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POWER QUALITY IMPROVEMENT IN RAILWAY TRACTION SYSTEM

Ms. Vidhi C. Pathak[1], Mrs. Dharmistha Makwana[2]
[1]M.E student, [2]Assistant Professor, Electrical Engineering (power system), Kalol Institute of Technology and Research

Abstract: with rapid development in China and Japan on high speed ac electrified railway, power quality issues becomes major concern.High speed and non-linearity is a source of power quality issues such as harmonics, sub-harmonics, negative sequence current and reactive power consumption. To overcome this power quality problems power quality conditioner used in railway system called Railway Power Conditioner (RPC)". By using proper controlled strategy for RPC we can improve power quality problems in railway network. This paper proposed control strategy for railway power conditioner which based on instantaneous power theory (pq theory). Simulation results and FFT analysis verified the proposed control strategy.

Key words: power quality, railway power conditioner.

I. INRODUCTION

Railway transportation is important for city and country's development. Among all other transportation way railway is more safe, clean and more efficient way. However power quality problems always been one of the important concern in railway system. Major issues in railway system are system unbalance, reactive power and presence of harmonics and negative sequence current. Due to non-linearity of traction load harmonics and sub harmonics are present in the system. Unbalance system is a source of negative sequence current. This unbalance inject large amount of NSC into power grid, causes damage of devices in power system. Moreover if affects the performance of transformer, malfunctioning of protective relay, motor vibration and other damages were done due to power quality problems. Locomotive carry power electronic devices which creates harmonic problems and resultant additional heat and power loss. As per IEEE standard 512-1992 THD must be less than 5% in power system. This standard should be also satisfied by traction system, otherwise it may cause damages to the system or penalties may be imposed. So, various conditioners have been proposed by researchers to satisfy this standard. Railway power conditioner is one of them which can unify power quality compensation. RPC is connected on substation side. RPC control is developed based on full compensation requirement and has no relation with power quality standards. This technique may not be the economic solution. There is tolerance on power quality standards; there are possibilities that the compensation target can be adjusted for lower compensation capacity cost. Unfortunately relationship between RPC and power quality is complicated and less study has been done related to this topic. This paper proposed control system for RPC based on pq theory. A simulation result shows the verification of proposed system. Principle of RPC, results of simulation and conclusion are covered in different section of this paper.

II. RPC PRINICIPLE

A. Selection of Transformer:

Transformer selection in railway system has done based on traction utilization factor (TUF), Line utilization factor (LUF), and NSC index. NSC index (R) is a ratio of negative sequence effective current to the positive sequence effective current. All the above factors depend on balance degree (η) which is defined as:

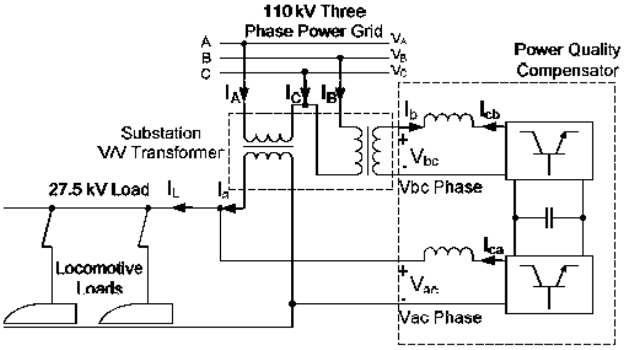
$$\eta = \frac{\left|I_{light-load\ \ side}\right|}{\left|I_{heavy-load\ \ side}\right|} \quad \ldots.. (1)$$

Table (1) shows the TUF, LUF and R for different transformers. Table I. shows TUF, LUF and R for four different kinds of traction transformers. As it can be inferred from it, the best performance belongs to Scott transformer; however, it is a special, complicated and costly transformer which is not very commercial in traction systems. Also, the single-phase transformer has the highest level of NSC index. Moreover, the Y/Δ transformer has the lowest TUF among the all transformers. As a result, V/V transformer becomes the most common traction transformers on the whole. Even so, if the NSC was compensated by a compensator (such as RPC) and the traction transformer becomes a symmetrical three-phase transformer from utility grid's point, the imbalance parameters would be changed considerably. As Y/Δ transformer is inherently a three-phase balanced transformer, its TUF and LUF are improved to 100% in balanced condition; whereas TUF in V/V transformer declines to 87%. In addition, Y/Δ transformer is more common, ordinary, cheaper and moreavailable device comparing to V/V transformer; therefore, the Y/Δ transformer can be considered as a better option to put into operation with RPC in traction substations.

