Unified Dynamic Rate System of Generation and Transmission Based on Technology of Condition Monitoring for Overhead Transmission Line

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***Abstract*—the unified dynamic rate system of generation and transmission based on technology of condition monitoring for overhead transmission line was introduced. Theories, components and structure of the system were analyzed. Condition monitoring technique and primary constrain condition applied in the system were discussed. The technical economy was proved in theory. The field test results and effects during commission and operation of the system were shown.**

Keywords—dynamic rate system; overhead transmission line; condition monitoring;

I. INTRODUCTION

Overhead line is the most primary transmission equipment in the power grid and occupies most of the asset value of transmission enterprises. Generally speaking, the construction cycle and service life of transmission lines are often more than 40 years, which could not adapt to the rapid development of demand, especially in developing countries. For the absolute safety of the power grid, the fixed or seasonal grading line rating was applied in load management of many countries including the China. The applied instance of dynamic rating for overhead transmission lines was most firstly reported by EPRI (Electric Power Research Institute, USA) in 1997 [1], and then a variety of dynamic rating device was developed respectively according to different principles [2][3]. It was reported recently that the dynamic rating systems based on condition monitoring of transmission line were widely applied in the transmission line for sending out the new power energy supply such as wind power [4].

In China, the scale of the power grid has been keep increasing rapidly for more than ten years, and constructing new transmission line is main method for solving the power supply sending out and power grid capacity bottleneck. With the development of the economic, the land price rise dramatically and the land resource fitted for power construction is decreasing, which has been the contradiction especially in economically developed areas. Thus, the firstly application of dynamic rating for overhead line was appeared in east China power grid. In the next few years, the electric power reform would step further in China, which must introduce competition in the field of power supplier. The transmission lines between the plant and main transmission grid are likely to be the key link.

The dynamic rating system unifying generation and transmission was present in the paper based on technology of condition monitoring for overhead lines. Constraints on the dynamic rate of grid structures were also discussed.

II. ANALYSIS ON CONSTRIANT CONTIONS OF APPLYING DYNAMATIC RATE SYSTEM IN MAIN GRID

A. Problems Faced in Applying Dynamic Rate System

Depending on the real-time ambient parameters, dynamic rate system is able to calculate the fact thermal rate and ahead of time give the available advice rate in condition of "N-1" fault (single transmission equipment fault). Under the guide of the dynamic rate system, the potential transmission capability of overhead line would be released. But the risk of ambient parameters suddenly changing exists at all the time.

Once the worst changing occurs, the dispatchers have to adjust the power flow of the transmission line in advance. If the amounts of dynamic rate system were too much in actual operation, the mechanism of manual dispatching of power grid could not adapt to requests of the real-time adjusting rate of transmission line. Therefore, the automatic mechanism of the dynamic rate system is necessary.

In the procedure of automatic rate adjustment, the rate boundary would be the most important parameters for ensuring the safe operation of the power grid. But these limit conditions of the dynamic rate are closely related to the grid structure.

B. Constraints on the Dynamic Rate of Grid Structures

According to the constraint reasons, the of grid structure being able to apply dynamic rate system could be divide into 3 kinds.

- Power supply limit type grid

With the performance of environmental protection policy from government of China, more and more small thermal power generating units were forcedly retired. The reduced generating capacity is always rearranged to the large power plants, which brought the requests of increasing the generating

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capacity. But capacity of the transmission channel is generally designed only a little higher than the capacity of full installed generators. Thus, the demand of dynamic rate system appears. But the goal range increased of the dynamic rate system depends on the requests and adjustment ability of the power supply. The kind of grid structure could be described as Fig. 1.

