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Comparative Analysis of Electric Traction System with PI Controller and PSO Optimization Algorithm

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Abstract: **Electrical traction refers to a system that uses electrical power for traction, such as railways, trams, trolleys, and other vehicles. The term "track electrification" refers to the type of power source that used power electric locomotive systems. It could be AC, DC, or a hybrid supply. This paper provides the comparative analysis of electric traction system with PI controller and PSO Optimization Algorithm.**

Keywords: **Electric Traction System, Non electric traction system,**

I. Introduction

Traction system is the process that provides vehicle movement by obtaining tractive or driving power from different devices such as turbo diesel drive, steam powered drives, electric vehicles, and so on. It is also known as the traction or locomotives, which is a railway engine that contains the required traction capacity to move the train. Diesel, steam, or electricity can all be used as traction power. The train's traction system is one of its components. It's a system that's mounted on the vehicle's roof or underneath it. The propulsion system transfers electrical energy gathered by the pantograph from the coiled wire into mechanical power, allowing the wheels to revolve and, as a result, the train to speed and stop.

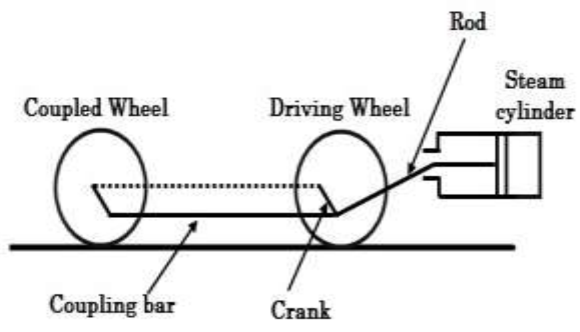

Figure 1 Traction System

Traction is a technique for moving any form of vehicle. Electric Friction is what this movement process is called when it is accomplished with the aid of electrical energy. Electric motors provide the necessary driving force for locomotion in electric traction. There are several traction systems that are typically classed as two phrases from an electrical standpoint:

1. Electrical Traction

2. Non – Electrical Traction

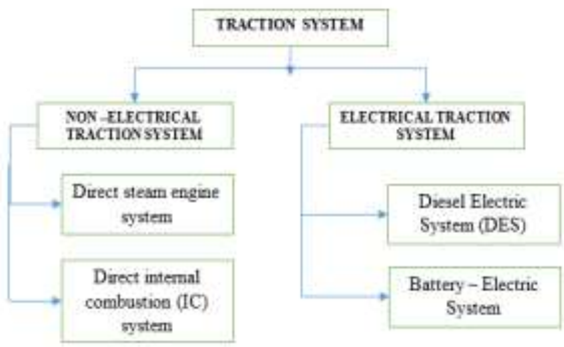

Figure 2 Categorization of Traction System

II. Literature Review

(Cordero-moreno & Espinoza, 2021) The power behaviour of a battery-electric bus (BEB) operating on major trade routes is studied, as well as the conceptual and operational of replacing an Andean growing urban public transit fleet completely with BEBs. Harmonic current distortion flow aberrations of less than (4%), which are within standards of quality, are obtained by analysing the electrical components in the Battery - powered electric Bus charging method. In order to precisely evaluate the energy usage of the fleet of 424 BEBs that would conduct the 28 routes in terms of energy demand, the article uses an approximation. A comparison of BEB consumers' preference to conventional buses is included in the report. Finally, the study indicates a realistic approach for integrating renewable energy sources for BEB recharging, depending on photovoltaic power sources and the use of ESS, as a way of contributing to public transportation's long-term sustainability (energy storage systems).

(Xue et al., 2021) The number of hidden layers and conductors size of helical windings in electric motors for electrical vehicles are investigated in this research. To begin, a review of hairpin winding technique for electric engines is presented, as well as fundamental design rules. A traction motor using hairpin winding technology is modelled in finite element analysis (FEA) software using these design criteria. The effect of the helical winding layers on DC and AC copper losses is explored based on data obtained at various operating locations and drive cycles. The findings show that having a larger amount of wrapping rounds does not automatically imply greater efficiency. When determining the appropriate number of wrapping sheets, the exchange between DC and AC losses at various operating points and driving cycles must be addressed. The best conductors size for electric engines with helical windings is determined in this work using optimizations that take drive system efficiency into account.

(Aykhadeev et al., n.d.) Due to the increasing importance of By-Wire systems and the existence of inventive controller design for normal driving scenarios, potential extreme circumstances, or the application of Driver Assistance Processes, new electric vehicle configurations require extensive physical and virtual testing for safety evaluation. The examination of such issues should be undertaken to save development cycles while boosting system reliability and a priori awareness of its safety criteria. Authors suggest a structured approach technologies such As virtual FMEA to assess the operational safety standard of hybrid braking plant in compliance with ISO26262 standard. In order to meet the needed Automotive Safety Integrity Level, plant modifications and security strategies were provided and implemented in a target vehicle model, with their performances evaluated in simulated environments. This work is being done as part of the OBELICS European Project.

