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Reactive Power Compensation in Railways Using Active Impedance Concepts

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***Abstract*:** Traction systems are huge consumers of reactive power. It due to the presence of inductive reactance in traction transformer, traction motors, auxiliary motors, smoothening reactor. Reactive power keeps on varying in a traction substation as the number of locomotives increases and decreases in its working environment. As a result of this a detailed study of reactive power is required in traction substation and the traditional fixed capacitors should be replaced with active filter based on PI controller.

Keywords**-** traction substation, Indian railway, reactive power, active power, voltage imbalance, PI controller, shunt active filter.

I. Introduction

A traction system is the most widely used transportation system across the world for long and short distance**.** India ranked fourth covering a total length of 64,015 kilometers. The most part of it is electrified. Annually, approximately 30 billion units of electricity is consumed by Railways, out of which 10.4 billion units are used for electric traction purpose. Railway is paying approximate Rs. 5000 crores every year on account of traction energy charges which constitutes about 20% of total revenue budget of railways.

An electrical traction system is pulled with an engine system which consist of highly reactance elements such as DC series motors transformer, auxiliary motors for compressors, baby compressors and cooling fans. Due to this reactive element in the engine traction system a large reactive power is consumed by the traction system. Also, nowadays single phase rectifiers are widely used in the electrical traction loads in many countries, which caused the issues of harmonics and reactive power.

The harmonics and reactive power have negative influences on the power supply system. To compensate reactive power, fixed capacitors have been widely used. One of the main disadvantages of fixed capacitor is that its compensation amount is also fixed and cannot be changed with the variation of load. Another one is that `resonance may occur between the fixed capacitor and the impedance of power supply system. Recently TSF (Thyristor Switched Filter) has been used in traction system.

There are several group of passive filter in TSF, with the variation of reactive power, an appropriate number of groups of TSF are switched on. Thus the compensation amount of TSF can be adjusted with the variation of load. However, resonance will still possible to occur between TSF and the impedance of power supply system.

This paper is concentrated on Palgat railway division traction substation,kerala State, India. The Indian Railways employ single phase 25 kV Traction Substation (TSS) for supplying power at Electric Traction loads. Few key features of Traction loads are single phase 25-KV system, high load dynamics, usually inject lower order harmonics and wide supply voltage variation. Conventional fixed shunt capacitor banks alone cannot maintain a good power factor at the incoming supply lines due to load dynamics. To achieve good power factor nearing unity to avoid penalty (for lagging or leading poor power factor), to gain the better power factor benefits in the electricity bills, to reduce the Maximum Demand and applicable charges in the electricity bills, and to improve power quality, the substations need to employ dynamic reactive power compensation equipment. The equipment needs to be connected on the 25 kV network and dynamic compensation of traction load reactive power is to be achieved using either Thyristor Controlled Reactor (TCR) or Thyristor Switched Capacitor (TSC) or IGBT based realtime advanced dynamic reactive power compensator.

In this paper use an IGBT based Shunt Active Power Filter (SAPF) is used, which utilize the features of modern power electronic technology. Different types of APFs are used in electric traction system. The reactive power, the harmonics, voltage imbalance and negative sequence current can be compensated effectively. However, when the complexity of control is increased the use of power electronics components in the topologies also increased. In addition, these APF use instantaneous power theory to determine the compensating currents, which is not suitable for single phase traction power systems.

Here proposed a new active power filter based on PI controller. Since the voltage source converter is important part in APF, more care is given to design of DC side capacitor. The controlling of DC capacitor voltage along with reactive power compensation and voltage balancing control is adopted here to improve the system behavior. The performance analysis will be done with comparative study of power factor and reactive power compensation. All the simulation work has been done on MATLAB.

II. Proposed System

Indian railways uses single phase 25kV, 50Hz supply system, by stepping down the 110kV grid supply voltage. An equivalent supply system and step-down transformer of equivalent rating is designed and developed using MATLAB/SIMULINK. According to the readings obtained from the traction substation, Palagat railway division we designed an equivalent traction load with fixed capacitance compensation. But this capacitor compensation won't be sufficient for compensating power quality problems like imbalance and sag in voltage, insufficient active and reactive power, harmonics and overcompensation in case of light loads in traction substation. As a result of this power quality problems in supply side also will get disturbed and the railways will have to pay extra penalties to the supply system authorities.

