A STUDY ON POWER QUALITY COMPENSATION IN RAILWAY TRACTION

N.GUNAVARDHINI
Ph.d Scholar
Asst.Exe.Engineer/TANGEDCO

Dr.C.SHARMEELA
Asst. Professor
Anna University, Chennai

Dr.M.CHANDRASEKARAN
HOD/Professor
Govt. College of Engg. Salem

Abstract: **The electrical railway transport is more economical and environmental friendly mass transit. The electrical Railway traction system is a source of large varying non-linear loads and polluting the electrical system by means of harmonics. Usually power is taken between two phases, thereby causing substantial unbalance between phases in networks, originally not at all built for this kind of operation. The power quality of traction power supply system has some characteristics, low power factor, high content of negative sequence and harmonic currents because the speed and load are changing constantly. Unless remedial action is taken, the result will be deterioration of power quality, not only harmful traction system itself, but also prone to spreading through the supply grid, disturbing other users of power in the same grid. Hence, various topology of compensation of the power quality suitable for Indian railways were case study was done, is studied in this paper as a literature study.**

Keywords: Harmonics, Power Quality, Passive Filters, Active Filters, RPQC

I. INTRODUCTION

The electrified railway is considered to be an important environment friendly transport way because of its high speed and remarkable transportation capability with great efficiency (1). The High electrified railway when compared to conventional electrified railway (2) the electrified railway has a higher density traffic, which needs a more reliable and large traction power. The large impactive traction loads call for a strong power supply system.

The ac traction loads are fed through single –phase transformer sub-stations. The primary winding of the transformer is connected (phase to phase) to a high voltage three phase network and then given rise to the presence of unbalanced system voltage in the three phase network. The traction overhead feeders have theoretically an infinite number of resonant frequencies (3). When any of these resonance modes are excited, as happens for example with non-linear thyristor loads, a large harmonic voltage can result at a pantograph. If this voltage is added to the fundamental voltage, it may produce a peak voltage at the pantograph with values significantly above nominal. This phenomenon, known as harmonic or resonant over voltage, can lead to failure of equipment connected to the system.

Electric railways are the major pollution sources of the power quality in the public power system. The low power factor and current harmonics caused by AC-DC locomotives are the difficult problems needed to be dealt with for long time. Most of the countries, imposing the penality for the consumers for polluting the utility system by means of harmonics. The consumers are also being penalized for maintaining lower power factor and leading power factor. Hence, remedial measure suitable for the individual system should be adopted to avoid penalty.

In section 2, various types of compensation methods available in the system were discussed with merits and demerits in respect of Indian railway system. In section 3, various new topologies discussed previously [8-10] were discussed based on its suitability to Indian railways system.

II. POWER QUALITY COMPENSATION TECHNIQUES

A case study was done in one of the Indian Railway traction. The voltage and current harmonics measured are shown in the Table 1 and in Table 2. It was found that the current harmonics available upto 25th order.

TABLE 1: ***VOLTAGE HARMONICS MEASURED IN PERCENTAGE***

HARMONICS order	Value in % (station 1)
THD	1.7
2	
3	0.745
4	0.011
5	0.944
6	0.021
7	0.781
8	
9	
10	
11	0.737
12	0.03
14	0.041
15	0.315
19	
25	0.528

TABLE 2: ***CURRENT HARMONICS MEASURED IN PERCENTAGE***

HARMONICS order	Value in % (station 1)
THD	26.1
3	23.4234
5	11.458
7	10.667
9	4.124
11	2.083
13	3.093
15	3.448
17	6.481
19	4.082
21	3.053
23	1.875
25	.671

The current unbalance measured is shown in the figure 1 and found that the current unbalance factor is about 240%.

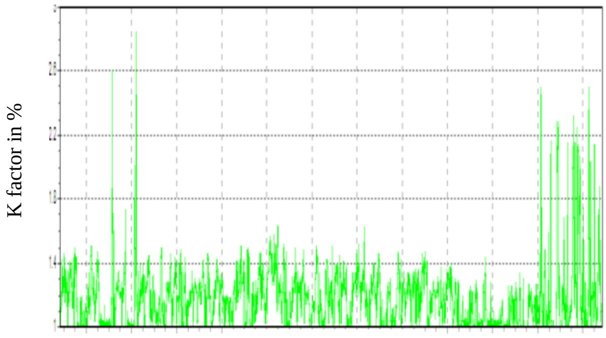

Figure 1 Current unbalance factor measured in railway traction.

Hence suitable compensation topology is studied and discussed in the following section.

A. Passive filters in Railway traction:

Since, utilities are imposing penalty for low power factor to the consumers, passive filters are commonly used to maintain the power factor and to limit harmonic current in distribution.