(Urazov et al., 2021) The vectors control mechanisms for an asynchronous machine fully satisfy all requirements, according to the system parameter assessment of electric traction motors of locomotive. A mathematical formalism of an induction motor is developed based on a T-shaped transmission line, taking into consideration losses in the stator steel, the influence of something like the rotor current, and saturation displacement. When employing a vector monitoring system with the alignment of the dimensions of the coordinate all along rotor magnetism, an algorithm for forming the optimum, from the standpoint of power dissipation, task for the rotor flux linkage is devised. The motor stator's current or voltage limits, as well as the motor's current / voltage, are the restricting considerations. A vector control scheme for an electrically powered motor with electric machines has been devised, which offers direct control of wheel slip while minimising power losses through a subsidiary vector control scheme. The results of modelling for an electrically powered drive of a two-axle bogie having axial support and 630 kW asynchronously motor in fairly constant and start-up modes with several choices for organising circuits reentrances are shown.

(Groschup et al., 2021) In synchronous generators, prefabricated coils are used to increase the copper slot fill factor. It is possible to improve the computer's efficiency. Low copper losses due to greater slot fill factor and enhanced heat transitions out of the slot account for the improvements. The impact of these two factors on the machine's process improvements is investigated in this study. The two effects can be separated using detailed computational methods. The comparison of a prototype wrapped winding to the round wires wrapping is investigated. The two concepts have whole machinery prototype as well as motorettes. With the use of motorette microsections, thermal numerical simulation simulations of the rotor slot are created and characterized. The thermally distributed parameter models that results is then scaled up to reflect the full electric machine. The temperature distributed parameter models and the magnetic numerical simulation models are calibrated using test bench observations. In compared to the test bench examination, the created models exhibit very excellent correlation. According to the findings, both enhancements in the heat shaping organizational and the benefits of lower slot losses contribute to a wider operational range in dependence on the examined process and outcome.

(Hadj et al., 2006) This study discusses a cost-minimization strategy for traction chains. Given the electric vehicle (EV) synoptic suction chain, we propose first modelling mathematically the chain's main component, the diesel engine, in order to calculate its measurements, performance (efficiency, specific power, and so on), and the various general populace, including the magnet volume, iron mass, and metal mass. Simulations employing the software calculation of the finite element analysis Maxwell-2D were used to validate this mathematical framework. We calculate the traction chain cost using an analysis method of an electric engine and a static converters (EM-SC). The evolutionary computation method is used to optimise this last step.

(C. Yang et al., 2019) This research presents a problem detection method for three-level converter in electrically powered networks reference voltage differential residuals. In compared to conventional open-circuit fault diagnostic methodologies, the suggested method can not only locate and identify problematic devices among semiconductors and clamping diode in both the rectification and inverters, but also diagnose leg-level and device-level defects hierarchically. Additionally, no further sensors are needed, and all of the parameters given can be recognised immediately. The current-related term in the DC-link voltage partial derivatives is investigated and modelled in semiconductors and clamp diodes, accordingly, under the normal and accessible fault conditions. The residuals and their appear in the form across estimate and real are next generated, followed by the modeling techniques of the DC-link voltage difference. Furthermore, hierarchical diagnosis techniques are provided to discover leg-level and device-level problems by assessing residual evaluations measures for diverse cases and constructing present resemblance values.

(Gronwald & Kern, 2021) The present state of electrically powered motors in electric vehicles, as well as their conditioning topology designs, are discussed in this article. A thorough review of heat and mass transfer equations and connections for various cooling designs and electric engine heat and mass transfer occurrences was conducted. The advantages of various cooling concepts were explored and explained. Its applicability in a thermal model was proved review of relevant literature, and a simulation comparison of several alternative cooling topologies was performed. The findings reveal that selecting a motor conditioning design is a multifaceted phenomenon that is influenced by motor development objectives, motor needs, and costs.

(Zhao et al., 2018) For conserving energy, this study optimised the functioning of a single rapid transit vehicle among stops. Previous research into energy conservation in train operating either looked at mechanical power consumption or presumed a constant efficiency number for straight energy to electricity energy transfer. However, just because a train uses little mechanical energy doesn't mean it uses little electrical power as well. As a result, the goal of conserving energy in passenger trains can only be realised by reducing electrical energy consumption directly. The results of simulations using the traditional mechanical model, the exact model, and the suggested model showed that the existing conventional prototype could not represent real electricity usage and thus could not produce the ideal railroad curve. The precise and suggested models' simulation results indicate minor discrepancies in their electricity consumption calculation findings. The model provided in this study considerably reduced computation cost.

III. METHODOLOGY

To evaluate the effectiveness of the proposed algorithms, the proposed algorithm is implemented using Matlab R-2020a. The simulations were conducted on an Intel i5, 3.7Ghz PC with 8 GB RAM. MATLAB is a high-level programming language and platform for designing technical programs. It is integrated with several features as well as with several toolboxes. It is high level programming language with the concept of object-oriented programming language with well-defined debugging tools as well as editing tools.

