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AC Traction Power Line Fault Analysis and Simulation

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Abstract: This paper analyzes the performance of traction system under various faults. The faults are generated in three phase grid and between the substations. To understand the effects and severity of faults the whole traction system is embedded and developed using MATLAB/Simulink model. Voltage sag and harmonic issues are source of concern when such type of fault occurs in traction system. FC-TCR (SVC) is used as a compensator which not only improves the voltage profile but also mitigates harmonics.

Keywords: AC Traction, FC-TCR scheme, Locomotive system, Traction substation, WPC fault.

I. INTRODUCTION

The basic function of AC Traction system is to deliver power to locomotive effectively and efficiently. Overhead catenaries are found safer compare to other schemes because it is out of reach to rail personnel. Generally, the voltage range to supply traction system is in between 11-50 kV. In 1957, Indian Railway has selected 25 kV AC 50 Hz as a traction supply.

Basically traction system categorised in three elements: Three phase grid, traction substation and locomotive system. Power is purchased by Indian Railway from regional grid. Supply may be varying according to region. Power is given to the traction substations where special type of transformer has been placed and step down the voltage to 25 kV. OHE are supplied by traction transformer and various locomotives collected the power to propel the vehicles.

Various faults take places in grid. Grid has three phase transmission line so three phase faults also occur in grid. WPC (Wrong Phase Coupling) fault take place when the bridging interrupter accidently closed by an operator in normal condition because of that both the substations are short circuited externally through the breaker. Due to these faults in grid system, voltage deliver to the locomotives is reduced and various harmonics are injected into the system. Various SVCs are used to improve the voltage profile in substation. FC-TCR is used here as SVC and connected to substation to solve both quality issues.

II. DETAILED SYSTEM

Any transportation system needs a source of power to transfer their vehicles from one place to other whether carrying goods or passengers. From early invention of steam locomotive to recent electric locomotives, railway transportation has had its long history to become one of the most popular modes of transportation over last decades. It is popularity which leads to unstable, unreliable and uneconomical mode of operations.

The basic scheme for AC Traction system is shown in fig1.

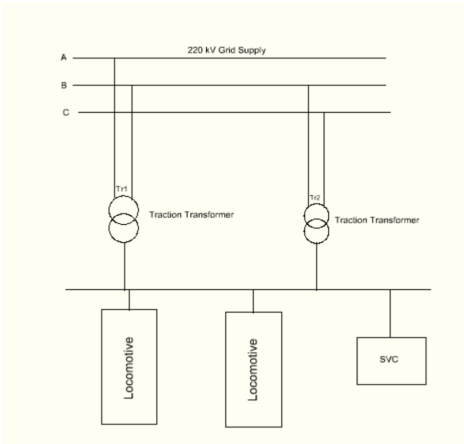

Fig-1 Basic Arrangement for Traction system

As shown in the above fig the three phase transmission lines are energized by three phase grid supply. The grid supply depends upon the regional supply of the grid. Three phase transmission lines are energized by three phase source from grid. Substations take power from three phase lines as shown in fig 1. A traction substation takes power from two of the phases of three phases. Traction transformers are placed in substation which step down the voltage level to 25 kV and power is supplied to different locomotives through catenary line via pantograph.

The traction power system is quite different from the conventional power system in many aspects. The load in conventional power system is steady so it is easy to analyze the readings from that but in traction power system the continuous movements of the load makes it even worst. Not only this but there are several other aspects also make the traction power system differ from conventional power system such as nature of loading, the length of catenary line is varying in nature, voltage drop due to which large reactive current flow in inductive components and the amount of harmonics generated into the system.

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The load current drawn by locomotives is reach in odd harmonics and it degrades the power quality of the traction supplies. Because of the large voltage drop occurs in the system due to sudden acceleration or decelerations of multiple locomotives under same section, sudden starting and stopping of the locomotives at the same time and multiple locomotives comes under a single track section these are the conditions make greater amount of voltage drop so the impedance seen by the relay is very low and hence unnecessary tripping of CB will take place. The relays sense the fault condition and actually there is not any kind of condition available so it is called transients conditions.

When the permanent fault take places such as three phase faults in transmission line placed in grid system or catenary faults in traction substation will lead to voltage drop and if it stays for a prolong period of time then the locomotive motor will be supplied by reduced amount of voltages and due to this vibration and torque reduction of motor occurs. So it is important to provide voltage regulation in traction system whether there are transient conditions or a permanent fault.

