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Transmission Line Congestion Management for Large-scale Renewable Energy Access to Power Grid with DSM

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Abstract. With the depletion of fossil energy, governments are paying more and more attention to wind power and photovoltaic power generation. The power price of demand side management (DSM) may be of volatility and spike because of transmission congestions. a congestion management strategy for large-scale renewable energy access to power grid with demand side management is proposed in the paper. This paper puts forward the goal of maximizing social benefits, analyses the congestion management model under the premise of considering demand elasticity, and puts forward two-level solutions. studies on the IEEE 30-bus system are presented to verify the validity of the method.

1. Introduction

Throughout the world, the continuous increasing load caused several major power outages, such as the California power outage in 2003 and the New Delhi power outage in 2012[1]. The large-scale new energy connects with the grid, and it puts more demands on security, stability and economic operation of the grid. A "strong" smart grid in China is being built. With large-scale of wind power and PV power connected to the grid, the transmission line may not be able to transmit all the power, so congestion management is very important. The demand side management (SDM) based on node electricity price [2-3] can realize power consumption optimization, reduce peak valley difference, increase new energy consumption and reduce the possibility of "wind abandoning" and "light abandoning", etc. It is the core of smart grid and can actively participate in the effective interaction between the grid. Therefore, it is of great practical significance to study demand response based on node pricing.

In a multi-energy trading marketplace, there is a complex relationship between multiple market subjects. The suppliers and consumers are the producers and demands of electricity[4]. Independent intermediaries between suppliers and customers are called system operators. As one of the tasks of system operators, Congestion management not only needs to ensure that every transaction is feasible, but also does not affect the transmission capacity of the grid. And the literature [5] has analyzed the process of power market pricing and system settlement in the case of blocking. Considering node spatial distribution and node marginal price, a power market zoning strategy based on the regional influence characteristics of blocking on node marginal voltage [6]. The literature [7] analyzed the influence of high capacity renewable power generation device on electricity price based on the

relationship between market price and supply quantity. Considering feeder reconstruction, literature [8] proposes an optimal dynamic congestion management method for congestion management and line loss reduction, which is applied to higher electric vehicle permeability of distribution network. A robust bilevel programming model is set for distributed day-ahead congestion management to mitigate the negative impact of distributed generation (DG) output and market price uncertainty in [9].

The literature above has made some achievements in the congestion pipe method, but little consideration is given to the response of consumers. The demand elasticity coefficient of the desired requirement is used to represent the consumer's reply to electricity, and then this paper puts forward a congestion management model. Finally, studies in Case are presented on IEEE 30 bus system illustrate the application of this method.

2. Demand Elasticity Model

The demand curve lacks elasticity when consumption decreases. On the contrary, it is more elastic to prices when met with consumers' needs in electricity. They are willing to pay a higher price to purchase their basic demand for electricity. But the demand for the part beyond the basic demand will become more flexible and particularly sensitive to the price.

Modifying and re-arranging usage are usually some scheme for customers to respond to electricity prices. The user will choose to reduce the electricity consumption while in the condition of high electricity price. On the other hand, they would consume more electricity and buy more services in the condition of low price. Customer may reschedule their usage if the price changes throughout the day.

$B_i(q_{di})$ represents the revenue when using q_{di} electricity. It is specified that $(B_i(q_{di}) - \rho_i q_{di})$ is a continuous derivable function, and its maximum value can be obtained according to the following formula.

$$\partial B_i(q_{di})/\partial q_{di} - \rho_i = 0 \tag{1}$$

Where, ρ is the power price.

The change trend of the function $\rho_i = f_{di}(q_{di})$ is shown in fig.2. $e_i = -(q_{di} - \tilde{q}_{di})/(\rho_i - \tilde{\rho}_i)$ represents the $(\tilde{q}_{di}, \tilde{\rho}_i)$. Demand characteristic function is like a linear function shown in (2), and benefit function can be denoted by (3) while considering the demand elasticity.

$$f_{di}(q_{di}) \approx -\frac{1}{e_i}(q_{di} - \tilde{q}_{di}) + \tilde{\rho}_i, (i = 1, 2, \cdots, N) \tag{2}$$

$$B_i(q_{di}) = B_i(\tilde{q}_{di}) - \frac{1}{2e_i}(q_{di} - \tilde{q}_{di})^2 + \tilde{\rho}_i(q_{di} - \tilde{q}_{di}) \tag{3}$$

Where, $B_i(\tilde{q}_{di})$ is the benefit in usage of $\tilde{q}_{di}$. Expected demand $\tilde{q}_{di}$ is nothing to do with the system operation conditions. Weather, time and season both play a role to influence the price.

