DISPATCH MODEL OF ACTIVE DISTRIBUTION NETWORK BASED ON DEMAND RESPONSE

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ABSTRACT

As one of the resources of peak load shifting, demand response has played an important role in active distribution networks(ADNs). A bi-level dispatch model of ADNs based on demand response(DR) is introduced in this paper. The upper level of the model is the dynamic optimal power flow in the ADN considering the incentive-based DR while the lower level is the dispatch of the price-based DR. An improved IEEE 30-bus system is used to test the model. Simulation results show that the proposed model can reduce the cost of ADNs system.

INTRODUCTION

The traditional distribution networks rely on the planning of the network structure and the large capacity margin to cope with load uncertainty. With the increasing penetration of distributed generation(DG) and electric vehicles, traditional dispatch method of distribution network cannot adapt the significant changes and the concept of active distribution network is put forward.

In 2008, the working group of C6.11 CIGRE proposed the concept of active distribution network[1]. ADNs can realize the dispatch, allocation and consumption of the intermittent distributed energy, enhance the economic efficiency and flexibility of power grid and, and improve power supply reliability and power quality[2]. Compared with the traditional passive distribution network, ADNs can dispatch the distribution network actively, which not only take the initiative to participate in the adjustment of generation scheme, but also exchange energy information and interaction with the main grid. Also, ADNs change the management of demand side from passive to initiative. ADNs will become the model with the development of future smart grid. So it is very important to study the dispatch scheduling of active distribution network.

Under the background of smart grid, many developed countries have begun studying the active control and management of distribution networks, in order to increase the acceptance ability of renewable energy, the utilization ratio of resource in distribution networks and power supply reliability. From the demand side, the continuous development and mature of demand response mechanism prompt users to change electricity consumption behavior according to the real-time power supply situation. Therefore, the introduction of demand response mechanism can significantly improve the flexibility of the distribution network.

Demand response refers that customers change the original power consumption behavior under the price signals or incentives. There are two categories of DR which can interact with the distribution networks: 1) price-based DR, price signals such as time-of-use and spot price guide the users' behavior; 2) incentive-based DR, users sign the contract for load cutting. In recent years, many researches have been made on the application of demand response in power system. Reference [3] [4] proposed a dispatch model of demand response to offset the uncertainty of wind farm. The application of demand response in the problem of unit commitment is studied in [5-8]. Price-responsive demand bid is modeled in the energy market and reserve market in [9].

In this paper, a bi-level dispatch model of active distribution network based on demand response is proposed, which can reduce the total cost of the system and peak load. The upper level is aimed at cost reduction in ADNs considering incentive-based DR and the lower level is used to increase the income of price-based DR. This paper is organized as follows: DR dispatch model, ADN dispatch model, solution methodology, simulation results and conclusions.

DR DISPATCH MODEL

Active distribution networks(ADN) have played an important part in the framework of smart grid. As one of the dispatchable resources in the ADNs, demand response can achieve load shifting and improve the capacity of intermittent energy joint to the grid. In this paper, the price-based DR and incentive-based DR are modeled based on the time-of-use(TOU) pricing mechanism.

Price-based DR

The model of price-based DR is as follows:

$$\min \sum_{t=1}^{T} (D^{\text{new},t} LMP^{t}) \tag{1}$$

$$D^{\text{new},t} = D^{\text{old},t} + d^{up,t} + d^{\text{down},t} \tag{2}$$

$$d^{up,t} d^{\text{down},t} = 0 \tag{3}$$

$$\sum_{t=1}^{T} d^{up,t} - \sum_{t=1}^{T} d^{\mathrm{down},t} = 0 \tag{4}$$

$$0 \le d^{up,t} \le D^{\mathrm{old},t} D^{up} \tag{5}$$

$$0 \le d^{\mathrm{down},t} \le D^{\mathrm{old},t} D^{down} \tag{6}$$

Where $D^{\mathrm{old},t}$ and $D^{\mathrm{new},t}$ refer to the actual load before and after load shift respectively, $d^{up,t}$ and $d^{\mathrm{down},t}$ are the amount increased and decreased by load shifting respectively, D^{up} is the maximum increasing ratio of load shifting, D^{down} is the maximum decreasing ratio of load shifting and LMP^{t} is the node price at the tth period.

Incentive-based DR

The model of incentive-based DR is as follows:

$$C^{IL,t} = \sum_{t=1}^{T} \gamma d^{IL,t} \tag{7}$$

$$d^{IL,t} = D^{old,t} D^{IL} \tag{8}$$

Where T is a scheduling period, $C^{IL,t}$ is the cost of load cutting compensation, γ is the compensation price for load cutting, $d^{IL,t}$ is the amount of load cutting, and D^{IL} is the maximum ratio of load cutting.