We designed a shunt active filter for which is the best and simplest solution for compensating these power quality problems in Indian environment. This system is also economically feasible with a simple PI controller. The shunt active filters are based on IGBT a solid state device. Fig.1 shows the schematic diagram of the proposed system based on the shunt active filter.

Fig.1 gives an idea of the proposed system which is a shunt active filter based on PI controller action which is simple and economically feasible for Indian environment. It consists of 25kV ,50Hz supply voltage, shunt active filter and traction load. PI control action is done by generating a reference current by comparing the input voltage and the load voltage and then the reference current is given to the PWM pulse generator which is given to the gate supply of the IGBT. A DC voltage is given as a backup supply for the compensation. Fig .1 shows the block diagram representation of the proposed system.

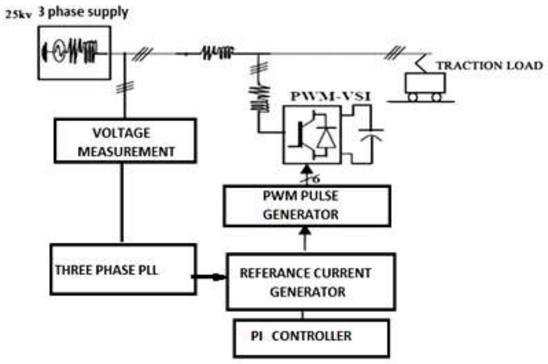

Fig.1 Schematic diagram of the proposed system with shunt active compensation.

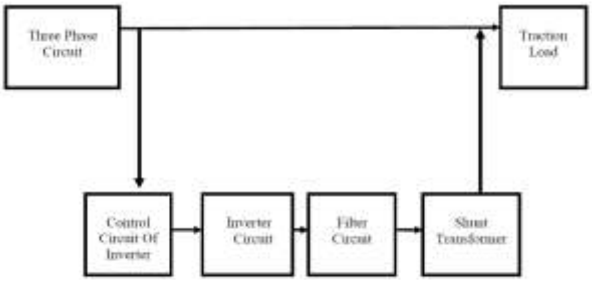

Fig.2 Block diagram representation of the proposed system

The block diagram of the proposed system is shown in the figure below. From the diagram can see that a three phase supply is supplying the traction load and the measurement of this voltage is given to the control circuit of the shunt active power filter. Were this measured value is compared with a reference value and given to a PI controller whose output is given to PWM pulse generator and is given to the gate circuit of the inverter circuit . the inverter output is given to a LC filter to reduce the distortions . this inverter output is given to the three phase circuit through a shunt transformer .

A three phase supply is given to the traction distribution system with maintaining equal load management done effectively. An equivalent traction load is also designed with the values of active and reactive power obtained from the traction substation. As the traction system is a highly inductive load there should be an effective dynamic reactive power compensation system. In accordance to the values obtained from the traction substation a traction load is modeled with equivalent RLC load with fixed capacitance compensation.

III. Simulation Of Proposed System

The circuit of a traction power system with equivalent traction loads on three phases supply and traction load with reactive power compensation is implemented using MATLAB/ SIMULINK.

A simulation model of traction power supply system with load is created in MATLAB/SIMULINK so as investigate circuit waveforms, dynamic and steady –state performance, voltage and current ratings and real and reactive power ratings. The case study of voltage imbalance, sag , low power factor at the load side is simulated and results are presented below.

TABLE I

SIMULATION PARAMETERS FOR TRACTION LOAD

Active Power	2.87MW
Reactive Power Inductive	1.44MVAR
Reactive Power Capacitive	7kVAR

TABLE II

SIMULATION PARAMETERS FOR LINE LOSSES IN THREE PHASE POWER SUPPLY

R – phase	R= 1000	L= .0138e-2	C= .24e-3
Y- phase	R= 2000	L= .0276e-2	C= .24e-3
B - phase	R= 3000	L= .0404e-2	C= .24e-3

TABLE III

SIMULATION PARAMETERS FOR THE PROPOSED SYSTEM

Phase to phase rms voltage	77.78 MV
Frequency	50 Hz
Nominal Power	13.5M W
Frequency	50Hz
Primary Voltage	110 kV
Secondary Voltage	25 Kv
Coupling Inductance,	L=1mH
Coupling Resistance	R=200Ω

IV. Results And Discussions

A simulation model of traction power supply system with load is created in MATLAB/SIMULINK so as investigate circuit waveforms, dynamic and steady –state performance, voltage and current ratings and real and reactive power ratings. The case study of voltage imbalance, sag, low power factor at the load side is simulated and results are presented below.