SVC (Static var Controller) is implemented in Traction system for compensation of various power qualities issues. Various well known FACTs devices are TSC, TSC-TCR, and TCSC etc. Voltage regulation and Harmonic distortion are two major problems in traction system compare to others. In order to mitigate harmonics and improve the voltage quality after the various faults has taken place this SVC is used

To simulate the Traction system for various fault analysis the whole traction system have to be implemented in MATLAB. Basically traction system divided into three parts:

1. Three phase Grid Subsystem
2. Traction Substation Subsystem
3. Locomotive Subsystem

A. Three Phase grid subsystem

It includes three phase supply of 220 kV at 50Hz which is obtained from the interconnected grid and power given to the substation subsystem through three phase transmission line with the physical length of 400km. Two substations are connected at different length to transmission line and bridging interrupter is connected across the substation subsystem. Here the arrangement is given for generating LLLG and WPC fault.

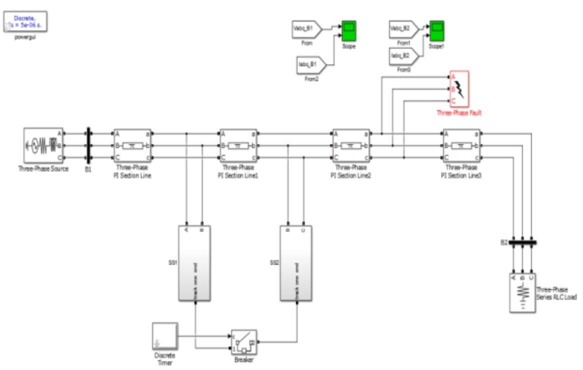

Fig 2 Arrangement for three phase grid subsystem

Three phase fault block is used to generate three phase LLLG fault in traction system and breaker is connected between two substations to generate WPC fault. The breaker is operated by discrete timer connected to it. Scope measures voltage and current of bus B1 and Bus B2.

B. Substation subsystem

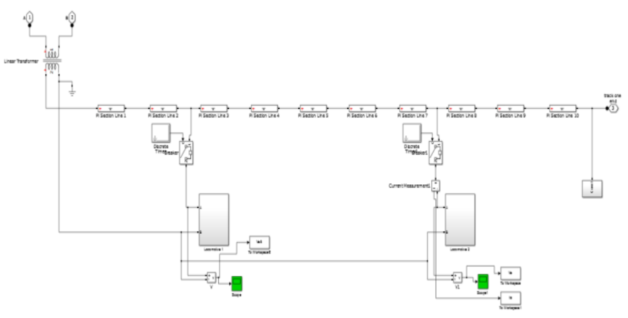

Fig-3 Arrangement of substation subsystem

It includes a single phase transformer which step down the voltage level 220kV to 25kV and supply is given to single phase overhead catenary line which is 40 km in length. Different locomotives are connected to catenary line at several distances. SVC is connected at the end of the substation for the voltage regulation purpose and mitigation of harmonics. The necessary details of system are listed below.

Traction transformer: 220 kV / 25 kV, 25 MVA, 50 Hz single phase transformer with 12% of impedance.

Pi Section single phase line: 40 km of length each section has 4 km of line; Section Line has resistance per unit length of 0.169 Ω/km and inductance per unit length 0.432 Ω/km. The capacitance per unit length is 0.011e-6 F.

C. Locomotive Subsystem

The power obtained and collected using current collector devices from OHE. The supply of OHE is 25 kV using a transformer placed in locomotive step down the voltage to 400-600 volts depending upon the motor used in the locomotive. In the system shown have two tires of locomotives. A DC series motor is used as a locomotive here and the voltage required is 400 volts. Single phase full bridge thyristorized converter will convert AC into DC and that 400 volts DC is given to the locomotive motor as an input to provide propulsion of vehicle.

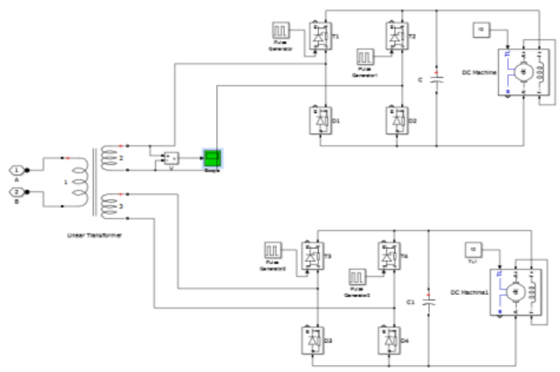

Fig-4 Arrangement of locomotive subsystem

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D. SVC (Static Var Compensator)

One of the primary requirements is to maintain the voltage profile to 25 kV in traction substation is to improve the harmonic performance of the traction system. This can be done by implementing SVC to traction subsystem. Various SVCs have been used in power system to regulate the voltage profile and improve harmonics simultaneously.

