IJSRD - International Journal for Scientific Research & Development| Vol. 2, Issue 06, 2014 | ISSN (online): 2321-0613

Simulation and Modelling of Railway Power Conditioner for A High-Speedrailway Traction Power Supply System

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Abstract— High-speed train traction power supply system causes serious negative current problem. Railway power conditioner (RPC) is efficient in negative sequence compensation. A novel power quality collaboration compensation system and strategy based on RPC is proposed in this paper. The minimum capacity conducted is 1/3 smaller than traditional single station compensation. Simulation results have confirmed that the collaboration compensation system proposed can achieve a good performance at the negative sequence compensation with capacity and cost efficient.

Key words: RPC, collaboration compensation, Unbalance compensation, Minimum capacity

I. INTRODUCTION

With the rapid development of high-speed railway in China, power quality has become a major concern for traction supply system. Compared with normal electrification railway locomotive load, high-speed locomotive load has some characteristics, such as big instantaneous power, high power factor, low harmonic components and high negative sequence component. A large amount of negative current is injected into grid, which causes serious adverse impact on power system, such as increasing motor vibration and additional loss, reducing output ability of transformers and causing relay protection misoperation. These adverse impacts threaten the safety of high-speed railway traction supply system and power system. Therefore, it's necessary to take measures to suppress negative current.

Many methods and power quality compensators are studied in order to solve the issue of power quality. The traditional methods adopted to suppress negative current are as follows: (1) Connect unbalanced load to different supply terminals;(2) Adopt phase sequence rotation to make unbalanced load distributed to each sequence reasonably;(3) Connect unbalanced load to higher voltage level supply terminals; (4) Use balanced transformers such as Scott transformer and impedance balance transformer. These methods have some effects on reducing unbalance degree, but they are lack of flexibility and can't adjust dynamically.

II. PRINCIPLE OF COLLABORATION COMPENSATION

Since phase sequence rotation is widely adopted in traction power supply system, 3 stations collaboration compensation is mainly discussed in this paper. The structure of 3 stations collaboration compensation is shown in Fig.1.

The capacity in phase CA, AB and BC is x,y,z, which has a relationship of $x>y>z$. The network of x,y,zcan be divided into two parts, the one is a balanced network of z,z,z, the other is an unbalanced network of $x-z$, $y-z$, 0. Assume that $X = x - z$,$Y= y - z$, the original network is simplified as $X,Y,0$. Set $X/2$ as the reference value, the p.u. value of the simplified network is $2,Y'$,0. Y' is varying from 0 to 2. The extreme case is Y' =0. The optimize compensation strategy is shown below:

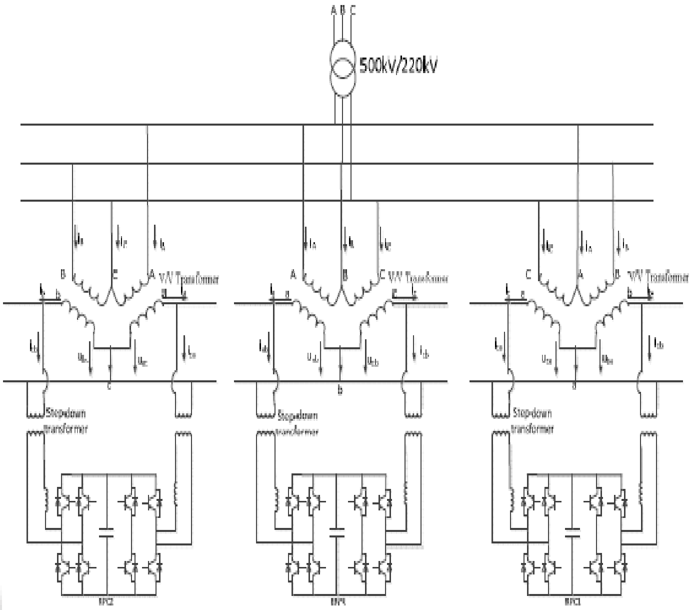


Fig. 1: Schematic diagram of collaboration compensation of three stations

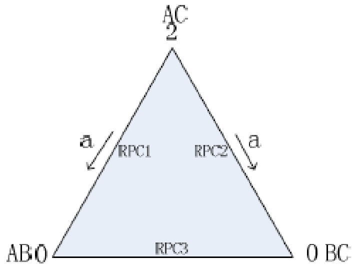
A. *Single RPC compensation*

Based on the compensation strategy of RPC, when there is a maximum capacity in one of the traction feeder arms, RPC transfers $\frac{1}{2} * \frac{X}{2}$active power from one traction feeder arm to another. And then compensates$\frac{1}{2\sqrt{3}} * \frac{X}{2}$reactive power to both traction feeder arms based on Steinmetz theory. So the compensation capacity of single RPC is

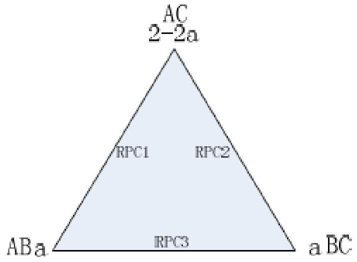
$$S = \sqrt{\left(\frac{1}{2}\right)^2 + \left(\frac{1}{2\sqrt{3}}\right)^2}\,\frac{X}{2} = 0.2885X$$

