Measurement and simulation of the electromagnetic transients of lifting pantograph for an electric multiple units train

Shi Dan, Wu Mingli, Zhang Honghe, Li Teng, Wang Hui, Song Kejian

***Abstract*-- The electric sparks and arcs occurred at the contact of a pantograph and an overhead contact wire are the emission source of electromagnetic interference in electric railways. It has been noticed by the train operators that CRH_2 EMU train has denser electric sparks more frequently than other EMUs when lifting its pantograph. The electromagnetic transients in the high voltage circuit may produce overvoltage and disturb the onboard electronic equipment, as well as emit high frequency electromagnetic interference. Some measurements of the charging transients when CRH_2 EMU lift the pantograph were conducted in the depot. Using PSCAD/EMTDC, a simulation circuit that includes external power source, the pantograph and the high voltage cable on the car roof is established. The simulations to analyze that how the circuit element parameters can affect the electromagnetic transients are given. The calculated results are compared with the measured data to validate the simulation model. Two solutions are put forward to improve CRH_2 charging transient performance.**

***Keywords*: electromagnetic transients, electric railway, overvoltage, high frequency oscillation.**

I. INTRODUCTION

IN recent years, high-speed railways have been developed rapidly in China. Some new technologies are used to meet the needs of high speed services, which also bring some new technical problems. One case in point is that the electric sparks and arcs occurred at the contact instant of a pantograph to the overhead contact wire, which are emission sources of electromagnetic interference in electric railways [1],[2]. The CRH_2 EMU train has more severe and more frequent electric sparks than other EMUs when lifting its pantograph to achieve the contact wire due to its distinct high voltage circuitry where there is a relatively long section of high voltage coaxial cable in front of the circuit breaker. It is the charging process of the cable that leads to the electric sparks of lifting pantograph.

This work was supported by the Fundamental Research Funds for the Central Universities of China (2010JBZ009, 2012JBZ006)

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Paper submitted to the International Conference on Power Systems Transients (IPST2013) in Vancouver, Canada July 18-20, 2013.

In this paper, a simulation circuit based on PSCAD/EMTDC is established. How the circuit element parameters can affect the electromagnetic transients including the peak voltage, the oscillation frequency and the transient duration are analyzed in virtue of simulation. The calculated results are compared with the measured data to validate the simulation model.

II. SIMPLE CIRCUIT ANALYSIS OF THE ELECTROMAGNETIC TRANSIENTS DURING LIFTING PANTOGRAPH

The circuit breaker is open when the CRH_2 EMU train lifts its pantograph. Then the high voltage circuitry of the EMU can be equivalent to a simple RLC series circuit as Fig. 1. R and L represent the source resistance and inductance of the contact wire. The capacitor C denotes the high voltage coaxial cable. The switch S describes the pantograph, which changes to close when the sliding strip of the pantograph reaches the contact wire. Assuming that the initial energy stored in the capacitor and the inductor is zero, when the switch closes the differential equation of the capacitor voltage u_c is

$$LC\frac{d^2u_C}{dt^2}+RC\frac{du_C}{dt}+u_C=e(t) \tag{1}$$

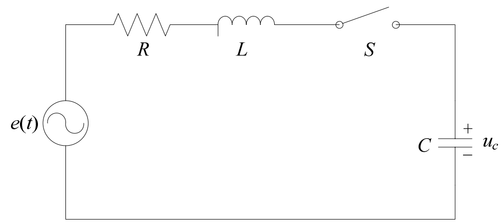

Fig. 1 Simple equivalent circuit

The CRH_2 EMU has a relatively long section of high voltage coaxial cable in front of the circuit breaker. Thus the distributive capacitance of the coaxial cable has significant effect on the charging oscillation process. In order to facilitate the analysis, the resistance in the circuit can be ignored. Therefore, a simple LC circuit can replace the original one. Consider the most adverse condition that the switch closes at the peak voltage. Then the capacitor voltage and the oscillation frequency can be calculated by

$$u_c=U_m(1-\cos\omega_0 t) \tag{2}$$

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad (3)$$

respectively.

u_c reaches the maximum at $t = \pi / \omega_0$. Actually, the oscillation process will be damped because the circuit resistance can cause energy loss. The attenuation coefficient is given by

$$\alpha = R / 2L \quad (4)$$

Obviously, greater resistance or smaller inductance can lead to a larger attenuation coefficient so that the transient component of the capacitor voltage decay faster and the transient duration become shorter.

