International Journal of Engineering and Techniques - Volume 4 Issue 4, July - Aug 2018

RESEARCH ARTICLE OPEN ACCESS

Power Quality Improvement using PID Controller Based RPC for High Speed Railway Traction

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Abstract:

Traction loads are varying dynamically and as we know the locomotives show the characteristics of non-linearity and single phase electrical loads. Various power quality problems that are generated by the electric traction have an important impact on the present distribution system network. The source of power quality issues such as harmonics sub harmonics negative sequence current, reactive power consumption and load imbalance. The power quality may get worsen if the train is running at higher speeds or trains with a heavier load.

To overcome these unbalance power electronics devices can be installed such as Railway power conditioner (RPC) which can mitigate unbalance in the grid as able to reduce the degree of current unbalance significantly.

This thesis determines the RPC as effective solution for the railway traction system. Further studies have been done in order to propose a control strategy for RPC along with PID controller to improve power factor, reduce harmonics and unbalance voltage due to current faults. Also, THD level is calculated using FFT analysis which is < 5%.The proposed method and technology is tested on MATLAB/SIMULINK environment.

***Keywords* —** RPC, power quality, harmonics, negative sequence current, unbalance, reactive power, traction, PID controller, THD, FFT analysis.

I. INTRODUCTION

In early 1960's railway electrification began [1, 2] to meet the growing industrial development. Despite of the competition of airplanes, buses trucks and cars, railway transport is being considered as the most popular transportation role in society, filling specific markets etc.

Normally, it is seen that in transportation system there is a relation between technical and safety performance. Hence every change according to the system design in terms of innovation has to be evaluated through system parameters, expressing not only quantitative technological performance but also the qualitative ones.

Compared with normal electrification railway locomotive load, low speed locomotive load there is no problem of power factor they run at low speed but high speed locomotive loads has some characteristics, such as big instantaneous power, high power factor, low harmonic components and high negative sequence component.

In case of three phase system the imbalance of current because of a railway load is always a single phase load which causes a negative sequence component (NSC) of current equal to the positive sequence component (PSC).This causes major impact on the safety of high speed railway traction supply system and power system. Therefore it's necessary to take accurate measures to suppress negative current.

With the view of the above issue of energy quality railway traction, "the traditional compensation techniques adopted to minimize NSC's are as follows:

- ➢ Connect unbalanced load to different supply terminals;
- ➢ Adopt phase sequence rotation to make unbalanced load distributed to each sequence reasonably;
- ➢ Connect unbalanced load to higher voltage level supply terminals;
- ➢ Use balanced transformers such as Scott transformer and impedance balance transformer.
- ➢ The above methods have some effects on reducing unbalance degree but they lack of flexibility and can't adjust dynamically.

. Recent years, high-voltage, large capacity Static Var Compensator (SVC), Active Power Filter (APF) and Static Compensator (STATCOM) have become focus on power quality compensation of electrified railway. However, these methods all need high-voltage transformers which increase cost.

To reduce the high compensator capacity, this paper puts forward a new railway negative unbalance compensation system based on the thought of multiple RPC collaboration compensation with the help of PID controller [6]-[13]. This method realizes a minimum compensation capacity which is strictly proved, which reduces 1/3 capacity compared with traditional single station RPC compensation method. As per IEEE standard 512-1992 THD must be < 5% in power system. This standard is satisfied by the traction by FFT analysis. System performance is evaluated by using MATLAB/SIMULATION results.

II.TRACTION SUPPLY SYSTEM

A. RPC structure and configuration

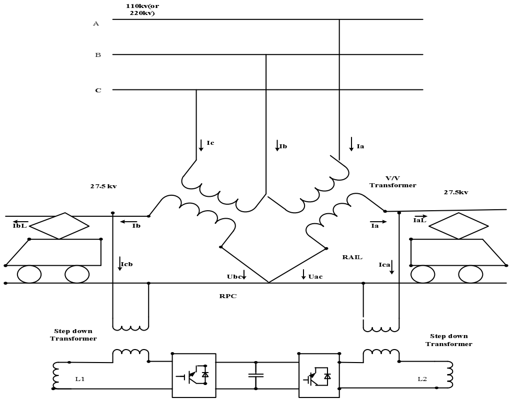


Figure 1: RPC structure

The structure of RPC is shown in Fig 1. Three phase 220kV voltage is stepped down into two single-phase power supply voltage at the rank of 27.5kV by V/V transformer. RPC is made of back-to-back voltage source converters and a common dc capacitor, which can provide stable dc-link voltage. Two converters are connected to secondary arms of V/V transformer by step down transformer. Two converters can transfer active power from one power supply arm to another, supply reactive power and suppressing harmonic currents. The main purpose with an RPC is to:

1. Transfer active power between two electrical subsystems.
2. Compensate reactive power on each side of the converters.
3. Mitigate harmonics.