Selecting Parameters	*Traction Transformer*			
	Single phase	*V/V*	*Y/Δ*	*Scott*
TUF	$\frac{1+\eta}{2}$	$\frac{1+\eta}{2}$	$\frac{1+\eta}{2.64}$	$\frac{3(1+\eta)}{3+2\sqrt{3}}$
LUF	$\frac{1+\eta}{2\sqrt{3}}$	$\frac{1+\eta}{3}$	$\frac{1+\eta}{2.64}$	$\frac{1+\eta}{2}$
R	1	$\frac{\sqrt{\eta^2-\eta+1}}{\eta+1}$	$\frac{\sqrt{\eta^2-\eta+1}}{\eta+1}$	$\frac{\eta-1}{\eta+1}$

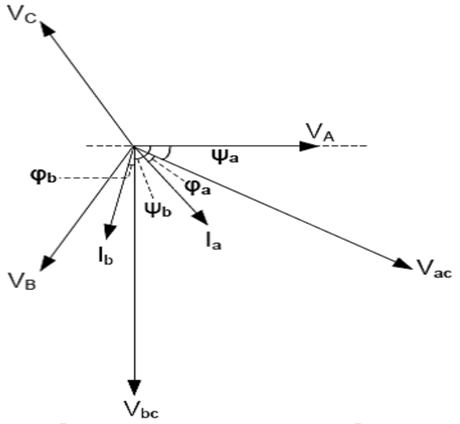
[Table (1) Traction Transformer Selecting Parameters]

B. Schematic of co-phase traction with RPC and description:



[Figure (1) a typical schematic of co-phase traction with RPC]

The schematic of typical co-phase traction with V/V substation transformer and RPC is as shown in figure 1. V/V transformer is used to transform power from three phase to two single phase outputs, known as Vac and Vbc. The RPC is connected across secondary side of transformer which provides compensation to primary side. Locomotive load is on Vac side and Vbc is unloaded. It is assumed that three phase primary current rms values are IA, IB and IC respectively; while the secondary current rms is defined as Ia, Ib and Ic. The load current rms is defined as IL and the Vacphase and Vbc phase compensation current rms are Ica and Icb. Furthermore, the voltage rms at of Vac and Vbc phase arec Vac and Vbc respectively.The other physical definition of the system is shown using vector diagram in figure 2.



[Figure (2) Vector Diagram]

C. RELATION BETWEEN HARMONICS AND NEGATIVE SEQUENCE:

Due to unbalance loading negative sequence is introduced in the traction system. If delta connection of transformer has been used the system is free from the zero sequence current. Because in delta connection of transformer, no ground path is available. Thus the current is circulating in the system and system becomes free from zero sequence current.

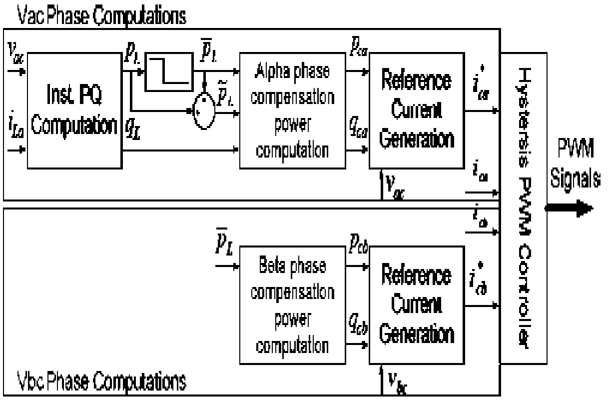
The NSC is mitigated with the reference of the harmonics. There is a relation between harmonics and NSC. Harmonics are nothing but the unwanted frequency which is integral multiples of fundamental frequencies. Some of the harmonics account to NSC. Thus by compensating harmonics in the system the NSC can be compensated to great extent. By definition harmonics are integral multiple of fundamental frequency. In any system the even order harmonics do not show any effect on the system as all ever order harmonics cancels out each other. All odd order harmonics affects the system and the lower orderharmonics are more predominant. Due to integral multiplication to the fundamental, positive negative and zero sequences currents are introduced in the system.Table (2) shows the relation between harmonics and NSC.