III. Field Measured

In September 2011 and April 2013, some measurements of the charging transients when lifting the pantograph were conducted in Qingdaosifang Rolling Stock Factory of China. The CRH_2 EMU has four motor cars and four trailer cars. There is a pantograph on both the fourth and sixth car roof. Three kinds of high voltage cable are used as shown in Fig. 2. How do the contact wire voltage and cable charging current change during lifting the pantograph are measured.

In the former measurement, the contact wire voltage signal was collected from a voltage transformer of another EMU docked on the neighboring track of the same workshop. While the corresponding voltage signal of the latter measurement was collected from the contact wire directly by a voltage divider placed on the top of the tested EMU._The current signals were measured by current clamps. The field measuring pictures are shown in Fig. 3 [3].

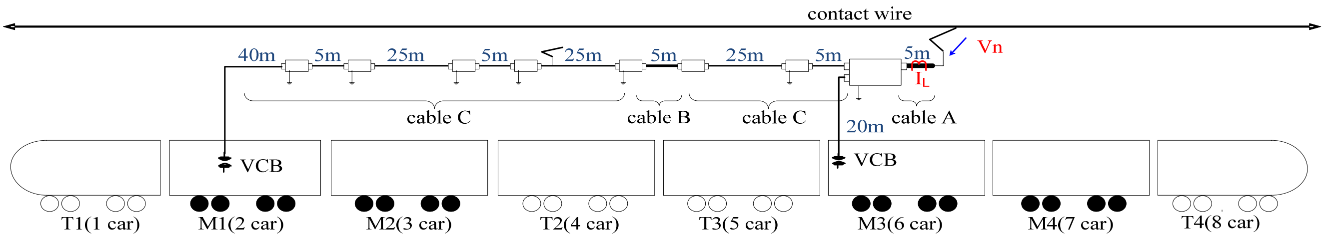

Fig. 2. Wire-connection diagram of high voltage cables

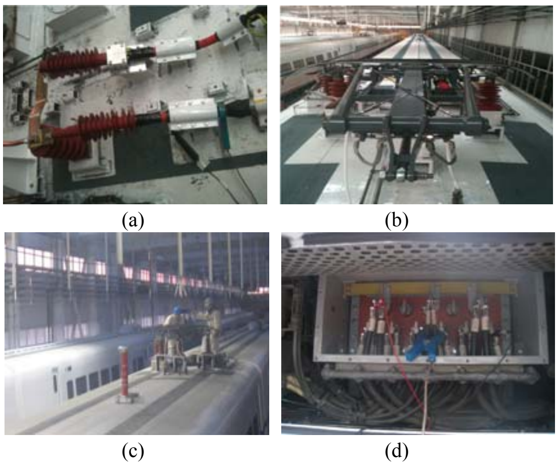

Fig. 3. Field measuring pictures

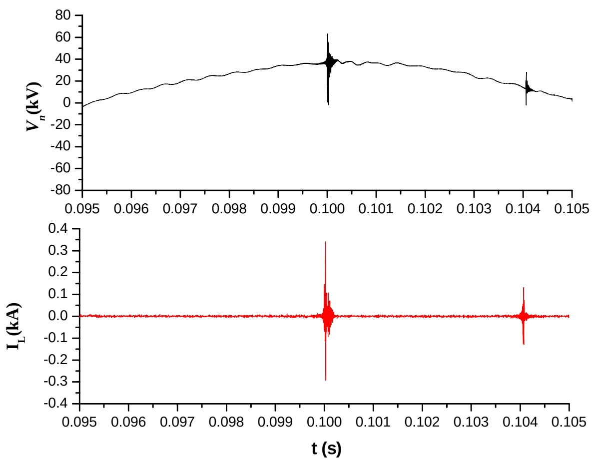

Fig. 4. Measured electrical quantities

During the test, the pantograph mounted on the sixth car was lifted and the following electrical quantities were measured:

