Power Quality Analysis of Electric Rail Traction System Utilizing Optimization Algorithm

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Abstract: **The electric traction system is the most efficient of all other traction systems such as steam systems and combustion engines. This work designs the 110KV/25KV electric traction system to driving induction motors in MATLAB/SIMULINK environment. The system comprises of the power converters both AC/DC and DC/AC for driving loads. To analyze quality issues in the system for three modes of operation that is acceleration, deceleration, and constant drive of the induction motor. And development of an AI optimization of the converters so as to improve the performance of the AC outputs in the system. So the algorithm chosen is PSO for controlling the quality issues to improve the performance of loads. The work has recognized an electric traction system at 110/25kv side of the operation. The model has been developed in MATLAB/SIMULINK environment for studying the quality issues in the system at the AC side as well as on the DC side in the operating modes, acceleration, constant drive, and deceleration. The power converters in the traction system in the first case were modeled with a conventional PI controller and then replaced by PSO optimizing control to reduce the quality issued in the second system. The distortion level of the voltage in all the three modes of operation was reduced as well as that of the current THD%. The DC bus of the traction system, 1950 volts, also saw a reduction in variation of its value with respect to time.**

Keywords: **DC, AC, PSO, MATLAB.**

I. INTRODUCTION

The electric traction system is the most efficient of all other traction systems such as steam systems and combustion engines. It offers numerous advantages over other systems including quick start and stop, very efficient, environmentally friendly, easy to use and simple speed control. The way the locomotive is operated is commonly referred to as the traction electrification system. Four types of track electrification systems are currently available, depending on the availability of energy. These are

- DC traction system
- Single phase AC traction system
- Three phase AC traction system
- Composite traction system

With the development, a lot of locomotives such as steam and diesel engines have become proficient with each other, which has led to the electrification of railway systems.

A. Electric Traction Systems

The system that uses electricity for a traction system, i. e. For trains, trams, carriages, etc. It is called electric traction. Track electrification refers to the type of power source system used to power the electric locomotive systems. This can be AC or DC or a composite power supply.

The choice of the type of electrification depends on several factors, such as the availability of the offer, the type of application or services such as urban, suburban and main line services, etc.

The three main types of electric traction systems that exist are as follows:

1. Direct Current (DC) electrification system
2. Alternating Current (AC) electrification system
3. Composite system.

II. LITERATURE REVIEW

BoškoMilešević et al. [1] Three-phase induction motors are widely used in electric traction systems. The effects of the traction vehicle equipped with three-phase asynchronous motors on the quality of performance differ considerably from those of vehicles equipped with DC traction motors. In this paper, the effects of the operation of a towing vehicle with three-phase asynchronous motors on the quality of power in the 110 kV transmission network are examined. The 25 kV, 50 Hz electric drive system and the traction vehicle with 3f induction motors have been modeled with AC / DC rectifiers and DC / AC inverters based on IGBT technology.

J.M. Carrasco et al. [2] In this article, the use of distributed energy resources is increasingly sought as a complement and alternative to large conventional power plants. The specification of an electronic power supply interface is subject to requirements that refer not only to the renewable energy source itself, but also to its effects on the functioning of the electricity grid, especially if the intermittent energy source represents a significant part of the total capacity of the system. This article presents new trends in power electronics for the integration of wind and photovoltaic generators. A review of the appropriate storage system technology to integrate intermittent renewable energy sources will also be introduced.

Marco Liserre et al. [3] in this article, renewable energy sources such as wind, sun and hydropower are considered a reliable alternative to conventional energy sources such as oil, natural gas or coal. This article offers an overview of DPGS structures based on fuel cells, photovoltaic and wind plants. In addition, the control structures of the line-side converter are presented and the possibility of compensating for low-order harmonics is discussed. Network failure control strategies are also discussed. This document contains an overview of synchronization methods and a discussion of their importance for monitoring.

Adel Tabakhpour et al. [4] this article provides a perspective on energy quality issues through the development of railway electrification and examines the need for energy quality and system requirements for adequate energy quality. Compensation strategies are classified and compared. The aim is to provide researchers and engineers working on railway electrification with a global vision of the problem of energy quality in electricity/railway distribution networks.

