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Load Characteristics Analysis and Simulation Study of Electric Locomotive

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Abstract

Electric locomotive is a kind of high power rectifier load, and its load characteristics will have a significant impact to safe, stable and economic operation of power system. This paper mainly analyses load characteristics of harmonic and reactive power for electric locomotive. Simulation model of electric locomotive is set up based on time trigger; it is so better conform to the dynamic characteristics of the electric locomotive. The mathematical model of SS_8 electric locomotive is built, using MATLAB simulation software, dynamic simulation of electric locomotive is realized, and dynamic harmonic current and reactive power demand are obtained for traction supply network. The simulation results well reflect the operation situation of electric locomotive. It indicates that the research method of electric locomotive load characteristics is correct and effective.

Keywords: *electrified railway, power quality, electric locomotive, load characteristic*

1. Introduction

Chinese electrified railway is developing greatly, and the percentage of electrified railway traction loads in power load grows rapidly. Electric locomotive is the most important part of the electrified railway. It is large power electrified railway traction load. The harmonic current and negative sequence current are in great significance impact to the security, stability and economical running of the power system. It also influences the running of master. So it is required to research the load characteristic of electric locomotives and formulate corresponding measures. The purpose is to reduce the degree of impact on power system, ensure reliable power supply for power users.

Reference [1] introduced locomotives with the most comprehensive and earliest in using MATLAB to simulate. The method of piecewise and sub-statuses simulation is adopted by most literatures. Reference [2] simplifies electric locomotive and makes it equivalent to single-phase controlled rectifier bridge. This method is simple and accurate when carrying out FFT analysis to harmonic. Reference [3] includes traction transformer, and implementing piecewise and sub-statuses simulation in one artificial circuit by setting pulse trigger delay angle in every thyristor. Reference [4] adopts MATLAB set_param function to carry out numerical transmission for time-varying parameters in different working conditions. It implements dynamic simulation to a certain extent. In the literatures mentioned, the commutation processes in one segment and between different segments are ignored for simplify the simulation process. This paper takes SS_8 electric loco- motive for example, then carries out simulation analysis by using the conduction angle (α) which calculated from relationship between locomotive pull-in control characteristic function and rectifier circuit.

2. Electric Locomotive Rectifier Circuit

Electric locomotive load is caused by the transformer, rectifier and DC motors consisting of a strong non-linearity, low power factor load. It is the main harmonic and fundamental reactive current source of the electric railway traction power supply system, and it is a fundamental source of negative sequence current. The operating conditions of electric locomotive is complex, the resulting variability of harmonics, reactive and fundamental negative

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sequence current is large, and causing the power quality of traction power supply system exceeds state standards.

This paper researches on AC-DC locomotive rectifier module based on the model of SS_8 electric locomotive as the representative. The locomotive is in type of SS_3 locomotive with major technical transformation. SS_8 electric locomotive has the following advantages. (1) With low traction rod, lower the towing point height of bogie and car body, and reduce the axle load transfer within each bogie axle load evenly, improving locomotive utilization coefficient of adhesion. (2) Adopting the method of front and rear bogie independent power supply, electric transformer is remolded into two independent windings, and the rectifier is separately. Then it can achieve electrical compensation. The adhesion utilization of front and rear steering is further improved. (3) Cancelling the voltage-regulate switch, equipping it into unequal three sections phase control, and adjusting voltage smoothly, so the phase control locomotive traction performance is good. Then the problems of discordant between regulating switch and electronic cabinet and the problems of idling protection slow are settled. It provides the conditions for the adhesive limit, constant current limit, and compensation for axle weight transfer. (4) Adopting the new design of rectifier device and electronic housing, improving the technical level of the locomotive and the key equipment into a perfect level, and electronic housing reached 8k locomotive introduced in the standard. (5) Incorporate feedback the resistance braking, improving the low-speed electric performance. Make it has maximum while spread out the area of the brake to 19km/h. Cancelling the braking switch, improving the reliability of the brake [5, 6].