V_n: Contact wire voltage

I_L: Total cable current

V_t: Traction transformer secondary winding voltage

I_p: Traction transformer primary current

One of the test results has been shown in Fig. 4. And its partially enlarged view is given in Fig. 5.

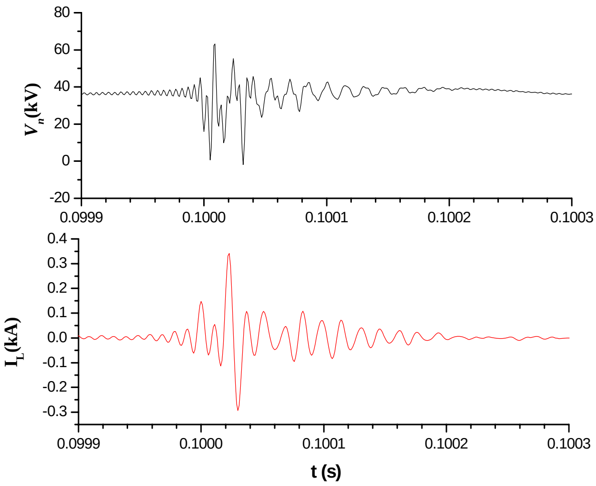

Fig. 5. Partially enlarged view

Figure 4 indicates that the pantograph contacts the overhead contact wire at around the peak value of 38.9kV, 50Hz supply voltage. The transient voltage is the sum of a high frequency component and a power frequency component. The decayed high frequency component represents the capacitive charging process, due to which, the voltage peak value reaches as high as near 65kV. The oscillatory frequency is about 66.67 kHz and the oscillation duration is approximate 0.2ms.

It is clear that the overvoltage caused by high frequency oscillation of the CRH$_2$ EMU is serious. This electromagnetic transient can cause interference to the electronic equipment onboard and will lead to electromagnetic emission to surroundings.

IV. Lifting Pantograph Simulation

A. PSCAD/EMTDC Simulation

The PSCAD/EMTDC model is given in Fig. 6.

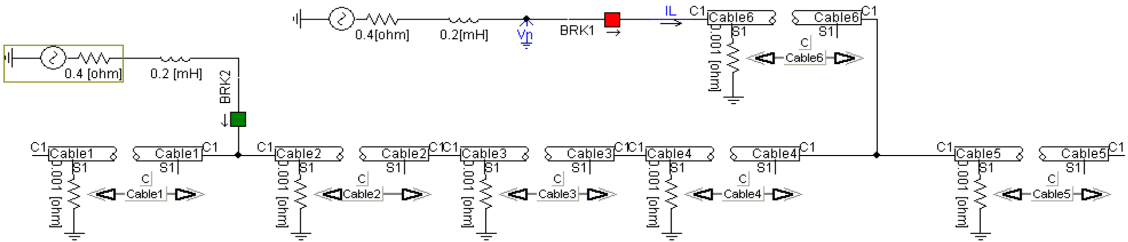

Fig. 6. Simulation model of the high voltage circuitry

In this model, the equivalent inductance and resistance of the power supply are set as 0.2mH and 0.4Ω respectively. Breaker 1 denotes the pantograph on the sixth car and breaker 2 denotes the pantograph on the fourth car. The high voltage cable configuration is shown in Fig. 7. The cable has a four-layer structure including a conductor, an insulating layer, a metal shield layer and an insulating sheath. The sizes of each layer for the three types of cable are marked on the Fig. 7.