The traction inverter is a device that directly convert energy out from vehicle's battery to power the drive train's motors. Because of their weight as well as size, this essential element has a direct effect on the vehicle's road capability, driving scope, and serviceability. A traction inverter is required in electric as well as hybrid vehicles to transform dc energy from the elevated battery or dc link bus towards the 3-phase alternating current energy required to operate the traction motor. Traction converter also perform the tasks like voltage enhancing, toggle safeguards, as well as regenerative braking. Traction inverters can extracting 20 to 100 kW of power, with swapping voltages ranging from 200 to 800 V as well as currents in the hundreds of amps.

Every one of the three divisions of the inverter has two switches. A Pulse width modulation based module that is used to ensure the proper functioning of switches. The traction vehicle modeling approach enables the study of any motor operating frequencies.

This inverter system employed in this research is a 3-phase grid-connected Voltage Source Inverter (VSI) arrangement, which is frequently utilized in decentralized power generating interfaces. The inverter was controlled by a synchronous frame PI current regulator. Figure 3 shows a 3 grid linked DC-AC inverter schematic diagram.

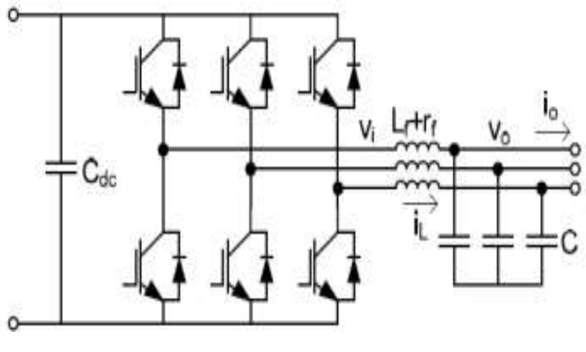

Figure 3 Block diagram of three phase inverter

Table 3.4 : Inverter Parameters	
Power electronic device	IGBT/Diodes
Snubber resistance	5000 ohms
Forward voltages	0

Ron	$1x10^{-3}$ ohms

PSO is a bio-inspired algorithm that searches for the optimal method in the decision space in a simplest way. It differs from those other optimization techniques in that it only requires the objective function and therefore is unaffected by the gradient or indeed any differential type of the objective. It also has a small number of hyper-parameters.

Optimization of particle swarms PSO is a new swarm optimization technique that Kennedy initially presented as an evolutionary algorithm depending on bird behaviour. PSO employs a collection of particles, each of which implies an answer to the optimization optimal issues

Initialization, fitness evaluation, upgrading the personal as well as global best value, upgrading the velocity as well as position of every particle, as well as convergence identification are the five basic steps in the flow diagrams procedure. Particles are randomly initialized in the allocation space or on explained grid nodes encompassing the search area throughout the first step.

The initial velocity values are also chosen at random. In the next step, the fitness value of every particle is assessed, with the fitness assessment leading to a solution space to the objective function. In the third step, pbest_i and gbest are computed to estimate the independent and global best fitness values.

The positions are then modified and, if better fitness values are discovered substituted. In the fourth phase, every particle's velocity as well as position are modified. The flowchart's final step verifies the convergence criterion. The process is done if the requirement is reached. Alternatively, the process comes back to step 2 and the iteration number is continued to increase.

The PI controller, that also tries to control the converter's input voltage, is the outer control loop. The Pulse width modulation component performs the pulse width modulation at a much high switching frequency of 100 KHz. KP is assumed to be 0.15 and KI is assumed to be 6.6 in our simulated world. The system will stabilise at a faster rate if the KI value is considerably large. By changing the duty cycle thru the switch, the PI controller tries to reduce the inaccuracy among Vref as well as the evaluated voltage.

IV. RESULT AND DISCUSSION

In the MATLAB software, a 110KV/25KV electric traction system framework was designed. In the structure, there are two power converters: AC/DC as well as DC/AC. The power from of the grid line is stepped down to 25KV and afterwards transformed to DC voltage via a transformer. The Pulse width modulation generator is used to power the two converters. The Particle swarm optimization (PSO) is being used to create the control system for grid voltage as well as current conditioning. The converters are designed to power a 525W three-phase induction motor.

THD level in the output waveforms on both the AC and DC sides of the traction system is calculated for the overall performance assessment. The chapter examines the modelled system's different output variables and performs a comparative power conditioning assessment of the control system's driving converters.

The very first system is controlled by traditional PI regulatory control, while the second is reconfigured to compensate for waveform disturbances employing PSO methodologies. The two following cases with three operating modes, acceleration, constant drive, and deceleration, are mentioned which also consist of THD waveforms.

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

The converters that transform DC to AC for trying to drive the induction motor are managed by a PI regulatory controller in this framework, that generates pulses. The voltage output on the 110 KV side has been seen, having a current output of 300 amperes on the 110 KV side.