B. *Three stations collaboration compensation*

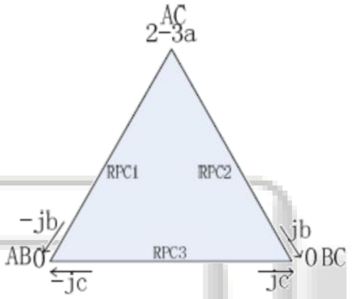
The simple model of 3 stations structure is shown in Fig.5. Since RPC could transfer a quantity of active power and compensate reactive power, a triangle is applied to illustrate the principle of collaboration compensation: apexes of the triangle are regarded as active load in Phase-AC, Phase-BC and Phase- AB, and edges of the triangle are regarded as three railway power conditioners. The arrows mean the delivery of active power (real part) and compensation of reactive power (imaginary part) . There are three steps to compensate. Firstly, transfer a quantity of active power. Secondly, separate the network into two parts: a balanced network and an unbalanced network. And last, make compensation to the unbalanced network based on the Steinmetz theory.



(a)Active power delivery



(b)Three phase power after active power delivery



(c) Reactive power compensation based on Steinmetz theory

Fig. 2: Compensation strategy under the condition of 2,0,0

According to the Steinmetz theory, fully compensation should satisfy the relationship of $b+c \geq \frac{2-3a}{\sqrt{3}}$.

The capacity of three RPC is $\sqrt{a^2+b^2}$, $\sqrt{a^2+b^2}$, c

The installed capacity will be the maximum of the three RPC capacities above. So we can obtain the minimum installed capacity when. $\sqrt{a^2+b^2}=c$

The results can be conducted a= $\frac{1}{3}$, b = $\frac{1}{3\sqrt{3}}$ and the minimum capacity is.

$$S_{\min}=\sqrt{a^2+b^2}=c=\frac{2}{3\sqrt{3}}$$

This is a fully compensation but the station where RPC2 installed is capacitive. To avoid this condition, RPC1 supply inductive reactive power with the value of *b*, and RPC2 supply capacitive reactive power with the value of *b*, too. So the capacitive condition is avoided and the system keeps balance at the same time.

Working condition of three stations is shown in Fig.6. The ellipses stand for different traction feeder arms, the squares stand for RPC which connect to traction feeder arms. The arrows stand for active power transfer and reactive power compensation.

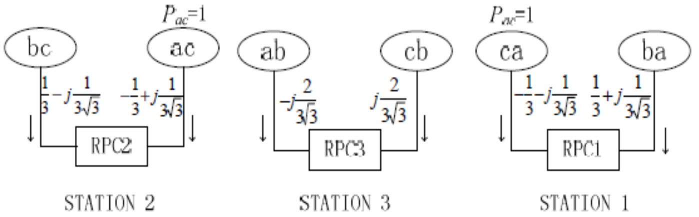


Fig. 3: Working condition of three stations which supply active power and reactive power

Three stations collaboration compensation minimum capacity is:

$$S_3=\sqrt{\left(\frac{1}{3}\right)^2+\left(\frac{1}{3\sqrt{3}}\right)^2}\,\frac{X}{2}=\frac{2}{3\sqrt{3}}*\frac{X}{2}=0.1925X \tag{3}$$

Which is 2/3 of the capacity of single RPC compensation. Tab.1 shows the compensation capacity of the two strategies.

Compensation mode	**Single station**	**Three station collaboration compensation**
RPC capacity	$0.2885X$	$0.1925X$

Table 1: Comparison Of Two Compensation Method

It can be proved that this installed capacity (0.1925*X*) can satisfy any condition when *Y*' varying from 0 to 2.

If there is *N* stations connect to one 220kV bus, *N* may be 3*n*, 3*n*+1 or 3*n*+2 (*n*=0,1,2…). When *N*=3*n*, it means there are n sets of 3-stations compensation. When *N*=3*n*+1, it means there are n sets of 3-stations compensation and a single station compensation. When *N*=3*n*+2, it means there are *n* sets of 3- stations compensation and 2 single station compensation.