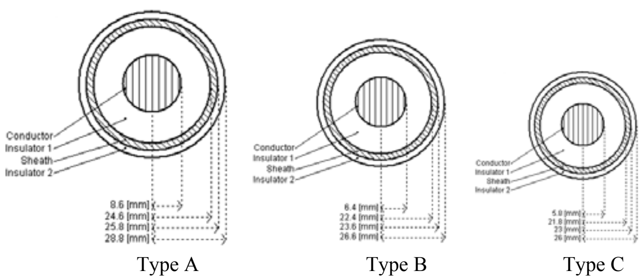

Fig. 7. Cable parameters

The simulation results under the condition that breaker 1 close at the peak voltage are given in Fig. 8 through Fig. 11.

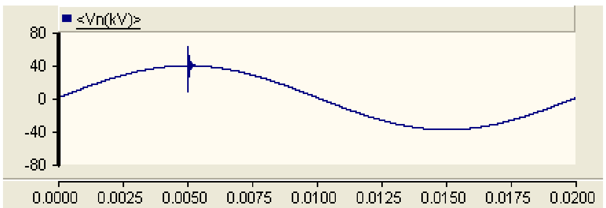

Fig. 8. Contact wire voltage V_n

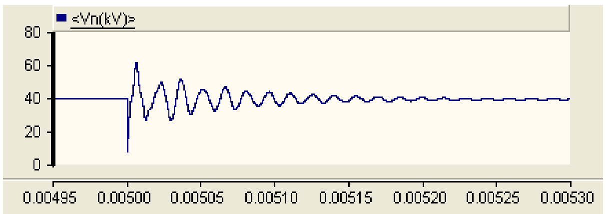

Fig. 9. Partially enlarged view of V_n

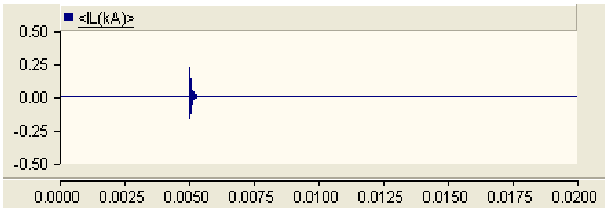

Fig. 10. Cable current I_L

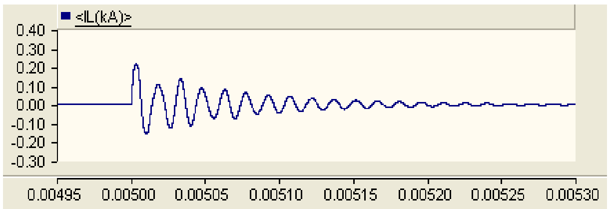

Fig. 11. Partial enlarged views of I_L

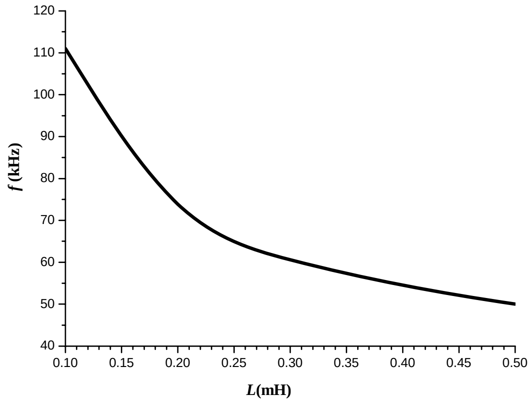

Fig. 12. Oscillation frequency

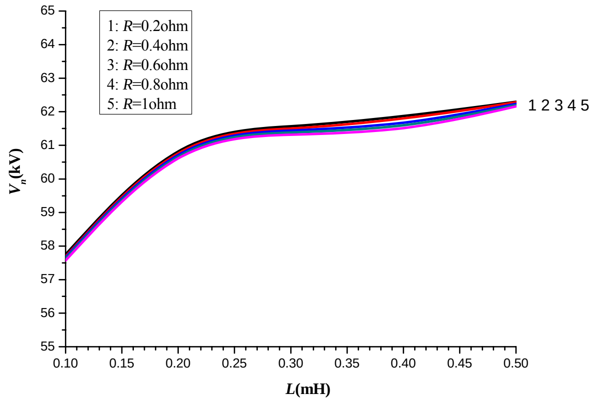

Fig. 13. Peak value of voltage

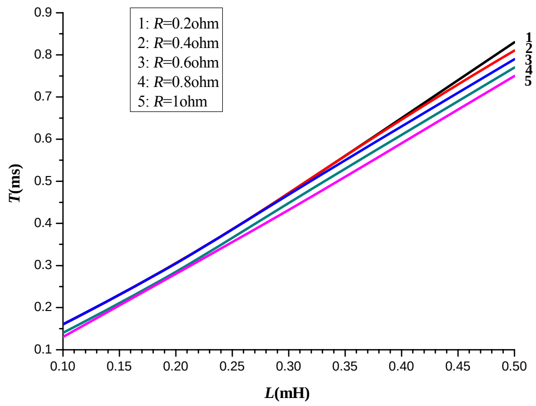

Fig. 14. Oscillation duration

It can be seen from Fig. 8 to Fig. 11 that how do the contact wire voltage and cable currents oscillate during lifting the pantograph. Some characteristic values from the simulation are shown in TABLE I.

TABLE I
SIMULATION VALUES AND MEASURED DATA

Characteristic values	Simulation values	Measured data
Oscillation frequency (kHz)	67.79	66.67
Peak voltage (kV)	61.35	63.27
Transient time (ms)	0.25	0.21
Peak I_L (kA)	0.21	0.35

The oscillation frequency, the overvoltage and the transient duration obtained by simulation are substantially identical with the measured values. However, the current value is smaller than the measured data. That may be because that the lifting pantograph process is in fact not an ideal closing switch process. The air will breakdown when the pantograph is approaching to the wire but before a contact occur. The electric sparks or arcs can cause severe interference to the measuring system..

