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Power Quality in Railway Traction and Compensation by Combining Shunt Hybrid Filter and TCR

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Original scientific paper

This paper analyses the quality of electricity in railway traction. Power quality characteristics have been measured as a case study in a traction sub-station in Tamil Nadu, India, where 1400 KVAR capacitor bank is installed. The actual data has been obtained through direct supply of traction load. Harmonics and various power quality problems are generated through the load of current. The emerging power problems need attention to rectify the "polluting" sites. Issues are measured by providing power quality analyzer and compared with IEEE standards 519-1992. Simulation has been done to improve the power quality issues such as harmonics, power factor and reactive power by using a combination of shunt hybrid filter and Thyrsitor Control Rectifier.

Key words: Power quality, Traction load characteristics, Harmonics, Traction station, Total harmonic distortion

Kvaliteta snage u željezničkim sustavima i kompenzacija zasnovana na šant hibridnom filtru i tiristorski upravljivom ispravljaču. U radu se analizira kvaliteta električne energije u željezničkim sustavima. Karakteristike kvalitete snage izmjerene su u studiji slučaja na elektrovučnoj podstanici u Tamil Nadu, Indija, gdje je priključen slog kondenzatora snage 1300 KVAR. Stvarni podaci dobiveni su direktnim mjerenjem vučnog opterećenja. Viši harmonici i razni problemi vezani uz kvalitetu snage primiječeni su pri strujnom opterećenju. Spomenuti problemi trebaju dodatnu pozornost kako bi se uklonili. Poteškoće su detektirane korištenjem analizatora kvalitete snage te su uspoređene s IEEE standardima 519-1992. Provedene su simulacije za umanjenje poteškoća povezanih s kvalitetom električne energije kao što su viši harmonici, faktor snage i reaktivna snaga pri čemu je korištena kombinacija šant hibridnog filtra i tiristorski upravljivog ispravljača.

Ključne riječi: kvaliteta snage, karakteristika vučnog opterećenja, harmonici, vučna stanica, ukupna harmonična distorzija

NOMENCLATURE

THD: Total harmonic distortion
TCR: Thyristor controlled rectifier
HV: High voltage

1 INTRODUCTION

An environmental friendly and energy efficient mode of transport is the electrified railway.The electrified railway lines need much consistency due to its high energy consumption [1]. The AC traction loads are fed through single phase transformer. In this system, the rise of unbalanced system voltage is due to the two phase connection from a high voltage three phase networks.

The increase in speed and weight hauled even by a single train demands high electrical power. This generates the harmonic pollution aspect.

In railway traction, converters cause the harmonic distortion and sudden changes of loads may cause voltage fluctuation and flicker.As per EN 51000 standards, the voltage and current profiles as well as the voltage and current harmonics are measured in the railway traction sub-station using Fluke analyzer 1735. The power quality problems are measured with the capacitors connected to the system. The capacitors are very much essential to maintain the power factor, to avoid the penalty that is being imposed by the utility and hence could not be disconnected during the study.

Section 2 discusses the power system that feeds the traction station and Section 3 studies and analysis the power quality issues like current unbalance, voltage sag, voltage transient, percentage of individual current and voltage harmonics of the railway traction sub-station and voltage and current harmonics in THD of the railway traction sub-station. In Section 4, simulation through MATLAB and its results are discussed.

2 POWER SUPPLY SYSTEM

The railway traction power supply is high short-current capacity system that is connected through single phase transformers [2, 3].

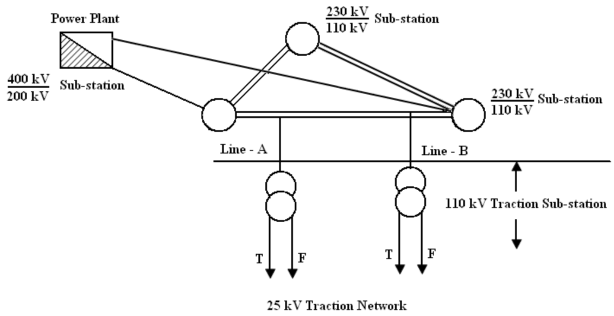

Fig. 1. Traction load power supply system

Figure 1, shows a 110 kV power supply system of Railway traction. It is connected to the system through two 110 kV/ 25 kV/ 21 MVA single phase traction transformers.Usually, one traction transformer alone supplies power to the traction loads and the other will be the standby. One terminal of 25 kV traction transformer's secondary coil is connected to earth and the other one splits. Therefore, the railway traction sub-station can be considered as a source of negative sequence current and harmonic current. In the railway traction taken for case study, supply is being provided through take off line from two numbers tie feeders.

