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Simulation and Results of Static Var Compensator for Electric Arc Furnace (No 1 Iron and Steel Mill, Pyin Oo Lwin, Myanmar)

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ABSTRACT
Electric arc furnace is unbalanced, nonlinear and time varying loads, which can cause many problems in the power system. Voltage variation problem is the major focus of the power system because the loads can vary anytime. Power quality issue has a very high attractive for power system engineers and try to solve these problems by several effective ways. In this thesis, Static Var Compensator (SVC), thyristor controlled reactor compensation with thyristor switched capacitor (TCR-TSC) type is designed and its performance is simulated in the case studies. This unique design of this device (SVC) is used for reactive power compensation for nonlinear loads such as electric arc furnace (EAF) in an industrial plant. Moreover, the SVC is more effectively enhance the voltage stability. Single tuned passive harmonic filter can reduce total harmonic distortion (THD) caused by thyristor controlled reactor of SVC. The installation site for this thesis is No. 1 Iron and Steel Mill, Pyin Oo Lwin. And then, data is taken from this Steel Mill. Simulation results will be provided by using MATLAB/SIMULINK.

KEYWORDS: *EAF, SVC, Harmonics, TCR-TSC, Matlab/Simulink*

I. INTRODUCTION

Electric Arc Furnace (EAF) is the most difficult load type in electrical distribution system. Electric arc furnaces are used for melting high melting point alloys such as steels. In these furnaces, electric energy is used to form an electric arc which heats the metal by the radiant heat evolved.

Heat is generated by electric arcs and in most types of furnaces also by resisting heating in the charge as the current passes from one arc to another.

The basic of electrical operation of arc furnaces is the optimum current for the selected voltages or lower current as required by the power factor. Electric arc furnaces have founded wide applications in the steel industry for refining and making alloy steels and in the production of alloys.

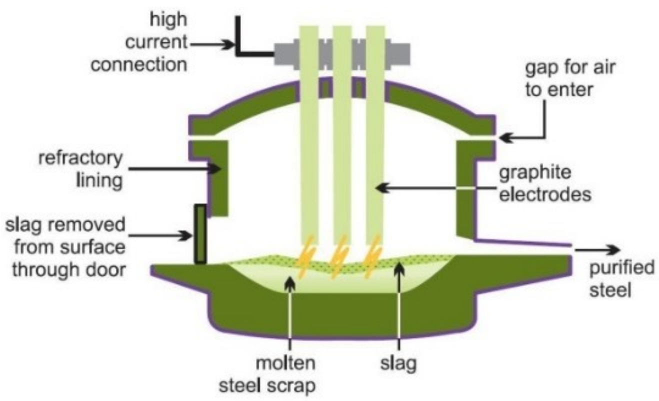

Figure1: Electric Arc Furnace [2]

Disturbances produces in electrical networks by electric arc furnaces can significantly affect the voltage quality supplied by electrical power companies. In fact, an electric arc furnace is a non-linear, time-varying load, which gives rise to harmonics, inter-harmonics and voltage fluctuations. The cause of harmonics is mainly related to the non-linear voltage-current characteristic of the arc while the voltage fluctuations are due to the arc length changes that occur during the melting of the scrap. The current and voltage harmonic distortion causes several problems in electrical power systems, such as incorrect operation of devices, premature ageing of equipment, and additional losses in transmission and distribution networks, overvoltage and over current [3].

II. OPERATION CYCLE OF ELECTRIC ARC FURNACE

The electric arc furnace operates as a batch melting process producing batches of molten steel known “heats”. The electric arc furnace operating cycle is called the tap-to-tap cycle and is made up of the following operations:

- Furnace charging
- Melting
- Refining
- De-slagging
- Tapping and
- Furnace turn-around.

Modern operations aim for tap-to-tap time of less than 60 minutes. Some twin shell furnace operations are achieving tap-to-tap times of 35 to 40 minutes [2].

III. STATIC VAR COMPENSATOR

The Static Var Compensator (SVC) is regarded as the first FACTS (Flexible AC Transmission System) devices. The SVC has become known for its ability to offer voltage stability to the power system and to compensate reactive loads. However, the SVC does not provide a means for controlling real power flow directly. It is important to ensure that the static compensators are switched at the appropriate times so that transients do not occur. For both capacitors and inductors, the appropriate switching times occur at the zero crossing of the current [2].