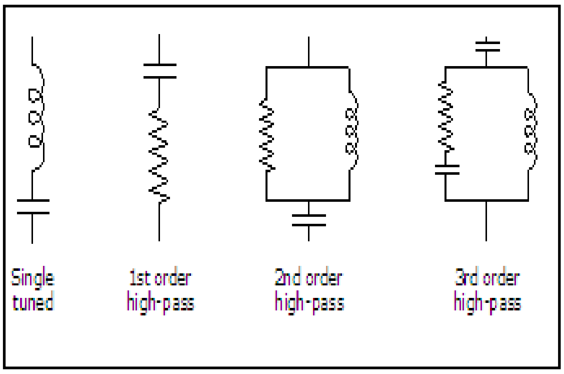

Figure 2 Passive filter

The passive filters are custom designed for the special applications. Their performance is limited to few harmonics and compensates a constant reactive power at fundamental frequency. Since, the current harmonics available in the Indian railway traction is upto 25th order the cost of implementation is very high. The passive filter would not control the reactive power for compensation and the reactive power produced by the compensator is more than the required amount since, the load in the traction system is variable..

This method is very expensive and impractical at high power. The loss in supply system will be increased and this is the drawback for the system, sometimes may lead to the leading power factor which leads to imposing of the penalty.

B. THYRISTOR CONTROL REACTOR IN RAILWAY SYSTEM

To overcome the problems due to passive filters, thyristor control reactors are introduced. A TCR is a variable reactor at the fundamental frequency [7]. The structure of TCR and waveform are shown in Fig 2.

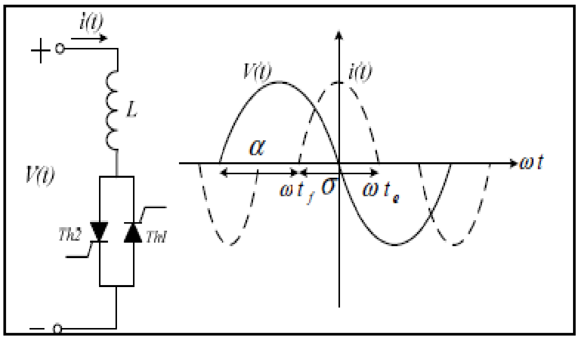

Figure 3 Thyristor controlled reactor and its waveform

Where α is the firing angle of thyristor 1, which conducts between time period of and t_f and t_e. Fig 2 the shows thyristor controlled reactor and its waveform. The firing angle of thyristor 2 logs 180 degrees from α. Voltage and current relationship of the TCR is

$$L\frac{di}{dt} = v(t), i(t) = 0$$

Although, the active filter completely compensates the system, the required power by it would be high and this limit the application of proposed system at high power. Implementation of this system is so expensive and further limits for high power. When TCR is used, the 3rd harmonic and the 5th harmonic become larger since TCR is also a harmonic source. These filters are controlled as current sources for producing non-sinusoidal currents according to non-sinusoidal currents of loads or system for removing the harmonics and making system are sinusoidal. These filters suffer from high rating that increase the cost of the project. Since, 3rd and 5th harmonics measured is already higher than the IEEE limits and railway traction is of higher rated, this type of compensation will not give solution to the traction system. Further this type of filters suffer from higher rating that increases the cost of the poject.

C. HYBRID FILTERS IN RAILWAY TRACTION

Hybrid filters consisted of Active and passive filters with different structures are used to overcome the disadvantages of passive filters such as probability of resonance and non-dynamic responses and also high cost of active filters, while using the advantage of both the filters with low costs [12]. Different structure of hybrid filters are show in Fig3.

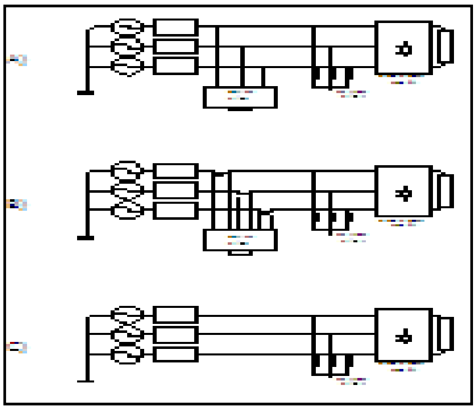

Figure 4 Different structure of hybrid filters.

In hybrid power quality compensator, the fixed reactive power compensation capacitor is designed to compensate 50% of the reactive power and the passive filter is designed to compensate the other 50% of the reactive power.

