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Load shedding in Energy Management of Micro grid

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The planning of dispatchable source such as diesel generator or storage devices and load shedding is the aim of the energy management for micro grid (MG) in islanded mode. This problem will be considered as a multi-objective problem in this paper. Besides, these objectives are conflicted such as: minimize cost for electricity production, minimize the amount of load to be shed. Applying the Particle Swarm Optimization algorithm (PSO) and membership function of fuzzy set, the paper introduced the way to determine load amount be shed for N ahead moments and the strategy of generating the power in MG. The application for one MG with two storages and two generators is also presented.

Keywords: Microgrid; PSO; load shedding; membership function.

1. Introduction

Distributed Energy resources in Micro Grid are generally divided into two types: non-dispatchable types such as wind and solar; dispatchable types such as diesel generators or storage devices. The concept of energy management is understood as the planning of regulated sources, the storage for N times ahead [1].

In grid-connected mode, the Micro grid regulates the power balance by taking electricity from the grid or pumping into the grid to optimize operating costs. In grid-unconnected mode, to balance the power when the output power of wind and solar sources changes, control strategies need to change the output power of the adjustable generators (including storage devices) and load shedding [1]-[3]. The power of load shedding can be achieved through the bidding strategy as in [4]. Planning of load shedding can be achieved by minimizing the cost of power generation and the costs related to power outage as in [5], [6]. These studies suggested that by taking the sum of these costs, the amount of load shed for N times ahead is based on solving a single objective function. However, this approach has two disadvantages:

- The determination of losses caused by power outage is very difficult, especially in many countries, when quantitative analysis on loss compensation is not available in the database.
- In this sum function, when the cost of electricity generation is much higher than the cost of losses due to power outage or vice versa, the minimum value of the objective function will be determined primarily by a component which has a higher value.

This paper proposed multi-objectives for load shedding planning and solving multi-objective problem to overcome these two disadvantages.

Energy management problems in MGs are nonlinear optimal planning problems. The proposed methods are mixed planning [5], consecutive sequential planning [6], neural network [7] and required high calculation capability. This article uses the PSO algorithm for multi-objective optimization using membership functions.

2. Problem Formulation

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The energy management problem for Micro grids for a future phase (N ahead hours) is to strategize the diesel generation, the amount of load shedding, the battery charge - discharge operations at each hour.

2.1. Goals

The first objective function is to operate the generators at the lowest cost:

$$F_1 = \sum_{j=1}^{N} \sum_{i=1}^{n} Cp_{i,j} \to \min \tag{1}$$

Where: $Cp_{i,j}$ is the cost of running the i^{th} diesel generator at j^{th} hour;

$Cp_{i,j} = \alpha_i + \beta_i * P_{i,j} + \gamma_i * P_{i,j}^2, \alpha, \beta, \gamma$ parameters of the cost function for each type of machine; $P_{i,j}$ is the output power of i generator at time j^{th};

The second objective function represents the desired shed load in N hours:

$$F_2(x) = \sum_{j=1}^{N} L_{sh,j} \to \min \tag{2}$$

Where $L_{sh,j}$-load is cut at j^{th} hour.

If there are specific data on the cost of losses due to power outages, we can replace (2) with the following function:

$$F_2(x) = \sum_{j=1}^{N} L_{sh,j}.U_j \to \min \tag{3}$$

Where U_j ($/kWh)-loss compensation due to outage of 1kWh.

2.2. Constraints

Energy Storage Device:

This is the most influential factor in the solution of the optimal problem.

Denoting $E_{i,j}$ -the amount of energy in the *i* storage device at time j, then the storage capacity constraint is:

$$E_{i\min} \le E_{i,j} \le E_{i\max} \tag{4}$$

Constraint of charge, discharge amount in one hour:

$$SP_{i,j} \le SP_{i,ch} \quad or\ SP_{i,j} \le SP_{i,disch} \tag{5}$$

With $SP_{i,disch}$, $SP_{i,ch}$ - Maximum discharge or charge for one hour.