A. *Input Voltage*

The diagram Fig. 3 the waveform of the input voltage 25kV. The voltage is obtained by stepping down the SEB supply voltage 110kV to 25kV in MATLAB simulation.

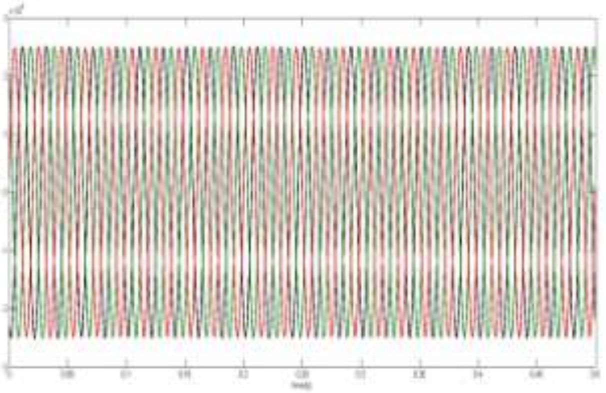

Fig. 3 Input voltages of the input bus

B. Load Voltage with Traction Load

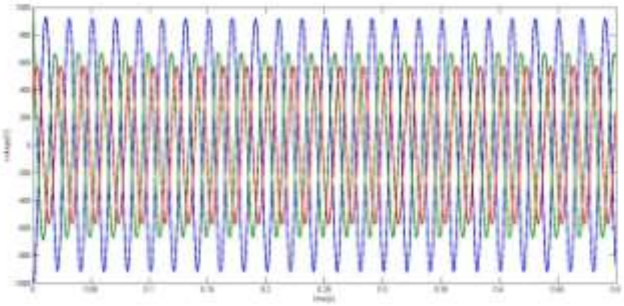

Fig. 4 load voltage without compensation

The above Fig. 4 shows the voltage waveform of the traction power supply with the load connected in each phase. From the diagram can see a voltage sag, unbalance in voltages and change in power factor from the input waveform. These problems are typical power quality problems and the traction distributions will have to suffer lot losses both in terms of efficiency and economy. Due to a reduce power factor in the power system they have to give penalties to the respective substation.

Active power consumption of traction load

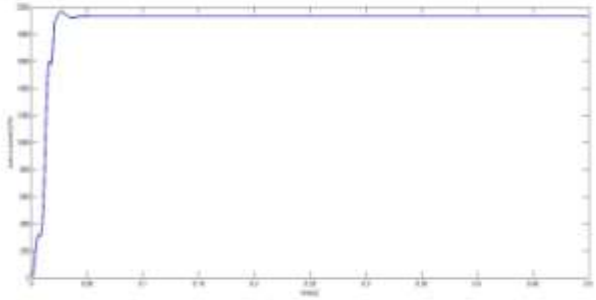

Fig. 5 Single phase active power without compensation

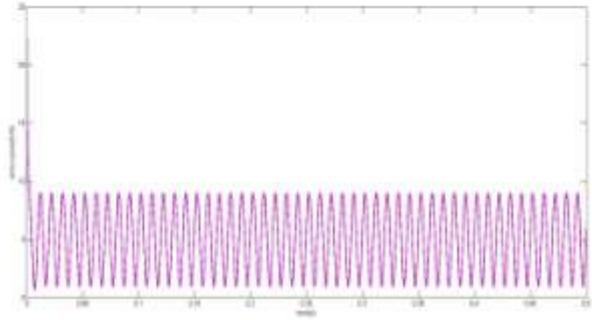

Fig. 6 Three phase active power without compensation

The Fig. 5 and Fig 6 shows the active power demand of the traction substation with traction load on traction substation without load compensation.