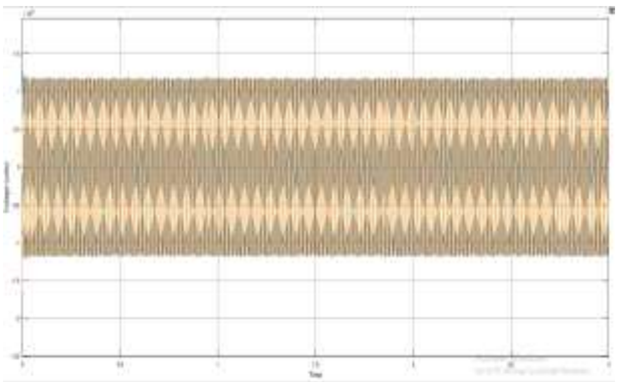

Figure 4 Voltage Output at 110KV side

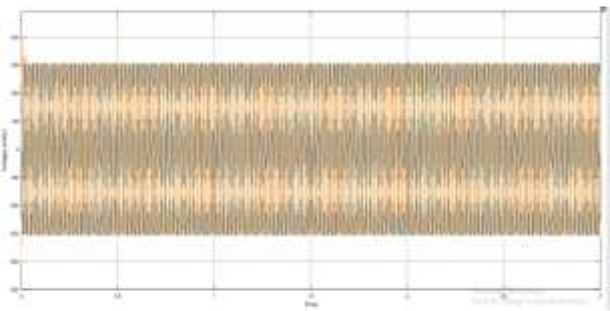

Figure 5 Current Output at 110KV side

For the high speed acceleration mode as can be seen in figure 6, the Fourier transform of the AC waveforms was performed at 1 second, the point at which the machine began to accelerate. The THD percent evaluated in the voltage and current waveforms at the 110 KV side is shown in the figures below:

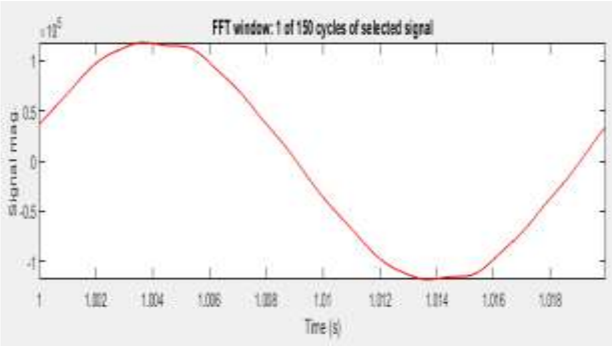

Figure 6 FFT analysis of Voltage Output at 110KV side

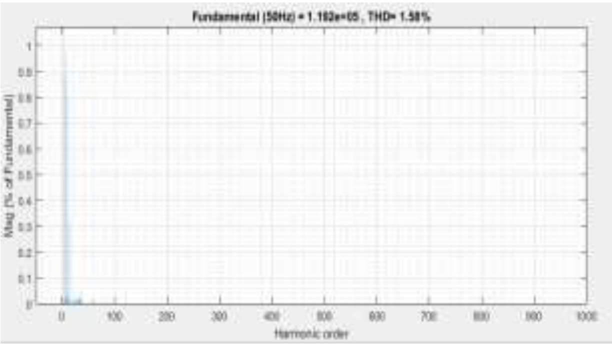

Figure 7 THD% in Voltage Output at 110KV side

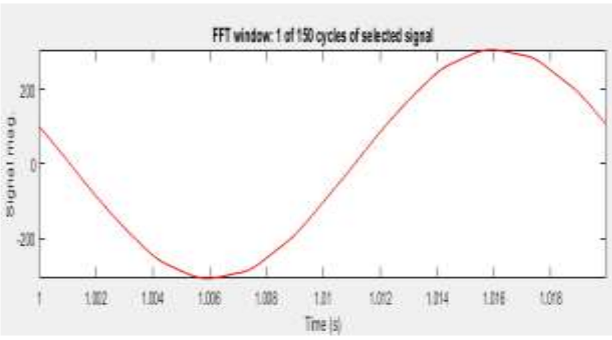

Figure 8 FFT analysis of current Output at 110KV side

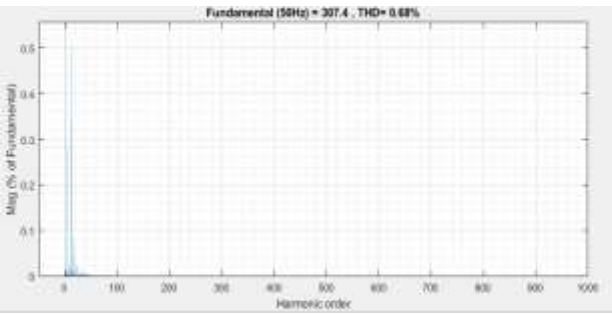

Figure 9 THD% in current Output at 110KV side

The motor's constant drive procedure lasts between 0.6 and 1 second, and then it begins to decelerate after 1.25 to 2 seconds. As a result, the FFT analysis is performed at 1.5 seconds, when the motor is running at a constant speed for a prolonged period of time. Here is a graph of the THD percent of voltage and current at this point.