V/V transformer is composed of two single-phase transformers which fed by two phase voltages. As a result of the advantages of simplicity and high capacity utilization of V/V traction transformer, it has been widely used in traction power supply system [4]. The configuration of this transformer is shown in Figure 2.

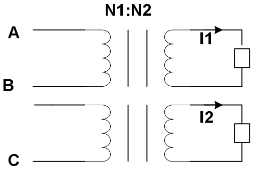


Figure2: V/V transformer connection

III. ANALYSIS OF NEGATIVE SEQUENCE COMPENSATION

A. Negative sequence Compensation

The right feeder section in Fig.1 is denoted as *a*-phase power arm, while that the left side is *b*-phase power arm. The corresponding phases on the primary side are denoted as Phase A and Phase B, respectively. Since using four-quadrant pulse rectifiers to feed electrical locomotives, the power factor of high speed electrical locomotive is close to 1. Set U_A as the reference value. Assume that the fundamental current vector of *a*-phase power arm is I_{aL} and the fundamental current vector of *b*-phase power arm is I_{bL}. I_{aL} and I_{bL} are shown as follows:

$$I_{aL}= I_{aL}e^{-30°} \qquad (1.1)$$

$$I_{bL}= I_{bL}e^{-90°} \qquad (1.2)$$

The turn's ratio of V/V transformer is *K*, so the three currents of the high-voltage side are shown as follows:

$$\left.\begin{aligned} i_A&=\frac{iaL}{K}=\frac{IaL}{K}e^{-j30°}\\ i_B&=\frac{ibL}{K}=\frac{IbL}{K}e^{-j90°} \qquad (1.3)\\ i_C&=-(i_A+i_B) \end{aligned}\right\}$$

Current unbalance index can find as per equation .And I_+ is a PSC and I- is NSC. In matrix form it can be writing as follow:

$$\begin{bmatrix} Ia\\ Ib\\ Ic \end{bmatrix}=\begin{bmatrix} 1 & 1 & 1\\ a^2 & a & 1\\ a & a^2 & 1 \end{bmatrix}\begin{bmatrix} I1\\ I2\\ I0 \end{bmatrix} \qquad (1.4)$$

And

$$\begin{bmatrix} I+\\ I- \end{bmatrix}=\frac{1}{3}\begin{bmatrix} 1 & a & a^2\\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} Ia\\ Ib\\ Ic \end{bmatrix} \qquad (1.5)$$

According to the former analysis of compensation principle, NSC and harmonics signals of RPC can be obtained by using instantaneous power theory (p-q theory).

Suppose, Feeder section reference current,

$$\left.\begin{aligned} i''_a &= \sqrt{2} I_s \mathrm{Sin}\,(wt + \theta_a) \\ i''_c &= \sqrt{2} I_s\ \mathrm{Sin}\,(wt + \theta_a + 120°) \\ i''_b &= \sqrt{2} I_s\ \mathrm{Sin}\,(wt + \theta_a - 120°) \end{aligned}\right\} \qquad (1.6)$$

RPC reference currents,

$$\left.\begin{aligned} i_{fa} &= i''_a - i''_{La} \\ i_{fc} &= i''_c - i''_{Lc} \end{aligned}\right\} \qquad (1.7)$$

Above equations load current can be expressed as follow, which consist of active power, reactive power and harmonic component

$$i_{L\alpha} = \sqrt{2}\, I_{L\alpha p}\ \sin(\,wt + \theta_{\alpha b}) + \sqrt{2}\, I_{L\alpha p} \sin(wt + \theta_{\alpha b} - \frac{\pi}{2}) + \sum_{h=2}^{\infty} I_{\alpha h} \sin(\,hwt + \theta_{\alpha h}) \qquad (1.8)$$

$$i_{L\beta} = \sqrt{2}\, I_{L\beta p}\ \sin(\,wt + \theta_{\beta b}) + \sqrt{2}\, I_{L\beta p} \sin(wt + \theta_{\beta b} - \frac{\pi}{2}) + \sum_{h=2}^{\infty} I_{\beta h} \sin(\,hwt + \theta_{\beta h}) \qquad (1.9)$$

As output currents of RPC can fully track the given fundamental and harmonic currents, it would achieve the compensation for NSCs and harmonic currents, and greatly improve power quality of electrified railway.

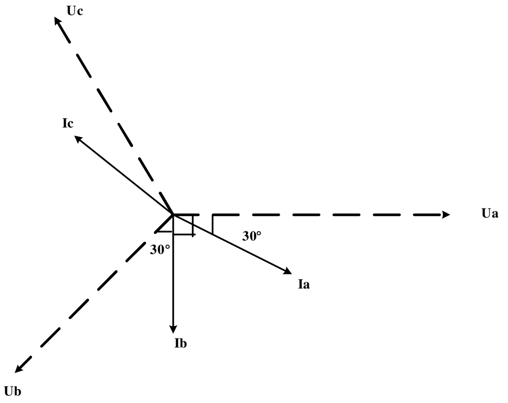


Figure 3: Phase Diagram of three phase currents before compensation

B. Active and Reactive power compensation

The phasor diagram of the system without compensation is shown in Figure 3. From the figure it is clear that the three phase currents of the grid are not balanced. Phase A current lags Phase A voltage by 30°; Phase B current leads Phase B voltage by 30°.