III. Objective

- To design the 110KV/25KV electric traction system for driving induction motors in MATLAB/SIMULINK environment. The system comprises of the power converters both AC/DC and DC/AC for driving loads.
- To analyze quality issues in the system for three modes of operation that is acceleration, deceleration and constant drive of the induction motor.
- Development of an AI optimization of the converters so as to improve the performance of the AC outputs in the system. The algorithm chosen is PSO for controlling the quality issues to improve the performance of loads.
- The algorithm is being implemented so as to provide pulses to the IGBT controlled converters to achieve the power smoothening.
- To reduce total harmonic distortion levels in the voltage and current waveform of the grid supplying the power.

IV. Methodology

A. *Inverter Model*

The traction inverter converts energy from the vehicle's battery in order to drive the motors in the drive train. This key component has a direct impact on road performance, driving range and reliability of the vehicle also as a consequence of their weight and size. Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) require a traction inverter to convert dc energy from the high-voltage battery or dc link bus to the three-phase ac energy used to drive the traction motor. In addition, traction inverters perform functions such as voltage boosting, switch protection and regenerative braking. Traction inverters are typically capable of transferring power in the 20 to 100 kW ranges, with switching voltages in the 200 V to 800 V range and currents in the hundreds of amperes.

Inverter contains three branches each with two switches. The control of switches operation is realized by a PWM module. The developed model of traction vehicle enables the analysis of any motor operation frequency.

The inverter system described in this paper is a three phase grid connected Voltage Source Inverter (VSI) configuration commonly used in distributed generation interfaces. A synchronous frame PI current regulator was chosen to control the inverter. Three phase grid connected DC-AC inverter block diagram is given in Figure 1.

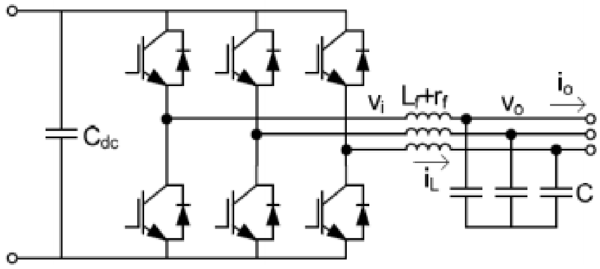

Fig.1 Block diagram of three phase inverter.

Table 4.1 : Inverter Parameters

Power electronic device	IGBT/Diodes
Snubber resistance	5000 ohms
Forward voltages	0
Ron	$1x10^{-3}$ ohms

B. PSO control

Particle swarm optimization PSO is a novel swarm optimization algorithm that is firstly proposed by Kennedy as an evolutionary algorithm based on behavior of birds. PSO uses a set of particles that each one suggests a solution to the optimization problem. It is based on the success of all particles that emulates a population where the position of each particle depends to the agent position to detect the best solution P_{best} by using current particles in the population G. The position of any particle xi is adjusted by

$$x_i^{k=1} = x_i^k + v_i \quad \text{Eq (1)}$$

where the velocity component vi represents the step size and is calculated by:

$$v_i^k = wv_i^k + c_1 r_1 (P_{best_i} - x_i^k) + c_2 r_2 (G - x_i^k) \quad \text{Eq (2)}$$

where x is the inertial weight, c_1 and c_2 are the acceleration coefficients, r_1 and r_2 are random values that belong to the interval of [0, 1], $P_{best_i}$is the best position of particle i, and G is the best position in the entire population. The algorithm is modified in order to reduce the harmonics in the output waveforms of the traction system. The optimizing population traces the lowest distortion level in the waveform by updating their positions. The algorithm is modified to generate pulses for DC/AC converter as well as the IGBT switch in the DC bus line.

C. The control System

PI Controller: The external control loop is the PI controller, which controls the input voltage of the converter. The pulse width modulation is carried in the PWM block at a considerably faster switching frequency of 100 KHz. In our simulation, K_P is taken to be 0.15 and K_I is taken to be 6.6. A relatively high K_I value ensures that the system stabilizes at a faster rate. The PI controller works towards minimizing the error between Vref and the measured voltage by varying the duty cycle through the switch.

V_{dc} Regulator: Determine the required active current reference for the current regulator.

Current Regulator: Based on the current references (reactive current), the regulator determines the required reference voltages for the inverter.

PLL & Measurements: Required for synchronization and voltage/current measurements.

The PLL system estimates the utility phase-angle that is used to generate the coordinates (sin(β), cos(β)) of the unit vector employed in the SRF-based algorithm, as well as to generate the sinusoidal current (i_{pv}) that composes part of the total PV reference current.