3 POWER QUALITY PROBLEMS IN TRACTION SUB-STATION

3.1 Voltage sag

Short duration voltage sag occurs at point A, B and C, when some of the operations carried out at one of the 230 kV/110 kV sub-stations feeding the railway traction to avail line clear in 110 kV bus as shown in Figure2. Voltage dips to 102.9 kV at point A, when the capacitor banks are hand tripped at one of the feeding sub-station. When the auto transformers are taken out of service in the same sub-station, the voltage dips to 102.55 kV at point B. When the bus coupler switch was opened to sectionalize the bus to avail the line clear in the bus, voltage dips to 103.9 kV at point C.

3.2 Transients

Transient that changes the voltage state and rises to 109.55 kV is shown in the Figure 3 at point A.The above instant of transient occurs during the opening of a tie feeder

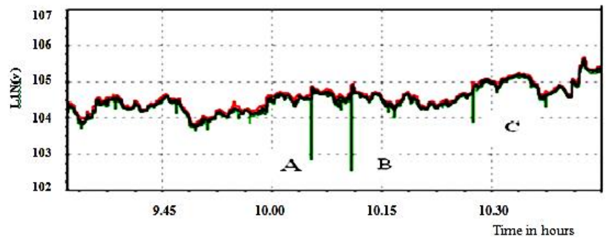

Fig. 2. Voltage sag in traction sub-station

bus and line switches at one of the sub-stations feeding the traction, in order to avail 110 kV bus line clear for maintenance.

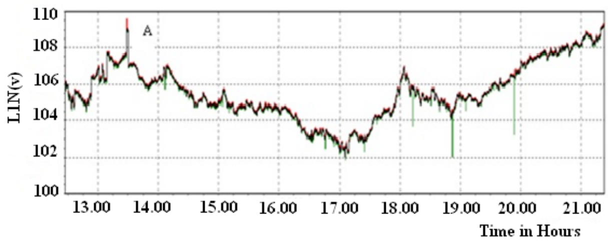

Fig. 3. Voltage transient in the traction station

3.3 Current imbalance

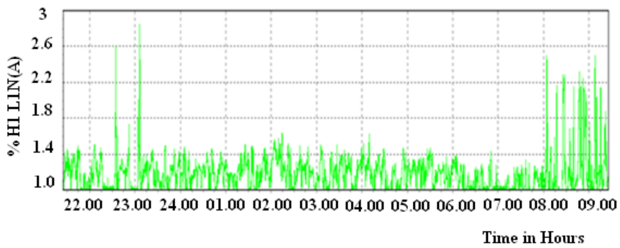

Fig. 4. Current imbalance in railway traction

The current imbalance factor for railway traction is $K = \frac{I_2}{I_1} = 100\%$ [3], where I_1 is a positive sequence and I_2 is a negative sequence. From Figure 4, the analyzed data notifies the imbalance factor K that varies from a maximum of 2.9 to a minimum of 1.01. This reveals that the negative sequence current is more than the limits, due to the traction loads.

3.4 Voltage imbalance

The simplified formula for evaluating the voltage imbalance factor for railway traction is K = $\%E_V = \frac{p}{P}$ where p is power rating of traction load and P is short circuit rating of HV terminal [4, 5].

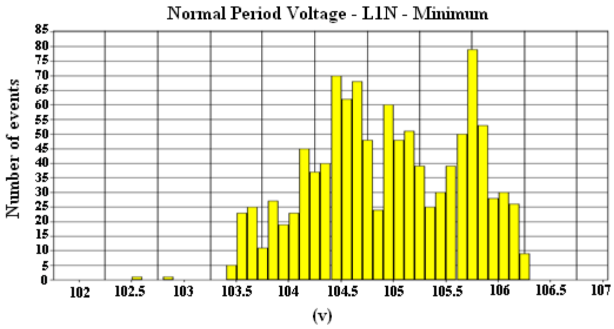

Fig. 5. Voltage statistics of traction sub-station

According to the criterion demanded in GB/T 15543-1995, the voltage imbalance factor should be below 2 percent for a short duration of time interval shorter than 10 minutes and 1 to 1.5 percent for a long duration which can be observed in many AC railway electrification systems and this is acceptable[6, 7].Figure 5 gives the statistics of voltage observed in the railway traction during the measurement period.The data taken from 11 MVA load traction sub-station have a short circuit capacity of 4185 MVA at the HV terminals and hence the voltage imbalance works out to 0.2 percent, which is well within the limits.