As a case study.the static var compensator installed in a traction sub-station is shown in Fig.4[9](China)

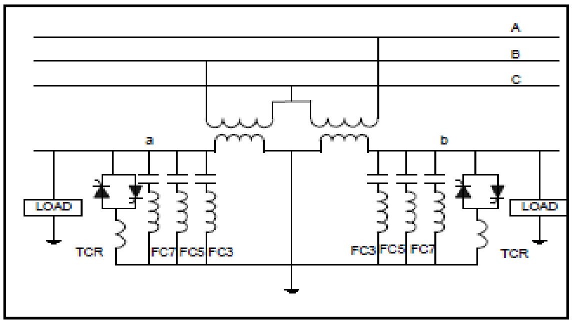

Figure 5. SVC installed in a traction sub station

An analysis was done [7] in a railway traction where SVC is installed. From the analysis, it was found that the filter effect of the SVC to harmonic current is obvious when the 3rd filter branch is put into operation, the 3rd harmonic current reduces markedly. At the same time, the 5th and 7th harmonic currents are also reduced somewhat. But, if only higher order harmonic filter branches are put into service, the lower order harmonic currents will be enlarged. It was also found that the total harmonic distortion also becomes lower.

One more case study was done in a traction station where Dynamic Reactive Power Compensation is installed .The voltage and current harmonics measured are shown in the table 3 and 4.

TABLE 3: VOLTAGE HARMONICS MEASURED IN PERCENTAGE

HARMONICS order	Value in % (station 2)
THD	3.9
2	0.041
3	1.217
4	.051
5	1.463
6	0.041
7	1.322
8	0.83
9	0.873
10	1.277
11	1.837
12	0.011
14	2.036
15	0.01
19	1.356
25	

3rd and 5th Harmonics are higher than the IEEE limits even after installation of DRPC.

TABLE 4: CURRENT HARMONICS MEASURED IN PERCENTAGE

HARMONICS order	Value in % (station 2)	IEEE LIMITS
THD	15.8	14
3	14.815	12
5	13.043	12
7	7.407	12
9	4.046	5.5
11	2.339	5,5
13	2.299	5.5
15	3.727	5
17	4.5445	5
19	0.971	5
21		
23		
25		

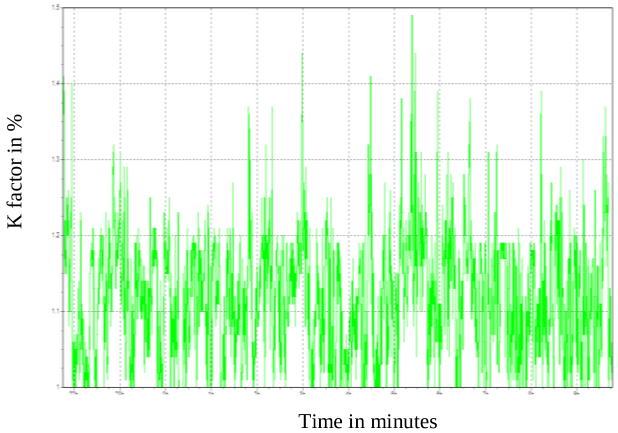

Figure 6: Current unbalance factor in station2

The current unbalance factor is shown in the fig 6. The factor is about 140% which required to be compensated.

III. VARIOUS NEW TOPOLOGIES FOR POWER QUALITY COMPENSATOR

A various new methods/techniques were discussed as an improvement in the existing techniques to have an improvement in the construction and to resolve the problems caused by the modern high speed and heavy load train effectively were discussed in Ref [8-10]. The same is discussed briefly hereafter.

A. Hybrid power quality compensator through Scott transformer in Railway traction.

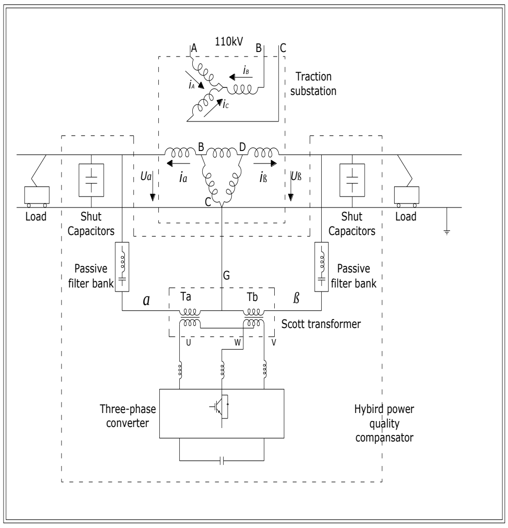

Figure 7: Construction of hybrid power quality compensator

To improve the performance and to reduce the cost, the hybrid power quality compensator with Scott transformers having two banks of passive filter and a three phase converter in series forming a series hybrid power filter. In order to reduce cost further, the fixed reactive power compensation capacitor banks are connected in parallel with a series hybrid filter forming a shunt hybrid structure. Functions of this type hybrid filter are

(i) Elective isolation between traction power supply system and three phase converter.

