 and T_d are the

Copyright © 2019 ICAE

time of fault beginning and removed, C_3^m is the fuel cost of MT *m*, which is the simplified model in [5], ρ_{gas} is the price of natural gas, $H_{gas} = 9.7kW \cdot h / m^3$, is lower heating value of natural gas, $\alpha_t^{mt,m}$ is ON/ OFF status of MT, C_{mt}^m is the startup cost of MT, $\Delta t = 15\min$, is the scheduling period.

3.1.2 Constraint conditions at the upper level

1) Power balance constraint

$$\begin{aligned} &P_t^{WT} + P_t^{PV} - \alpha_t^{ess,m} P_t^{ch,m} + \beta_t^{ess,m} P_t^{dis,m} - P_t^{l,m} + P_t^{mt,m} \\ &= P_t^{net,m} + \sum_{i=1}^{N_{ev,m}} (\alpha_t^{ev,i,m} P_t^{ev,c,i,m} - \beta_t^{ev,i,m} P_t^{ev,d,i,m}) \end{aligned} \tag{12}$$

$$\alpha_t^{ess,m} + \beta_t^{ess,m} \le 1 \quad (\alpha_t^{ess,m}, \beta_t^{ess,m}) \in \{0,1\} \tag{13}$$

2) Power constraints of IL and ERL

$$P_t^{\mathrm{int},m} \le P_{\max}^{\mathrm{int}} \tag{14}$$

$$P_t^{adj,m} \le P_{\max}^{adj} \tag{15}$$

3) Constraints of ESS

$$P_t^{ch,m} \le P_{\max}^{ch,m} \tag{16}$$

$$P_t^{dis,m} \le P_{\max}^{dis,m} \tag{17}$$

$$Soc_{\min}^m \le Soc_t^m \le Soc_{\max}^m \tag{18}$$

4) Constraint of net injection power

$$P_t^{net,m} \le P_m^{\max} \tag{19}$$

5) Constraints of V2G are expressed as Eq. (2) -(4).

6) Constraints of MT

$$P_{\min}^{mt,m} \le P_t^{mt,m} \le P_{\max}^{mt,m} \tag{20}$$

$$-R_{down}^{mt,m} \Delta t \le P_t^{mt,m} - P_{t-1}^{mt,m} \le R_{up}^{mt,m} \Delta t \tag{21}$$

where $R_{down}^{mt,m}$ and $R_{up}^{mt,m}$ are ramp rate of MT.

3.1.3 The solution method of the upper model

The proposed optimization dispatch model of single MG is a mixed integer linear programming (MILP) model, which can be solved by CPLEX [5].

3.2 Multi-microgrids optimization dispatch model

3.2.1 Power headroom index of multi-microgrids

Combining market prices, MMG participate actively in the critical loads restoration of post-fault. TOU price is determined by peak valley difference of loads, which is not suitable for post-fault restoration. During the restoration period of DNs fault, both the critical loads demand of DNs and the residual power of microgrid should be considered. Therefore, the power headroom index of the microgrid (PHIM) should be considered which is expressed as Eq. (22).

$$PHIM = (\textstyle\sum_{m=1}^{N_m} P_t^{net,m} - P_t^{\exp}) / P_t^{\exp} \tag{22}$$

If $PHIM \ge 0$, it shows that the residual power of MMG meets the demand of restoration. Otherwise, if $PHIM < 0$, it is necessary to raise the RP of DNs. By this way, controllable load and EV can participate more actively in improving the restoration of DNs fault.

3.2.2 Optimal mechanism model of restoring price

Three stages of RP are implemented, including basic price, rising price and maximum price. The objective function of RP to minimize purchase cost of distribution networks is proposed, which is expressed as Eq. (23)- Eq. (25).

$$F_d = \min \sum_{m=1}^{N_m} \sum_{t=T_0}^{T_d} p_t^{phl} P_t^{net,m} \tag{23}$$

$$p_t^{phl} = \begin{cases} p_{base}, & PHIM_{base} \ge 0 \\ p_{dich}, & \text{others} \\ p_{\max}, & PHIM_{\max} \le 0 \end{cases} \tag{24}$$

The constraint of CRCL is expressed as Eq. (26).

$$\sum_{m=1}^{N_{mg}} R_{com}^m \le 1 \tag{25}$$

where p_{base} is TOU price of the normal operation, $p_{\max}$ is 1.5 times the peak price of TOU, the rising price is determined iteratively by the dichotomy method [6] and the single microgrid optimization model (DMMO). The flowchart of the DMMO is illustrated in Fig 1.

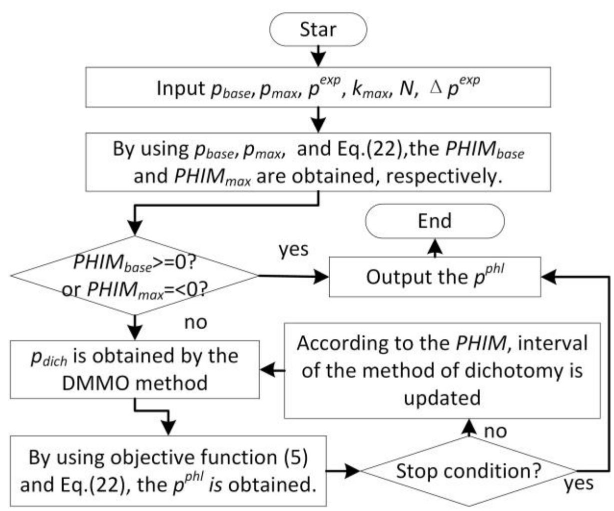

Fig 1 The flowchart of the DMMO method

4. SIMULATIONS ANALYSIS

4.1 Test system and cases setting

A distribution network with two microgrids is selected as a test system. The profiles of typical daily load, PV, and WT are shown in Fig 2. Table 1 shows the configurations of the MMG. The travel rule of EVs refers

Copyright © 2019 ICAE

to the statistical results in [7]. Parameters of MT can be found in [5]. It is assumed that the fault occurs in the upstream power grid of DNs at 6:00 a.m., which will take 6 hours to restore power supply.