PWM Generator: Use the PWM bipolar modulation method to generate firing signals to the IGBTs.

V. Results

The work has developed a 110KV/25KV electric traction system model in the MATLAB environment. There are two power converters deployed in the system, AC/DC and DC/AC. The power from the grid line is being stepped down to 25KV via transformer and is then converted to DC voltage. The two converters are being driven by PWM generator. The control system is being developed utilizing the PSO algorithm for conditioning purpose of grid voltage and current. The converters are meant to drive three phase induction motor of 525 KW rating.

The overall performance analysis is carried out by calculating the total harmonic distortion level in the output waveforms at the AC side as well as on the DC side of the traction system. The chapter discusses the various output parameters of the modeled system and carries out a comparative power conditioning analysis of the control system driving converters.

The first system being driven by conventional PI regulatory control and the other one is being modified to adjust the disturbances in the waveforms by using PSO algorithms. The THD waveforms are being discussed in following two cases with three mode of operation, acceleration, constant drive and deceleration.
Case 1: Traction system with PI regulatory power control of converters
Case 2: Traction system with PSO optimizing power conditioning control of converters

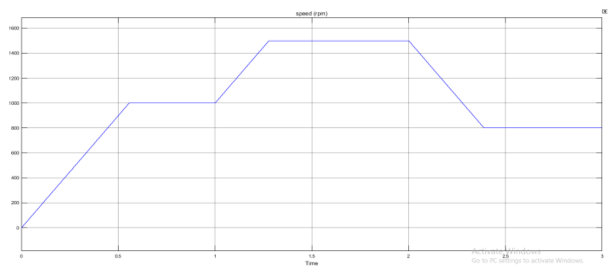

Fig. 2 Speed of the motor in various operation mode

The fig. 2 shows the changes in the speed of the motor at various time intervals. The simulation is being carried out for 3 sec with varying speed. The quality analysis has been carried out on the 110 KV side for AC and DC link voltage is also studied for fluctuations.

A. Case 1: Traction system with PI regulatory power control of converters

In this system the converters which converts DC to AC for driving the induction motor is controlled by PI regulatory controller for generating pulses. The voltage output at the 110 KV side is shown with current output at the 110KV side being 300 amperes.

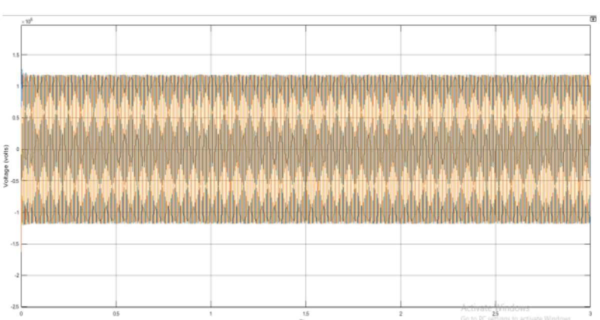

Fig.3 Voltage Output at 110KV side

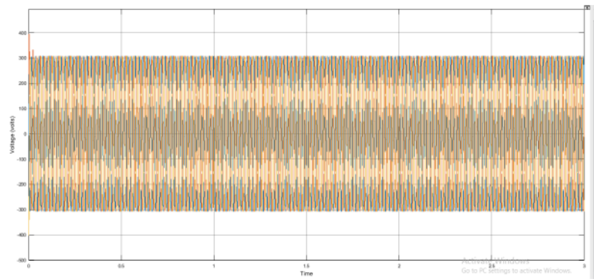

Fig. 4 Current Output at 110KV side

a. Acceleration mode of operation

For acceleration mode fast Fourier transform of the AC waveforms has been carried out at 1 seconds the point at which machine starts accelerating as shown in fig 2. The figures below show the measured THD% in the voltage and current waveforms at the 110 KV side.