Fundamental	A	B	C	ABC POSITIVE SEQUENCE
	0	120	240	
3rd Harmonic	A’	B’	C’	NO ROTATION
	0	360	720	
	0	0	0	
5th Harmonic	A’	B’	C’	CBA NEGATIVE SEQUENCE
	0	600	1200	
		-120	-240	
7th Harmonic	A’	B’	C’	ABC POSITIVE SEQUENCE
	0	840	1680	
	0	120	240	
9th Harmonic	A’	B’	C’	NO ROTATION
	0	1080	2160	
	0	0	0	

[Table (2) Relation between harmonics and NSC]

III. PROPOSED CONTROL ALGORITHIM

After system modeling the next step is to develop a proper control algorithm for RPC.The goal behind this algorithm is to compensate or mitigate power quality issues in traction system. Here we are present control strategy based on instantaneous power theory. Following figure (3) shows the proposed control system.



[Figure (3) block Diagram shows the control strategy of power quality conditioner for traction system]

Here, following equations are required to develop above control algorithm. It Is assumed that the three-phase voltage at the grid side are expressed as,

$$\begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix} = \begin{bmatrix} \sqrt{2}V_A \sin\omega t \\ \sqrt{2}V_A \sin(\omega t - 120^\circ) \\ \sqrt{2}V_A \sin(\omega t + 120^\circ) \end{bmatrix} \qquad (2)$$

Voltage at the secondary side,

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} v_{ac} \\ v_{bc} \end{bmatrix} = \begin{bmatrix} \sqrt{2}V_{ac} \sin(\omega t - 30^\circ) \\ \sqrt{2}V_{bc} \sin(\omega t - 90^\circ) \end{bmatrix} \qquad (3)$$

Without the power conditioner the load current at secondary side of traction transformer,

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} i_L \\ 0 \\ -i_L \end{bmatrix} \qquad (4)$$

Load current is divided into the fundamental frequency component $il1$ and harmonic component, i_lh as,

$$i_L = i_{L1p} + i_{L1q} + i_{Lh} \qquad (5)$$

$il1p$, $il1q$ are active and reactive component of load current expressed as,

$$i_{L1p} = \sqrt{2}I_{L1p} \sin(\omega t - 30^\circ)$$

$$i_{L1q} = -\sqrt{2}I_{L1q} \cos(\omega t - 30^\circ) \qquad (6)$$

If power quality works, compensating current are injected,

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} i_L - i_{pa} \\ -i_{pb} \\ -i_L - i_{pc} \end{bmatrix} \qquad (7)$$

Current at grid side are balanced with unity power factor,

$$\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} = \begin{bmatrix} \sqrt{2}I_A \sin\omega t \\ \sqrt{2}I_A \sin(\omega t - 120^\circ) \\ \sqrt{2}I_A \sin(\omega t + 120^\circ) \end{bmatrix} \qquad (8)$$

The root mean square (rms) value of the source current could be deduced,

$$I_A = \frac{1}{\sqrt{3}K} I_{L1p} \qquad (9)$$

The compensating current of the power conditioner are given by,

$$\begin{bmatrix} i_{pa} \\ i_{pb} \\ i_{pc} \end{bmatrix} = \begin{bmatrix} i_L \\ 0 \\ -i_L \end{bmatrix} - K \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} \qquad (10)$$