B. Simulation Analysis

To investigate the effect of circuit parameters on the transients, we change the equivalent inductance and resistance values of the power supply while keeping the cable configuration unchanged. The resistance value is taken as 0.2Ω, 0.4Ω, 0.6Ω, 0.8Ω, 1Ω and the inductance as 0.1mH, 0.2mH, 0.3mH, 0.4mH, 0.5mH respectively. The simulation results are shown in Fig. 12 through Fig. 14. These results indicate that the oscillation frequency and the peak value voltage are mainly affected by the inductance, but the transient duration is influenced by both the inductance and resistance. This is consistent with the theoretic analysis.

Based the simulation, the relationship of the voltage value with the angle of the contact voltage when lifting the pantograph can be obtained. The measured results are consistent with the simulated curve as shown in Fig. 15.

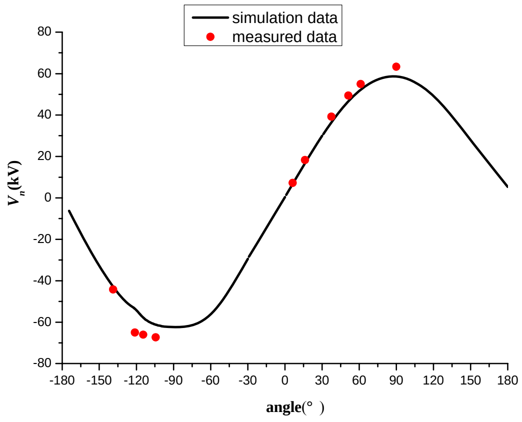

Fig. 15. Relationship between the angle of contact voltage and the peak value of V_n

V. Possible Solutions to Suppress the Transients

A. Solution 1: Insert inductors

In order to suppress the overvoltage, two inductors can be appended at the start terminal of the cable, which is shown in Fig. 16. This can be realized by sleeving some iron rings around the cable terminals.