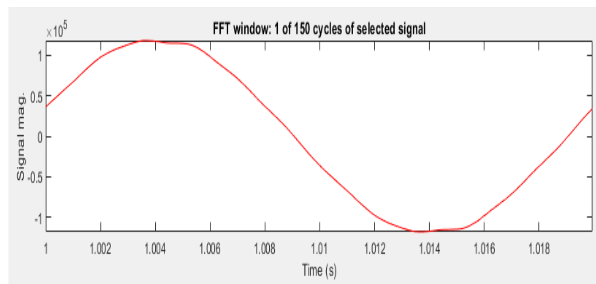

Fig. 5 FFT analysis of Voltage Output at 110KV side

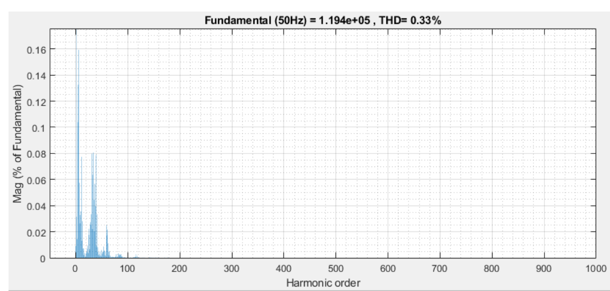

Fig. 6 THD% in Voltage Output at 110KV side

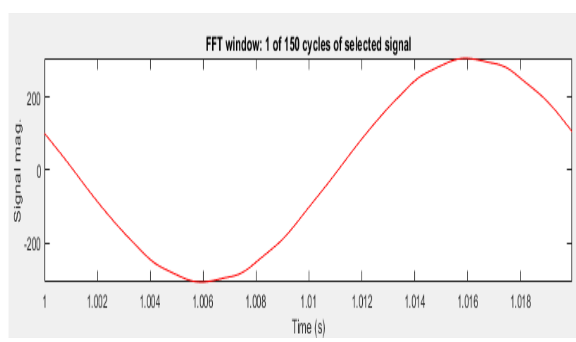

Fig. 7 FFT analysis of current Output at 110KV side

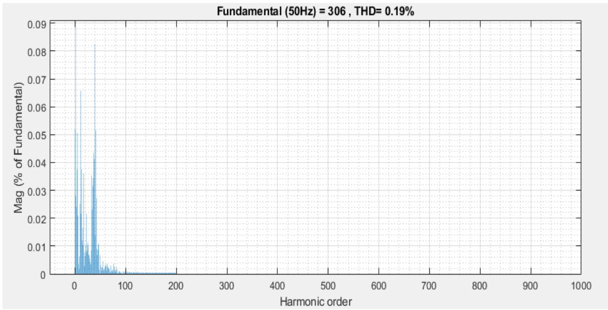

Fig. 8 THD% in current Output at 110KV side

b. *Constant drive operation*

The motor constant drive operation takes place in between 0.6 to 1 seconds as well as 1.25 to 2 seconds after which it starts decelerating. The FFT analysis is therefore carried out at 1.5 seconds where the motor is running at constant speed for longer time duration. The THD% of voltage and current at this point has been depicted below.