As Figure 1 shown, SS_8 locomotive rectifier module adopts rectifying voltage regulation circuit, which thyristor three sections of not equal half-controlled bridge. Three taps in transformer two sides are a1-b1, b1-x1 and a2-x2. No-load voltage rating is 347.7V, 347.7V and 695.4V respectively. VD1, VD2, VD3 and VD4 are diodes. VT1, VT2, VT3, VT4, VT5 and VT6 are thyristor rectifier bridges. M1 and M2 are DC traction motors. L_f is traction motor excitation winding. R1 and R2 are fixed shunt resistances. L1 and L2 are flat wave reactors. Through the transformer windings inputs and the change of the thyristor phase angle, the size of the voltage on the traction motor is controlled, and the speed of electric locomotive is adjusted [7].

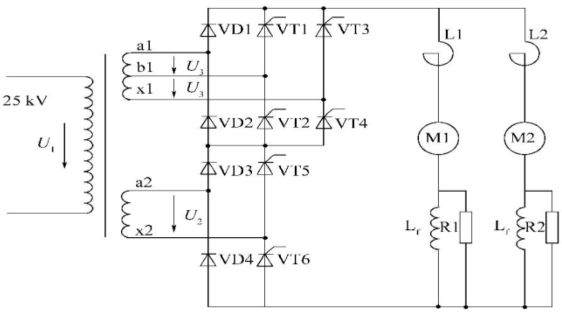

Figure 1. SS_8 Type Electric Locomotive Rectification Voltage Regulating Circuit

It can get to know from references, the traction control characteristic function of SS_8 is as follows:

$$I_a = \begin{cases} 120n \\ 875n - 87.5v \\ 1360 \end{cases} \tag{1}$$

n is series, and its stages is 18. v is speed (km/h). I_a is the motor armature current.

According to series and speed, it can gain the current of motor armature. From the DC motor basic formula in motor learning, we can get:

$$U_d = I_d \sum R + Cv\phi \tag{2}$$

C is electrical machine constant ($C = \mu_c C_z / 60\pi D$, μ_c is transmission ratio, D is wheel diameter). ϕ is flux per pole. R is the resistance of the rectifier reflux.

The angle of α can be calculated from equation (1) and equation (2). In the first bridge plot, $U_d = U^{'}$, $\alpha = \arccos[(\pi U^{'} / \sqrt{2}U_2) - 1]$. When it is in the second bridge plot, $U_d = U^{''}$, $\alpha = \arccos[(\pi U^{''} / \sqrt{2}U_3) - 5]$, and the third bridge plot is coming, $U_d = U^{'''}$, $\alpha = \arccos[(\pi U^{'''} / \sqrt{2}U_3) - 7]$ [8].

3. Electric Locomotive Load Characteristic Analysis

When the sinusoidal voltage applies to the passive linear load, the resulting current is a sine wave with the same frequency. When a sine wave voltage applies to the non-linear load, the current includes to the other frequency components, which is a non-sinusoidal. Defines the total harmonic distortion coefficient of THD (total harmonic distortions) to describe the harmonic, the formula is shown as Equation (3).

$$THD = \frac{\sqrt{I^2 - I_1^2}}{I_1} \tag{3}$$

From Equation (3), I_1 is fundamental current valid values, I is the total current valid values. Based on reference [9], also using the power factor, fundamental voltage and current phase coefficient represents the total harmonic distortion coefficient. The relationship shows in Equation (4).

$$THD = \sqrt{(\frac{\cos\varphi_1}{\cos\varphi})^2 - 1} \tag{4}$$

Electric locomotive speed control is in close relationship with the rectifier circuit, AC-DC electric locomotive adopts thyristor rectifier phase to achieve a smooth speed regulation. When the semi-phase-controlled rectifier control mode and large inductor with a counter electromotive force load, the average thyristor rectifier output voltage shows in Equation (5).

$$U_d = \frac{1}{\pi}\int_{\alpha}^{\pi} \sqrt{2}U_2 \sin(\omega t) d(\omega t) = 0.9U_2 \frac{1+\cos\alpha}{2} \tag{5}$$

Which U_2 is the locomotive main transformer secondary side voltage RMS. α is control angle of thyristor rectifier bridge ($0° \le \alpha \le 180°$). As can be seen, it can change terminal voltage of the DC locomotive traction motor by adjusting the control angle so as to realize smooth regulating.