C. Reactive power consumption by traction system

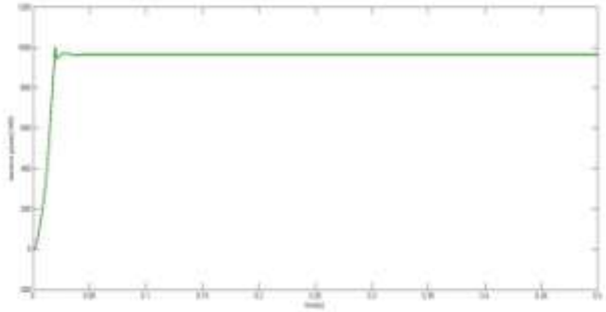

Fig. 7 Single phase reactive power without

With dynamic load variation in traction substation reactive power gets variation. This is shown in the above diagram compensation

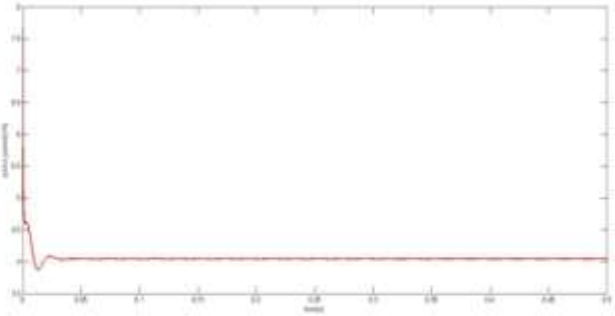

Fig. 8 Three phase reactive power without compensation

The single phase and three phase reactive power is shown in the above waveform shown in Fig. 5.6 and Fig. 5.7 , from this can conclude that a high reactive power compensating device is needed to supply reactive power to the dynamic traction load which will also boost active power and voltage in the system.

D. Load Voltage after Compensation

The voltage across the load with shunt active filter compensation is shown in the figure 5.8 . can see an increase in the voltage after compensation to 4000V

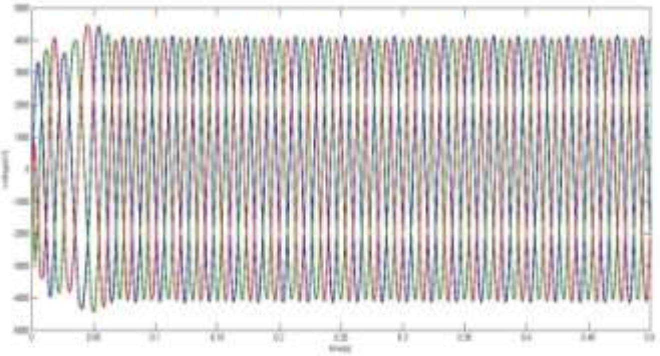

Fig..9 Voltage waveform at the load terminals after compensation

E. Active Power after compensation

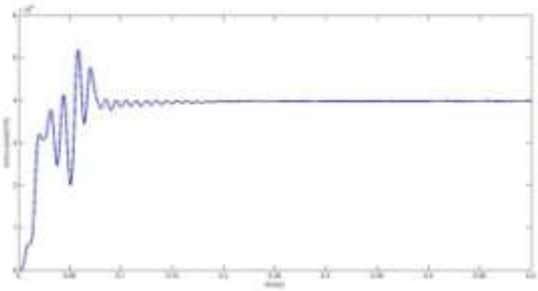

Fig. 10 Single phase active power after compensating

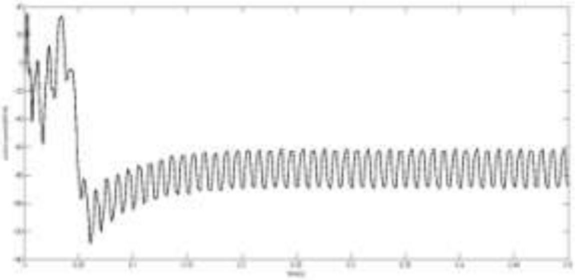

Fig. 11 Three phase active power after compensating

The above figures fig 10,11 shows the single phase and three phase active and reactive power after connecting the reactive power compensating device system, the shunt active filter in the system. see an increase in the active power from the figure.

