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The Study about Penalties for Violation of Voltage under Pool Model in Power Market

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Abstract: Two models in Power Pool about the penalties for violating the desired voltage maintained by the generators were put forwarded based on the theory of spot price using optimal power flow. One is for the system that the reactive power services are paid based on real-time pricing of reactive power while the other one is for the system that the reactive power services are paid based on the capital costs. Also, the proposed approaches were tested on an IEEE 30-bus system. The results show that the corresponding penalties quantities can be gotten according to the variation of reactive power demand in power market and the models are effective.

Key words: Pool model; Violation of voltage; Reactive power market; Penalties

1.Introduction

At present, power market has gradually developed in China. In order to maintain the security and reliability of the electricity networks, bus voltages are arranged in major generating stations, and the voltage and reactive power factor are tested at intervals under different operating models. When there is any voltage deviation, the generating station will be punished unless the power factors of the units have been adjusted according to the contract. For example, when there is any voltage deviation, some electricity networks punish the generating stations by decreasing futures quantity of electricity of the station. However, the measurement has no strict theory basis, the punishments are the same regardless of the different deviations, lack of economic signal, and difficult for every generating station to believe. Therefore, how to define the compensation of the voltage deviation for safe, reliable and economic operation of the electricity networks is an important problem to be settled. The paper build the compensation model when voltage deviation occurs under Pool Model in power market based on the theory of real-time price. Because the voltage and reactive power can't be separated, voltage deviations are reflected by reactive power changes. Meantime, we can use Newton optimal power flow to obtain the real-time real power and reactive power price of the model. Also, the proposed approaches were tested on an IEEE 30-bus system. The results show that the corresponding penalties quantities can be gotten according to the variation of reactive power demand in power market and the models are effective.

2. Voltage Compensation Model With Reactive Power Market

Now the pricing model mainly depend on real power not reactive power, and corresponding economic dispatch only depend on minimal real power cost not maximal reactive power cost. Because the fixed cost of reactive power compensation apparatus is much more than the changeable cost, it is reasonable to ignore the reactive power cost. The reactive power cost contain maintaining cost, energy loss cost, apparatus depreciation cost, risk management cost and opportunity cost. The generator's operation is confined to stator current and rotor field current and the real power generating is affected by reactive power service, which forms the opportunity cost. Therefore, it is not reasonable to ignore reactive power cost for generators. So it is necessary to build reactive power market in the future.

After opening the reactive power market, real power service and reactive power service are separated, and reactive power cost will be another important factor. We can calculate the optimal price under pool model as follows.

Objective function:

$$\mathrm{F} = \sum_{i=1}^{ng} \left[\mathrm{F}_{pi}(P_{gi}) + \mathrm{F}_{qi}(Q_{gi}) \right] \qquad (1)$$

This paper assumes that generating cost and reactive power cost are the quadratic function of real power and reactive power output..

$$\left.\begin{array}{l} \mathrm{F}_{pi}(P_{gi}) = \frac{1}{2} a_i P_{gi}^2 + b_i P_{gi} + c_i \\ \mathrm{F}_{qi}(Q_{gi}) = \frac{1}{2} d_i Q_{gi}^2 + e_i Q_{gi} + f_i \\ (i = 1, 2, \cdots ng) \end{array}\right\} \qquad (2)$$

Where ng is the number of generators

The constraint conditions contain equality constraints and inequality constraints.

Equality constraints are power flow equation:

$$\left.\begin{array}{c} \Delta P_i = P_{gi} - P_{di} - \sum_{j \in i} V_i V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0 \\ \Delta Q_i = Q_{gi} - Q_{di} - \sum_{j \in i} V_i V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) = 0 \\ (i, j = 1, 2, \cdots, n) \end{array}\right\} \qquad (3)$$

Where n is the number of bus; $\theta_{ij} = \theta_i - \theta_j$; P_{di}、Q_{di}、V_i、θ_i、G_{ij}、B_{ij} are real power load, reactive power load, maximal bus voltage ,phase angle and conductance and

Inequality constraints contain invariable inequality and function inequality. Invariable inequality contain generator real power and reactive power output, on-load tap-changing transformer ,the maximal bus voltage constraints; function constraints contain real power and apparent power of transmission lines constraints.

