A Review on Power Quality Problems and its Compensating Technique in Railway Traction System

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Abstract --- **Now a days many development has done in electrified railway in world. With development power quality is become a major issue in AC electrified railway. This system has power quality problems such as harmonic current pollution, reactive power consumption, negative sequence current, and load imbalance. A large amount of negative current is injected into grid, which causes serious impact on power system, such as motor vibrations and such additional losses; reduce output ability of transformer and misoperation of protective relay. This impact intimidates railway traction supply system and power system. Therefore, it is necessary to suppress negative sequence current and harmonic current. To solve the issue of power quality in electrified railway many methods and power quality compensators are used. This paper presents why this power quality issues has been occurred in railway system, its effects and how we can comprehensively compensate this issues.**

Keywords: **Power quality issues, harmonics, negative sequence current (NSC), Railway Power Conditioner**

I. INTRODUCTION

Today is an era of development and technology. The power system is developing very fast. With rapid development demand of the users for power quality is become high. In routine life transportation plays a very important role in everyone's life. Indian railway is one of the largest transportation networks in India. The growth of electrified railway in India proves the successful solution to enhance the capacity of public transportation. Electrified railway was adopted by Indian Railways in, 1957. With electrified railway power quality issues becomes a subject to concern because traction load is considered as a non-linear and dynamic load. This peculiarity becomes the source of large amount of harmonics, sub-harmonics and negative sequence current (NSC). These problem causes many problems like, motor vibration, effect on transformers performance and its efficiency, noise, malfunction of protective schemes and effect in sensitive relays. So it is necessary to compensate power quality issues in traction system.

Railway network is very large and complicated network and difficult to understand. For easiness we can divide this network into two sections. One is called Over Head Equipment (OHE) and other one is called locomotive. Locomotive is considered as a non-linear load. Basically locomotives are source of harmonics and other power quality problems. How locomotive effect on power quality of system will discuss in next section. OHE carry the filter which compensate power quality issues.

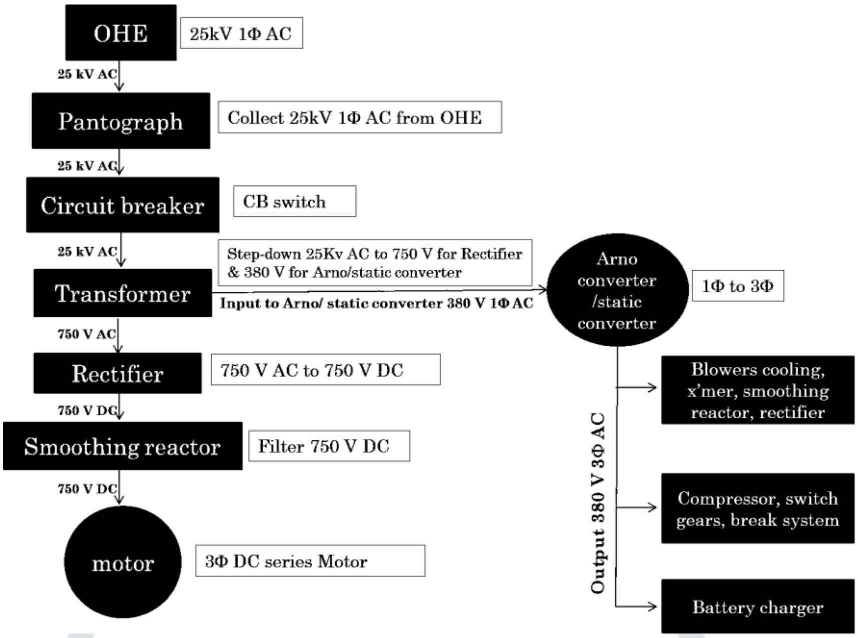
To compensate power quality issues in railway traction system transformer connection is very important. Different type of transformers compared with each other on the basis of its transformer utilization function (TUF) and then it select for the traction system **[13].** It is very important part in traction system design to choose a transformer because power of locomotive is generally huge. So it is convenient to choose the transformer with high TUF which reduce the cost of transformer.

To overcome power quality issues numerous methods and devices have been proposed and imposed. Static Var Compensator (SVC) is one of them but it is not able to comprehensively compensate NSC and reactive power; in fact it generates harmonic which is already one of power quality problem. Active power filters (APF) are widely used to solve these issues but they are not able to compensate NSC. STATCOM (STATic COMpensator) the FACTs device also used in power system to comprehensively compensate power quality issues. But it installed under three phase sides which bear high voltage, hence cost and capacity is high.

RPC was firstly introduced by Railway Technical Research Institute (RTRI) in Japan, 1993; which comprehensively compensate harmonics, NSC and reactive power. Indian Railway is still not adopting this technology, Instead of this capacitor bank is used in Indian railways which compensate 3rd harmonic, reactive power and maintain power factor.

II. RAILWAY TRACTION SYSTEM OF INDIAN RAILWAYS

After adopting electrified railway, engine is drawn by 25kV AC single phase voltage. That single phase system is connected with the three phase grid system. Locomotive consume 25kV, 50Hz AC supply from three phase grid 66/110/220kV through traction transformer. Working of locomotive can be understood from following block diagram figure (1). As shown in block diagram locomotive collects 25kV AC from OHE with the help of pantograph. This electrical energy converts into mechanical energy in control manner through traction motors.



