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Analysis and research on calculation method of ac and dc power supply in urban rail transit

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ABSTRACT

Nowadays, in the traction power supply field of urban rail transit, AC traction power supply system usually carries out at DC traction side or executes separately at AC/DC sides, which simplifies the internal relationship and reduces the calculation precision. As to this condition, the research explores a new calculation method of traction power supply, which based on the unified AC/DC power supply system of rectifier unit model. Besides, it also discuss the traction power supply calculation method based on rectifier unit model, in which the improved Newton method and Gauss-Seidel method is applied. After the application, the method and model are verified. The power supply system in the verification is 10-node AC/DC traction power supply system, which indicated that the method is correct. In the unified AC/DC urban rail, the 12 pulse rectifier unit model based traction power supply calculation method would dynamically simulate the parametric variation of the node electric in the urban rail transit traction power supply system under different traction load. The method is proved to be feasible and the result is effective, moreover, it would also give further guidance to the analysis and design of the power supply system.

KEYWORDS

Urban rail transit; Traction power; Unification of AC/DC; Rectifier unit.

INTRODUCTION

With the development of urban economy, urban rail transit also develops rapidly. However, the problem of the reliability and security of the traction power supply system goes follow. As an essential part of the urban rail power supply system, traction power supply calculation is the key factor in the design of urban rail transit traction power supply system. Many researchers have already conducted researches on the calculation of urban rail traction power supply. Through the application of power voltage equation based on Newton method, Tylavsky resolved the unified AC/DC power flow of traction power supply. Taking communication resistance and harmonic current into consideration, Yii-Shen Tzeng raised the calculation method of the urban rail transition system. Node voltage method is applied in Yan CAI's solution to the figures, and complicated ground grid model is added in the construction of the model. C.S.Chen and Y.S Tzeng improved the 6 pulse rectifier unit to 12 pulse rectifier unit and established fundamental harmonic mathematical model. The simulation method raised by Xiaodong WANG is based on CAD technology and circuit network technology theory, part of which has been applied in the research of traction power supply system. There are still other researches inject fresh blood to the system by developing simulation software and system, and raising new calculation methods.

With the rapid development of domestic urban rail transit, it requests more and higher demands of the reliability and security of the traction power supply system. The application on simulation technique in the design of traction power supply system enables the convenient selection among various plans and also the rectification of parameter during the operation process. Thus, the design can be optimized to improve efficiency and reduce investment, so as to reduce the operation cost. Computer is an effective instrument and method in the design of traction power supply system. Based on the 12 pulse rectifier unit model, this essay raises a traction power supply calculation method that iterates the unified AC/DC. In the calculation of train traction, the position and power distribution of the train should be acknowledged according to train diagram. Given the acknowledgment of the position of all the running trains, the power supply calculation should be done based on rectifier unit model. Through the calculation, the electric tension and loan in any node of the system can be obtained with the passing of time.

RECTIFIER UNIT MODEL

12 pulse rectifier units are utilized in this research. The core technology of electric automobile is relatively mature after decades of development. The electric automobile on the market can mainly be divided into 3 categories: pure electric vehicles, hybrid electric vehicles and fuel electric vehicles. Fuel electric vehicle and pure electric vehicle are theoretically similar in the transformation from the vehicle battery power into electricity, which is comparatively efficient and non-polluting. Due to the high cost, it is not available for manufacturing. As to hybrid electric vehicles, two or more power sources are installed in the vehicles. A relative common example is that the internal combustion engine and electric motor are installed together. As is shown in Figure 1.