In order to make the three phase currents balanced, it is necessary to add certain reactive current to phase a and the phase b to shift the phase angle to the currents to be in phase with the phase voltage.

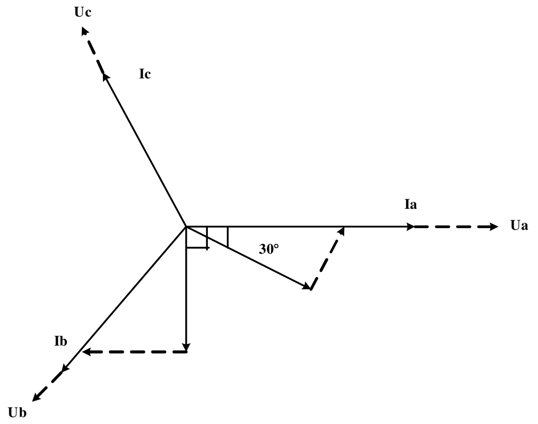


Figure 4: Phase diagram of three phase current after adjusting active and reactive power by RPC

IV. PRINCIPLE OF COLLABORATION COMPENSATION

Since phase rotation is generally received in traction power supply system, 3 stations coordinated effort remuneration is primarily examined in this paper. The structure of 3 stations coordinated effort remuneration is appeared in Figure6.1.

The 3 RPC's are arranged in order to collaborate into one. As, my paper puts forward a compensation strategy in which 3 station of railway power conditioner are made which reduces the compensation capacity of traditional single station railway power conditioner by 1/3. The streamline compensation technique is demonstrated as follows figure 5:

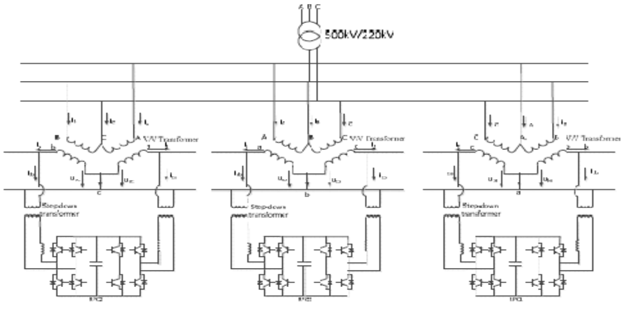


Figure 5: Three stations compensation scheme

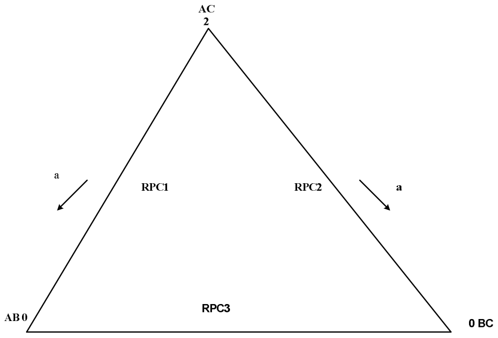
i. Single RPC compensation:

In light of the compensation methodology of RPC, when there is a most extreme maximum value in one of the traction feeder arms, RPC exchanges dynamic power from one traction feeder arm to another. And afterward remunerates responsive energy to both traction feeder arms in light of Steinmetz hypothesis. So the remuneration limit of single RPC is:

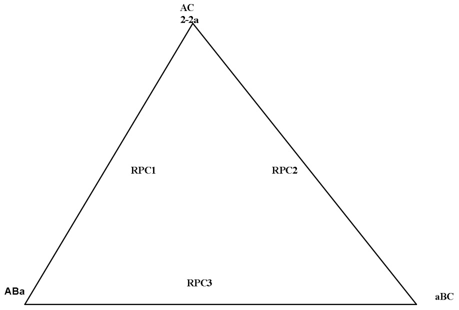
$$S=\sqrt{\left[\frac{1}{2}\right]^2}+\left[\frac{1}{2\sqrt{3}}\right]^2\frac{X}{2}=0.2885X \qquad (1.10)$$

ii. Three station collaboration compensation

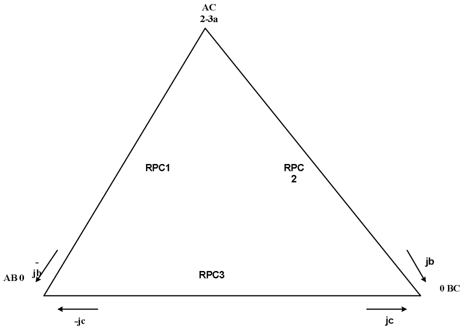
The basic model of 3 stations structure is appeared in Figure5. Since RPC could exchange an amount of dynamic power and repay receptive power, a triangle is connected to represent the rule of coordinated effort compensation: zeniths of the triangle are viewed as dynamic load in Phase-AC, Phase-BC and Phase-AB, and edges of the triangle are viewed as three railroad control conditioners. The bolts mean the conveyance of dynamic power (genuine part) also, compensation of reactive power (fanciful part). There are three stages to adjust. Firstly, exchange an amount of dynamic power. Furthermore, isolate the system into two sections: a adjusted system and an uneven system. Also, make compensation to the unbalanced system in light of the Steinmetz hypothesis.