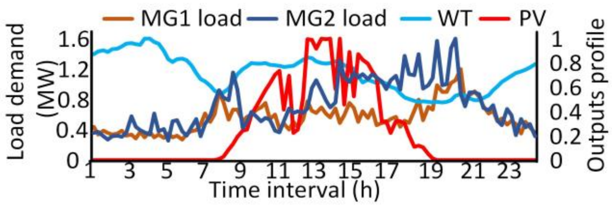

Fig 2 The profile of PV, WT, and loads

Table 1. the configurations of the microgrids

	PV kW	WT (kW)	MT (kW)	ESS (kWh)	EV (kWh)	IL (%)	ERL (%)
MG1	800	600	115	800	20*20	30	40
MG2	600	1000	115	1000	20*30	30	30

4.2 Analysis results of restoration enhancement

The TOU price of the normal operation is shown in Fig 3 [2]. Based on the TOU price, the restoration of the critical loads is shown in Fig 4. The net injection power of MMG fails to satisfy the expected restoration of critical load of DNs. Especially, the CRCL is 0 in three time stages. The reason mainly is that the power outputs of PV and WT are small but the load demands of MG are large, which is shown as in Fig 2.

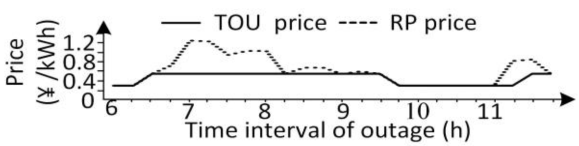

Fig 3 The prices of TOU and RP

Applying the proposed DMMO model, the RP is obtained as shown in Fig 3. Based on the RP price, the restoration of the critical loads is shown in Fig 5. It can be found that the restoration meets the expectation during the restoration period of DNs fault.

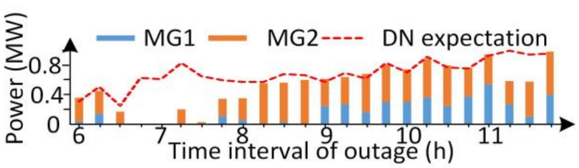

Fig 4 The TOU price based restoration result

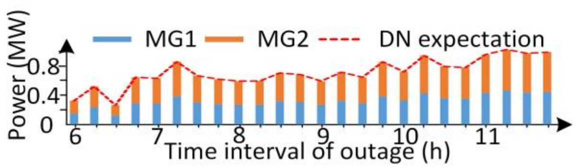

Fig 5 The RP price based restoration result

5. CONCLUSIONS

This paper has proposed a bi-level optimization dispatch model of MMG. The optimal dispatching of MMG aims to maximize the benefit of MG and improving the restoration of critical loads of DNs. PR mechanism is introduced to guide the controllable loads, including IL, ERL, MT, and EV, to actively participate in the restoration of DNs fault. By contrast, the proposed RP is effective enhancing the restoration of critical loads in distribution networks. The simulation results imply that the proposed method is reasonable and successful, and worth of applying in the restoration of distribution networks fault.

ACKNOWLEDGEMENT

This work was supported in part by State Grid Corporation of China Science and Technology Project

REFERENCE

[1] Li Y, Zhao T, Ping W, et al. Optimal Operation of Multi-Microgrids via Cooperative Energy and Reserve Scheduling. J IEEE Transactions on Industrial Informatics; 2017; 14(8):3459-3468.

[2] Li Y, Yang Z, Li G, et al. Optimal scheduling of isolated microgrid with an electric vehicle battery swapping station in multi-stakeholder scenarios: A bi-level programming approach via real-time pricing. J Applied Energy;2018; 232:54-68.

[3] Amirioun M H, Aminifar F, Lesani H. Resilience-Oriented Proactive Management of Microgrids Against Windstorms. J IEEE Transactions on Power Systems; 2017; 33(4):4275-4284.

[4] Bian Y, Bie Z. Multi-Microgrids for Enhancing Power System Resilience in Response to the Increasingly Frequent Natural Hazards. J Ifac Paersonline;2018;51(28):61-66.

[5] Men X, Cao J, Wang Z, et al. The Constructing of Multi-energy Complementary System of Energy Internet Microgrid and Energy Storage Model Analysis. J Proceedings of the CSEE; 2018;38(19):5727-5736

[6] Maulik A, Das D. Determination of Optimal Reserve Requirement for Fuel Cost Minimization of a Microgrid Under Load and Generation Uncertainties. J Arabian Journal for Science and Engineering; 2019;44(3):2003-2031.

[7] Sun H, Chen Z, Wu J. Online energy dispatch strategy for residential micro-grid considering the uncertainty of electric vehicle. J Power System Technology;2019; https://doi.org/10.13335/j.1000-3673.pst.2018.2847.

Copyright © 2019 ICAE