III. SIMULINK MODEL OF OF COLLABORATION COMPENSATION OF THREE STATIONS

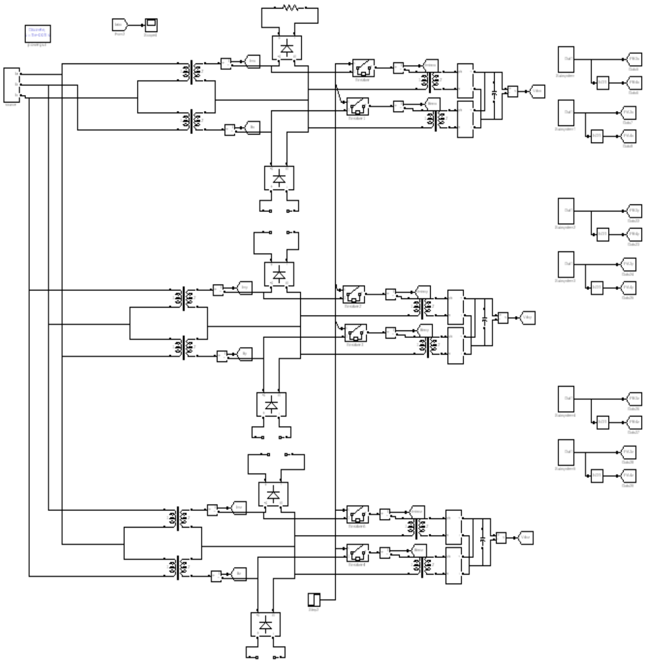


Fig. 4: simulink model of collaboration compensation of three stations

IV. SIMULATION RESULT

The simulation result of collaboration compensation of three stations are shown in Fig(5)

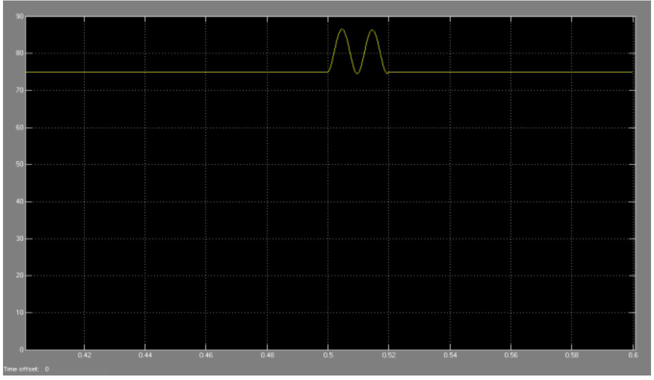


Fig. a: Positive sequence current

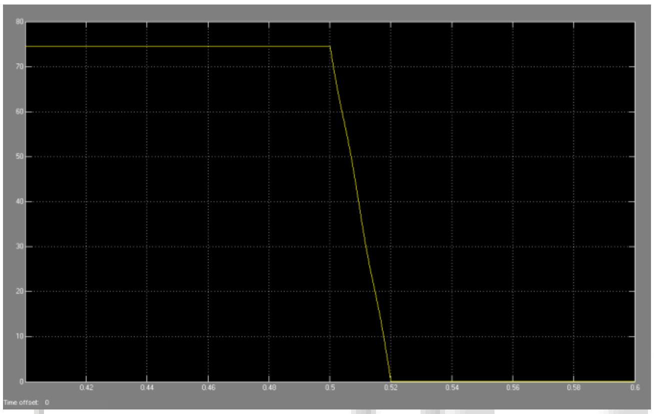


Fig. b: Negative sequence current

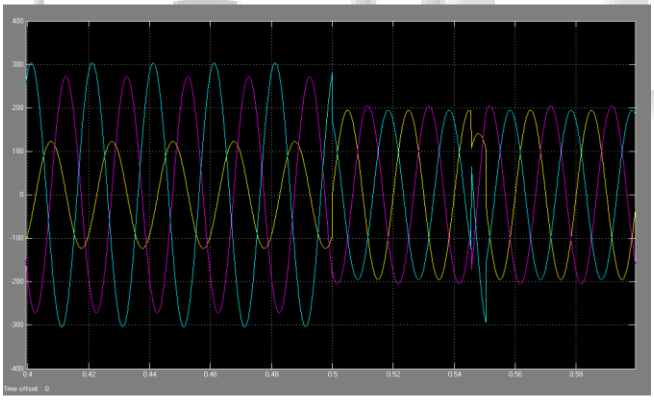


Fig. c: Current of tractive transformer high voltage side ($0 \le Y \le 2/3$)

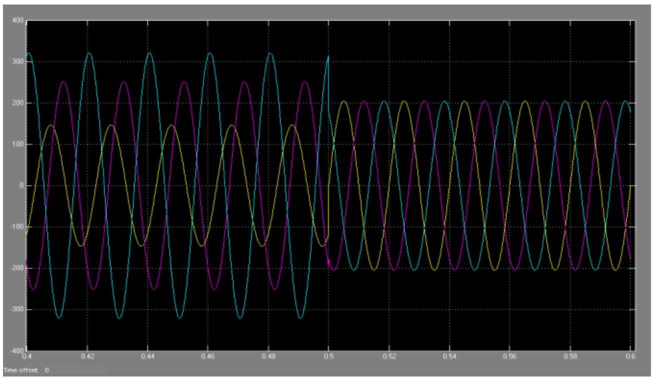


Fig. d: Current of tractive transformer high voltage side($2/3 \le Y \le 1$)

Fig. 5: Three station collaboration compensation result under the condition of 2,Y,0

V. CONCLUSION

This paper proposes a new power quality compensation system which is composed of several railway power conditioners. The proposed system can be used to compensate negative sequence current in high speed electrified railway. A minimum installed capacity is conducted which is 2/3 of the traditional single station compensation capacity. A new compensation strategy is raised Simulation results show that the proposed collaboration compensation of railway power conditioners is effective. It can reduce compensation capacity and has a good performance at negative sequence current compensation.

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