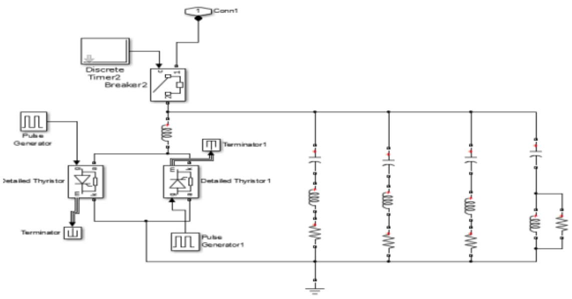

Fig-5 Arrangement of FC-TCR system

Various conditions generates all of sudden such as sudden locomotives comes under a single section,

Starting and stopping of locos at the same time and various faults that has taken place in three phase grid and substation degrades the voltage profile and harmonic performance.SVC installed in substations not only improves the voltage profile by injecting reactive power into the system but also improves the harmonics performance specially compensation of lower order harmonics at the same time.

FC-TCR is used and implemented in traction substation to improve the power quality issues discussed above.

III.SIMULATION AND RESULTS

The whole traction system is implemented using MATLAB. The elements of traction system are modelled in MATLAB. Fig 2 shows the arrangement of WPC fault and three phase fault. WPC fault take places when accidentally the bridging interrupter is close by an operator under normal conditions will short circuit substations externally. Here the arrangement for generating LLLG and WPC fault. Three phase fault block is used to generate three phase LLLG fault in traction system and breaker is connected between two substations to generate WPC fault. The breaker is operated by discrete timer connected to it. Scope measures voltage and current of bus B1 and Bus B2.

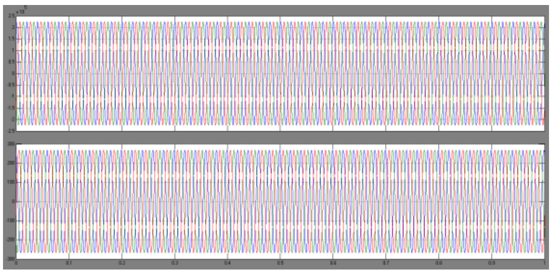

Fig-6Voltage and current of Bus B1 (Normal Condition)

Fig 6 shows Bus B1 measured voltage and current in normal conditions on source side. The voltage measured is 220 kV and current is 300 Amps.

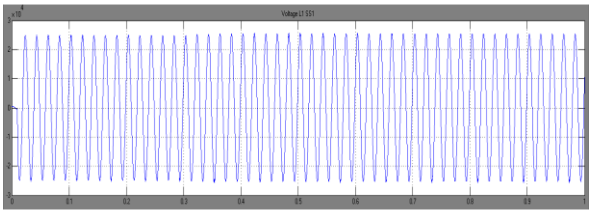

Fig-7 Voltage of Locomotive-1 in SS-1

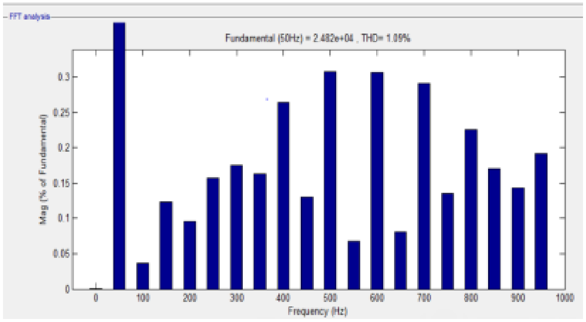

Fig-8 FFT analysis on Locomotive-1 voltage in SS-1

The LLLG fault occur at t=0.3s and WPC fault occur at t=0.5s. Fig 9 shows the voltage and current of bus B1 during WPC fault and LLLG fault It also shows that at when t=0.3s the three phase fault occurs and fault current will increased when WPC fault occur at t=0.5s there is slightly unbalance generated between phases lead to negative sequence current flow in the traction system and grid as well which is very sever and affects the power quality of traction supply. Fig 10 shows degradation of voltage profile because of these faults. As seen when LLLG fault occurs the voltage reduced at t=0.3s further reduction will take place at t=0.5s because of WPC fault. Fig 11 shows the FFT analysis during faulty conditions the THD becomes 14.61% from 1.09%.