(ii) Connection between the two-phase current of traction power supply system and the three phase converter. The two phase system is transferred to an approximate balanced three phase's system, so a common three phase converter can be used to improve the power quality in two feeders of a traction sub-station.

(iii) Two banks of passive filters are in series with two phase output ports of the Scott transformers. One bank of passive can be reduced compared with the common three phase series hybrid power filter.

Using scott type transformer type filters found to be higher in cost and it will not solve the unbalance current.

B. MULTI LEVEL HYBRID POWER FILTER IN RAILWAY TRACTION

Another possible solution to mitigate the harmonic complication is to connect a power quality conditioner based on voltage detection is at the end of the traction feeder [1-2]. In a traction system, the locomotive load moves, hence, this is also likely to be most suitable location for the active filter considered in traction application.

To reduce the cost of the topology described in section III(A),Multi level hybrid power filter is proposed based on voltage source for compensating currents [9] is shown in fig.6

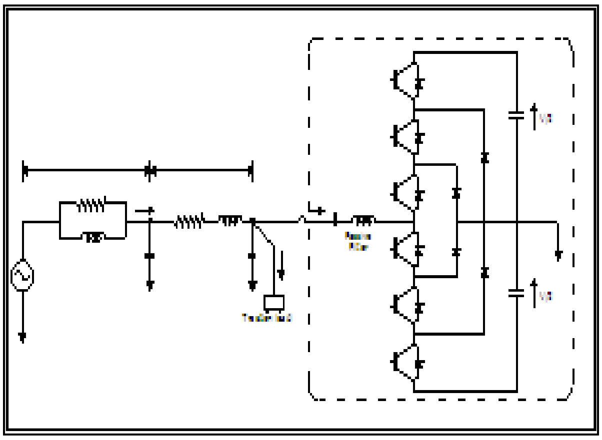

Figure 8: Multilevel Hybrid Power Filters with Control Block.

The advantage of multi level inverter is that they can reduce voltage or current rating and power rating of the semi conductor switching devices and improves compensation characteristics of the active filter. Since, the above filter is to be placed at the end of the feeders, the ac source will be physically quite distance from PCC. Therefore harmonic voltage measuring approach was found as the only feasible possibility for active filter control. Since space vector PWM has a disadvantage due to increase of vector space with increase of level, a multi carrier based PWM method is used in the inner control loop to tract the reference filter current.

In the analysis [9], it was found that THD of supply voltage reduced from 31.08% to 0.12% and THD of supply current from 33.73% to 0.5 and the system maintains unity power factor.

In this topology voltage harmonic is measured by a band pass filter, which extract the fundamental voltage to create a harmonic currents afer multiplying by a constant Gain.

Hence this topology is not suitable solution for Indian railway system where voltage harmonics are within the limits, futher , the topology has not given any solution for the voltage and current imbalance.

D. RPQC FOR POWER QUALITY IMPROVEMENT IN ELECTRIFIED RAILWAYS.

To compensate harmonic currents, reactive power and current unbalance, as a noval topology RPQC was proposed [10]. The RPQC consists of two single phase inverters sharing a DC link capacitor. The RPQC is shown in the fig9.

The DC link voltage for the DC link voltage regulation. the inverter current for the current control and the load current for the harmonic extraction used as controlled inputs.

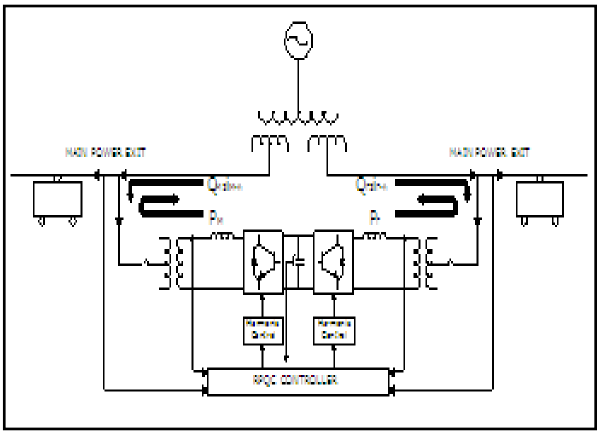

Figure 9: Railway Power Quality Compensation(RQPC)

CONCLUSION:

The electric railway traction loads is the major source of affecting the quality of the power system. Since, penalty is being imposed in most of the countries for low power factor and for polluting the supply by means of harmonics, the consumers are in a position to take remedial action to avoid penalty. Hence, various methodologies have been discussed in this paper.