[Figure. (1) Block Diagram of Locomotive **(ref. loco shed)**]

In conventional locomotive 25000V single phase collect by roof mounted pantograph and step down by transformer inside locomotive. Circuit breaker is on the roof for the protection purpose. This supply converted into DC supply by full wave silicone rectifier and then through smoothing reactors it supplies to traction motors. There are six motors in locomotive. Generally DC motors are used in locomotive. Torque and speed control is achieved by variations of AC input voltage to rectifier through an on load tap changing arrangement on primary side of traction transformer. 380V, single phase supply from auxiliary winding of loco transformer is fed to ARNO converter which converts this supply in to 380 V, 3-phase. This 3-phase supply is utilized to run blowers provided to cool traction motors, loco transformer, smoothing reactor, silicon rectifiers, and run exhausters to create vacuum and compressors to build up air pressure.

This arrangement in loco causes an unbalance in the system; resulting NSC occurred in the system and inject NSC in grid. Presence of NSC make AC input current to silicon rectifier damaged and because of this DC output also gets damaged. Nature of nonlinearity introduced harmonics and sub-harmonics in the system. Presence of NSC causes presence of odd harmonics. This issues effect on the performance of power system. Solution of this issue is major concern for engineers. Balance transformer can be used to balance the system. But perfectly balance system is practically not possible, so it's necessary to find another way of compensation.

III. NEGATIVE SEQUENCE AND HARMONICS CURRENT

Due to unbalance loading presence of NSC is natural. As we discussed perfectly balance system is not possible. So NSC needs to be assumed. As we know there are three sets of independent component in every three-phase system. Positive sequence, negative sequence and zero sequence. Utility side is free from zero sequence because there is no ground path. Zero sequence is only flow when there is presence of ground path. If we are taking delta connection on secondary side then it also becomes free part from zero sequence, resultant there is no zero sequence in system. But there is a presence of NSC. We can compensate this NSC with reference to harmonics.

As per definition harmonics are unwanted frequency which is integral multiple of fundamental frequency. To mitigate NSC with reference to harmonics we have to understand relation between them. Following table (1) shows relation between harmonics and NSC. In power system even number of harmonics are not affected to system; however odd number of harmonics is damaged the system. In fact lower order harmonics are the reason of major damage. From following table, harmonics which rotate with the fundamental (A-B-C) are known as positive sequence (1st, 7th, 13th, 19th ….). Harmonics which rotate opposite to the fundamental (A-C-B) are called Negative sequence (5th, 11th, 17th, 23rd…). And harmonics which are do not rotate known as zero sequence (3rd, 9th, other triplet harmonics). So, when we mitigate 5th harmonic we can mitigate NSC with reference to it.

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 1. Relation between harmonics and NSC]

In perfectly balance system,

$$I_a + I_b + I_c = 0 \qquad \text{….. (1)}$$

$$I_1 + I_2 + I_0 = 0 \qquad \text{….. (2)}$$

During unbalance condition,

$$I_a + I_b + I_c \neq 0 \qquad \text{….. (3)}$$

$$I_1 + I_2 + I_0 \neq 0 \qquad \text{….. (4)}$$

As per IEEE standard system unbalance is define as the ratio (%) of negative sequence current to positive sequence current, known as Current Imbalance Index.

$$K = \frac{|I_-|}{|I_+|} \qquad \text{….. (5)}$$

Equation to find total harmonic distortion,

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} Y_h^2}}{Y_1} \qquad \text{….. (6)}$$

Where, Y is a signal. We can put voltage and current at the place of Y. As per IEEE std 519-1992 THD should be less than 5% (<5%) in any system.

IV. METHODS TO COMPENSATE HARMONIC AND NEGATIVE SEQUENCE CURRENT

Sr. No.	Compensation strategies	Harmonic compensation	NSC compensation	Reactive power compensation	Total cost
1	Balance transformer	-	*	-	-
2	SVC	-	**	**	**
3	Passive filter	*	-	-	*
4	RPC	**	**	**	****
5	APQC	**	**	**	***
6	Co-phase	***	***	***	***
7	HPQC	***	***	***	***