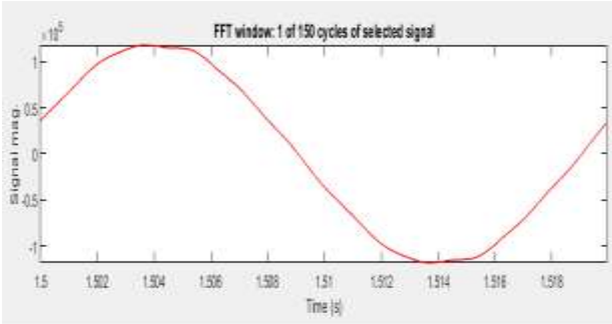

Figure 10 FFT analysis of Voltage Output at 110KV side

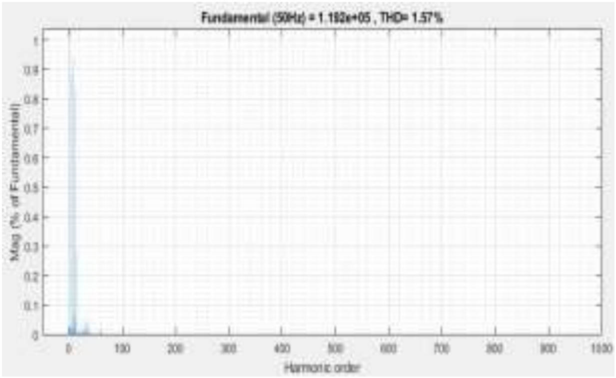

Figure 11 THD% in Voltage Output at 110KV side

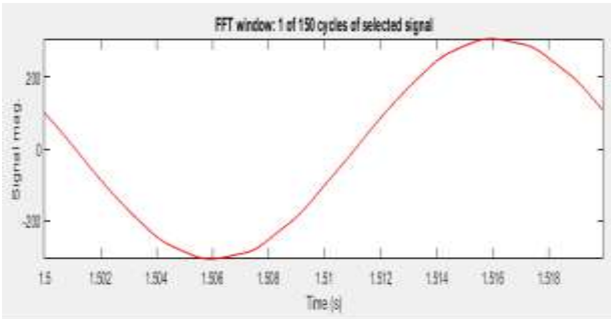

Figure 12 FFT analysis of current Output at 110KV side

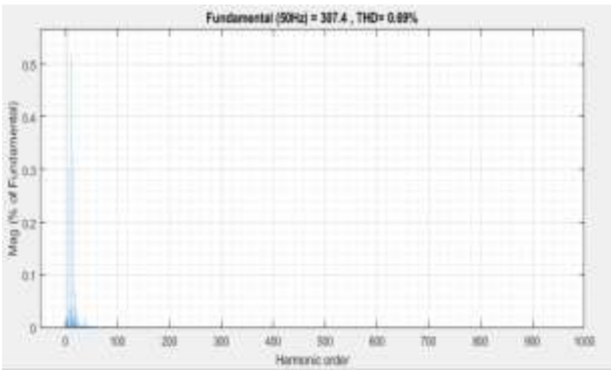

Figure 13 THD% in current Output at 110KV side

The voltage as well as current waveforms are examined for distortion levels at 2 seconds after the motor switches from constant drive to deceleration mode in this phase. The speed is progressively lowered from 1500 to 800 rpm, whereby it continues to run continuously for 3 seconds.