Note that, the state at t + 1 depends on the discharge (charge) and the previous time state, so:

$$E_{i,j+1} = E_{i,j} + SP_{i,j} \tag{6}$$

Constraints on the generator:

The active power of the i^{th} generator needs to be satisfied:

$$P_{i\min} \le P_{i,j} \le P_{i,\max} \tag{7}$$

In addition, the power delivered at time j (L'_j) must be no less than the amount of the load that is not allowed to be cut (denoted as the base load-L_{base}) at that time:

$$L'_j \ge L_{base,j} \tag{8}$$

With $L'_j = L_j - L_{sh,j}$

Power balancing: At hours when available generation can cover the load, the amount of power supplied from the sources (diesel generators and storage batteries) must be equal to the demand for MG loads (including power losses), for example with N = 24:

$$L_j = \sum_{i=1}^{n} P_{i,j} + \sum_{i=1}^{m} SP_{i,j} \tag{9}$$

Where: n-number of generator; m-number of storage devices; $SP_{i,j}$-discharge (or charge) amount of i storage in j-hour; L_j is the demand of the system (excluding the output of wind and solar sources).

For hours when available generation is smaller than the load, the unbalanced quantity is the amount of power to be cut

3. Multi-objective resolution

3.1. Define objective functions

Functions (1) and (2) have different units of measurement. These two objectives are even conflicted: achieving the objective (1) can cause the maximum of (2). The paper uses an approach of membership functions in fuzzy theory [9] to convert the objective functions as follows:

$$\mu_i(x) = \frac{F_{i\max} - F_i(x)}{F_{i\max} - F_{i\min}} \tag{10}$$

Where F_{imax}, F_{imin} is the largest and smallest value of F_i.

Note that, $\mu_i(x)$has the value greater than 0 and less than 1. It reaches a value of 1 when $F_i(x)$ reaches the smallest value. In other words, (10) represents the level of achievement of the i^{th} objective.

To calculate the minimum value of the F_1 function, solve the nonlinear problem (1), (4) - (9). We solved this problem using the PSO algorithm.

To find the maximum value of $F_1(x)$, the (1) function changes back to:

$$F = \sum_{j=1}^{N} \sum_{i=1}^{n} Cp_{i,j} \to \max \tag{11}$$

The problems (11), (4) - (9) are solved also by PSO algorithm.

To calculate the maximum value of the F_2 function, the amount of power to be cut at the hours when the available generation is smaller than the load, will be considered. It is equal to the difference between the required load (ignore discharge of the storage devices) and the base loads (L_{base}). To calculate the minimum value F_2, the amount of shedding load at each hour is consider as the difference between the available generation (taking into account the discharge of the storage devices at the beginning of the cycle) and the base loads (L_{base}).

Note that, if (3) is used, then formula (10) computing the membership function also will be applied.

3.2. Problem solving

From two objective functions, a unique goal is created:

$$\mu(x)=\mu_1(x)+\mu_2(x)\rightarrow\max \tag{12}$$

Thus (12) is the Fitness function of PSO.

To avoid violating constraint (9) and avoid initialization repeating, one generator (for example the generator k) must be chosen as the "slack" node. $P_{k,j}$ will be a dependent variable. Then (9) will have the following formula:

$$P_{k,j}= \sum_{i=1, i\neq k}^{n-1} P_{i,j} + \sum_{i=1}^{m} SP_{i,j} - L_j \tag{13}$$

At the i^th^ iteration of PSO:

$$v_i^{k+1} = v_i^k + c_1 rand_1 (pbesti - x_i^k) + c_2 rand_2 (gbest - x_i^k) \quad (14)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (15)$$

Where:

- x: is the variable set (output power of generator, charge, discharge of storage);
- $rand$: is a random function that has the value of 0-1;
- C_1 : the weight of the information of each individual;
- C_2 : weight of information of the whole swarm;
- x_i: location of the ith individual in the search area;
- v_i : the speed of the ith individual;
- g^{best} : the best value of the whole swarm;
- p^{best_i} : the best value of the ith individual.

There are some effects of initial population on computational efficiency. If we start randomly, the probability of violation (4) at the first steps is very high. For example, when the initial startup has a large $SP_{i,j}$ and when at the beginning, the storage level is high, it is possible that after two or three times, formula (4) may be violated. So, we have to return to the original solution.