F. Reactive Power after Compensation

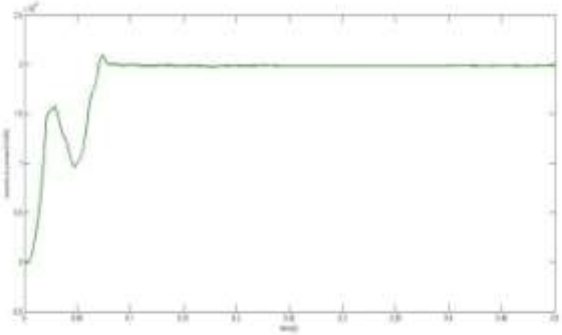

Fig.12 Single phase reactive power after compensating

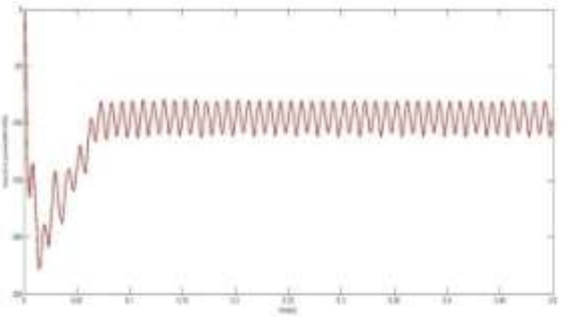

Fig. 13 Three phase reactive power after compensating

The above Fig. 12 and Fig. 13 shows the waveform of reactive power after applying the compensation to it. can see that as the active power is boosted to the system, the reactive power reduces and stabilizes the system.

G. Output Voltage with Single Phase Distribution of Traction

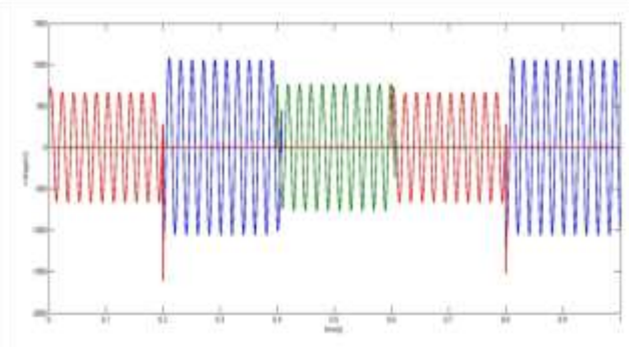

Fig.14 Output voltage with Single Phase Distribution of Traction

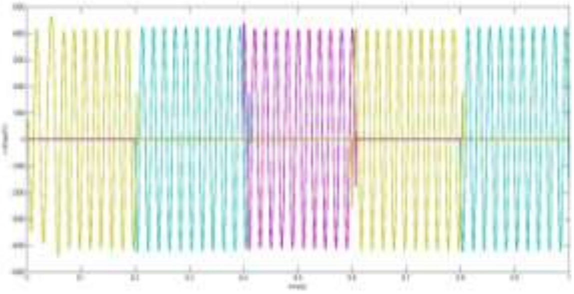

Fig. 15 Output voltage after compensation

H. Total Harmonic Distortion (THD)

The THD of a signal is a measurement of the harmonic distortion present and defined as the ratio of the sum of the powers of all the harmonic components to the power of fundamental frequency. THD is used to power quality of electric power systems, in power systems, lower THD means reduction in peak currents, heating, emissions and core loss in motors. In this MATLAB simulation can compute THD by Fast Fourier Transforms (FFT) analysis. THD of input voltage current, load voltage with or without load can be analyzed with FFT as follows.

I. THD in Input Voltage

THD can be computed with FFT analysis.thw below diagram shows the THD levels in the input voltage, THD is.01%.