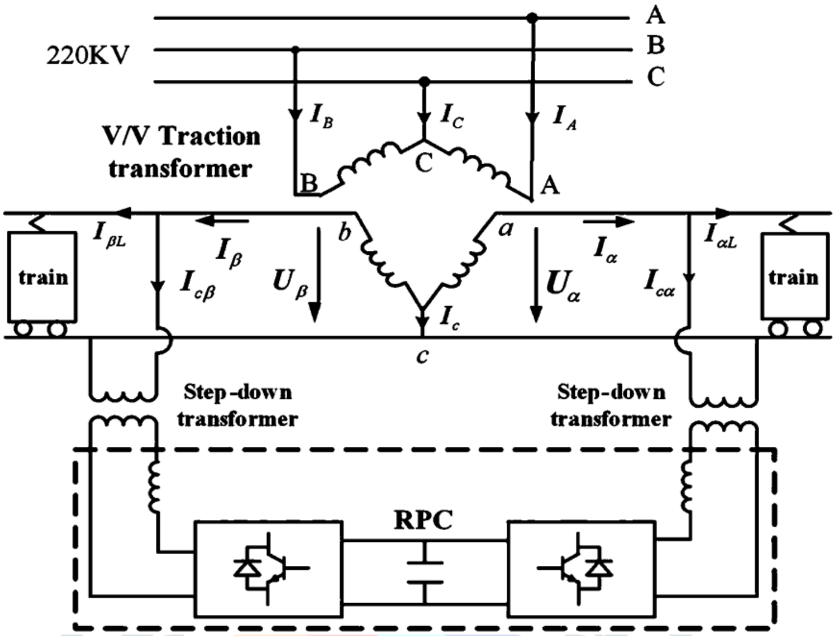
[More * shows more ability to compensate]

[Table (2) Ability of Different equipment for power quality improvement]

There are numerous methods for power quality improvement. In Indian railways capacitor bank is used to compensate problems related to power quality. Capacitor bank can compensate 3rd harmonic and reactive power, but NSC is presence with 5th harmonic. It is necessary to compensate 5th harmonic to mitigate NSC. So, to comprehensively compensate power quality issues many researches have been done by scientists. Contribution of China and Japan on power quality improvement techniques in traction system is significant. Following table (2) shows comparison of different techniques and its ability to solve power quality issue.

V. RAILWAY POWER CONDITIONER (RPC)

For railway traction system Railway Power Conditioner (RPC) is proposed by researchers in Japan, which consist of arbitrary topology ac-dc-ac converter on the secondary side of transformer. Power quality in traction can be improved by controlling the quality of transferred active power, harmonic and reactive power in RPC two ports. Structure of RPC is as shown in figure 2. As shown in figure, three phase 220 kV high voltage step down into two single phase power supply voltages of 27.5 kV by V/V Connected transformer. RPC is made by two back to back converters with common dc link. Both converters are connected on the secondary side of transformer through output reactance and step-down transformer. By using reasonable control strategy output current of the both converter can be adjust. It would achieve the purpose of transferring active power from one power supply arm to other power arm, which suppresses harmonics and NSC.



[Figure (2) Compensation topology of RPC]

Right side is α-phase and left side β-phase. Assume that the fundamental current vector of α phase arm is I_α and current vector of β phase isI_β. According to the characteristics of V/V traction transformer, three-phase current of the high voltage side are shown as follows:

$$I_A = \frac{I_\alpha}{K_B} \quad …..(7)$$

$$I_B = \frac{I_\beta}{K_B} \quad ..... (8)$$

$$I_C = \frac{-(I_\alpha + I_\beta)}{K_B} \quad ….. (9)$$

Where, K_B is the ratio of V/V connected transformer and $a = e^{j\,120^\circ}$. Current imbalance index can find as per equation (5). And I_+ is a PSC and I_- is NSC. In matrix form it can be writing as follow:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix} . \begin{bmatrix} I_1 \\ I_2 \\ I_0 \end{bmatrix} \quad ….. (10)$$

And,

$$\begin{bmatrix} I_+ \\ I_- \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad ..… (11)$$

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

Suppose, Feeder section reference current,

$$i_a'' = \sqrt{2} I_S \sin(\omega t + \theta_a)$$
$$i_c'' = \sqrt{2} I_S \sin(\omega t + \theta_a + 120^\circ)$$
$$i_b'' = \sqrt{2} I_S \sin(\omega t + \theta_a - 120^\circ) \quad ….. (12)$$

RPC reference currents,

$$i_{fa} = i_a'' - i_{La}$$
$$i_{fc} = i_c'' - i_{Lc} \qquad \text{….. (13)}$$

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

$$i_{L\alpha} = \sqrt{2} I_{L\alpha p} \sin(\omega t + \theta_{\alpha b}) + \sqrt{2}\, I_{L\alpha q} \sin\left(\omega t + \theta_{\alpha b} - \frac{\pi}{2}\right) + \sum_{h=2}^{\infty} I_{\alpha h} \sin(h\omega t + \theta_{\alpha h})$$
$$i_{L\beta} = \sqrt{2} I_{L\beta p} \sin(\omega t + \theta_{\beta b}) + \sqrt{2}\, I_{L\beta q} \sin\left(\omega t + \theta_{\beta b} - \frac{\pi}{2}\right) + \sum_{h=2}^{\infty} I_{\beta h} \sin(h\omega t + \theta_{\beta h}) \qquad \text{…..(14)}$$

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.

VI. CONCLUSION

After referring working of locomotive and working of traction system we can understand why this power quality issues has been occurred in the system, how it is presence in system and the Effect of power quality issues on whole network. After referring different methods to compensate power quality issue it is conclude that only RPC can comprehensively compensate this issues. Mathematical expressions to analysis harmonics and NSC are also studied in this paper. It is also observed that by using reasonable control strategy with help of pq theory mitigation of harmonics and NSC is possible.

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