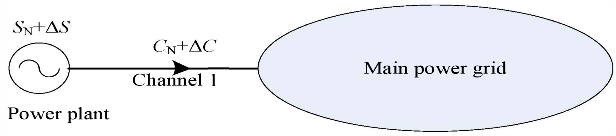


Fig. 1. Power supply limit type grid

In fig.1, the S_N is the approved generating capacity of the power plant. C_N is the approved rating of the transmission channel. ΔS is the demand generating capacity. ΔC is the increasing goal capacity of the transmission channel 1. Generally speaking, the S_N is less than C_N and approach C_N to full installed power plant in planning cycle.

ΔS is limited by ΔC and satisfies (1).

$$\Delta S<\Delta C+ (C_N- S_N) \quad (1)$$

It is obvious that ΔC has to less than the maximum decrease capacity ΔS_{MD} in given time of pre-alarm under the condition of no generator tripped. Thus, the constraint condition of ΔC can be described as (2).

$$\Delta S_{MD} >\Delta C > \Delta S-(C_N- S_N) \quad (2)$$

- Power load limit type grid

Increment of the power load is general responded to the economic development. But the grid planning could not be responding to the power load change. The bottleneck of the power supply is always to appear in the region with the rapid economic development. The kind of grid structure could be described as Fig. 2.

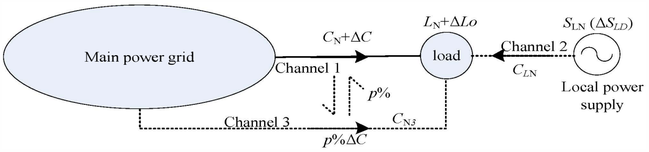


Fig. 2. Power load limit type grid

In the balance condition between supply and load, local power supply S_{LN} and the outer power from channel 1 are able to common support local load L_N. Assuming that during the period of the peak demand the power flow pass channel 1 has attained to the approved rate C_N and the power flow pass channel 2 has not yet reach the approved rate C_{LN}, then the local power supply possesses adjustable capacity space ΔS_{LD}. If the load increment is ΔL_O, then the increasing goal capacity of channel 1 ΔC would be limited as (3).

$$\Delta S_{LD} >\Delta C > \Delta L_O \quad (3)$$

If channel 1 has not been full load when the channel 2 attains the approved rate C_{LN}, then the dynamic rate system is probably not necessary.

It is more general grid structure that multiple external power channels are connected with load, such as channel 1 and channel 3 in Fig.2. The boundary of ΔC would be related to the transfer ratio $p\%$.

- Stability constraint limit type grid

There are always multiple channels between the two synchronous power grids. The power flow is difficult to be distributed according to the transmission ability, which would cause the bottleneck of power flow. The kind of grid structure could be described as Fig. 3.

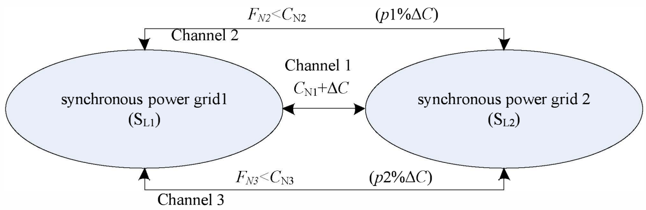


Fig. 3. Stability constraint limit type grid

In fig.3, the channel 1 has attained the approved rate C_{N1}, the power flow F_{N2} and F_{N3} are less than the approved rate C_{N2} and C_{N3} respectively. The increasing goal capacity ΔC is related to the transfer ratio $p1\%$, $p2\%$ of the two channels and stability constraint S_{L1}, S_{L2} of the two synchronous power grids.

III. Composition and Operation of the Dynamic Rating System Unifying Generation and Transmission

In China, the dynamic rating system of the transmission line has not been accepted by power grid enterprise widely. The dispatching organization is dominated by extreme conservative safety requirements currently. They have no enough interesting on responding the demand of the dynamic rating system. But the generation enterprises have strong desire to elevating the capacity of transmission channel. Therefore, the dynamic rating system is most likely to be accepted firstly in the power supply limit type grid. The dynamic rating system unifying generation and transmission is suitable for the kind of application requirement. The composition is as shown in fig.4.