The first strategy is feed forward control, which repeatedly solves modelled equations to determine the optimum inductor firing angle and the number of capacitor and inductor size needed. Feed forward control is a good choice when performing load compensation because at any time the load characteristics can be measured and the optimum compensating susceptance can be calculated.

The second strategy, feedback control, is useful for closed-loop control when minimization of error signals is the primary goal. Feedback control is useful when terminal voltages are being maintained because the error signal can represent the difference between a desired voltage and an actual voltage. Any change in the error signal will result in a change in the susceptance of the compensator. The controllable susceptance of the inductor (B_L) can be defined as a function of the conduction angle and the reactance of the inductor (X_L). The conduction angle σ, opposite from the firing angle α, is defined as the time that the thyristors are tuned on.

IV. SVC CONFIGURATIONS

Controlled reactive power compensation in electric power systems is usually achieved with the following configurations:

- Thyristor controlled reactor, Fixed capacitor (TCR_FC)
- Thyristor controlled reactor, Thyristor switched capacitor (TCR_TSC)
- Thyristor controlled reactor, Mechanically switched capacitor (TCR_MSC)
- Thyristor switched reactor, Thyristor switched capacitor (TSR_TSC)

V. MATLAB BASED MODELING ELECTRIC ARC FURNACE (EAF)

The power quality means voltage quality for this work and to enhance the power quality. Voltage stability problems usually encounter in heavily loaded systems. EAF is operating to melt down the scrap in a moment. During melting cases, generally, the system voltage decreased from the constant level. If the running condition stopped, the voltage will suddenly rise. The main purpose of this chapter is building simulation model of static var compensator by using one of programs for modeling called MATLAB and specially part of MATLAB program called SimPowerSystems and analyzing the simulation results. This chapter is specially oriented on static var compensator model which is used in SimPowerSystems as part application in MATLAB program. A simplified single line diagram of the main components in No. 1 Iron and Steel Mill is shown in Figure 2.

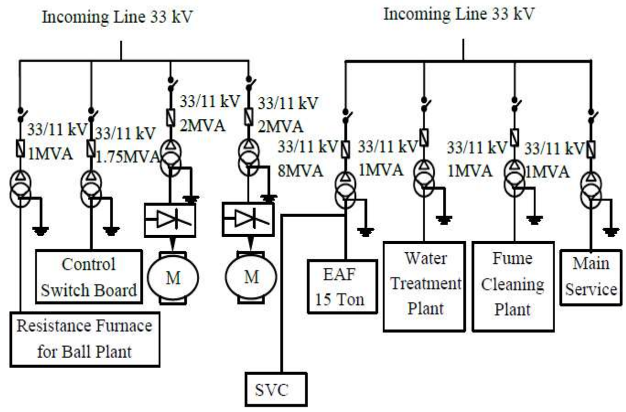

Figure2. Single Line Diagram of No. 1 Iron and Steel Mill

VI. BASIC ARRANGEMENT

The compensator is a thyristor controlled reactor (TCR) with thyristor switched capacitor (TSC).The compensator is connected to the system through 8 MVA, 33 kV/11 kV step down transformer. On secondary side, reactor bank rated 22.7534 mH of TCR is paralleled with the capacitor bank rated 222.6504 μF of TSC. The rating of the reactor bank and capacitor bank may be variable. Moreover, 22.7534 mH of reactor bank and 222.6504 μF of capacitor bank rating is the most suitable for Electric Arc Furnace in No. 1 Iron and Steel Mill.

VII. COMPONENTS OF STATIC VAR COMPENSATOR

The static var compensator (SVC) is a shunt device of the flexible AC transmission systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. A static var compensator (SVC) is used to regulate voltage on 11kV, 8MVA system for Electric Arc Furnace in No. 1 Iron and Steel Mill. When system voltage is low, the SVC generates reactive power (SVC capacitive).

When system voltage is high, it absorbs reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor bank and inductor bank connected on the secondary side of a coupling transformer. Reactors are either switched on and off TCR. Each capacitor bank is switched on and off by three thyristor switches TSC.