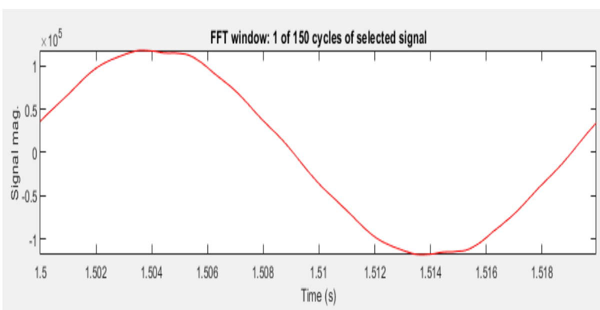

Fig. 9 FFT analysis of Voltage Output at 110KV side

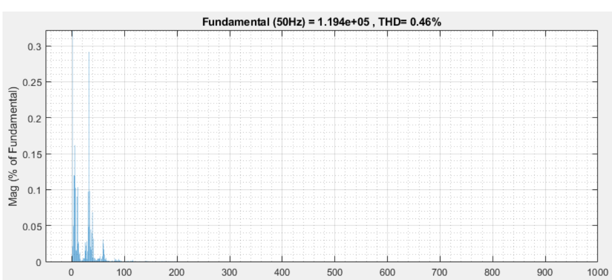

Fig. 10 THD% in Voltage Output at 110KV side

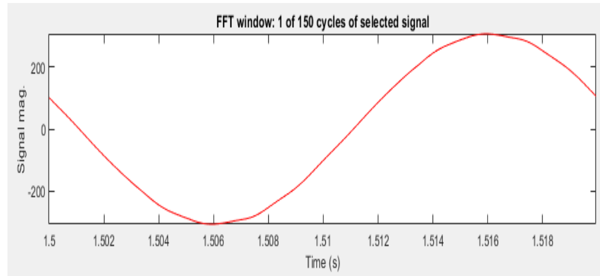

Fig.11 FFT analysis of current Output at 110KV side

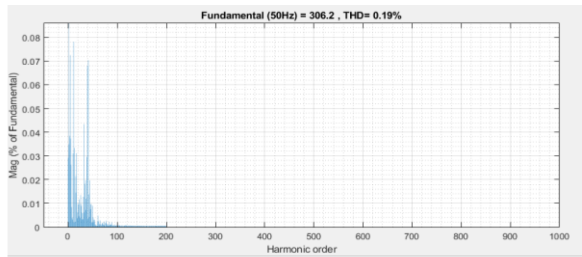

Fig.12 THD% in current Output at 110KV side

c. *Deceleration mode of operation*

In this mode the voltage and current waveforms are studied for distortion levels at 2 seconds the moment at which the motor switches its operation from constant drive to deceleration mode. The speed is gradually reduced from 1500rpm to 800 rpm after which it runs constantly upto 3 seconds.

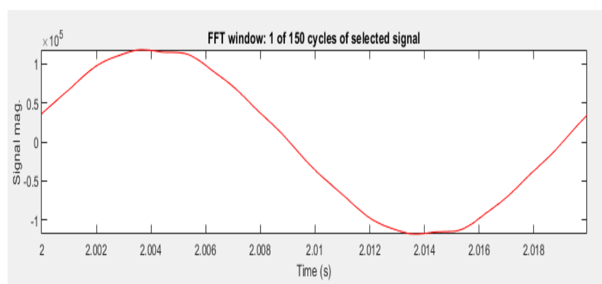

Fig.13 FFT analysis of Voltage Output at 110KV side

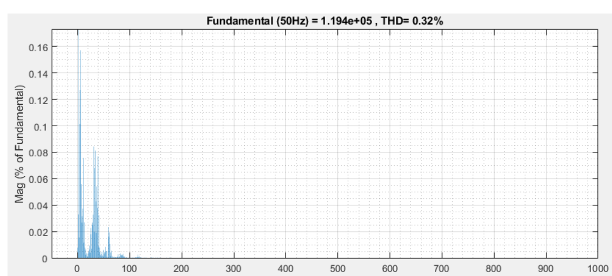

Fig.14 THD% in Voltage Output at 110KV side

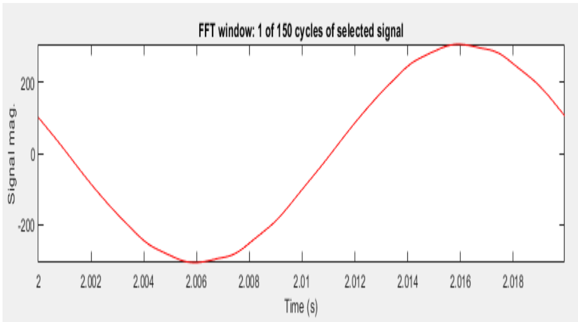

Fig. 15 FFT analysis of current Output at 110KV side

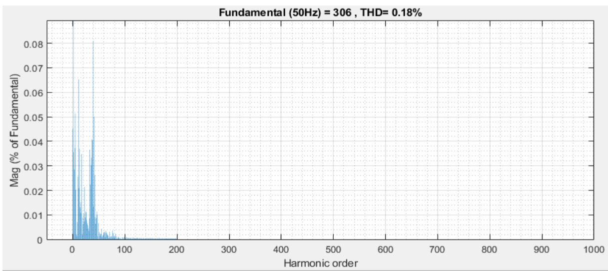

Fig. 16 THD% in current Output at 110KV side

B. *Case 2: Traction system with PSO optimizing power conditioning control of converters*

The particle swarm optimization control has been carried out for the converters in traction system. The PSO system takes in DC voltage and current along with AC voltage and current outputs as its input to regulate them to minimum distortion level. The particles in this algorithm continuously update position to ascertain the smooth waveform is achieved at the end. The analysis is being carried out at the 110 KV side in three operating modes. The current is 300 amperes.