3. Congestion Management Model

3.1. Target Function

Electricity price settlement will change while considering network congestions. The require elasticity offered by consumers are meaningful while ISO controls the management process.

It is stipulated that each node has at most one generator/load. Bidding price is as follows.

$$f_{si}(q_{si}) = c_{2i}q_{si}^2 + c_{1i}q_{si} + c_{0i}, (i = 1, 2, \cdots, N) \tag{4}$$

Where, q_{si} is the electricity supplied. The cost function of the generator can be gotten as follows.

$$C_i(q_{si}) = \frac{1}{3}c_{2i}q_{si}^3 + \frac{1}{2}c_{1i}q_{si}^2 + c_{0i}q_{si} \tag{5}$$

The total social welfare (TSW) is as follows.

$$TSW = \sum_{i=1}^{N} B_i(q_{di}) - \sum_{i=1}^{N} C_i(q_{si}) \qquad (6)$$

In the equation, the number of notes is N. The demand benefit and cost are the basic information. And the consumers' demands have no elasticity. (i.e. $e_i = \infty$, $q_{di} = \tilde{q}_{di}$, and $B_i(q_{di}) = B_i(\tilde{q}_{di})$)

With the congestion management, the curve of the supply cost and the consumer demand have an intersection point C which corresponding to ρ_C, $q_{d\Sigma} = q_{s\Sigma}$, $q_{d\Sigma} = \sum_{i=1}^{N} q_{di}$ and $q_{s\Sigma} = \sum_{i=1}^{N} q_{si}$ when do not to considering net constraints. And prices of electricity would different from the Market Clearing Price ρ_C while considering the constraint condition.

3.2. Constraints in Network

The direct current power flow of net topology with N bus and L branches is considered in this paper. $q_i = q_{si} - q_{di}$ is the Injection Power at node i. The energy balance constraint is as follows.

$$\sum_{i=1}^{N} q_{si} - \sum_{i=1}^{N} q_{di} - \tilde{L} = 0 \qquad (7)$$

In the equation, $\tilde{L}$ is transmission losses.

K_l is capacity of conduction, and the transmission capacity constraints can be expressed by:

$$\left| \sum_{i=1}^{N-1} h_{li} q_i \right| \leq K_l, (l = 1, \cdots, L) \qquad (8)$$

This paper proposes a method to evaluate the spot price of consumers' nodes as follows Without considering network constraints.

$$Min \; TGC$$
$$s.t. \quad \sum_{i=1}^{N} q_{si} = \sum_{i=1}^{N} \tilde{q}_{di} \qquad (9)$$

Calculate the power generation plan while considering the network constraints and node requirements and node prices in the model (11). The customer's demand changed with price fluctuations caused by system congestion. Conclusion proves that this model can be used for congestion management.

$$Min \; -TSW$$
$$s.t. \quad \sum_{i=1}^{N} q_{si} - \sum_{i=1}^{N} q_{di} - \tilde{L} = 0 \qquad (10)$$
$$\left| \sum_{i=1}^{N-1} h_{li} q_i \right| \leq K_l, (l = 1, \cdots, L)$$

And the two-step method can optimize interests of all the participants.