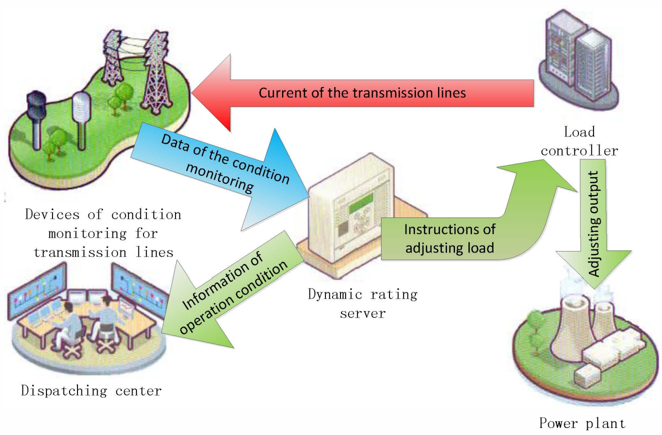


Fig. 4. Compositions of the dynamic rating system

Dynamic rating server is the center of the system. Several monitoring devices were installed in the field, which is used to collect multiple kinds of condition data, such as the temperature of the conductor, ambient temperature in transmission channel, humidity of the air, wind speed near the channel and so on. Condition data of the transmission lines are all transferred to the server arranged in the power plant. The server provides the service of calculating dynamic rate, reporting the information of system operation and determination of adjusting load.

Load controller is performance equipment arranged in the inner information safe network which is responsible for communication of control information and has no any link to the outer network. Then the determination of the server need to transferred into switching signal of relay and read by the load controller directly. The current of line in SCADA was read and sent to the field device by load controller, which was used to verify the online monitoring data.

After the dynamic rating system put into operation, the dispatching department performed elevated rate. The system was supervised by power plant and the operation information of the system was real-time reported to the dispatching center. Once the ambient condition changed disadvantageously and exceed the preset threshold, the dynamic rating server would engender determination of decreasing power load. The determination would be transferred into corresponding switching signal. The load controller would send the instruction of decreasing load to the DCS (Distributed Control System). The DCS would reduce the output of the generator uniformly, and the load of transmission line would be limited under the safe rating. If the instruction of DCS does not take effect in given time, the load controller would trip any one coal mill directly at once. The dynamic rating controlling system has one main soft switch. When output of the power plant would attain full capacity, the dynamic rating controlling logic would be released.

IV. KEY PRINCIPLE AND OF THE DYNAMIC RATING SYSTEM

A. *Thermal Balance of Overhead Lines*

Overhead lines in operation are generally in a continuous dynamic thermal equilibrium with the changing of the load and ambient. The principle of thermal balance of conductors is generally described as (4).

$$I = \sqrt{\frac{q_r + q_f - q_s}{R}} \tag{4}$$

q_r is reactive thermal power from surface of the conductor; q_f is the convective heat transfer power; q_s is solar heat absorption power; R is the alternative resistance of the conductor. The dissipation of the conductor was the function of current and R. The R is related to the temperature of the conductor. The thermal balance determines the temperature of the conductor. The process of thermal balance has been given in IEEE standard [5], as shown in (5).