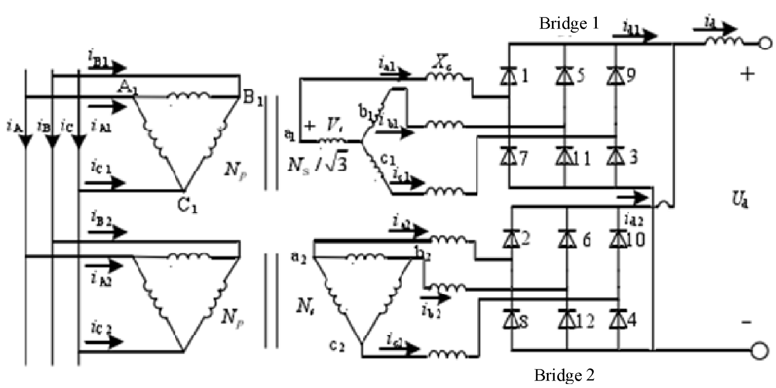

Figure 1 : Connection method of 12 pulse rectifier unit

In this research, the connection of the rectifier unit is completed without bridge balanced reactor, which leads to the interaction between the two electric bridges in the operation of the rectifier unit. There are 7 operation modes in the interaction, which can be distinguished from the differences of diode conduction numbers. With the variation of reactor factor, there are four operation modes in normal operation. Generally, 5-4 mode refers to the normal operating state in the traction power supply calculation of urban rail transit. Under 5-4 mode, the conduction number of the diode is conducted by 5 and 4 in proper sequence. Load current should be continuous with π/6 conversion cycle, then the DC voltage and current and AC fundamental power can be calculated by the formula, which is shown in formula (1)-(5) as follow

$$E_d = \frac{6U}{\pi}\left\{\begin{array}{l}\frac{\sqrt{2}(3+2\sqrt{3})}{7}\left[\sin(\alpha_1+\mu)-\sin\alpha_1\right]+\\ \frac{1+\sqrt{3}}{2}\left[\sin\left(\alpha_1+\frac{\pi}{12}\right)-\sin\left(\alpha_1+\mu-\frac{\pi}{12}\right)\right]\end{array}\right. \quad (1)$$

$$I_d = \frac{\sqrt{2}U}{Xc}\left\{\begin{array}{l} -\sqrt{3}\left[\sin(\alpha_1+\mu)-\sin\alpha_1\right]+2\left[\sin\left(\alpha_1+\mu-\frac{\pi}{6}\right)-\sin\left(\alpha_1-\frac{\pi}{6}\right)\right]+ \\ \frac{\sqrt{3}-1}{4\sqrt{2}}\left[\sin\left(\alpha_1-\frac{5\pi}{12}\right)-\sin\left(\alpha_1+\mu-\frac{7\pi}{12}\right)\right] \end{array}\right\} \quad \textbf{(2)}$$

$$P_1 + jQ_1 = 2\sqrt{3}U(I_{a2,r1} + jI_{a2j1}) \quad \textbf{(3)}$$

$$P_1 = \frac{4\sqrt{3}U^2}{\pi X_c}\left\{\begin{array}{l} \sin\mu\phi_{31}(\mu)+\sin(\frac{\pi}{6}-\mu)\phi_{32}(\mu)+\sin(\mu+\alpha_1-\frac{\pi}{3})\phi_{33}(\mu)+ \\ \sin(\mu+\alpha_1+\frac{\pi}{3})\phi_{34}(\mu)+\sin(\mu+\alpha_1)\phi_{35}(\mu)+0.7588 \end{array}\right\} \quad \textbf{(4)}$$

$$Q_1 = \frac{4\sqrt{3}U2}{\pi X_c}\left\{\begin{array}{l} -\sin\mu\Psi 31(\mu)-\sin(\frac{\pi}{6}-\mu)\Psi 32(\mu)- \\ \cos(\mu+\alpha_1-\frac{\pi}{3})\Psi 33(\mu)-\cos(\mu+\alpha_1+\frac{\pi}{3})\Psi 34(\mu)- \\ \cos(\mu+\alpha_1)\Psi 35(\mu)+0.4375\mu+0.058(\frac{\pi}{6}-\mu) \end{array}\right\} \quad \textbf{(5)}$$

In the above formula, U refers to the RMS of the AC voltage in 12 pulse rectifier unit; P1 refers to the active power of the rectifier unit fundamental power; Q1 refers to the reactive power of the rectifier unit fundamental power; Ed and Id refers to the DC voltage and current of the rectifier unit; Xc refers to the commutating reactance of the rectifier unit; the value ofα1 is approximately 2.192°, indicating Delayed conduction angle; μ refers to Commutation overlap angle. The calculation formula is shown in formula (6).