Generally, it has the following two points to evaluate the performance of the electric locomotive. The first is the locomotive of dragging the level of efficiency and energy saving of the motor. The second is that produced the size of the harmonic current and negative sequence current in the runtime. Setting electric locomotive main transformer secondary side the effective values of voltage and current for U_2 and I_2, the apparent power of electric locomotive is $S = U_2 I_2$, locomotive power factor is as shown in Equation (6).

$$\cos\varphi = \frac{P}{S} = \frac{U_d I_2}{U_2 I_2} = \sqrt{\frac{1}{2\pi}\sin 2\alpha + \frac{\pi - \alpha}{\pi}} \tag{6}$$

Among them, $\cos\varphi$ is the power factor, α is control angle of thyristor rectifier bridge. According to knowledge of the circuit power, the power factor reflecting the degree that active power is close to the apparent power. Reactive power reflects in the flow and exchange of energy, does not reflect the consumption of energy in the load. Specific to the reactive power of the electric locomotive is used to electric locomotive traction motor that build in electromagnetic places of power. Through equation (6), the relationship between the reactive power and control angle of thyristor rectifier can be deduced, such as Equation (7).

$$\sin\varphi = \frac{Q}{S} = \sqrt{\frac{\alpha}{\pi} - \frac{1}{2\pi}\sin 2\alpha} \quad (7)$$

By the above Equation (6) and Equation (7), known power factor will change as the control angle changes. Reactive power will also change in the share of the apparent power. When the output voltage of the rectifier circuit electric locomotive is small, the power factor values is low, at this time, most of the energy is used for establish excitation.

4. Simulation of Electric Locomotive Load Characteristics

In the MATLAB, established simulation model of SS_8 electric locomotive is as shown in Figure 2.

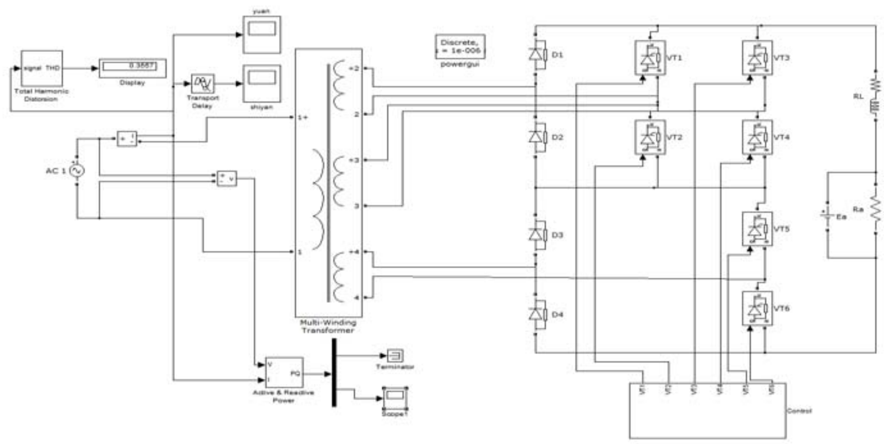

Figure 2. Simulation Model of ss_8 Electric Locomotive

According to Reference [10] set parameters, AC1 is the equivalent network traction module, voltage parameter is $25\times\sqrt{2}$ kV. Multi-winding transformer is equivalent transformer module. It is set to 50MVA. And the primary side parameters are $25/\sqrt{3}$ kV. Three taps on the secondary side under the previous parameters are $347.7/\sqrt{3}$ V, $347.7/\sqrt{3}$ V and $695.4/\sqrt{3}$ V in sequence. The motor is equivalent to inductance load RL module, the parameters are 0.5Ω, 0.01H respectively. Counter electromotive force is 100V, internal resistance of series parallel form is 0.2Ω. Simulation algorithm adopts ode23tb, simulation time 0.6 second.

Based on the simulation method of timing trigger thought, the goal is within a predetermined simulation time. Electric locomotives from the first period of conduction angle $\alpha = 60^\circ \sim 30^\circ$ changes, then jumped to the second conduction angle $\alpha = 60^\circ \sim 30^\circ$ changes, and finally jumped to the third paragraph of the conduction angle $\alpha = 60^\circ \sim 30^\circ$ changes. Making electric locomotive that access the current from traction network exhibits dynamic, fit to the actual operation of the electric locomotives working conditions. Which, control modules is the key subsystem. The output clock module is to trigger VT5/VT6-control module, VT1/VT2-control module and VT3/VT4-control modules. It is as shown in Figure 3.