3.5 Voltage harmonics

The IEEE standards indicate that for a voltage level of 69 kV to 161 kV,the Total harmonic distortion level limit is 2.5 percent for normal operations when the conditions lasts for longer than an hour. For shorter periods, the limit might exceed by 50 percent(Total harmonic distortion level limit=3.75 percent).

Table 1 gives the voltage harmonics values of railway traction sub-station measured in percentage by providing analyzer on the high voltage side.

From the Table 1, it is clear that the voltage harmonics in THD of the railway traction sub-station is well within the limits.The negative sequence of voltage harmonics of orders 4,6,12 and 14 are well within the limits specified by IEEE standards 519-1992. The voltage harmonics of orders 2,8, 9 and 10 are not presented.

3.6 Current harmonics

According to IEEE standards 519-1992, based on the short circuit strength of the system, the current harmonic limits vary. The customer might be allowed to inject the harmonics when the system is strong.

The individual current harmonics and THD measured by installing harmonic analyzer directly on the HV side of the railway traction sub-station are given in the Table 2.

Table 1. Voltage harmonics

Harmonics order	Harmonics in percentage
THD	1.7
2	0.00
3	0.745
4	0.011
5	0.944
6	0.021
7	0.781
8	0.00
9	0.00
10	0.00
11	0.737
12	0.03
14	0.041
15	0.315
19	0.00
25	0.528

Table 2. Current harmonics

Harmonics order	Harmonics in percentage
THD	26.1
3	26.1
5	23.4234
7	10.667
9	4.124
11	2.083
13	3.093
15	3.448
17	6.481
19	4.082
21	3.052
23	1.875
25	0.671

The current harmonics present in the traction stations are due to the fast varying traction loads.

It is found that the 3^{rd} and 5^{th} order current harmonics present are in the range of 26.1 percent and 23.42 percent respectively. The 17^{th} order of current harmonics is also available at 6.481 percent. The THD of current harmonics has the value of 26.1 percent. The above mentioned harmonic orders and harmonics in THD are higher than the limits specified by IEEE standards 519-1992. The 3^{rd} and 5^{th} order harmonics are on higher side due to resonance effect for the capacitors connected for PF correction in addition to the effect of traction loads. Hence, it is necessary to take action to reduce the harmonics level to avoid the penalty.

3.7 Power factor

In the railway traction sub-station, where the case study has been done, a total capacity of 1400 kVa capacitors is connected. At present, the utility imposes penalty when the power factor in facility goes below 0.85. Hence, the railway traction is maintaining the power factor within the limits by varying the capacitors manually to avoid the penalty that is being imposed by the utility. The harmonics available in this case study are of order 3^{rd}, 5^{th} and 17^{th}. The 3^{rd} and 5^{th} order harmonics are created due to resonance between capacitors used for power factor correction and the line impedance.Hence,a suitable compensator should be provided to maintain the harmonics and power factor within the standards.

4 POWER QUALITY COMPENSATION

The railway traction loads are high power non-linear loads. Hence, the passive filters do not give effective solutions because these filters suffer from resonance. The active filters are more effective but cost is relatively high. Hybrid filters are more effective for high-power non-linear loads. These filters compensate harmonic distortion, unbalance and reactive power [8] and are cost effective because of the reduction in kilovolt ampere rating of power electronic devices.

In [8], a combination of a thyristor controlled reactor and hybrid active filter with voltage vector transformation control strategy has been proposed for harmonic suppression, load balancing and reactive power compensation.

In [9, 10], a combination of shunt hybrid filter and TCR has been proposed for reactive power and harmonic current compensation, for 3 and 4 wire systems. In addition, it reduces the volt ampere rating of active power filter significantly.

The system is based on a decoupled control strategy in which current injected by shunt active filter is controlled in synchronous orthogonal dq frame and dc linear voltage is controlled by output feedback linearization control.Since, the railway traction loads are high power non - linear, signal phase loads and the harmonics of order 3, 5 and 17 are predominant. The combination of shunt hybrid filter with TCR is proposed for harmonic and reactive power compensation.

The above proposed topology has been simulated by decoupled control strategy with nonlinear loads using MATLAB. The experiment results show that the proposed topology is suitable for railway traction loads even after removing the capacitor banks connected to improve power factor.

4.1 Configuration of SHUNT HYBRID filter - TCR

Figure 6 shows the proposed single phase shunt hybrid filter combined with TCR. The shunt active filter is connected in series with fifth order tuned passive filter. The tuned passive filter in parallel with TCR is used for fifth order harmonic compensation and P.F correction.The small rated active filter is used to remove the harmonics generated by TCR and the rest of resonance between the grid and shunt passive filter. Figure 7 shows the control scheme for the proposed compensator for the railway traction.