(a) Active power delivery



(b) Three phase power after active power delivery



(c) Reactive power compensation based on Steinmetz theory

As indicated by the Steinmetz hypothesis, completely remuneration ought to fulfil the relationship of b + c ≥ $\frac{2-3a}{\sqrt{3}}$. The limit of three RPC is $\sqrt{a^2+b^2}, \sqrt{a^2+b^2}$, c independently. The introduced limit will be the greatest of the three RPC limits above. So we can acquire the base introduced limit when$\sqrt{a^2+b^2}=c$.The outcomes can be led a=$\frac{1}{3}$, b =$\frac{1}{3\sqrt{3}}$ and the base limit is $S_{\min}=\sqrt{a^2+b^2}=c=\frac{2}{3\sqrt{3}}$.

Three stations collaboration compensation minimum capacity is:

$$S_3=\sqrt{\left[\frac{1}{3}\right]}\text{^2}+\left[\frac{1}{3\sqrt{3}}\right]\text{^2}\,\frac{X}{2}=\frac{2}{3\sqrt{3}}*\frac{X}{2}=0.1925\ X \qquad (1.11)$$

Table 1: Comparison of single RPC and the three RPC

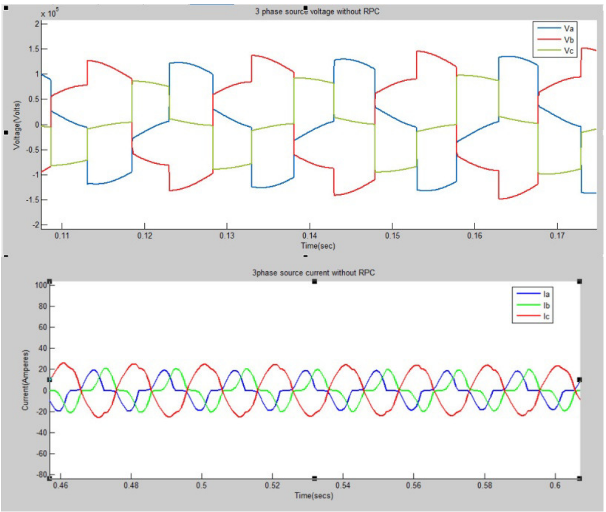
Compensation mode	Single station	Three station collaboration
RPC capacity	0.2885X	0.1925X

V.SIMULATION RESULTS

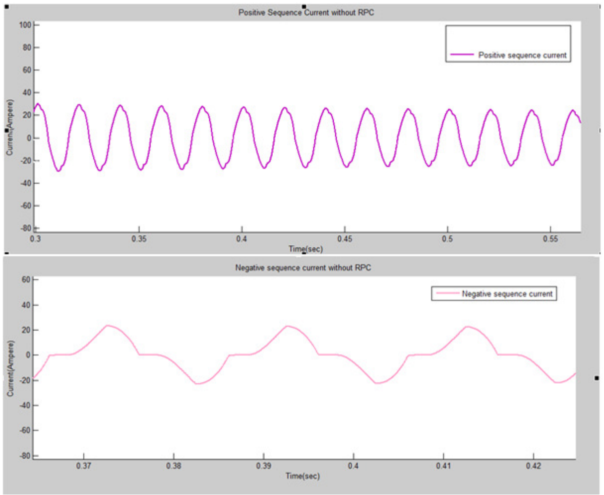
In order to verify the effectiveness of the proposed compensation and control strategy, simulations based on MATLAB software have been carried out. Since the reduction of capacity is based on NSC compensation, traction loads are modelled as resistive linear load. The system is simulated with both traditional and proposed compensation strategies separately to prove the validity of the proposed control method.

Case 1: Analysis of single stations without RPC

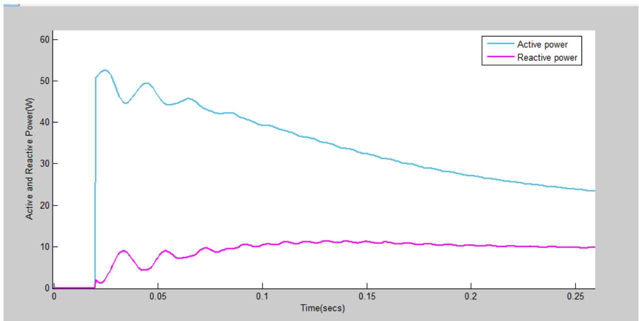
When RPC is not provided, the voltages and current of all the phases are unbalanced.