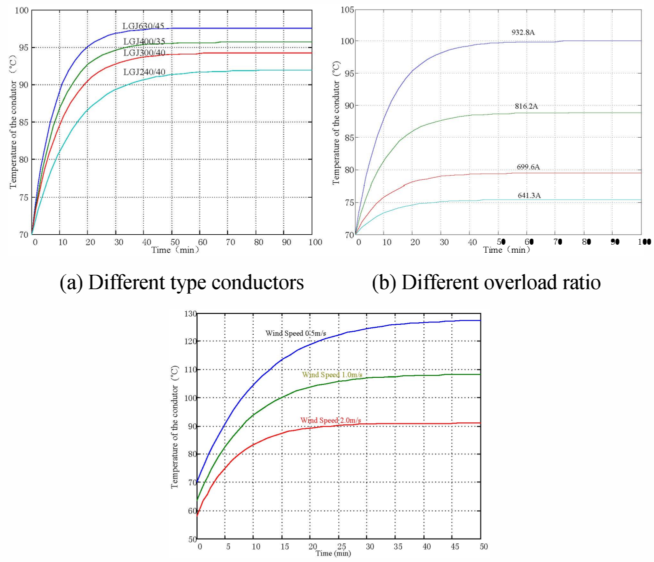
$$q_c + q_r + m \cdot C_p \frac{dT_c}{dt} = q_s + I^2 R(T_c) \tag{5}$$

T_c is the temperature of conductor; m·is the mass of unit length conductor; C_p is the specific heat capacity of unit length conductor. The thermal balance process of several kinds of conductor were calculated, the parameters of the conductor are list in Table I.

TABLE I. PARAMETERS OF THE COMMON CONDUCTORS

Nominal Section Al/St (mm)	Structure		Calculation Section (mm^2)		Mass per Unit Length (kg/m)		Calculation Diameter (mm)	20°C DC Resistance (Ω/km)	Specific Heat(J/m·°C)
	Al	St	Al	St	Al	St			
LGJ240/40	26	7	238.85	38.9	0.646	0.303	21.66	0.1209	760.987
LGJ300/40	24	7	300.09	38.9	0.811	0.303	23.94	0.09614	919.07
LGJ400/35	48	7	390.88	34.36	1.057	0.268	26.82	0.07389	1136.58
LGJ630/45	45	7	623.45	43.1	1.685	0.336	33.6	0.04633	1769.37

The temperature increasing speed of the 4 kinds of conductors are different with same overload ratio, as shown in Fig.5 (a). The transient time of increasing temperature is different with different overload ratio, and the transient time of LGJ400/35 type conductor is shown in Fig. 5(b). The ambient condition has obvious effect on the temperature increasing process, and the temperature increasing process of LGJ400/35 type conductor with different wind speed is shown in Fig.5(c).



(a) Different type conductors (b) Different overload ratio

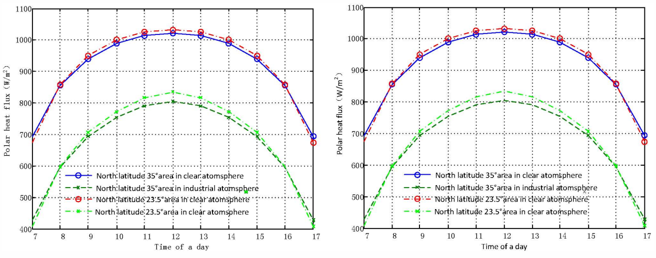
(c) Different wind speed

Fig. 5. Balance process of the conductor and effect factors

B. *Effects of Solar Heat Flux on Temperature of Conductors*

According to the Eq.4, the solar played import role in the thermal balance of conductors. The irradiance of solar has ever been real-timed monitored with irradiance sensor equipped in the field. But the measurement result showed dramatic variety within a large range. In the engineering practice, it is strongly recommended that the maximum possible solar heat flux is taken as basis value in the dynamic rating system.

In IEEE standard [5], calculation method of the solar heat flux is given in detail. In this paper, the maximum possible solar heat flux in the area of east China is worked out, as shown in Fig.7.



(a) February (b) August

Fig. 6. Solar heat flux in clear and industrail atmosphere at Feb. and Aug.