VT5/VT6-control module, VT1/VT2-control module and VT3/VT4-control module are three similar modules. Their basic working process is logical comparison between simulation time being from clock module and a specific point in time constitute a constant module, thus forming a step response signal in specific point. This signal together with the corresponding pulse flip-flops are constituting the corresponding time-pulse. Taking an example of VT1/VT2-control module, before 0.2 second, the bridge rectifier section 2 does not work, so it does not output pulses. Secition 2 of rectifier bridge begin to input after 0.2 second. While 0.2 to 0.3 second, the conduction angle $\alpha = 60^{\circ}$, While 0.3 to 0.4 second, the conduction angle $\alpha = 30^{\circ}$, after 0.4 second, the full-on state. It is as shown in Figure 4.

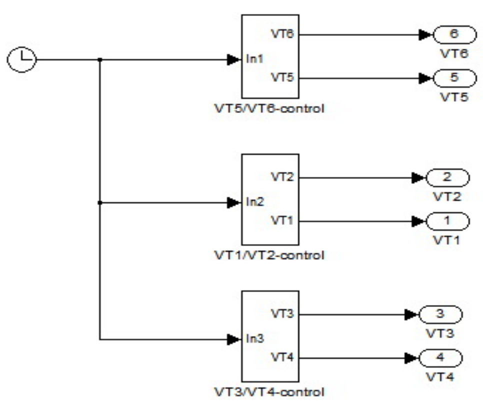

Figure 3. Control Module of Key Subsystem

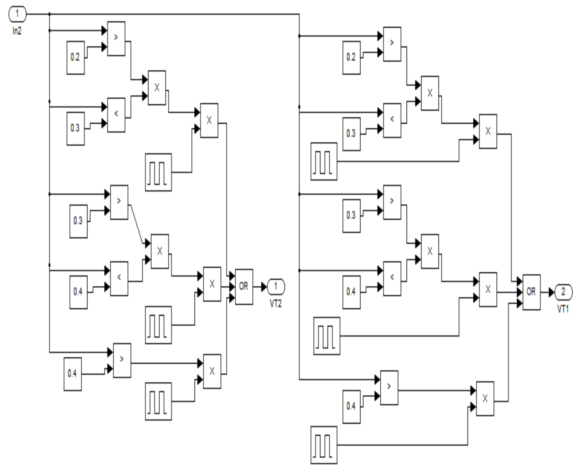

Figure 4. VT1 / VT2 Control Module

Simulation time is 0.2s each phase, the first paragraph conduction angle of electric locomotives changes from $\alpha = 60^{\circ}$ to $\alpha = 30^{\circ}$. The second paragraph simulation time is from 0.2s to 0.4s, the conduction angle changes from $\alpha = 60^{\circ}$ to $\alpha = 30^{\circ}$, when it jumps to the third paragraph 0.4~0.6s, the conduction angle changes from $\alpha = 60^{\circ}$ to $\alpha = 30^{\circ}$. It can be get traction network side current changes as shown in Figure 5, and the current distortion rate is equal to 0.3557 through current total distortion module. This suggests that traction network current includes harmonics component. Reactive power demand change is as shown in Figure 6. Values of current measurements module are import into the MATLAB workspace, sampling frequency is 1000Hz, and sampling points are 600. It can be obtained the size of the harmonic components that generated by electric locomotive, as shown in Figure 7.