VIII. SIMULATION OF ELECTRIC ARC FURNACE BEFORE USING SVC (TCR-TSC)

In this work No. 1 Iron and Steel Mill in Pyin Oo Lwin is composed of the various departments, namely Electric Arc Furnace (EAF), Ladle Refining Furnace (LRF), Continuous Casting Machine (CCM), Water Treatment Plant (WTP), Fumes Treatment Plant (FTP), Air Separation Plant (ASP), Wire Production Plant, Air Compressor, Bolt Nut and Shredder. Among these departments, EAF is studied as research area. FFT Analysis is used to know the THD. Function block of load (EAF) is shown in Figure 3. The Simulink block diagram of EAF before using SVC is described in Figure 4. The results of EAF before using static var compensator are shown in Figure 5 and Fig. 6.

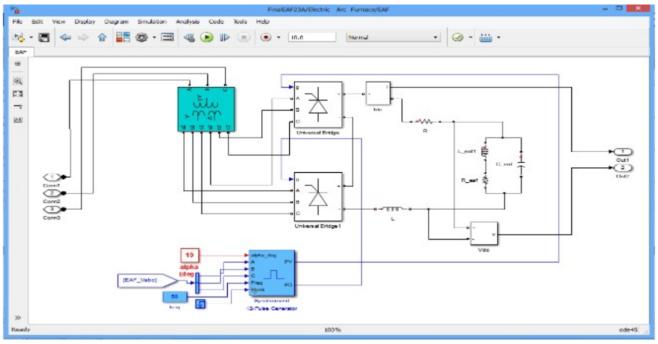

Figure3 Function Block of Load (EAF)

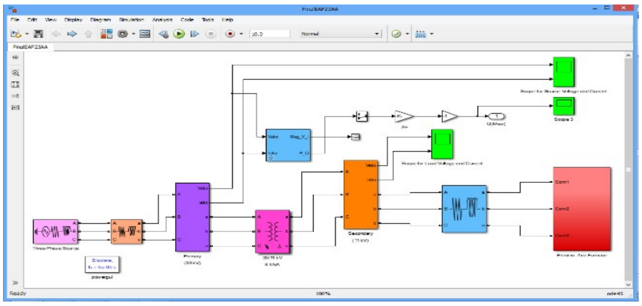

Figure4 Simulink Block Diagram of EAF before Using SVC

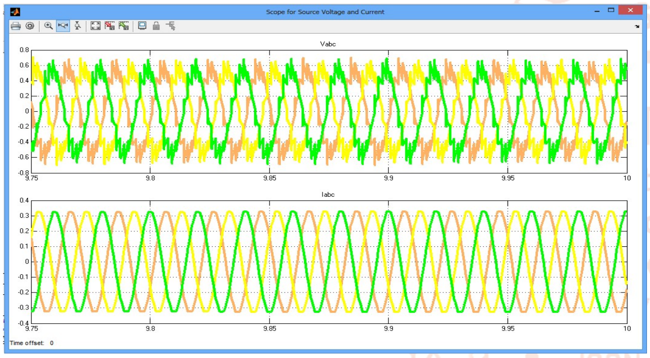

Figure5 Simulation Results of Source Voltage and Current before Using SVC

When the electric arc furnace is operating with every load of steel mill on condition without static var compensator, the condition of source voltage and current waveforms before using SVC are shown in Figure 4. And, the condition of load voltage and current waveforms before using SVC are shown in Figure 5. Regarding to Figure 4 and Figure 5, voltage and current waveforms are too much distorted by the effect of electric arc furnace.

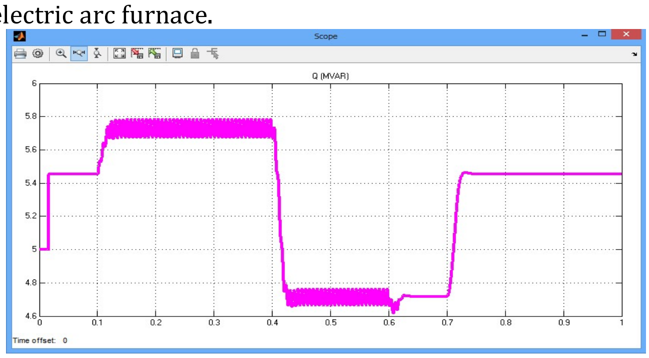

Figure6. Simulation Results of Reactive Power before Using SVC

And then, simulation results of reactive power before using SVC show in Fig. 5.15. To obtain the desire results, TCR-TSC type is add to the EAF. Fig. 5.16 shows the simulation result of harmonics order content and THD percentage. It is clear that the total harmonics distortion is 67.60%.