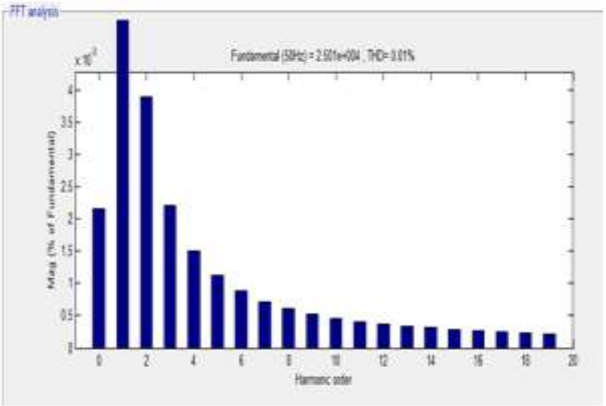

Fig. 15 THD of input voltage

J. THD of Input Current

THD can be computed with FFT analysis.thw below diagram shows the THD levels in the input current, THD is .01%.

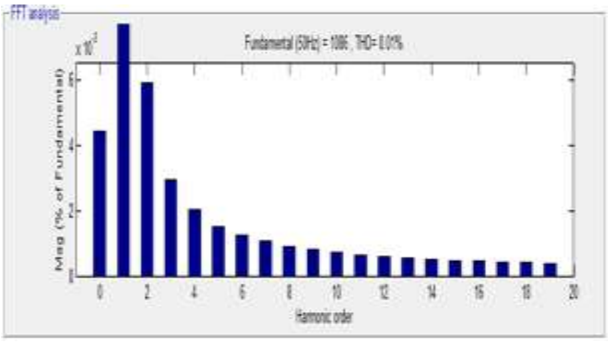

Fig. 16 THD of input current

K. Load Voltage THD without Compensation

THD can be computed with FFT analysis.thw below diagram shows the THD levels in the load voltage without Compensation circuit, THD is 10.45%.

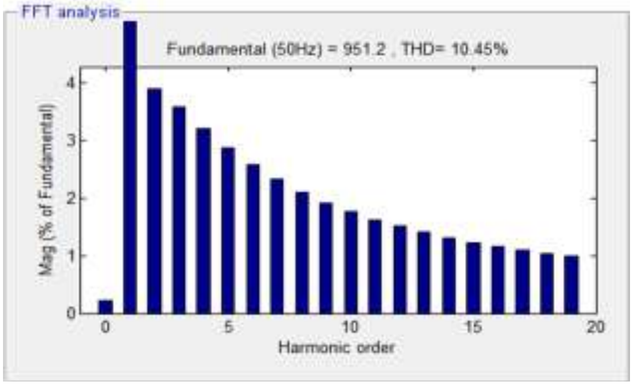

Fig.17 Load Voltage THD without Compensation

L. Voltage THD with Compensation

THD can be computed with FFT analysis.thw below diagram shows the THD levels in the voltage with Compensation circuit, THD is 3.66%.

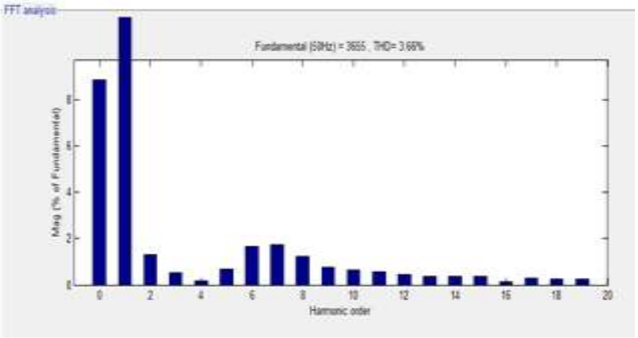

Fig. 18 Voltage THD with Compensation

V. Conclusion

As per the objective work is to develop reactive power compensation in the traction substation based on the values, active and reactive power of daily current, voltage obtained from the traction substation. An equivalent traction load is developed in this paper with this with an RL parallel load with the values obtained.

Reactive power requirement of traction system is studied and a similar circuit for traction power supply is simulated using MATLAB. The reactive power demand was minimised by the proposed system using active filters which is a dynamic power compensating system based on inverters with PI controller and is simulated with the help of MATLAB.

In this work a 3-phase inverter is used for the reactive power compensation. The inverter with the proposed approach can be utilized for the following

- Inject real power
- Compensates reactive power
- Compensate voltage imbalance in the system
- Reducing negative sequence current in the system

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