The optimal problem can be described as:

$$\left.\begin{array}{ll} \min & \mathbf{F}(\mathbf{y}) \\ \mathrm{S.T.} & \mathbf{g}(\mathbf{y}) = 0 \\ & \underline{\mathbf{h}} \le \mathbf{h}(\mathbf{y}) \le \overline{\mathbf{h}} \end{array}\right\} \qquad (4)$$

The problem is OPF problem. The paper use Newton method. Generator bus optimal real and reactive price are:

$$\left.\begin{array}{l} \lambda_{pi} = \dfrac{\partial F}{\partial P_{gi}} - \lambda_{pi,\min} + \lambda_{pi,\max} \\ \lambda_{qi} = \dfrac{\partial F}{\partial Q_{gi}} - \lambda_{qi,\min} + \lambda_{qi,\max} \end{array}\right\} \qquad (5)$$

Where λ_{pi}、λ_{qi} are Lagrange multiplier of bus real power and reactive power equality equation. $\lambda_{pi,\max}$、$\lambda_{pi,\min}$、$\lambda_{qi,\max}$、$\lambda_{qi,\min}$ are Lagrange multiplier of bus real power and reactive power output constraints.

System dispatchers direct the reactive operation by defining the voltage level which every power station must achieve. The centre dispatches according to the objection to define the voltage curve of every power station. When testing its voltage, if there is any deviation, the power station will be punished. The punishment includes reactive quantity of electricity, loss cost of networks and re-dispatch cost. The punishment cost is:

$$Penalty = Penalty_E + Penalty_L + Penalty_D \qquad (6)$$

$$Penalty_E = \left| \lambda_{qk} (Q_k - Q_{k0}) \Delta t \right|$$

$$Penalty_L = \max((\max_i \lambda_{pi})(P_{Loss} - P_{Loss0})\Delta t, 0) + \max((\max_i \lambda_{qi})(Q_{Loss} - Q_{Loss0})\Delta t, 0)$$

$$Penalty_D = \sum_{i=1, \neq k}^{ng} \left| (Q_i - Q_{i0}) \max(\lambda_{qi}, \lambda'_{qi}) \Delta t \right| + \left| (Q_k - Q_{k0}) \max(\lambda_{qk}, \lambda'_{qk}) \Delta t \right|$$

Where Q_i is actual reactive power output, Q_{i0} is the needed reactive power output according to the arranged voltage; λ_{pi}、λ_{qi}、P_{Loss}、Q_{Loss} are bus real and reactive price, real power and reactive power loss of the networks when the generators are operating regularly; k is the number of generator whose voltage is deviated, 0 is the corresponding quantity when the generators are operating regularly; ‘ is the corresponding quantity when occurs re-dispatch; Δt is time interval.

When there is any voltage deviation, the reactive electric power generator generates in the time interval is called deviated reactive electric power, and the deviated part must be compensated by the power station. Meantime, the loss of the networks may increase, and the cost must also be compensated by the power station. If the loss decrease but the voltage deflects, the power station can’t have benefit and the cost is zero. Moreover, if there is voltage deviation, we believe that the reactive power output can’t be adjusted in the next period. In order to satisfy the economic need of the networks, re-dispatch the reactive power, then reactive power output in every power station will change, and corresponding increased or decreased cost must be compensated by the deviated power station.

3. Voltage Compensation Model Without Reactive Power Market

Now, reactive compensation cost is generally regarded as transmission cost, so we can use stamp method, MW-kilometer method, contract method, flow-tracking method and so on. In order to satisfy the operation of electricity networks, the generators should have the capability of generating reactive power , and the increased cost usually belong to station cost. Former reactive services don’t allow for the reactive cost, actually, we pay reactive cost in form of capacity cost. The power stations have the responsibility to supply reactive power, system dispatcher direct the reactive operation to satisfy the voltage level. Therefore, we must make some compensation measurements.