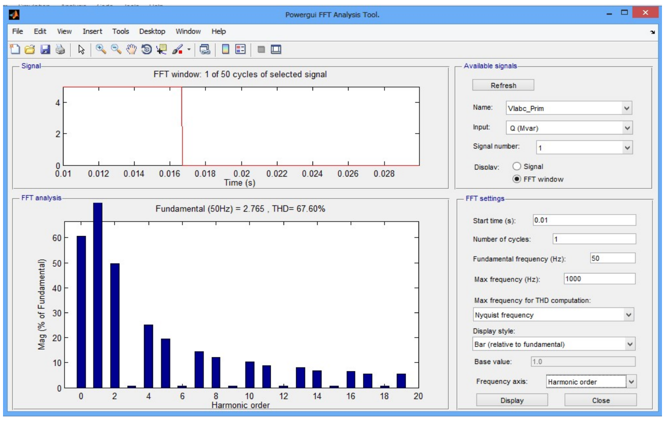

Figure7. Total Harmonic Distortion of EAF before Using SVC

IX. SIMULATION OF ELECTRIC ARC FURNACE AFTER USING SVC (TCR-TSC)

After using static var compensator (SVC) for electric arc furnace are described in the following. Switching the TSC in and out allows a discrete variation of the secondary reactive power from zero to 222.6504 μF capacitive at 11 kV, whereas phase control of the TCR allows a continuous variation from zero to 22.7534 mH inductive. Moreover, the SVC is in voltage control mode and its reference voltage is set to V_{ref} = 1.0 pu. The voltage droop of the regulator is 0.01 pu/ 100 VA. The Simulink block diagram of EAF after using SVC is described in Figure 8.

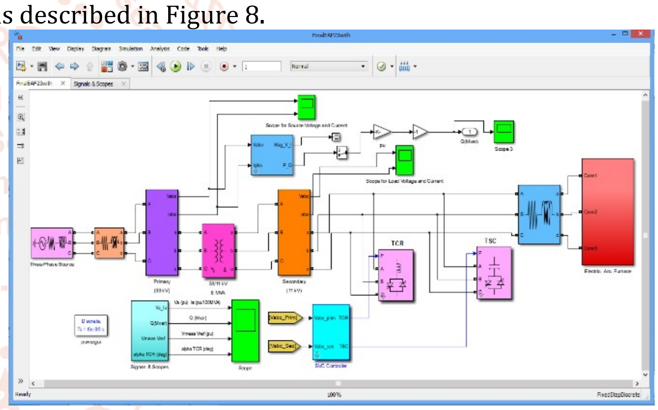

Figure8. Simulink Block Diagram of EAF after Using SVC

The Static Var Compensator (SVC) regulates voltage on 8 MVA, 11 kV system. The SVC consists of a 33 kV/11 kV, 8MVA step down transformer, 22.7534 mH thyristor controlled reactor bank (TCR) and 222.6504 μF thyristor switched capacitor bank (TSC) connected on the secondary side of the transformer.