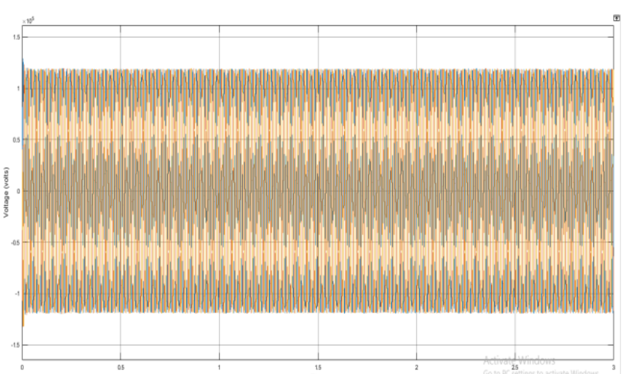

Fig. 17 Voltage output in the system with PSO controlled converters at 110KV side

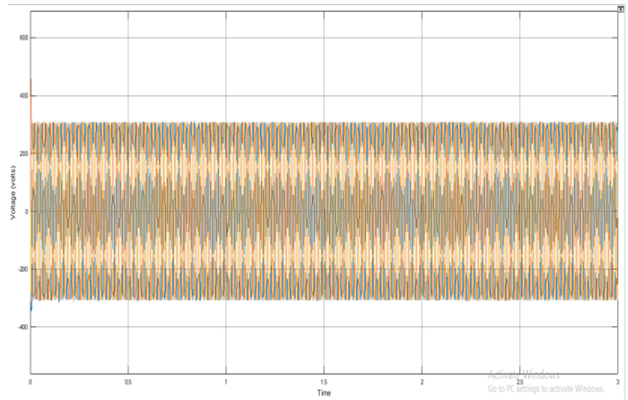

Fig. 18 Current output in the system with PSO controlled converters at 110KV side

a. *Acceleration mode of operation*

In this case also the same speed reference is taken for comparative analysis. The motor acceleration is also studied at one second and therefore the FFT of the output waveforms is carried out at 1 second to study the harmonic level in them.

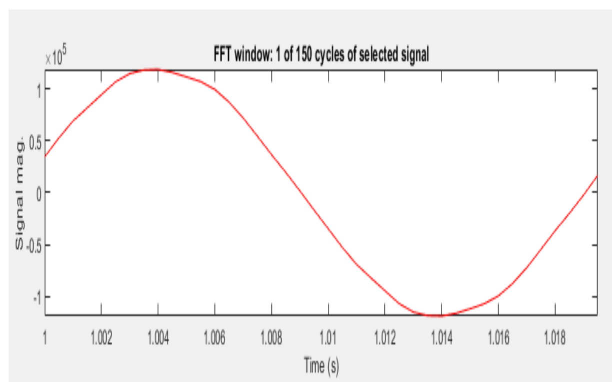

Fig. 19 FFT analysis of Voltage output in the system with PSO controlled converters

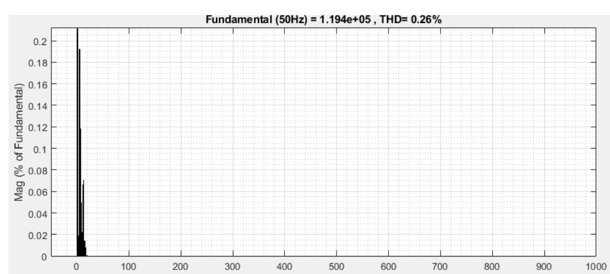

Fig. 20 THD% in Voltage output in the system with PSO controlled converters

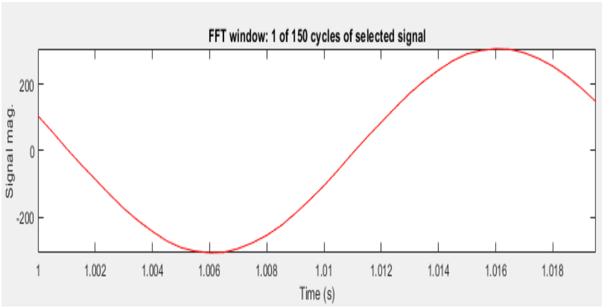

Fig. 21 FFT analysis of Current output in the system with PSO controlled converters

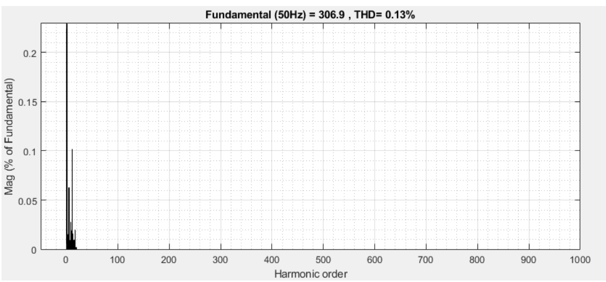

Fig. 22 THD% in Current output in the system with PSO controlled converters

b. *Constant drive operation*

In this mode the fast Fourier transform is studied at 1.5 seconds for both voltage and current output waveforms. The motor at this point is under constant drive operation. The waveforms below show the THD% in the voltage and current waveforms of the system at 110KV side where the converters are being driven by PSO optimizing control.