(a) 3∅ source voltage (top)and 3∅ source current (bottom) sequence current (single station without RPC



(b)Positive sequence current (top) and Negative sequence current (bottom)

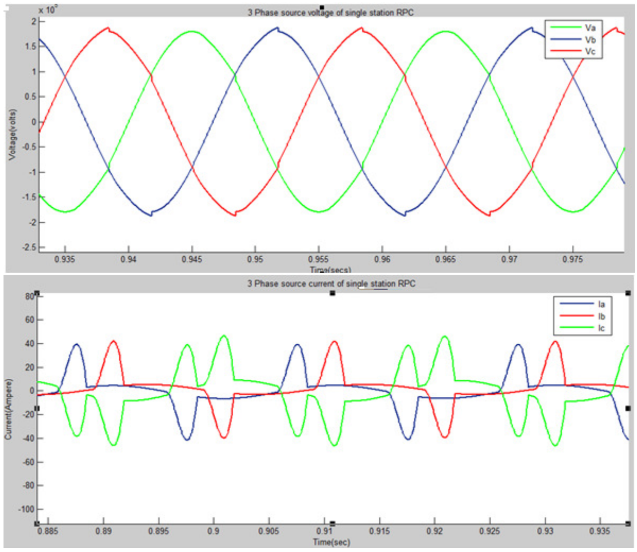


(**c**)Active and Reactive power

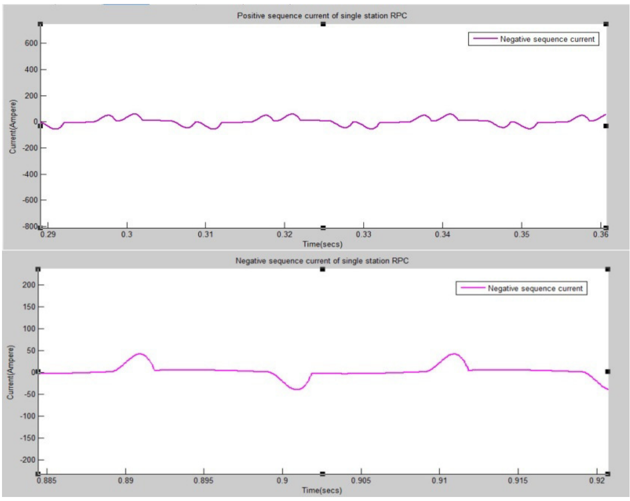
Figure 5: Compensation result under single station without RPC

Case 2: Analysis of single stations with RPC and PID

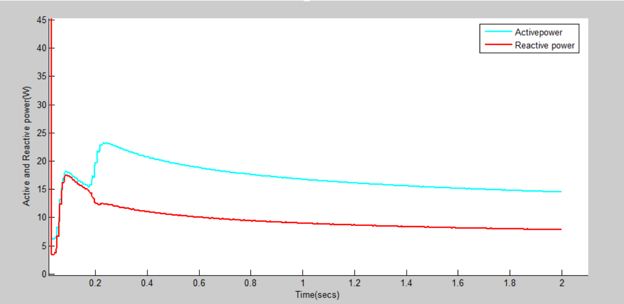
Assuming the maximum load capacity appears at a -phase power arm. The power of b-Phase locomotive load is 0. The a-phase load was switched on at 0s; the compensation ran at 1s. The three phase source currents and compensation results are shown in Figure 6. As it is presented in this figure6 (a), before compensation the network-side three-phase currents are significantly balanced and symmetrical, but after the compensator were carried out and the unbalance level was reduced to 0.



(a) 3∅ source voltage (top)and 3∅ source current (bottom) sequence current (single station with RPC and PID



(b) Positive sequence current (top) and Negative sequence current (bottom)