4. Case Study

The congestion management problem is solved by MATLAB programming on IEEE 30 - node system, and the system model[12] is shown in fig. 1
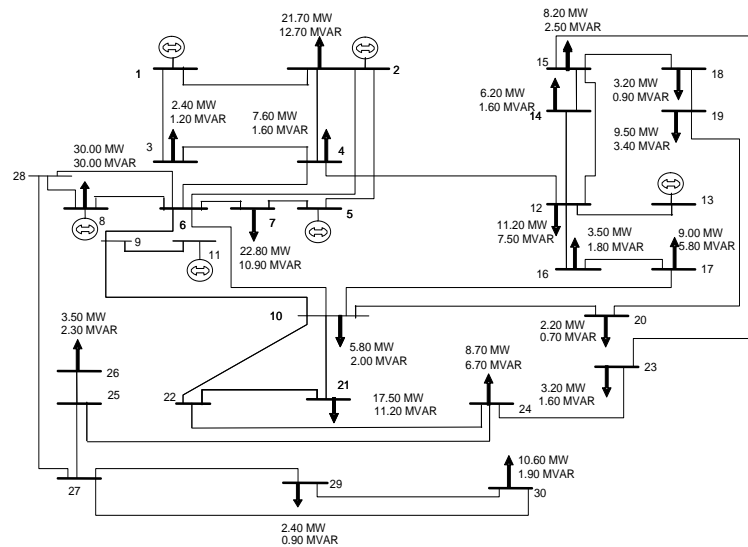
Figure 1. The IEEE 30-bus Test System

The generator cost is shown in the following table

Table 1. Cost Function Coefficients of Generations

Bus	c_2	c_1	c_0	q_s^{min}	q_s^{max}
1	0.005	0.32	2	0	200
2	0.0053	0.51	2	0	200
5	0.0074	0.83	2	0	200
8	0.01	0.03	2	0	200
11	0.01	0.83	2	0	200
13	0.0025	0.53	2	0	200

The customer demand price curve with uniform elasticity coefficient is used to describe the influence of demand elasticity on congestion management in this paper. Assuming customer demand and node demand prices are stay the same. The elasticities are 0.0, 0.2, 1.0 and 5.0, respectively.

Constraints are as follows.

Cog. 1: line 1-2 is limited at 20.0MW.

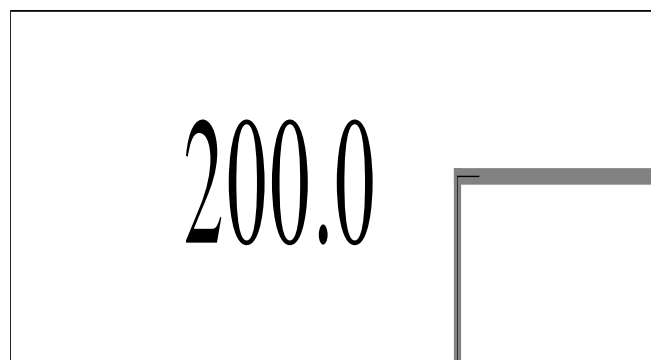Cog. 2: lines 1-2 are limited at 25.0MW and 26-27 is limited at 10.0MW.

Figure 2. TS versus. demand elasticity

It can be seen that TS changes with demand elasticity are decreasing in the Simulation results shown in fig. 2, and Cog.2 is more congested than Cog.1.
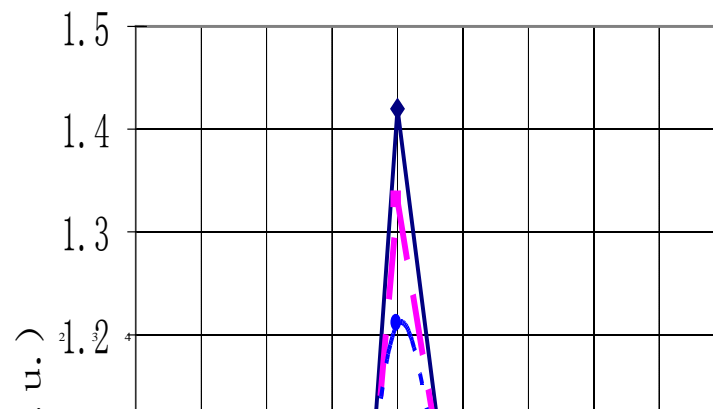
Figure 3. Price vs. Demand Chart

The ratio of the demand price of Cog1 to the system unconstrained clearing price under different demand elasticity levels are shown at Fig. 3. The price during congestion is low and the demand price deviation is very low compared with that of no load when the elasticity value is high. The demand price is very high in the case of inelasticity. All the prices of requirement are equivalent to the Market Clearing Price in the case of infinite elasticity.

5. Conclusion

The Blocking Management method based on demand elasticity is studied by using demand elasticity index to represent the electricity price demand and electricity demand to an essential control variable in congestion management. study shows that demand price and the impact of blocking lessened with the increase of demand elasticity.

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