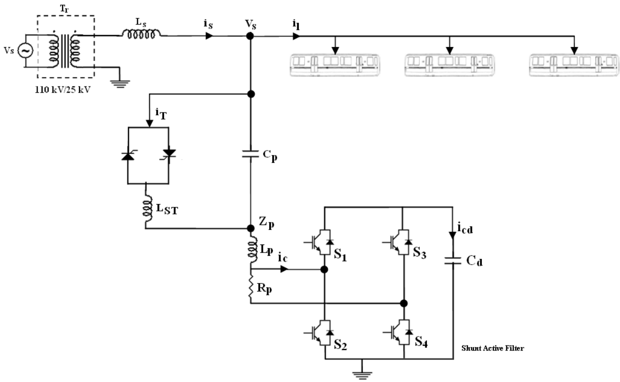

Fig. 6. Single Phase Shunt Hybrid Filter combined with TCR for Railway Traction

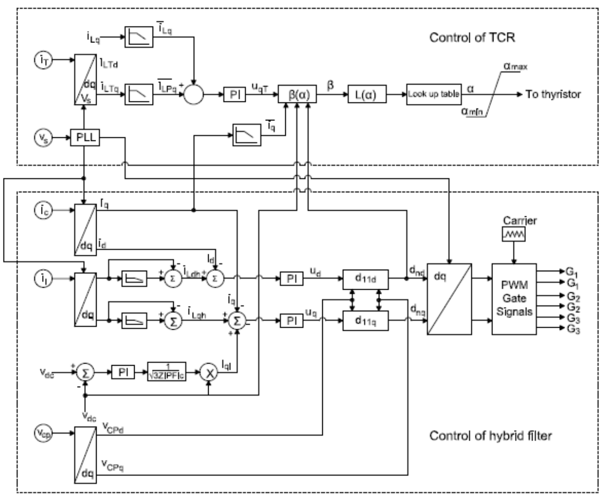

Fig. 7. Control scheme of the proposed SHF-TCR compensator

Table 3. Apparent power ratings of active filter

	Harmonics generated load	Reactive power and harmonics type of loads
The apparent power of the Shunt Active Filter: $S_a = \sqrt{3}\frac{V_d}{\sqrt{2}}I_{arms}$	148.2 VA	151.2 VA
The apparent power of the load: $S_A = 3V_{phrms}I_{Lrms}$	2861 VA	3391 VA
The apparent power ratio between the active part of the SHF-TCR S_a and the load $S_A : \frac{S_a}{S_A}$	5.1%	4.27%
The apparent power ratio between shunt active filter when used alone and the load: $\frac{S_a}{S_A}$	27%	16%

The rating of active power filter used for the simulation is given in the Table 3. The specification of the components arrived are listed in the Table 4.

Table 4. Specification parameters

Line to Line source voltage, and frequency	V_{s-L-L}=25 kV, f_s=50 Hz
Impedance of Line	L_s=0.5 mH, R_s=0.1 ω
Non linear load	L_{NL}=10 mH,R_{NL}=27 ω
Linear load	L_{LL}=20 mH, R_{LL}=27 ω
Passive filter parameters	L_p=1.2 mH, C_p=240 μF
Active filter parameters	C_d=3000 μF, R_p=1 kω
DC bus voltage of APF of SHAF	V_d=50 V
Switching frequency	1920 Hz
Inner controller parameters	$K_{p1} = K_{p2}$=43.38; K_{i1}=37408;
Outer controller parameters	K_1=0.26;$K_2 = 42$
Cut off frequency of the low pass filters	F_c=60 Hz
Inductance of TCR	L_{ST}=25 mH

4.2 Simulation Results

Simulation has been done using MATLAB and the results obtained show that the combination of Shunt hybrid filter and TCR is suitable for the Power factor and harmonic correction in the railway traction.