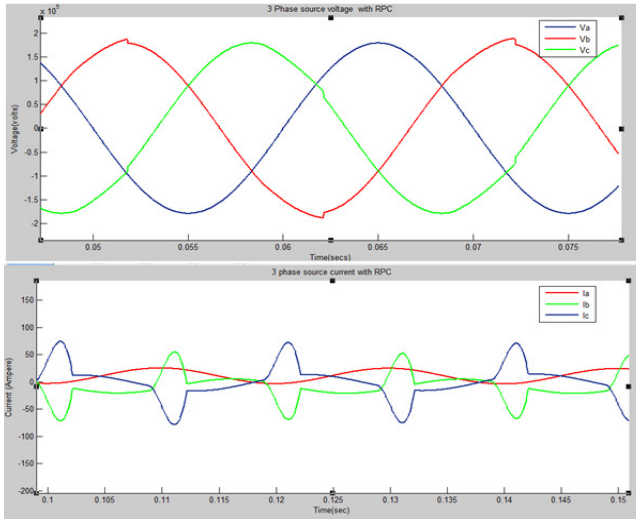
(c) Active and Reactive power

Figure6: Compensation result under the condition of single station RPC

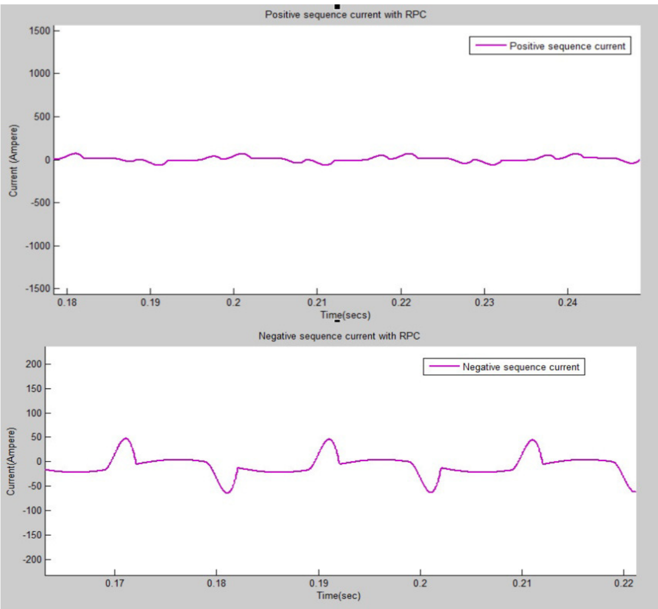
Case 3: Analysis of three stations with RPC and PID

In this paper, to improve the power factor, unbalancing voltage and current faults in the transmission line a new device of three stations RPC with PID (Proportional Integral Derivative) technique is used to operate unbalanced condition to balanced condition.

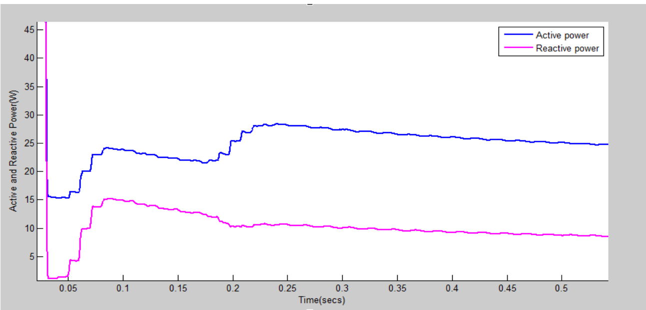
It can be seen through the simulation that there is a serious unbalanced condition before compensation the collaboration compensation network is effective in reducing the voltage unbalance as shown above in figure5.1 (a).



(a) 3∅ source voltage (top)and 3∅ source current (bottom) sequence current (three stations with RPC and PID



(b) Positive sequence current (top) and Negative sequence current (bottom)



(b) Active and Reactive power

Figure 7: Three station collaboration result with RPC

Table2: Comparison Current unbalance index and power factor

	Before compensation	Single station With RPC and PID	Three station With RPC and PID
Current unbalance (%)	99	4.25	3.46
Power factor	0.82	1.0	1.0

VI .FFT ANALYSIS OF COMPENSATION

A. FFT Analysis without PID and RPC

Generally FFT analysis is done to determine THD of the system. As per IEEE standard 512-1992 THD must be less than 5% in power system. This standard should be satisfied by the traction system, otherwise the system may be damaged or penalties might be imposed. Hence various power conditioners have been proposed by researchers to satisfy this standard.

Figure8 shows the three-phase power voltage and current without compensating. Figure 9 shows the FFT analysis for the same.