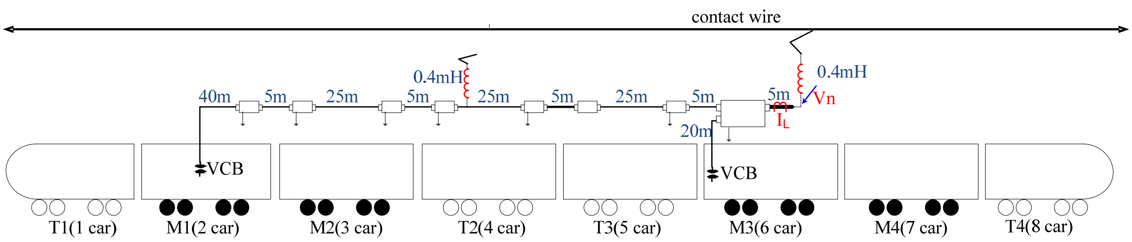

Fig. 16. Wire-connection diagram of high voltage cables

For the purpose of simplicity, two identical suppression inductors are assumed, which are inserted just at the cable terminal under the pantograph. In order to select an appropriate inductance, the different values of 0.1mH, 0.2mH, 0.3mH, 0.4mH and 0.5mH are taken to simulate. The calculated results are shown in Fig. 17.

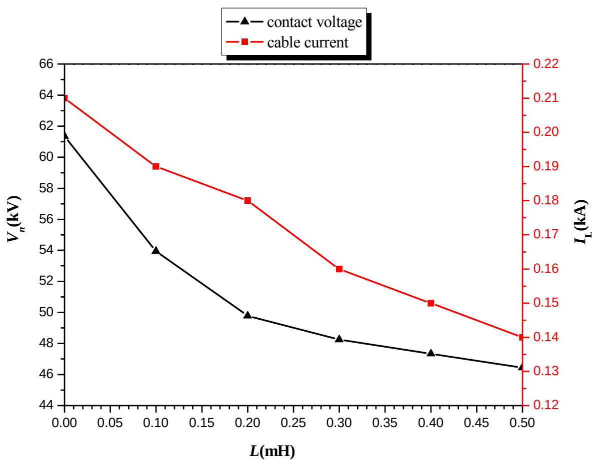

Fig. 17. Effect of appended inductor on transient process

Obviously, the peak value of V_n drops significantly when the inductance is less than 0.3mH while it drops somehow slowly when more than 0.3mH. The cable current almost drops linearly as the inductance increase. Therefore, taking the cost and the suppression effect into account, the inductance value should be selected as 0.4mH.

When 0.4mH inductors are adopted, the corresponding transient simulation results are given in Fig. 18 and Fig. 19.

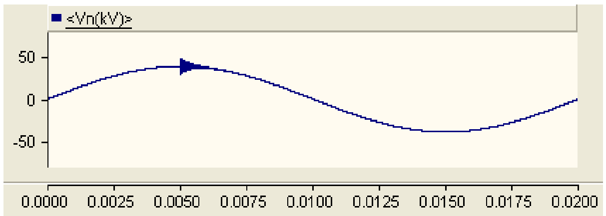

Fig. 18. Contact wire voltage V_n

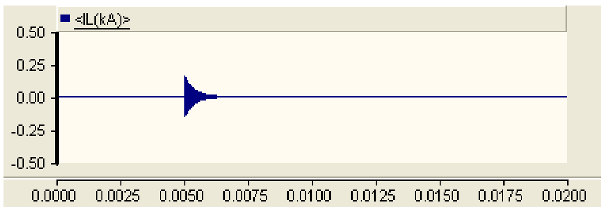

Fig. 19. Cable current I_L

The improvement of the electromagnetic transient process after 0.4mH inductances are appended is shown in TABLE II.