4. Implementation

The medium-voltage Micro grid (Figure 1) [8] is connected to the grid via a 6MVA transformer, with a secondary voltage of 13.8 kV. MG has 2 diesels, 6 loads, two storage devices. The wind and solar sources are located at load nodes. The loads of the MG after subtracting the power from these two sources are given in Table 1 (including the power loss in system). In Figure 1, the network parameters are given in the per unit system.

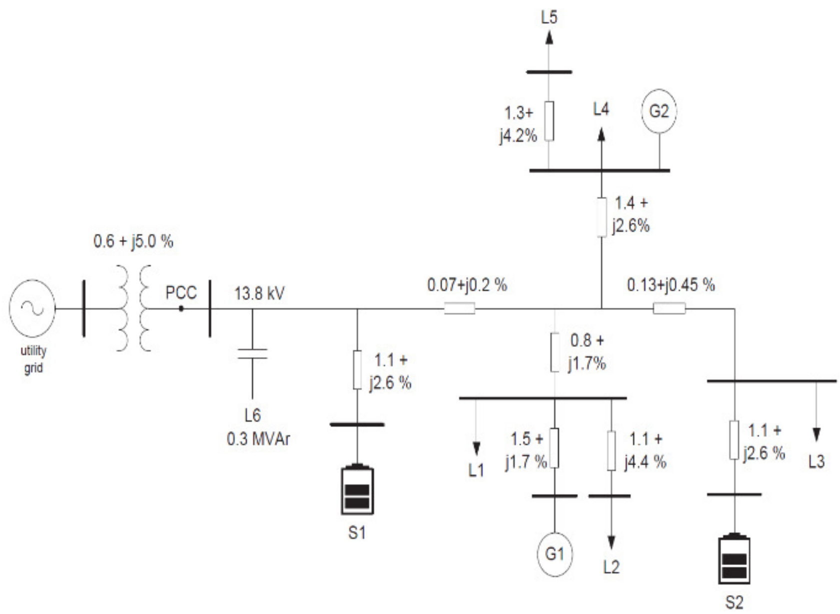

Fig. 1 Micro Grid Model

Parameters of the diesel generators:

- Gen.1: P_{max}=1.5MW; α=0.3312; β=15.6; γ=248.4;
- Gen.2: P_{max}=1.79MW; α=0.4969; β=11.6; γ=198.7
-

Parameters of the storage devices:
- S1: E_{max}=0.5MWhr; E_{min}=0 MWhr; $SP_{,ch}$ =0.05; SP_{disch} =0.05MW. The initial state is 0.3MWh
- S2: E_{max}=0.8MWhr; E_{min}=0MWhr; $SP_{,ch}$ =0.1MW ; SP_{disch} =0.1MW. The initial state is 0.5MWh

The base load at every hour is 60% of the required load. The problem is to find the output power of each generator, of each storage device.

Table 1: The Daily Load

Hour	Load(MW)	Hour	Load(MW)
1	2.3	13	2.75
2	2.3	14	4.05
3	1.76	15	4.05
4	1.76	16	4.2
5	1.76	17	4.25
6	1.92	18	4.25
7	1.92	19	4.4
8	2.5	20	4.4
9	4.125	21	4.25
10	4.125	22	4.01
11	4.125	23	3.47
12	2.75	24	2.3

Formula (2) has the smallest value with the status of two storages as the following: fully charged at night, discharged fully from 9-11 hours, from 12-14 hours recharged to the full level, then discharged at the next stage. At the times when the available generation is lower than the load, the generators operate at full capacity.

Formula (2) has the maximum value when the available power is less than the load, the amount of supplied load is equal to the L_{base}.

To build the μ_1 (x) function, the smallest and largest values of the first objective function are defined by the PSO, resulting in: the minimum is 14118.97; the maximum is 23811.07.

The result of (12) is: μ = 1.3062. The generators power, charge (or discharge) of storage devices are shown in Table 2.

The first generator has higher cost characteristics, so it generates less than the second generator.