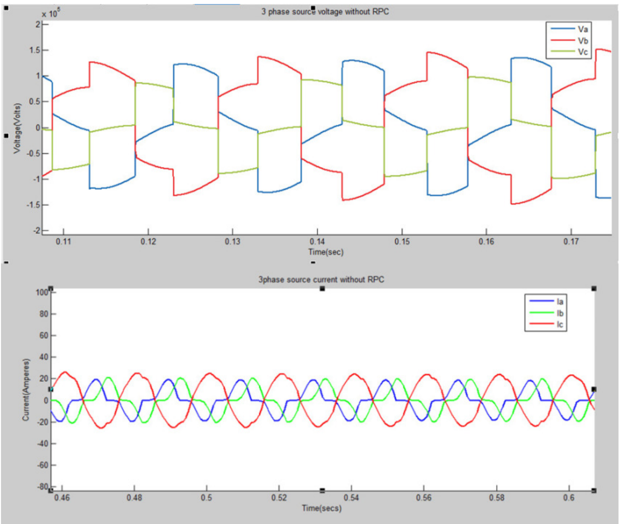


Figure8: Three phase power voltage and current without compensating

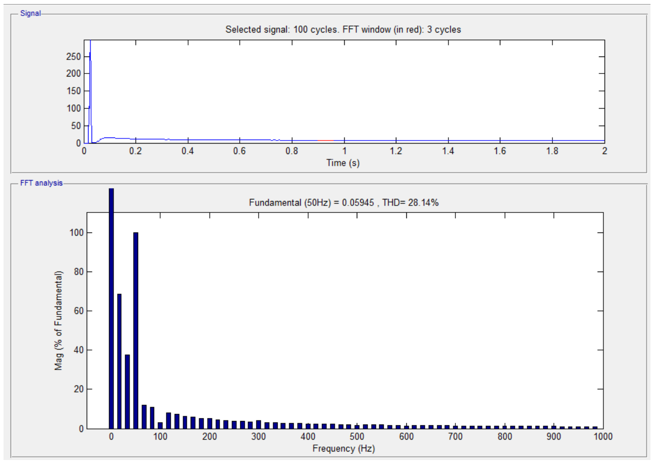


Figure 9: FFT analysis of harmonics presence in the system before compensation

B. FFT Analysis of PID with RPC

Figure 5.7 shows the current waveform after compensation and figure 5.8 shows the FFT analysis for the compensated system. The waveforms show that RPC can comprehensively compensate harmonics, NSC and reactive power. Before compensation we could see the waveforms for power voltage and current so obtained was with the harmonic content in it but after compensating it the harmonics as well as NSC's are minimized and reduced to much lower level. As from the FFT analysis thus obtained we can find it as <5% i.e THD level obtained is 3.61%.

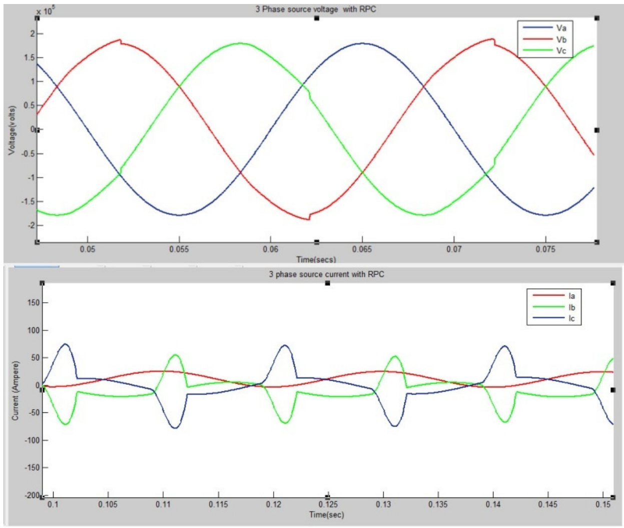


Figure 10: Three phase power voltage and current after compensation

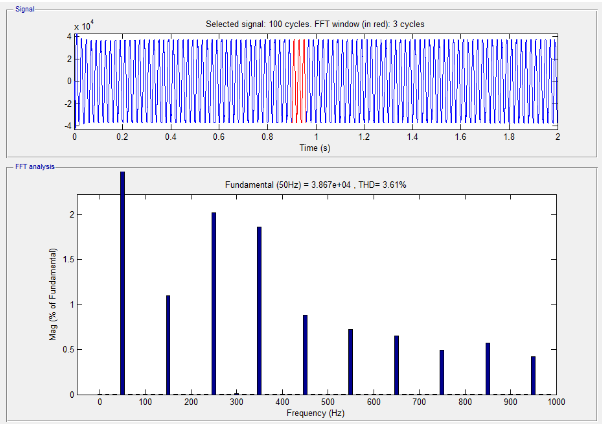


Figure 11: FFT analysis after with PID and RPC

Table 3: THD level

THD	Without PID and RPC	With PID and RPC
	28.14%	3.61%

V.CONCLUSION

This paper put forwards many PQ problems have been reviewed for electric railway propulsion and possible methods to suppress power quality problems.

The PQ improvement strategies are proposed based on important concepts which help us understand the ideas about power quality occurring in railway system. The SVC was the 1st active method used to compensate NSC's and reactive power but in turn increases amount of harmonics in the network. The RPC is widely used in East Asia which compensates all the PQ issues simultaneously.

Hence, a power quality conditioning system is proposed with several power conditioners along with PID controller. Above strategy significantly improves PQ problems and simulation results shows good wave action with the idealized form. From the FFT analysis we can see that IEEE standard is satisfied and the THD in the system is $< 5\%$. Finally, from the simulation results it is clear that the proposed system is very efficient in compensating negative sequence currents, harmonics and improves power factor than conventional methods thereby improving system performance.

REFERENCES

[1] .Power Quality Issues in Railway Electrification: A Comprehensive Perspective Sayed Mohammad Mousavi Gazafrudi, Adel Tabakhpour Langerudy, Ewald F. Fuchs, Fellow, IEEE.