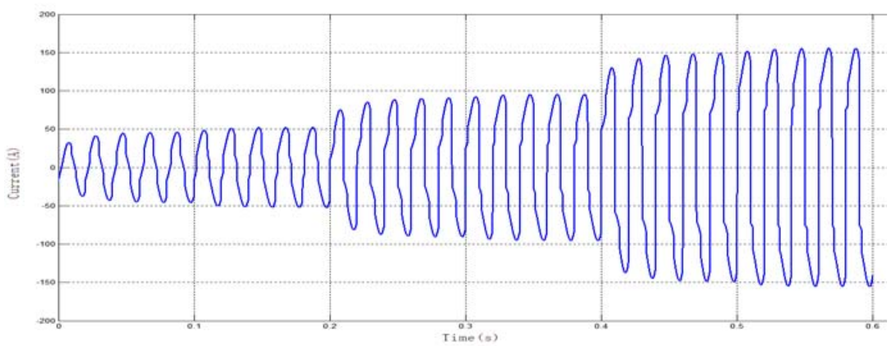

Figure 5. Traction Net Side Current Variation

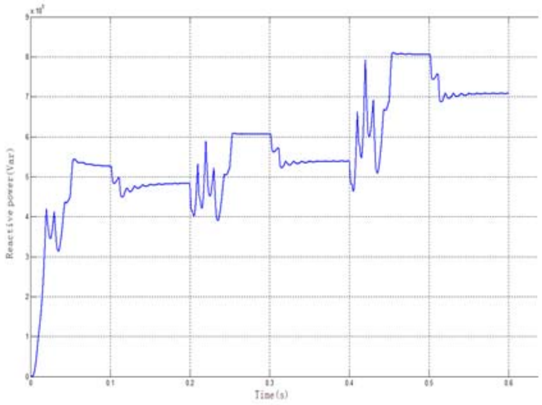

Figure 6. Electric Locomotive Reactive Power

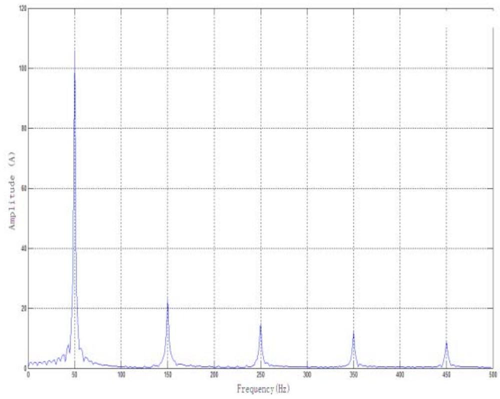

Figure 7. Harmonic Content Analysis Diagram

5. Conclusion

This paper takes SS_8 electric locomotive as the research object, then establishes the mathematical model. The simulation method based on the idea of time trigger, conduct touch off the pulse when it satisfies with certain conditions, then to realize dynamic simulation of electric locomotive through using simulation software named MATLAB. The simulation results indicate that the research method of electric locomotive load characteristics is correct and effective.

References

[1] Li CY, Huang XF, Jin JD. SS_{3B} the Overall Circuit of Electric Locomotive. *Electric Locomotive Technology*. 1993; 10(1): 8-10.

[2] Huang SZ, Li JH, Zhao J. The Electric Locomotive Digital Simulation Model Based on MATLAB. *Automation of Electric Power Systems*. 2002; 26(2): 51-60.

[3] Zhao SD. SS_8 Type Electric Locomotive. Beijing: China Railway Publishing House. 2004.

[4] Li Y, Liu MG, Li N. Research on Simulating Electric Locomotive Regenerative Braking. *Railway Computer Application*. 2007; 16(10): 1-3.

[5] Risnidar C, Ismail D, Syafruddin H, Norhaidar H. Influence of Harmonics in Laboratory due to Nonlinear Loads. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2012; 2(2): 219-224.

[6] Wang B, Gao SB, Han XD. Power Flow Calculation for Traction Networks under Regenerative Braking Condition Based on Locomotive-Traction Network Coupling. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2013; 11(2): 848-854.

[7] Zhang JJ, Xiao XN, Yin ZD, Jiang PS. Simulation Model of SS6B Electrical Locomotive Based on PSCAD. *Electric Drive for Locomotives*. 2008; 10(6): 27-29.

[8] Zheng Q, Liu JJ, Guo JL. Study of Radiant Interference Based on Model of Electric Locomotive in Underground Tunnel. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(9): 5091-5096.

[9] Zhang GD, Li XR, Li PQ. Simulation Research on Load Characteristics of Electric Locomotive Traction motor. *Electric Drive for Locomotives*. 2009; (1): 21-24.

[10] Li W, Zhu L, Ma ZG. Type SS_8 Electric Locomotive Power Supply System Modeling and Simulation Based on Matlab/Simulink. *High Power Converter Technology*. 2009; 12(6): 6-9.