Now, calculate the optimal price as follows:

Objective function:

$$\mathrm{F} = \sum_{i=1}^{ng} \mathrm{F}_{pi}(P_{gi}) \qquad (7)$$

Constraint conditions are the same as the former model and the reactive power output constraints are formulated as function constraints.

Under the condition, the punishments also contain reactive quantity of electricity, loss cost of networks and re-dispatch cost. They can be calculated as the former model except economic dispatch as (7).

The spot price of reactive capacity used to calculate punishment is obtained as follows:

$$\lambda_{qi}(t) = C_f \times \frac{r(1+r)^n}{(1+r)^n - 1} \div (8760 \times L)(\$/MVarh) \qquad (8)$$

Where C_f is increased investment

4. Simulation And Analysis

We use an IEEE 30-bus system to simulate and calculate, table 1 is real power and reactive power cost factor, if without reactive market, the price is 0.2$/*MVarh*。

Tab.1 The parameters of tested system

Unit	Active power cost coefficient ($/h)			Reactive power cost coefficient ($/h)		
	a	b	c	d	e	f
1	75	200	0	120	1	0
2	350	175	0	120	1	0
5	1250	100	0	120	1	0
8	166.8	325	0	120	1	0
11	500	300	0	120	1	0
13	500	300	0	120	1	0

The system test the voltage curve every 15 minutes and 96 test spot every day. If the 5th and the 11th power station occur voltage deviation and the deviation is ±1%～±5%, in order to compare, we show the compensation when the deviation is −5% in table 2 and 3. When we dispatch according to (1), we draw the spot price curves, one have no voltage deviation, another have −5% deviation.

table.2 The penalty results considering spot prices of reactive power

Unit	Violation of voltage	voltage	Cost ($)			
			Reactive market			
			Reactive power cost	Losses cost	Redistribution cost	total
5	-5%	0.94	2.512	1.015	15.015	18.541
11	-5%	1.03	0.911	0.065	2.313	3.289
5 and 11	-5%	0.94 1.03	3.267	1.075	22.491	26.833

table.3 The penalty results without considering spot prices of reactive power

unit	Violation of voltage	voltage	Cost ($)			
			Reactive power cost	Losses cost	Redistribution cost	total
5	-5%	0.96	2.304	0.879	5.249	8.431
11	-5%	1.03	0.858	0.040	1.704	2.602
5 and 11	-5%	0.96 1.03	3.024	0.979	6.279	10.281

From the result, we can see that with reactive power, we must consider the real cost and also the reactive cost, which will make the operation condition worse. To avoid the high operation cost because of long-distance transmission, the reactive deviation cost is higher. From the result we can see that as the voltage deviation increases, compensation cost will increase correspondingly. When there is voltage deviation and long-distance transmission, the punishment cost will be high. What’s more, if the deviation is plus ,the punishment cost is higher . Without reactive market, reactive power price is constant, and the voltage deviation cost is lineared with the deviation.Because loads fluctuate and operation conditions change, the voltage can’t keep steadily and will fluctuate. After calculation, the less the voltage deviation is, the cheaper the punishment cost will be. Therefore, if the deviation is in some scope, the compensation is not needed.

5.Conclusion

In order to maintain the reliability of the electricity networks, we must monitor the voltage. If there is any deviation, it will be punished. But we have no reasonable measurement to punish. This paper builds the voltage deviation compensation model based on the real-time pricing theory. Its punishment can reflect the reactive need in the power market, and punish the power station which occurs voltage deviation, and it has theoretical basis. Every power station will improve their management on reactive power to guarantee the reliability of the electricity networks. We must point out that reactive power is regional and not suitable to transmit, so in some region, lacking of reactive power leads to manipulated reactive power price in some places. We should know the price beforehand to avoid it.

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