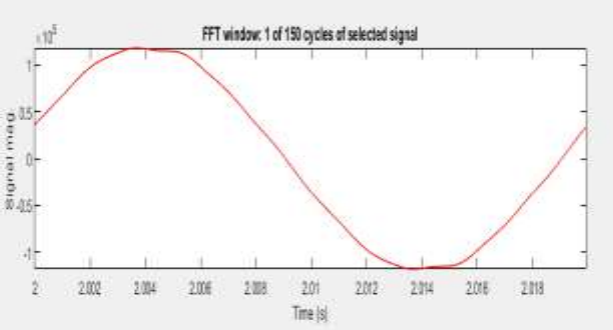

Figure 14 FFT analysis of Voltage Output at 110KV side

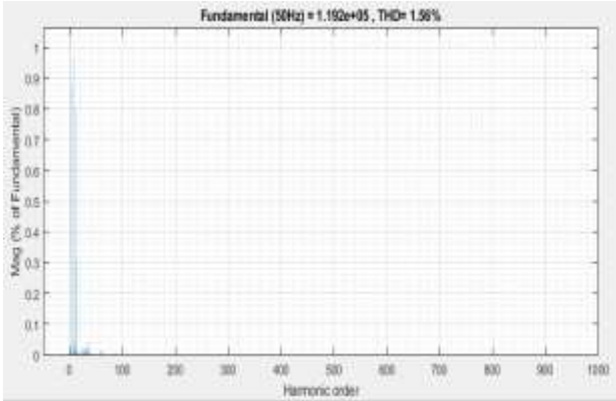

Figure 15 THD% in Voltage Output at 110KV side

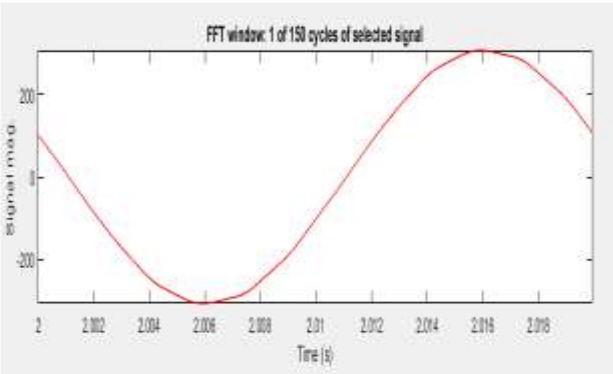

Figure 16 FFT analysis of current Output at 110KV side

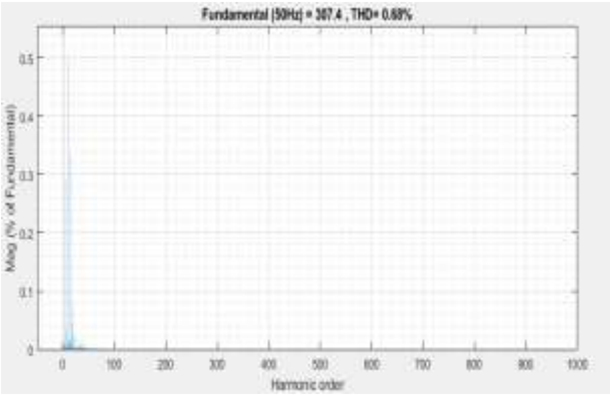

Figure 17 THD% in current Output at 110KV side

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

The converter topologies in the traction system were subjected to particle swarm optimization (PSO) control. The PSO system regulates DC voltage as well as current, as well as AC voltage as well as current outputs, to achieve the lowest possible distortion level. The particles in this algorithm keep updating their positions to ensure a proper waveform at the end. The assessment is being carried out in three operational modes on the 110 KV side. 300 amperes is the current.

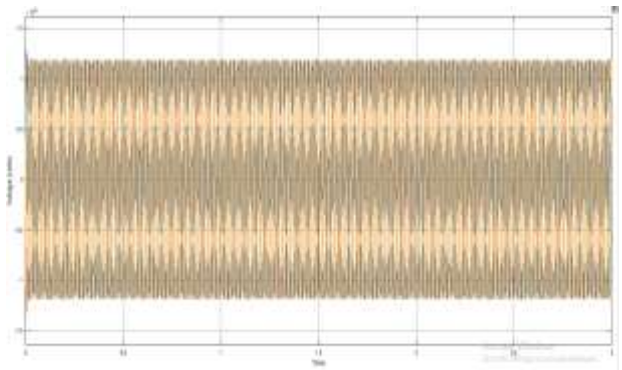

Figure 18 Voltage output in the system with PSO controlled converters at 110KV side

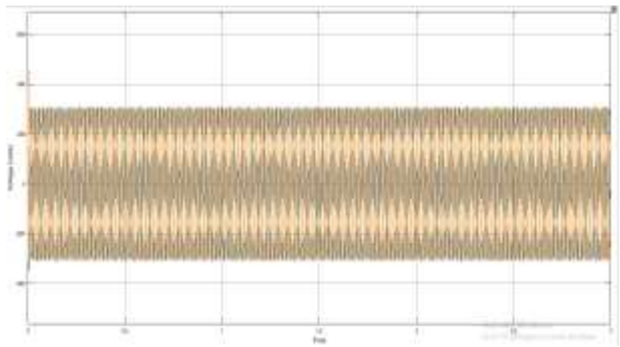

Figure 19 Current output in the system with PSO controlled converters at 110KV side

The very same speed reference is used for comparison assessment in this case as well. The motor acceleration is however researched at one second, so the FFT of the output waveforms is done at one second to investigate the harmonic level.

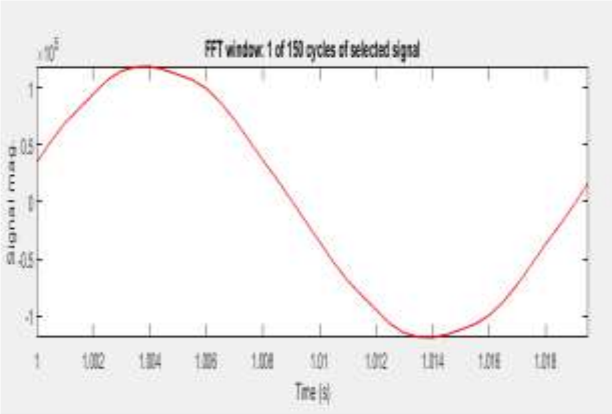

Figure 20 FFT analysis of Voltage output in the system with PSO controlled converters

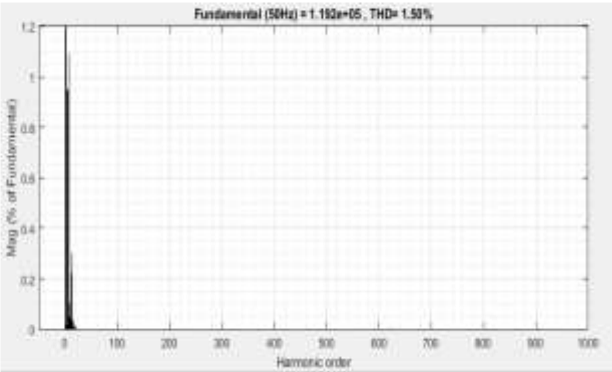

Figure 21 THD% in Voltage output in the system with PSO controlled converters

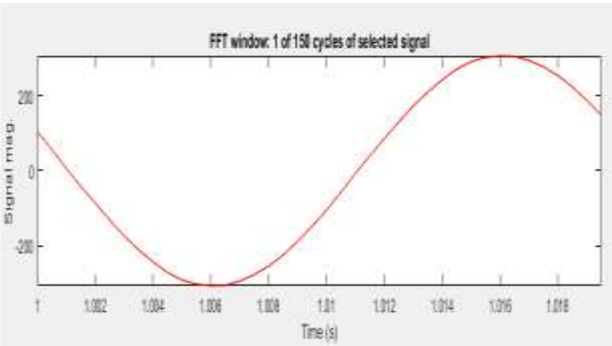

Figure 22 FFT analysis of Current output in the system with PSO controlled converters