ADN DISPATCH MODEL

AND dispatch model aims at minimizing the operating cost in a scheduling period, which including the generation schedule of DGs in the ADN as well as DR resource.

$$\min \sum_{t=1}^{T} \left(\lambda_{DG}^{t} P_{DG}^{t} + \sum_{k=1}^{n_{DG}} F_{DG}^{k}(P_{DG}^{k,t}) + C^{IL,t} \right) \tag{9}$$

Where λ_{DG}^{t} is the node price at period t, F_{DG}^{k} is the cost function of DG k at period t, $P_{DG}^{k,t}$ is the active power of DG k at period t, n_{DG} is the number of DGs in the ADN, and P_{DG}^{t} is the power bought from the main grid. The constraints are as follows:

$$P_G^i - P_D^i - V_i \sum_{j=1}^{n_i} V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) = 0 \tag{10}$$

$$Q_G^i - Q_D^i - V_i \sum_{j=1}^{n} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right) = 0 \tag{11}$$

$$P_{ij\min} \le P_{ij} \le P_{ij\max} \tag{12}$$

$$V_{i\min} \le V_i \le V_{i\max} \tag{13}$$

$$P_{G\min}^{k} \le P_{DG}^{k} \le P_{G\max}^{k} \tag{14}$$

$$F_{DG}^{k} = \mathrm{a}^{k} (P_{DG}^{k,t})^2 + \mathrm{b}^{k} P_{DG}^{k,t} + \mathrm{c}^{k} \tag{15}$$

Where P_G^i and Q_G^i are active and reactive power input at node i, P_D^i and Q_D^i are active and reactive power output at node i, V_i and V_j are the node voltage at node i and j, G_{ij} and B_{ij} are the conductance and susceptance from node i to node j, θ_{ij} is the phase angle difference between node i and j, P_{ij} means the transmission power from node i to j, $P_{ij\min}$ and $P_{ij\max}$ are transmission power limits, $V_{i\min}$ and $V_{i\max}$ are the voltage limits, and $P_{G\min}^{k}$ and $P_{G\max}^{k}$ are generator output limits. Constraints in (10) and (11) mean the active and reactive power limits. Constraints in (12)-(14) represent the transmission power limits, node voltage constraint and the generator output constraint respectively. Constraints in (15) means the cost function of the kth DG with cost parameters a^{k}, b^{k} and c^{k}.

SOLUTION METHODOLOGY

Solution procedure

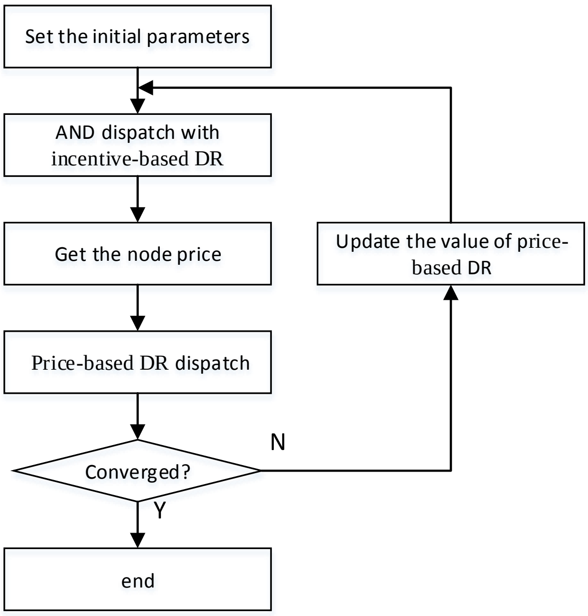

Fig.1. Flowchart of the ADN dispatch model

Step 1: Set initial values of price-based DR $D^{\mathrm{new},t}$.
Step 2: Calculate the ADN dispatch model with the incentive-based DR in (7)-(15).
Step 3: Get the node price of the price-based DR.
Step 4: Calculate the price-based DR model.
Step 5: Inequation (16) is used to check the convergence of algorithm process. If not converged, update the values of the price-based DR $D^{\mathrm{new},t}$ and return to step 2. Otherwise, stop and get the final results.

$$\sum_t \left| D^{new,t} \right| \le \varepsilon \tag{16}$$

The flowchart of the proposed model is shown in figure 1.

Solution method

The dispatch model of active distribution network based on demand response is a non-liner problem. An improved particle swarm optimization method is used to solve the dispatch model.