$$\begin{array}{l} \frac{X_c I_d}{\sqrt{2}U}+\cos(\alpha_1+\mu)-\cos\alpha_1- \\ \frac{\sqrt{3}-1}{4\sqrt{2}}\left[\sin(\alpha_1-\frac{5\pi}{12})-\sin(\alpha_1+\mu-\frac{7\pi}{12})\right]=0 \end{array} \quad \textbf{(6)}$$

The equivalent 24 pulse rectifier unit is also applied in the research. It is made up of two 12 pulse rectifier units by side-prolonging triangle connection method. In constitute of line side winding, phase-shift should be ±7.5°, which would form a 15°phase among the four Valve windings. Through uncontrolled three-phase bridge rectifier, it will give a parallel output in DC side. Generally, a 24 pulse rectifier unit can be acknowledged as the joint work of two 12 pulse rectifier unit, which the two unit working independently. In this research, the simple depiction of equivalent 24 pulse rectifier unit is shown as follow in Figure 2. The DC voltage of 12 pulse rectifier unit and 24 pulse rectifier is the same, whereas the current, fundamental active power and fundamental reactive power of 24 pulse is two times that of 12 pulse.

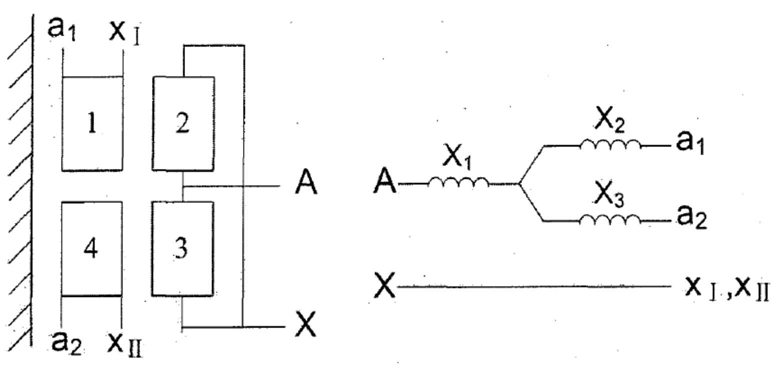

Figure 2 : Structure of split transformer and equivalent circuit

CALCULATION OF TRACTION POWER SUPPLY OF UNIFIED AC/DC IN URBAN RAIL TRANSIT

Resolution based on newton method

The power supply system of urban rail transit is AC and DC, and the system connects the AC side. Then, there are three power supply methods of depressurization as follow: Centralized power supply, decentralized power supply, and integrated power supply. The system power will then be rectified into DC current to provide motivation for the train. As to the calculation, the model of 12 pulse rectifier unit is listed in Figure 3, in which the formula of DC/AC node in rectifier unit is the same with formula (1). Node voltage can be expressed in the form of polar coordinates. Thus, formula (3) and (4) can be applied to calculate the capacity of the DC and AC side node in the rectifier unit. In the formula, p refers to AC side node; t refers to DC side node; N refers to the node volume of AC system; M refers to the node volume of DC system. Through the application of Newton method, Jacobi matrix can be got as shown in formula (5)