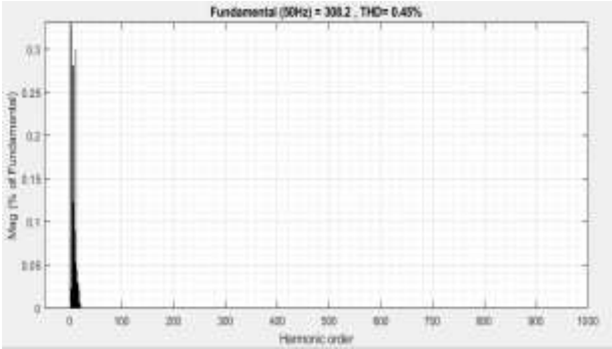

Figure 23 THD% in Current output in the system with PSO controlled converters

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.

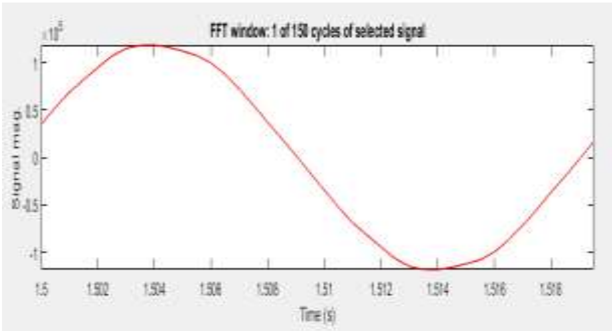

Figure 24 FFT analysis of Voltage output in the system with PSO controlled converters

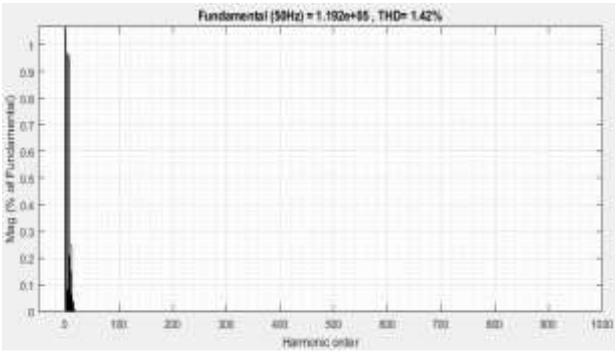

Figure 25 THD% in Voltage output in the system with PSO controlled converters

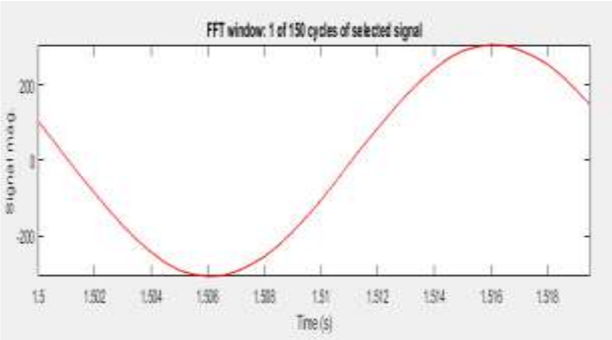

Figure 26 FFT analysis of Current output in the system with PSO controlled converters

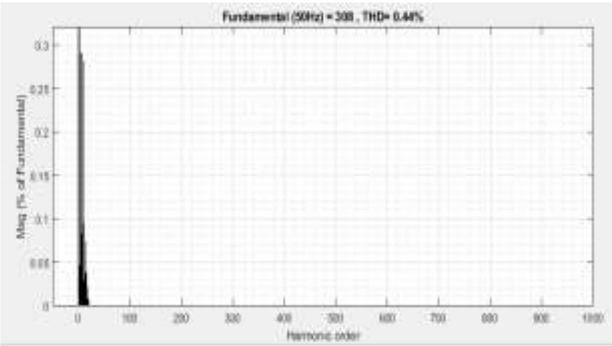

Figure 27 THD% in Current output in the system with PSO controlled converters

The speed is dramatically decreased from 1500 to 800 rpm, after which it continues to run continuously for 3 seconds. As a result, in this mode, the voltage and current waveforms in the suggested traction system, in which the converters are controlled for quality control using the PSO technique, are examined for distortion levels at 2 seconds.