The traditional PSO is as follows:

$$v_{d+1} = c_1 v_d + c_2 \left(p_{i,d} - x_d \right) + c_3 \left(p_d - x_d \right) \tag{17}$$

$$x_{d+1} = x_d + v_{d+1} \tag{18}$$

Where d means the dth iteration, v_d is the velocity at the dth iteration, x_d is the position at the dth iteration, $p_{i,d}$ is the best position of ith particle during d times of iteration, p_d is the best position of the whole population during d times of iteration, and c_1, c_2, c_3 are the parameters of the PSO.

In (17), the velocity is determined by the distance between the best position and the real position. However, another character of particle motion is that the optimal solution often departs from the worst position. So a modified velocity formula is given as follows:

$$v_{d+1} = c_1 v_d + c_2 \left(p_{i,d} - x_d \right) + c_3 \left(p_d - x_d \right) - c_4 \left(p_{-d} - x_d \right) \tag{19}$$

Where p_{-d} is the worst positon during d times of iteration and c_1 is the parameter correspondingly. (19) means that the particle not only moves towards the best position, but also departs from the worst position.

SIMULATION RESULTS

In this paper, the IEEE-30 bus system is applied to test the performance of proposed model. Load at all the bus is set as the price-based DR. The maximum increasing and decreasing ratio of load shifting are both 0.05. Load at bus 7 is set as the incentive-based DR. The maximum ratio of load cutting is 0.1. The compensation price for load cutting is 3.5$/kW. The load curve at bus 7 in one-day is shown in figure 2.

DR dispatch result is shown in figure 3. When the proposed model is used, load curve is smoother than that without load shifting and load cutting. Due to high node price at peak hours, the price-based DR is shifted to off-peak hours. At the two peak hours from 6:00 to 22:00, the incentive-based DR is more economic than the high generation cost of DGs.

In order to research the performance of the proposed model further, the following four cases are studied.

Case 1: The proposed DR dispatch model.

Case 2: The traditional dispatch without DR.

Case 3: The dispatch with the price-based DR.

Case 4: The dispatch with the incentive-based DR.

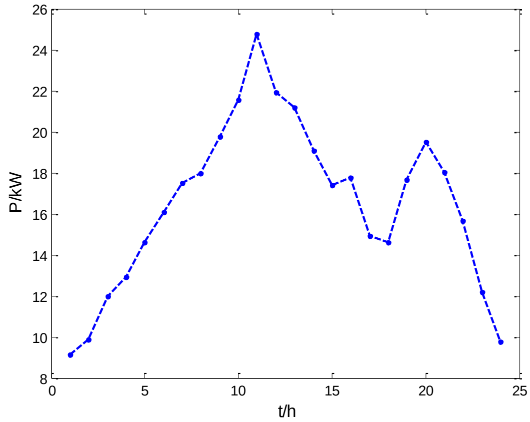

Fig.2. load curve at bus 7

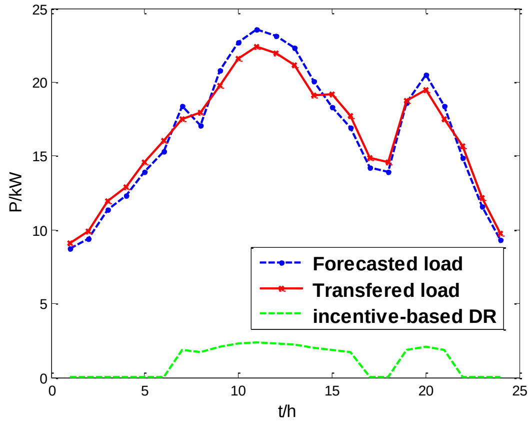

Fig.3. Load dispatch result of the proposed model

TABLE I

Dispatch solutions of different cases($)

case	Total cost	Generator cost	Income of price-based DR	Cost of incentive-based DR
1	9225.0	9133.8	11886.1	91.3
2	9327.5	9327.5	0	0
3	9230.0	9230.0	11899.2	0
4	9323.3	9240.3	0	83.0

Dispatch solutions of different cases are shown in table I. In the table, we can see that the total cost of the proposed model is the lowest. The dispatch results of price-based DR and incentive-based DR can interact with each other, since the dispatch solutions of case 1,2 and 3 are different. The optimal result can be reached when price-based DR and incentive-based DR are both introduced.

CONCLUTIONS

In this paper, we proposed a bi-level dispatch model of ADNs with demand response. The upper level is the dispatch of ADNs with the incentive-based DR. The lower level is the optimization of the price-based DR. The whole model is converged through the iteration. Furthermore, the improved particle swarm optimization method is used to solve the upper level to improve the calculation efficiency. Simulation results show that the proposed model can reduce the total cost and take advantage of the potential of demand response.

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