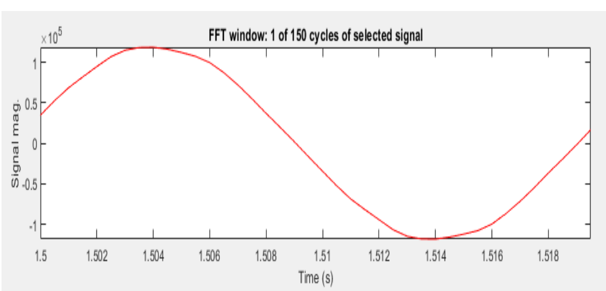

Fig. 23 FFT analysis of Voltage output in the system with PSO controlled converters

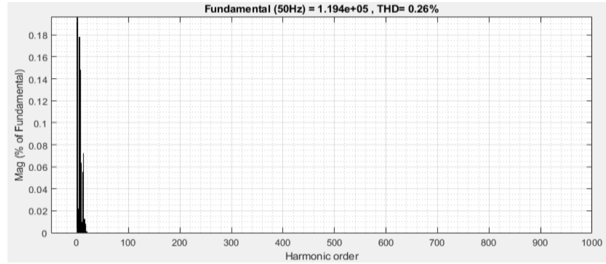

Fig. 24 THD% in Voltage output in the system with PSO controlled converters

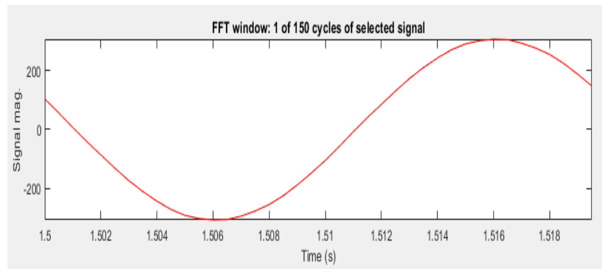

Fig. 25 FFT analysis of Current output in the system with PSO controlled converters

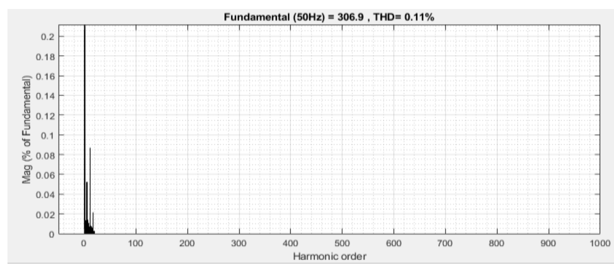

Fig. 26 THD% in Current output in the system with PSO controlled converters

c. *Deceleration mode of operation*

The speed is gradually reduced from 1500rpm to 800 rpm after which it runs constantly upto 3 seconds. Hence in this mode the voltage and current waveforms are studied for distortion levels at 2 seconds in the proposed traction system where the converters are regulated for quality control by PSO technique.

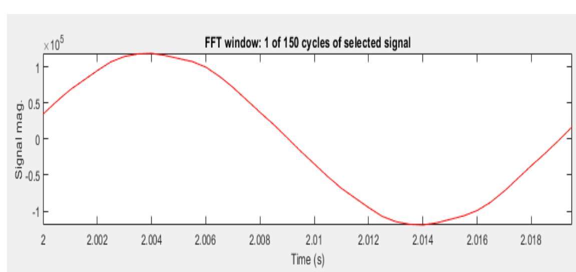

Fig. 27 FFT analysis of Voltage output in the system with PSO controlled converters