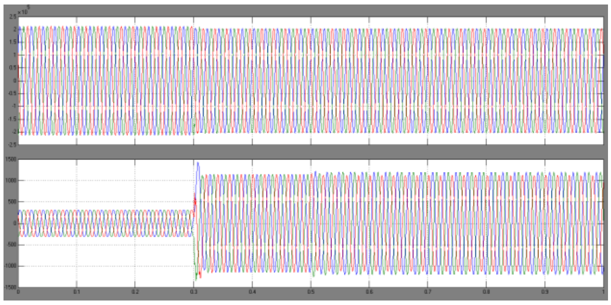

Fig 9 Voltage and current of Bus B1 during WPC & LLLG fault

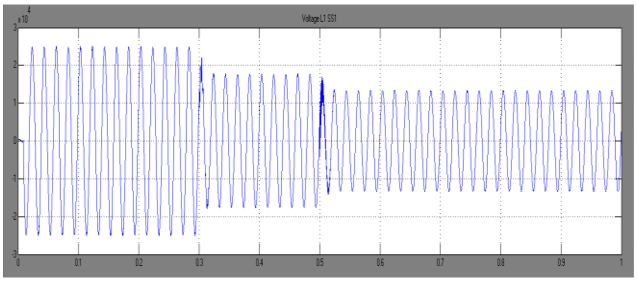

Fig 10 Voltage of Loco-1 in SS-1 during WPC & LLLG fault

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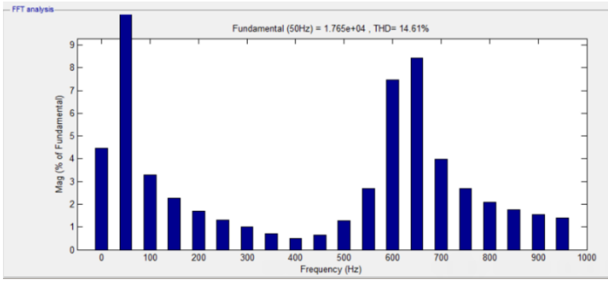

Fig11FFT of Voltage of Loco-1 in SS-1 during WPC & LLLG fault

The LLLG fault occur at t=0.3s and WPC fault occur at t=0.5s. Fig 12shows the voltage of Loco-1 in SS-1 during WPC fault and LLLG. FC-TCR operated at t=0.6 s and provides reactive power externally to improve the voltage profile.

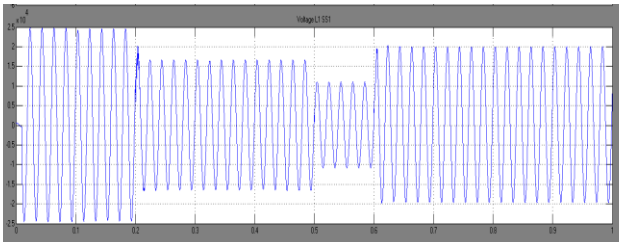

Fig 12 Voltage of Loco-1 in SS-1 during WPC & LLLG fault and with SVC

Fig 13 shows the improvement in THD from 14.61% to 2.41%. According to IEEE standards for traction supply the voltage THD should not more than 5%. So the THD for voltage is within its limit

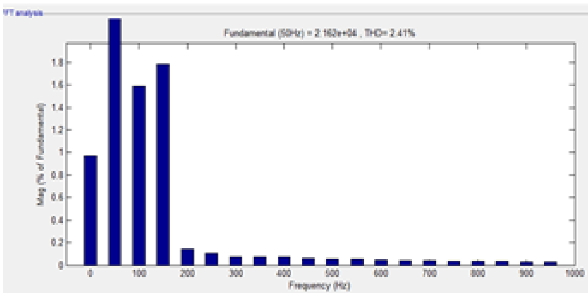

Fig 13 FFT of Voltage of Loco-1 in SS-1 during WPC & LLLG fault.

IV. CONCLUSION

Traction system is different from the conventional power system in many ways. It is nature of traction load that make the things different. Though there are other aspects also there. Also power is taken from grid using two phases only of three phase supply. It creates large amount of unbalance on supply side and cause unbalance current to flow in the system. Due to sudden many locomotives comes under a single section, sudden acceleration and deceleration creates voltage dip. Due to this voltage profile is degraded leads to stopping of train after long distance. Harmonics also cause EMI problems to adjacent communication lines, mal operation of relay and hence unnecessary tripping of CB. SVC is used to maintain the voltage profile to its reference value by injecting reactive power into the system and also improves the harmonic performance of traction system.

Various faults take places in grid and substation will create voltage reduction and harmonics problems SVC is also used to solve and mitigate these issues even in faulty conditions.

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