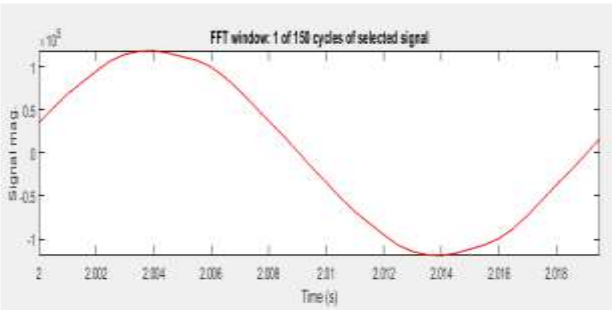

Figure 28 FFT analysis of Voltage output in the system with PSO controlled converters

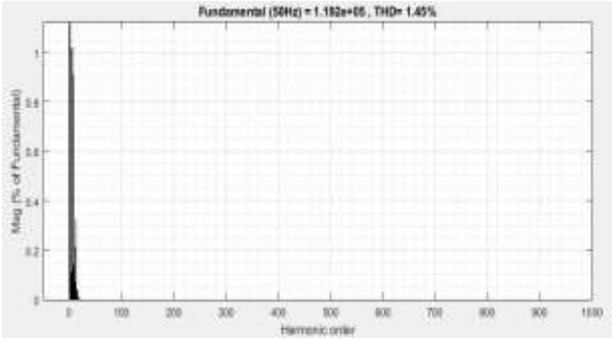

Figure 29 THD% in Voltage output in the system with PSO controlled converters

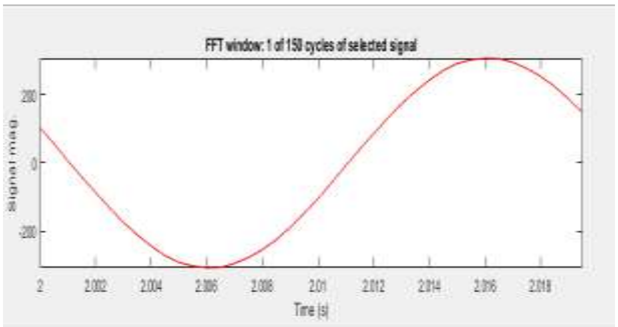

Figure 30 FFT analysis of Current output in the system with PSO controlled converters

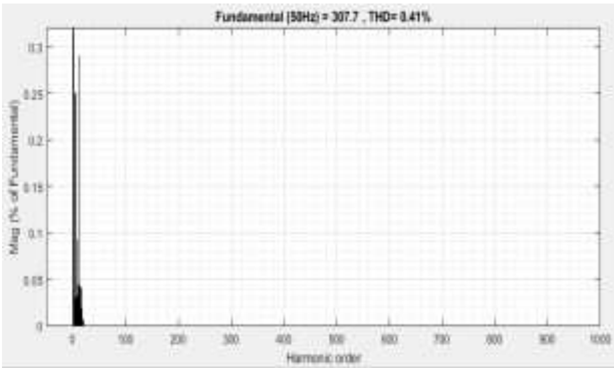

Figure 31 THD% in Current output in the system with PSO controlled converters

The DC bus link voltage of the traction system is shown in the diagram below. The red graph depicts the DC voltage of a system that consist of a traditional PI controller, while the green graph depicts the DC voltage of a system having PSO control of the power-converters. The voltage across the DC link is around 1950 volts.

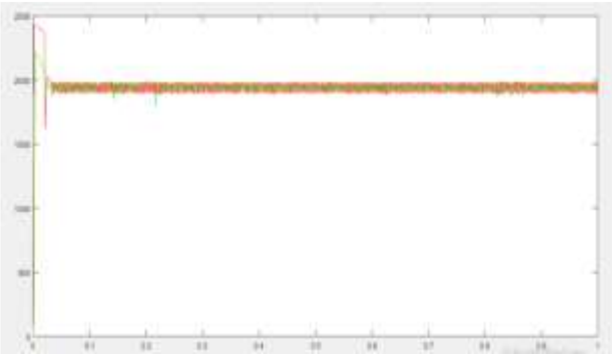

Figure 32 Comparative graph of the DC bus voltage of the traction system in the two cases

V. CONCLUSION

The work has identified an electric traction system that operates at 110/25kv. The model was created in the MATLAB/SIMULINK environment to investigate quality problems in the organization in the operating phases of acceleration, constant drive, as well as deceleration on both the AC and DC sides. In the first case, the power converters in the traction system were modelled with a traditional PI controller, but in the second system, they were replaced with PSO optimising control to reduce the quality issues. The major findings from the system in terms of Total harmonic distortion level at the 110KV side are shown in table 1 and 2.

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

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

Both the tables depicts the efficacy of the modelled controller combined with the PSO optimization technique in reducing AC quality problems. The voltage distortion level, as well as the current THD percent, were lowered in all three modes of operation. The traction system's DC bus, which runs at 1950 volts, has also seen less variation in its value over time.

Electric traction systems seem to be the most effective system having several advantages over other systems, such as rapidly start and stop, high efficiency, pollution-free operation, ease of handling, and speed control. Converters are used in the systems for power regulation and to drive other auxiliary devices. Electric system quality issues are frequently caused by sudden loading offloading or other factors. To improve its performance, these systems can be analysed using recent advanced artificial methodologies for minute regulatory oversight. The same technique can be used to continue improving the magnitude of the DC bus voltage in order to increase the system rating.

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