Value of (5), (6), (8) and (9) put into (10) and we get,

$$\begin{bmatrix} i_{pa} \\ i_{pb} \\ i_{pc} \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\sqrt{2}I_{L1p} \sin(\omega t - 30^\circ) - \left(\frac{1}{2\sqrt{3}} I_{L1p} + I_{L1q}\right)\sqrt{2}\cos(\omega t \\ -\frac{1}{2}\sqrt{2}I_{L1p} \sin(\omega t - 90^\circ) + \frac{1}{2\sqrt{3}}\sqrt{2}I_{L1p} \cos(\omega t - \\ -i_{pa} - i_{pb} \end{bmatrix}$$

(11)

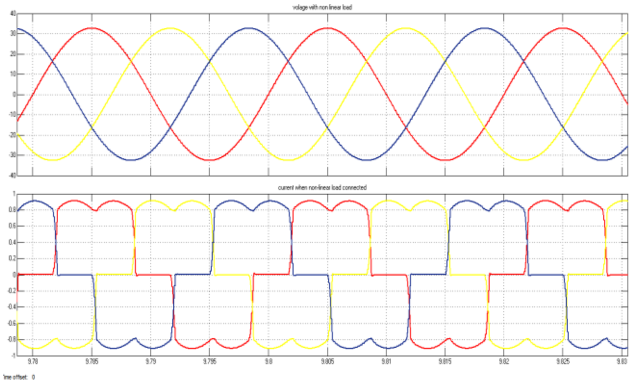
And by using equations of cleark transformation, reference current calculation can be done by as follow,

$$i_{pa}^* = \frac{1}{v_\alpha^2 + v_{\alpha d}^2} \begin{bmatrix} v_\alpha & v_{\alpha d} \end{bmatrix} \begin{bmatrix} p_{pa} \\ q_{pa} \end{bmatrix}$$

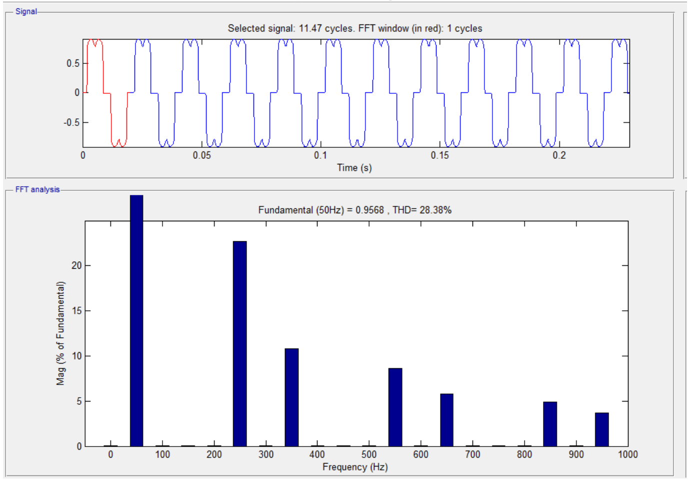
$$i_{pb}^* = \frac{1}{v_\beta^2 + v_{\beta d}^2} \begin{bmatrix} v_\beta & v_{\beta d} \end{bmatrix} \begin{bmatrix} p_{pb} \\ q_{pb} \end{bmatrix} \qquad (12)$$

IV. RESULTS

In order to verify the performance of the RPC control algorithm, simulation verifications are done using MATLAB. Following results shows the verification of control algorithm. Figure (4) shows the three phase power voltage and current without compensating. Figure (5) shows the FFT analysis for the same. Figure (6) shows the current waveform after compensation and Figure (7) shows the FFT analysis for the same.

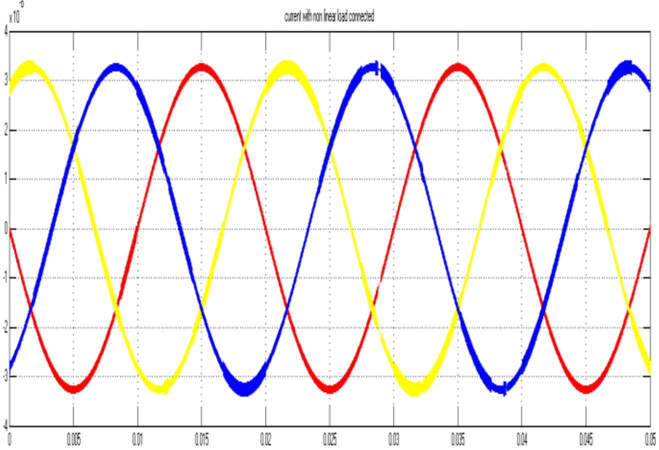


[Figure (4) three phase power voltage and current without compensating]