TABLE II
SIMULATION VALUES AND MEASURED DATA

Peak values	Without inductors	With inductors
Peak voltage (kV)	61.35	47.33
Peak I_L (kA)	0.21	0.15
Transient time (ms)	0.25	1.00

TABLE II shows both the voltage and current peak value are obviously lower than before. However, the transient duration is increased. During lifting the pantograph, a longer transient duration is acceptable for a lower overvoltage.

So the additional inductors are appropriate to improve the electromagnetic transients. This solution has almost no influence on the power frequency performance of the high voltage system of the CRH_2 EMU.

B. Solution 2: Add RC filters

As is shown in Fig. 20, two RC absorption circuits also can be used to reduce the overvoltage. In this case the resistance is 50Ω and the capacitance is 0.2uF. The simulation results are shown in Fig. 21 and Fig. 22 and the concrete value is given in TABLE III.

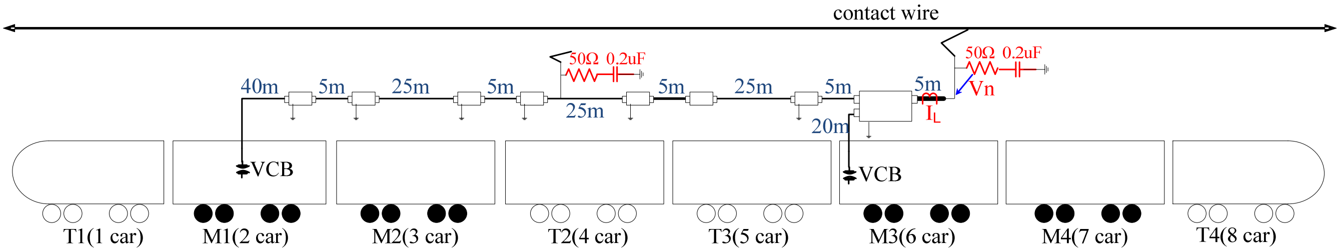

Fig. 20. Wire-connection diagram of high voltage cable

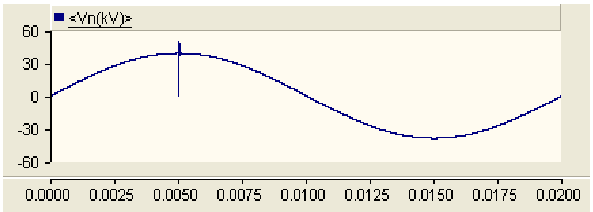

Fig. 21. Contact wire voltage V_n

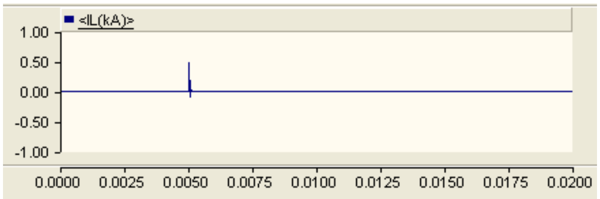

Fig. 22. Cable current I_L

TABLE III
SIMULATION VALUES AND MEASURED DATA

Peak values	Without inductors	With inductors
Peak voltage (kV)	61.35	48.62
Peak I_L (kA)	0.21	0.48
Transient time (ms)	0.25	0.05

Table III indicates that this solution can also restrain the overvoltage. In addition, the transient duration is reduced. But the current peak value increased. This approach is applicable since the RC filter can also improve the high frequency performance of the EMU.

VI. CONCLUSIONS

The lifting pantograph sparks and arcs of CRH_2 EMU are due to the charging process of the high voltage cable. The source inductance and resistance have effects on the transient process by affecting the damping component.

The PSCAD/EMTDC simulation model has been verified by field tests, which can help to study the mechanism of the electromagnetic transients and how do the circuit elements affect this process.

Two solutions to reduce the overvoltage have been proposed. Their feasibilities have been validated by simulation.

VII. REFERENCES

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