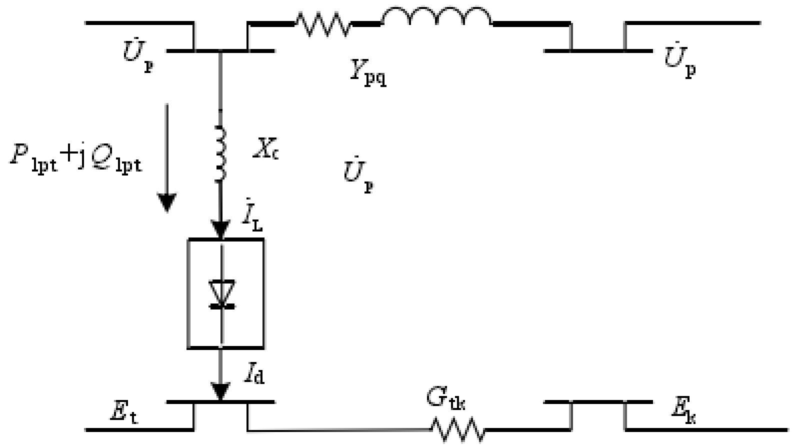

Figure 3 : Model of 12 pulse rectifier unit

$$\Delta P_p = P_p - \sum_{i=1}^{N} U_p U_i (G_{pi}\cos\delta_{pi} + B_{pi}\sin\delta_{pi}) - P_{1pt}$$
$$\Delta Q_p = Q_p - \sum_{i=1}^{N} U_p U_i (G_{pi}\sin\delta_{pi} - B_{pi}\cos\delta_{pi}) - Q_{1pt} \quad \textbf{(7)}$$
$$\Delta P_t = P_t - \sum_{i=1}^{M} E_t E_i G_{ti} + E_t I_d$$

Two joint-working 12 pulse rectifier unit have the same effect of an equivalent 24-pulse rectifier unit. Its AC and DC side power deviation is shown in formula 6. Jacobi matrix can be drawn up according to formula 8.

$$\Delta P_p + j\Delta Q_p = P_p + jQ_p - \dot{U}_p\left(\sum_{q=1}^{N} Y_{pq}\dot{U}_q\right)^* - 2P_{1pt} - j2Q_{1pt}$$
$$\Delta P_t = P_t - E_t\left(\sum_{k=1}^{M} G_{tk}E_k\right) + 2E_t I_d \quad \textbf{(8)}$$

Resolutions based on gauss seidel method

The rectifier unit can be seen as a load in the iteration of AC power supply system, and a voltage source with internal resistance in DC power supply system. (See Figure 4) The calculation steps of DC traction power supply system based on Gauss Seidel method are as follow.

(1) Confirm the current position and capacity of the running train, which is calculated according to the running chart and train traction.

(2) The initial value of node voltage, commutation overlap angle of the rectifier unit, and the DC current should be set.

(3) With the application of formula (1), the capacity of the rectifier unit in AC side can be calculated according to the AC side voltage and commutation overlap angle.

(4)The capacity can be calculated through the above steps, and then the capacity data can be iteratively calculated to update the AC system voltage.

(5) The node voltage of DC side should be calculated firstly, and then calculating the DC system voltage.

(6) Calculate the injection current of the DC side node in the rectifier unit.

(7) If the vector difference is smaller than the permissible tolerance, go on to step (8), if not, go back to step (2) to calculate it once again.

(8) If it isn't the end of the simulation, further the execution next time. If it is the end, the simulation is over.

Comparison between model and calculation methods

The unified AC/DC traction power supply calculation method and 10-node hybrid traction power supply system should be compared in terms of the calculation result of 6 pulse rectifier unit. Based on Newton method, the unified AC/DC traction power supply calculation method, 12 pulse rectified unit should be conducted in the calculation of Gauss Seidel method. In the above three models, commutation resistance is not considered, and the convergence accuracy is $1X10^{-8}$ in calculation. The result needn't to be listed here, but we can draw the conclusion clearly that the total voltage of the traction network increases after the rectification of the 12 pulse rectifier unit. That is to say, the calculation method based on 12 pulse rectifier unit is feasible and the result is effective.

CASE STUDY

Based on the theoretically researches, with the application of VC.Net2005 language, the essay conducts simulation software exploration in urban rail transit traction power supply system. The distribution network will be seriously impacted when large amounts of vehicles connect it. First, the electric load will put more pressure on the total electric load of the distribution network. Second, if there is no limitation in vehicle charging, the load and deterioration of the distribution network will also worsen, which not only damage the distribution network but also lead to unnecessary waste of electricity. Therefore, the charge process of vehicles should be controlled to reduce the load and deterioration of distribution network, and thus the reliability of facilities and efficiency of electricity transmission would also be optimized. To better the control of electric vehicle charging, first, information communication between electric vehicles and distribution network should be improved; second, energy exchange between vehicles and distribution network should be promoted, which indicates that the electric information of the battery in the vehicles can be reflected to the network when the vehicles are not used. Thus, the energy exchange is achieved. For the convenience of discussion, this essay only focuses on the charging process and leave out the discharging process. In the charging process, the energy flow is unidirectional, but the information exchange is bidirectional. The information exchange contains: battery information and customer's requirements. Therefore, communication technology, request management technology, and dispatching technology are added into the charging control system of the vehicles. Train performance calculation results of up direction are listed in Figure 4.