In Indian Railway system, Thyristor switched capacitor along with the static capacitor are alone are installed to maintain power factor to avoid penalty from being imposed. Now the utilities are taking action to impose penalty for polluting harmonics. Since, in the Indian Railway system, distribution is in ac system to the loads, multilevel inverter hybrid filter or the scott transformer hybrid can be implemented to avoid penalty for polluting the supply by means of harmonics. But the above two topologies have not given given any solution to the voltage and current unbalance apart from cost of implementation.

The RPQC discussed in section III© is suitable for Railway system which gives compensation to harmonics, reactive power and unbalance voltage and current. But in railway system, the locomotive moves and hence, the best solution is to have power quality conditioner at the end of the feeder where voltage dip experience when loco moves from one feeder to another. The RPQC to be installed at the end of the feeder to be controlled by measuring voltage and current at the station itself and the operation to be carried by means of relays. This will be the scope for the future study.

REFERENCES

[1] National Development Reform Commission Long Term integrated Network Development Plan (Z) 2007.

[2] Li Q Unzhan, on "Some Technical Key problems in the Development of Traction Power Supply System for High Speed Railway" ;in China (J) Journal of the China Railway Society, 2010, 32(4) : 119-124.

[3] M.Salehifar,M Ranjbar on "A Combined System of Passive Filter and TCR for Power quality improvement in a 25 KV Electrified Railway system

[4] Pee-Chin Tan, R.E Morrison, and D.G Holtmes, "Voltage from factor control and Reactive Power compensation in a 25-kv Electrified Railway system using a shunt active filter based on voltage detection" – IEEE Trans on Ind Appl. Vol 39, No.2, March/April 2003.

[5] Pee-Chin Tan, Pon Chiang Loh and D.G Holmes, " A Robust Multilevel Hybrid Compensation System for 25 KV Electrified Railway Application" – IEEE Trans. On Power Elec., Vol.19 No.4, July 2004.

[6] P.Kiss and A Dan " The application of the Double Domain Simulation by Different Harmonic Filtering Method of 25 KV Electric Traction systems" Harmonics and Quality of Power, 2008, ICHQP 2008, 13th Int. Con on Sep 2008.

[7] "The Application of SVC of the Power Quality Control of Electric Railways" by Ma Jianzong, Wu Mingli and Yang Shaobing

[8] "Study of Noval Traction substation Hybrid poer Quality Compensator " by Sunzhuo and Jiang Xinjian and Zhu Dongqi

[9] A Single phase Multilevel Hybrid Power filter for Electrified Railway Application" by Salem Rahmani and Kamal Al-Haddad – IEEE ISTE 2006, July 9-12, Canada

[10] "A Noval control algorithm for Railway power quality conditioner in AC electrified Railway system " by Haneol park, Jungho Han and Joonghosong, Journal of international council on Electrical Engineering Vol 1. No,2, pp 145-150.

[11] Y Sun W Zhen, Wils UM XU " A new method to model the harmonic generation characteristics of the Thyristor Controlled reactors" IEEE Power Tech 2007, July 2007

[12] Power Quality Improvement of DC Electrified Railway Distribution System sing Hybrid filters by Seyed Hossein Hosseini, Farhad Shania, Mitra Sarhengzadah

[13] F Z Peng and D J Adams "Harmonic and Reactive Power Compensation based on the generalized instantaneous rective power theory for three phase four wire system" IEEE Trans on Power Elect. Vol 13 No.6, pp 1174-1181 Nov 1998.

[14] D.G Marques "A Comparison of active Power Filter contol methods in unbalanced and non sinusoidal conditions" in Proc of IEEE 24th Annual Conf. on Ind Electronics Society, Vol1, pp 444-449, 1998.

[15] V.Soares, P.Verdelho and G.D Morques, "An Instantaneous active current component method for Active filters" IEEE Trans. On Power Electronics, Vol15, No.4, pp 660-669, July 1998.

[16] "A Novel Control Scheme of the STATCOM for power quality improvement in Electrified Railways by Seyed Hossein Hosseini, Mitra SarhangZadah, IEEE Trans. On Power Electronics, Vol15.No4,pp660-669,July 1998.

[17] K.Wada,H,Fujila and H.Akag. " Consideration of a shunt action filter based on voltage detection for installation on a long distribution feeder' IEEE Trans.Ind.Applicant. ,vol 38.pp1123-1130, July/Aug2002.