Table 2: The Power of MG Elements (MW)

t	Storage 1	Storage 2	Gen.1	Gen.2	Shed load
1	0.0077	-0.0031	0.9680	1.3274	0.0000
2	-0.0018	0.0204	0.8981	1.3833	0.0000
3	0.0039	0.0005	0.7025	1.0532	0.0000
4	0.0065	-0.0208	0.8831	0.8913	0.0000
5	-0.0257	0.0194	0.7663	1.0001	0.0000
6	-0.0025	0.0056	1.0441	0.8728	0.0000
7	0.0408	0.0151	0.9083	0.9558	0.0000
8	-0.0318	-0.0177	1.0662	1.4833	0.0000
9	0.0142	-0.0015	0.8509	1.6260	1.6353
10	0.0201	0.0015	1.0551	1.4304	1.6178
11	-0.0011	-0.0032	0.9643	1.5376	1.6274
12	-0.0129	0.0050	0.8538	0.8851	1.0190
13	-0.0012	0.0040	0.7562	0.9648	1.0262
14	-0.0185	-0.0314	1.2419	1.2834	1.5747
15	0.0302	0.0303	0.9434	1.4560	1.5901
16	0.0338	-0.0024	0.7452	1.7473	1.6762
17	0.0075	0.0022	1.1206	1.4502	1.6696
18	0.0119	-0.0131	1.0339	1.5397	1.6776
19	-0.0080	0.0380	1.1286	1.5068	1.7347
20	-0.0037	-0.0200	0.8544	1.8078	1.7616
21	0.0053	0.0037	1.0373	1.5272	1.6765
22	0.0007	0.0303	0.7842	1.6071	1.5876
23	-0.0424	0.0113	0.9272	1.2355	1.3384
24	0.0159	0.0189	1.0375	1.2276	0.0000

5. Conclusion

The planning of load shedding problem in Micro grids is a multi-objective problem with conflicted objectives or with different units of measurement. The optimal solution is the generation plan of the diesel generators, the charge-discharge plan of the storage devices for the N future moments. By building a membership function for each objective, it is possible to convert objectives with different units to one objective function. PSO algorithm is used successfully to find the optimal solution.

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References

[1] Quanyuan Jiang, Meidong Xue, and Guangchao Geng, "Energy Management of Microgrid in Grid-Connected and Stand-Alone Modes," *IEEE Transaction on Power System*, Vol.28, no.3, August 2013.

[2] J. A. P. Lopes, C. L. Moreira, and A. G. Madureira, "Defining control strategies for Micro Grids islanded operation," *IEEE Trans. Power System,* vol. 21, no. 2, pp. 916–924, May 2006.

[3] Wenbo Shi, Xiaorong Xie, Chi-Cheng Chu, and Rajit Gadh, "A Distributed Optimal Energy Management Strategy for Micro grids," *IEEE Transactions on Smart Grid,* Vol.6, Issue 3, May 2015.

[4] A. G. Tsikalakis and N. D. Hatziargyriou, "Centralized control for optimizing micro grids operation," *IEEE Trans. Energy Convers*, vol. 23, no. 1, pp. 241–248, Mar. 2008.

[5] S. Choi, S.Park, D.J. Kang, S.J.Hang and H.M.Kim, "A micro grid energy management system for including optimal response," in *Proc. IEEE Smart grid Comm,* Brussels, Belgium, Oct. 2011.

[6] C.Cecati, C.Citro, and P.Siano, "Combined operations of renewable energy systems and responsive demand in smart grid," *IEEE Trans. Sustain Energy,* Vol.2, no.4, p 468-476, Oct.2011.

[7] P.Siano, C.Cecati, .Yu, J.Kolbusz, "Real time operation of smart grid via FCN network and optimal power flow," *IEEE Trans, Ind. Informat,* Vol.8, no.4, p 944-952, Nov. 2012.

[8] Yoash Levron, Josep M. Guerrero, Yuval Beck, "Optimal Power Flow in Micro grids with Energy Storage," *IEEE Transaction on Power System,* Vol.28, Issue 3, 3226 – 3234, August 2013.

[9] H.J.Zimmermann. "Fuzzy programming and linear programming with several objective functions," *Fuzzy set and Systems,* Vol.1,1978.