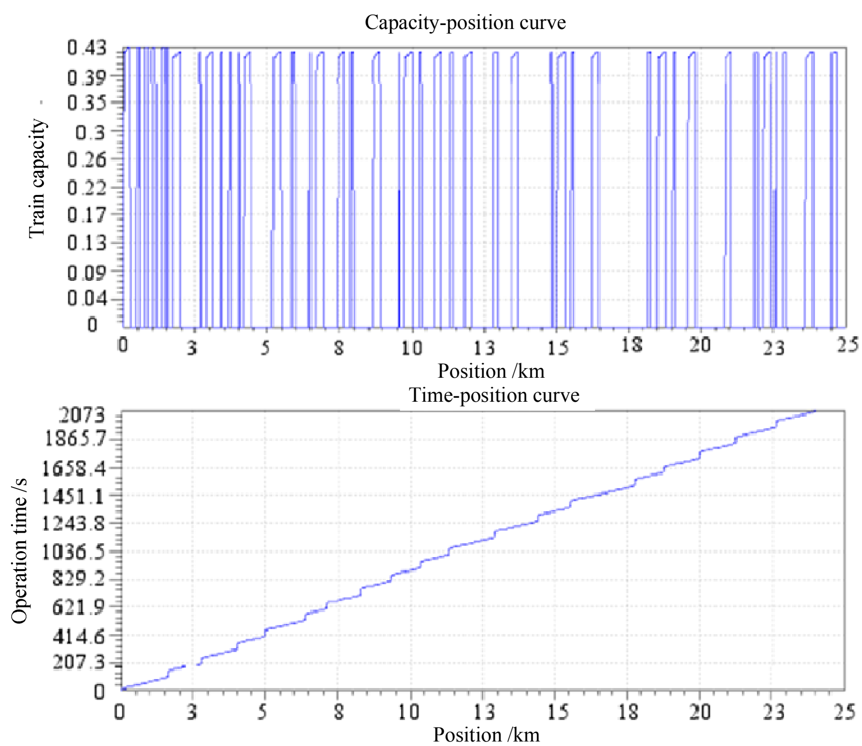

Figure 4 : Train performance calculation result of up direction

Equilibrium node is selected to be set in the PCC of the traction power supply system. The short-circuit capacity of each line-end system is also set to a fixed value---2000MVA. After the setting, the calculation method of unified AC/DC traction power supply in urban rail transit should be conducted according to the Newton method. Convergence accuracy should be set at $1X10^{-8}$ as above in the calculation. Train departure interval is 20 pairs / hour, in the unified AC/DC traction power supply system; DC side electric topology change is cyclical. The lowest voltage in the traction network is 1274V in a cycle, 180s.

CONCLUSION

Traction power supply system in urban rail transit seldom takes ground electric braking system into consideration in practical application. In this regard, in order to avoid high-order matrix solver, this essay comprehensively discuss the calculation method of both AC and DC traction power supply. Based on the ground electronic braking system, the calculation method of unified AC/DC traction power supply in urban rail transit is discussed in this essay. The calculation methods take 12 pulse rectifier unit and 24 pulse rectifier as models. Moreover, Newton method and Gauss Seidel method is introduced in this essay. After the introduction of methods, the research conducted verification on methods and models. 10-node hybrid traction power supply system is applied in the verification, which demonstrates that the method is correct. In the unified AC/DC urban rail, the 12 pulse rectifier unit model based traction power supply calculation method would dynamically simulate the parametric variation of the node electric in the urban rail transit traction power supply system under different traction load. The method is proved to be feasible and the result is effective, moreover, it would also give further guidance to the analysis and design of the power supply system.

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