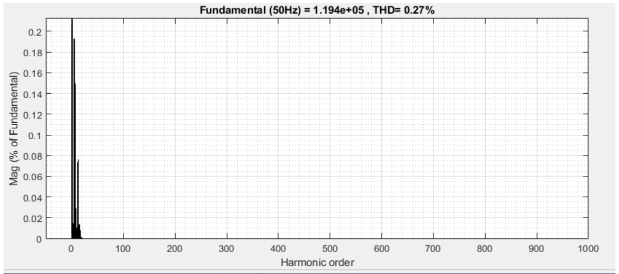

Fig. 28 THD% in Voltage output in the system with PSO controlled converters

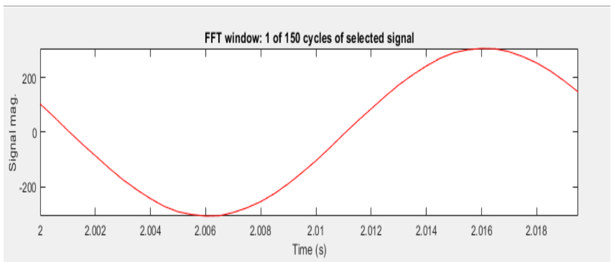

Fig. 29 FFT analysis of Current output in the system with PSO controlled converters

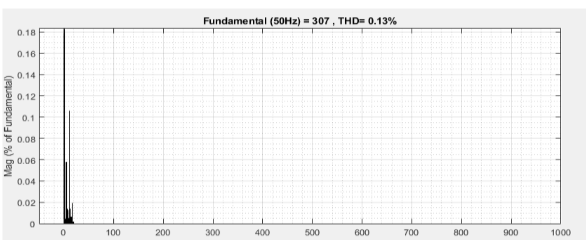

Fig. 30 THD% in Current output in the system with PSO controlled converters

5.4 DC link bus analysis:

The figure below shows the DC bus link voltage of the traction system. The red graph is the DC voltage of the system with conventional PI controller and the green graph is the DC voltage of the system in which the power converters have PSO control. The DC link voltage is approximately 1950 Volts.

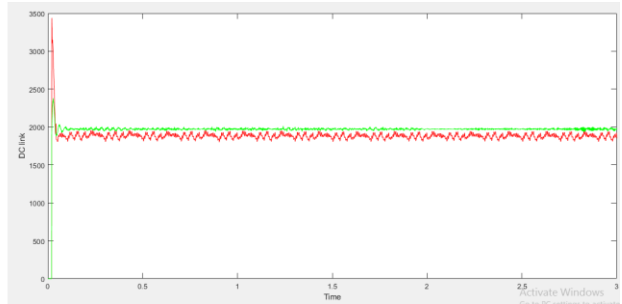

Fig. 31 Comparative graph of the DC bus voltage of the traction system in the two cases

The stabilization in the DC link voltage is observed in case of the proposed system with PSO optimization control.

VI. Conclusion

The work has recognized an electric traction system at 110/25kv side of operation. The model has been developed in MATLAB/SIMULINK environment for studying the quality issues in the system at the AC side as well as on the DC side in the operating modes, acceleration, constant drive and deceleration. The power converters in the traction system in first case were modeled with conventional PI controller and then replaced by PSO optimizing control to reduce the quality issued in the second system. The Table 2 depicts the major outcomes form the system in respect of THD level at the 110KV side.

Modes of operation	Time of analysis	Traction system with PI regulated converters		Traction system with PSO regulated converters	
		THD% in voltage	THD% in current	THD% in voltage	THD% in current
Acceleration	1 second	0.33 %	0.19 %	0.26 %	0.13 %
Constant Drive	1.5 second	0.46 %	0.19 %	0.26 %	0.11 %
Deceleration	2 second	0.32 %	0.18 %	0.27 %	0.13 %

The table shows the effectiveness of the modeled controller with PSO optimization technique to reduce the quality issues on the AC side. The distortion level of the voltage in all the three modes of operation was reduced as well as that of the current THD%.

The DC bus of the traction system, 1950 volts, also saw reduction in variation of its value with respect to time.

VII. FUTURE SCOPE

The electric traction systems are the most efficient systems that offers several benefits over other systems, including quick start and stop, very efficient, pollution-free, easy to handle and easy speed control. The systems employ converters for power regulation and driving other auxiliary devices inside the system. The quality issues with the electric systems often arise with sudden loading offloading or other factors. The analysis of these systems with recently developed artificial techniques for minute regulation can be done to further enhance its performance. The same technique can be further modeled to make an improvement in the magnitude of the DC bus voltage to improve the system rating.

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