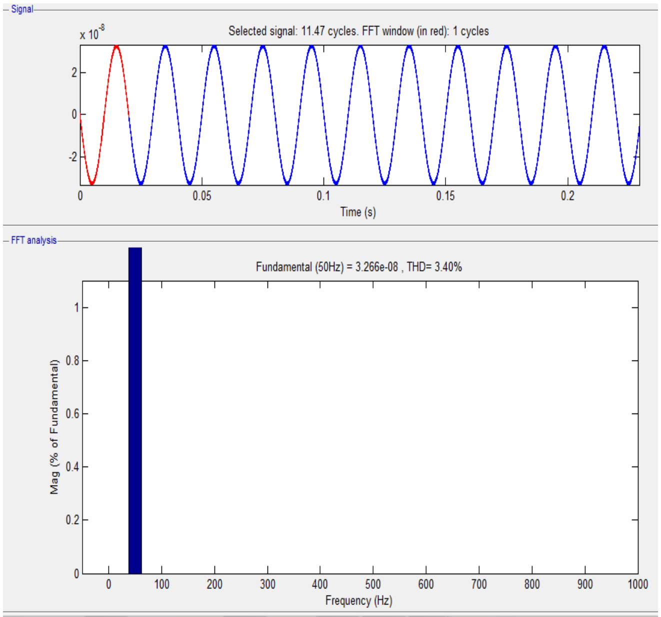

Selected signal: 11.47 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 0.9568 , THD= 28.38%

[Figure (5) FFT analysis of harmonics presence in the system before compensation]



[Figure (6) three phase current after compensation]



[Figure (7) FFT analysis after compensation]

V. CONCLUSION

In this paper, a control algorithm of RPCin co-phase traction system is developed based on instantaneous power theory. This strategy significantly improve power quality problems including NSC, harmonic and reactive power in the traction power supply system. A result shows the verification of the control strategy. From FFT analysis we can see that IEEE standard is satisfied and THD in the system is <5%. Finally simulation results have confirmed that RPC can comprehensively compensate harmonics, NSC and reactive power.

REFERANCES

[1] Keng-Weng, LAO; Dr. NingYi DAI; WeiGang Liu; Prof. Man-Chung WONG; and Dr. Chi-Kong WONG : "Modeling and Control of Railway Static Power Conditioner Compensation based on Power Quality Standards." in IEEE 2012, 978-1-4244-9373-9/12.

[2] Alireza Ghassemi, Seyed Saeed Fazel, Iman Maghsoud, and Siamak Farshad: "Comprehensive study on the power rating of a railway power conditioner using thyristor switched capacitor." in IET Electr. Syst. Transp., 2014, Vol. 4, Iss. 4, pp. 97–106.

[3] AlirezaGhassemi, ImanMaghsoud, SiamakFarshad, SeyedSaeedFazel : "Power Quality Improvement in Y/Δ Electric Traction System Using a Railway Power Conditioner." in IEEE 2013, 978-1-4673-3059-6/13.

[4] Hirofumi Akagi, Edson Hirokazu Watanabe and Mauricio Aredes : " Instantaneous power theory and applications to power conditioning."

[5] Gopi Krishna Allaboyena: "Mitigation of NSC and Alleviate of Magnetic Inrush Currents in Indian Traction System." in International Journal of Science and Research (IJSR) ,Volume 4 Issue 11, November 2015, pp-1680-1684.

[6] N.Y. Dai K.W. Lao M.C. Wong C.K. Wong: "Hybrid power quality conditioner for co-phase power supply system in electrified railway." in IET Power Electron., 2012, Vol. 5, Iss. 7, pp. 1084–1094.