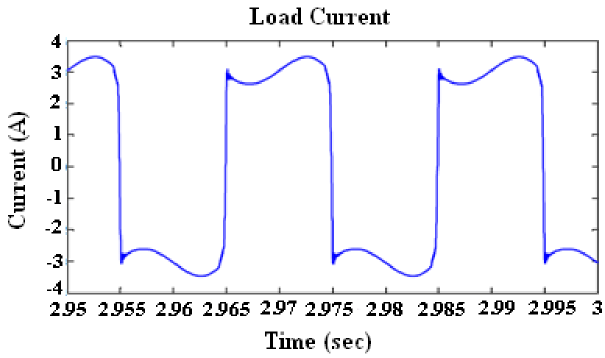

Fig. 8. Load current

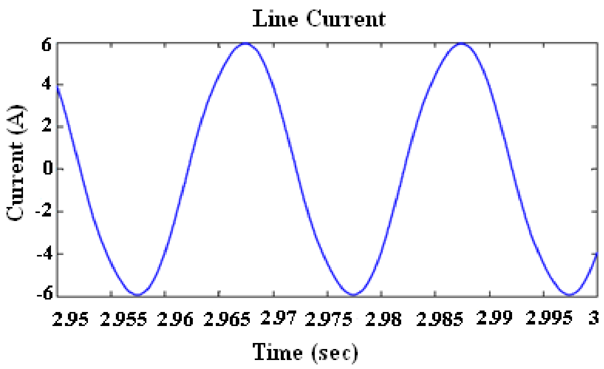

Fig. 9. Line current

Figure 8 depicts the load current before compensation and Figure 9 shows the line current after compensation. Figure 10 shows the harmonic order spectrum on the incoming side before compensation and Figure 11 shows the harmonic order spectrum after compensation.

The load current, line current, the TCR current and the hybrid filter current waveforms are shown in the Figure12. From the above, it is seen that the line current is close to sinusoidal and is in phase with supply voltage and thus the reactive power and harmonic currents are effectively compensated.

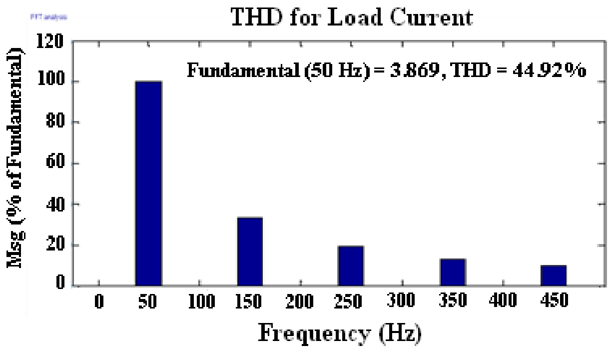

Fig. 10. THD for load current

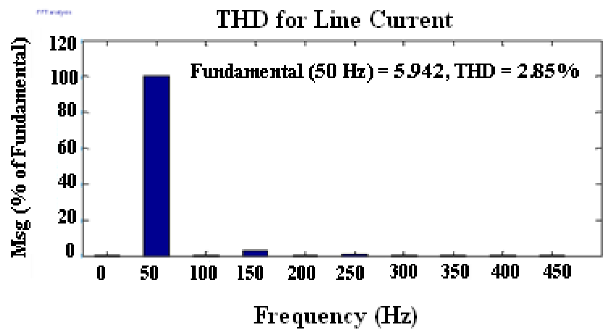

Fig. 11. THD for Line current

5 CONCLUSION

The increasing attention of power quality problems in railway electrification studies leads totechnical solutions. The measured individual and THD forms of current and voltage harmonics in the traction sub-stationareanalyzed and compared with the IEEE standards 519-1992. It is evident that the 3^{rd}, 5^{th} and 17^{th} orders of current harmonics and the Total Harmonic Distortion (THD)are higher than the IEEE standards 519-1992.

In most of the countries, consumers are penalized for polluting the utility supply by means of harmonics. In India, the Central Electricity Authority is now enforcing the utilities to maintain the quality of supply within the limits. Since, the utilities has not framed any limits generally,they strictly instructed that the consumers should maintain the quality of supply as per the IEEE standards 519-1992.

To resolve the above problems, the combination of single phase Shunt hybrid filter with Thyristor controlled single phase filter has been proposed and simulated. The above topology has been proposed to improve the performance of filtering and to reduce the power rating requirements of an active filter. It has been found that the above proposed topology can effectively eliminate current harmonics and reactive power compensation during the steady and transient condition and will be able to reduce the THD of current on the utility side well below the limit of 5

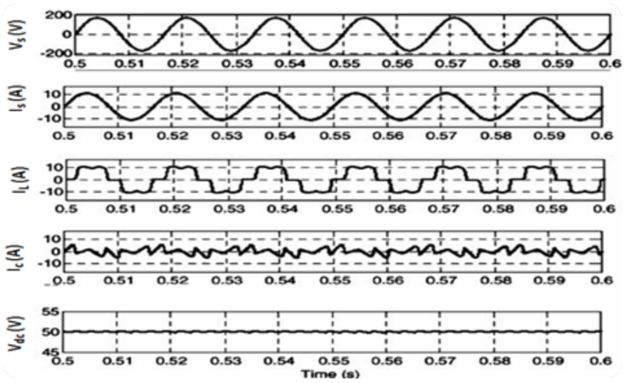

Fig. 12. Steady state response of the proposed topology

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