V. DEMONSTRATION PROJECT OF THE DYNAMIC RATING SYSTEM

A. Distribution of the Monitoring Devices

The demonstration project was put into operation and serving to a coal-fired power plant with 2 overhead 500kV transmission lines connected to the east China power grid in Zhejiang province, China. The transmission line between the power plant and the 500kV substation is 65km. There are 6 monitoring points was setup. All monitoring devices were equipped on the LGJ400/35 type conductor. The type of conductor without monitoring device in the middle section is LGJ630/45, which possessed ability enough to increasing capacity. The monitoring points was shown in Fig.7, and indicated by red stars.

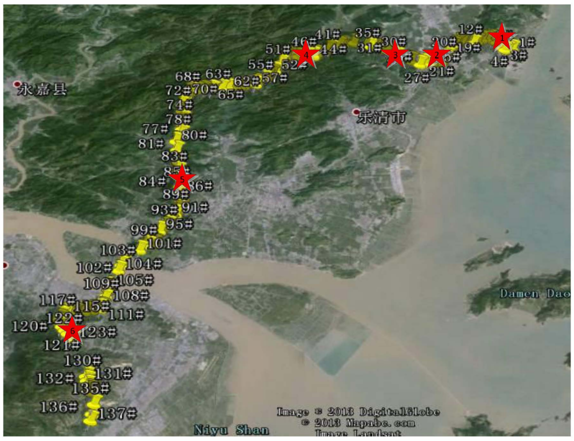


Fig. 7. Distribution of condition monitoring device

B. Field Test for Verifying the Calculation Model

Calculation model is the core of the dynamic rating system. For verifying the model the test was performed. The temperature of conductor was tested by infrared thermal imager near the monitoring point 5. The test results and inverse calculation value from the model are listed in Table II.

TABLE II. PARAMETERS OF THE COMMON CONDUCTORS

Sampling No.	Calculation value	Monitoring value	error value
1	35.8	38.1	-2.3
	36.2	34.6	1.6
2	34.8	37.1	-2.3
	35.1	34.6	0.5
3	33.4	36.8	-3.4
	33.6	34.6	-1
4	33	36.4	-3.4
	33.1	33.8	-0.7
5	32.4	36.8	-4.4
	32.5	33.5	-1
6	31.6	34.7	-3.1
	31.7	33.3	-1.6
Maximum error			**-4.4**

Though measurement of the infrared thermal imager in daytime is easier to be affected by sunshine, the error of results had been able to adapt the engineering requests enough.

C. Closed Loop Test

For checking the function of hardware and investigating the availability of software closed loop test was performed. The results were shown in Fig.8.

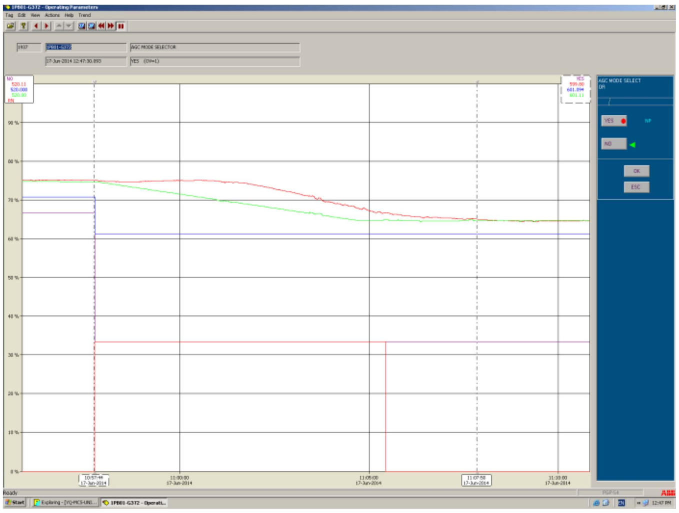


Fig. 8. Screen copy of DCS duiring the test in power plant

The instruction of decreasing load was given in 10:57, the generator output start to decreasing. At 11:07 the load of transmission line has decrease to 65% full capacity from 75%, which indicated the load decreasing speed is about 1% full capacity per minutes.

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