[2] .Er. N. Gunavardhini, Dr. M. Chandrasekaran," Power Quality Conditioners for Railway Traction - a Review" Online ISSN 1848-3380, Print ISSN 0005-1144 ATKAFF 57(1), 150–162(2016).

[3] .Goli Chandra Sekhar, V.S.Kale ,G.Vamsi Krishna, "Application of DVR to Improve Voltage Profile of Indian Railway Traction System".

[4]. Ms. Vidhi C. Pathak, Mrs. Dharmistha Makwana," Power quality improvement in railway traction system" in IJTRE Volume 3, Issue 9, May-2016 ISSN (Online): 2347 – 4718 www.ijtre.com.

[5]. Mr. Kundan A. Otari, Mr. Ravindra Joshi,"A Review on Power Conditioning for High-Speed Railway Systems" in IJSETR Volume 4, Issue 4, April 2015 ISSN: 2278 – 7798.

[6]. Morimoto H, Ando M, Mochinaga Y, et al. Development of railway static power conditioner used at substation for Shinkansen. Proc Power Convers Conf, IEEE. 2002;3:1108–1111.

[7]. Lao K-W, Wong M-C, Dai NY, et al. Analysis of DC link operation voltage of a hybrid railway power quality conditioner and its PQ compensation capability in high speed cophase traction power supply. IEEE Trans Power Electron.2016;31(2):1643–1656. doi:10.1109/TPEL.2015.2417356.

[8] .P.-C. Tan, P. C. Loh, and D. G. Holmes, "A robust multilevel hybrid compensation system for 25-kVelectrified railway applications," IEEE Trans. Power Electron., vol. 19, no. 4, pp. 735 1043–1052, Jul. 2004.

[9]. H. L. Ginn and G. Chen, "Flexible active compensator control for variable compensation objectives," IEEE Trans. Power Electron., vol. 23, no. 6, pp. 2931–2941, Nov. 2008.

[10]. M. Jianzong,W.Mingli, and Y. Shaobing, "The application of SVC for the power quality control of electric railways," in Proc. Int. Conf. Sustainable Power Gener. Supply, pp. 1–4，2009.

[11] .A. Luo, Z. K. Shuai, W. J. Zhu, and Z. J. Shen, "Combined system for harmonic suppression and reactive power compensation," IEEE Trans.Ind.Electron., vol. 56, no. 2, pp. 418–518, Feb. 2009.

[12]. A Novel Collaboration Compensation Strategy of Railway Power Conditioner for a High-Speed Railway Traction Power Supply System Chenmeng Zhang(Student), Baichao Chen, Chao Cai, Mengkui Yue, Cuihua Tian, Bo Chen, Jiaxin Yuan(*Corresponding Author) Wuhan University Wuhan, Hubei, China Jiabin Jia University of Leeds , UK.*

[13].S. S. Fazel1, H. Jafari Kaleybar2, H. Madadi Kojabadi3," An Efficient Strategy for Power Rating Reduction of Back-to-Back Converters Used in Railway Power Conditioner" International Journal of Railway Research, Vol.3, No.1, (2016), 19-28.*

[14].Hu Yu,1,2 Yuan Yue1,Chen Zhe1, Chen Zhifei2, Tao Ye2"Research on the Selection of Railway Traction Transformer", 978-1-4244-7398-4/10/$26.00 ©2010 IEEE.

[15] .L. Sainz, L. Monjo, S. Riera, and J. Pedra, "Study of the Steinmetz Circuit Influence on AC Traction System Resonance," IEEE Trans. Power Del., vol. 27, pp. 2295-2303, 2012.

[16] .C. Wen-Shyan and G. Jyh-Cherng, "A new hybrid SVC scheme with Scott transformer for balance improvement," in Rail Conference, 2006, pp. 217-224.

[17] .G. Zhu, J.Chen, and X.Liu,"Compensation for the negative-sequence currents of electric railway based on SVC," in IEEE Conf. Ind. Electron. Appl., 2008, pp. 1958-1963.

[18]. Z. Zhiwen, W. Bin, K. Jinsong, and L Longfu, "A Multi-Purpose Balanced Transformer for Railway Traction Applications,"IEEE Trans. Power Del., vol. 24, pp. 711-718, 2009.

[19] .W. Chuanping, L. An, J. Shen, M. Fu Jun, and P. Shuangjian, "A Negative Sequence Compensation Method Based on a Two-Phase Three-Wire Converter for a High-Speed Railway Traction Power Supply System," IEEE Trans. Power Electron., vol. 27, pp. 706-717, 2012.

[20]. N. Y. Dai, K. W. Lao, M. C. Wong, and C. K. Wong, "Hybrid power quality conditioner for co-phase power supply system in electrified railway," IET Power Electron., vol. 5, pp. 1084-1094, 2012.