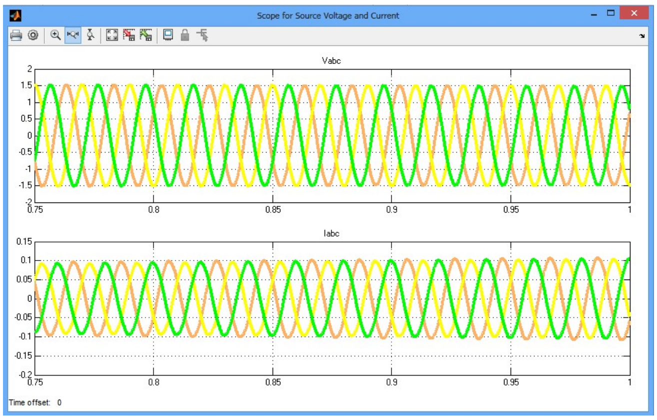

Figure9. Simulation Results of Source Voltage and Current after Using SVC

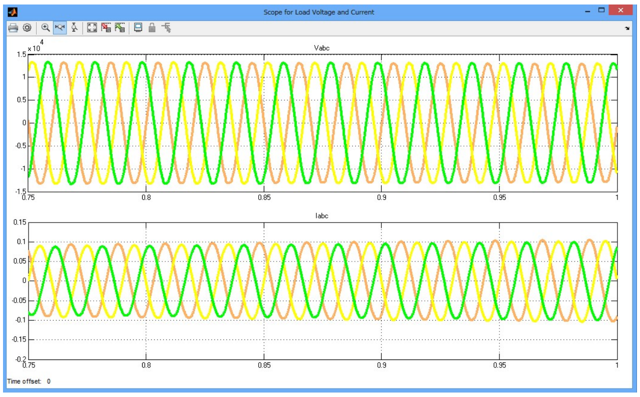

Figure10. Simulation Results of load Voltage and Current after Using SV

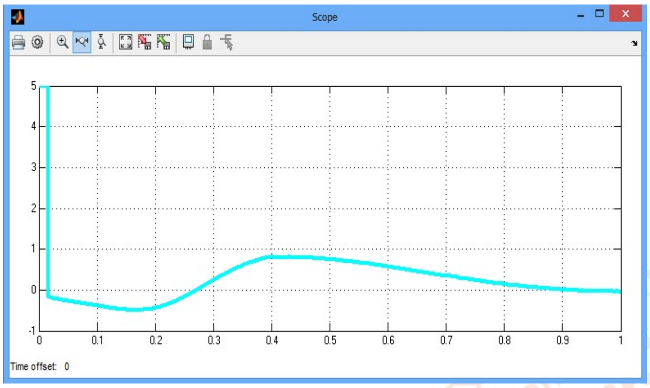

Figure11. Simulation Results of Reactive Power after Using SVC

When the electric arc furnace is running with all loads of steel mill on condition with static var compensator installation, the status of source voltage and current waveforms after using SVC are shown in Figure 9. And, the condition of load voltage and current waveforms after using SVC are shown in Figure 10.

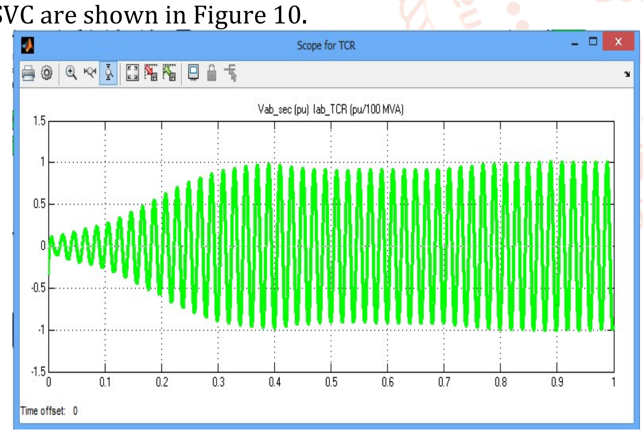

Figure12. Simulation Results of Voltage and Current for TCR

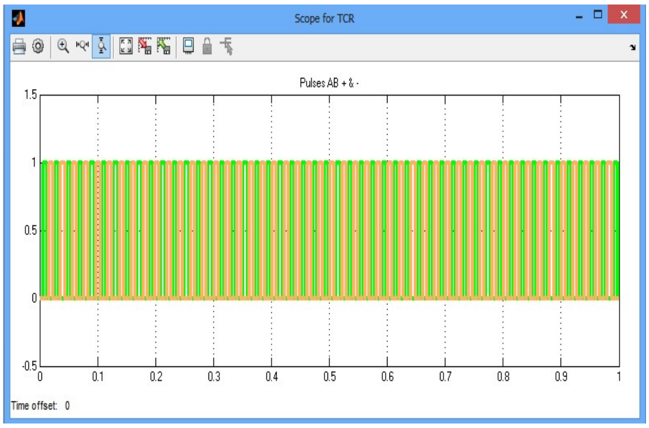

Figure13. Simulation Results of Pulses for TCR

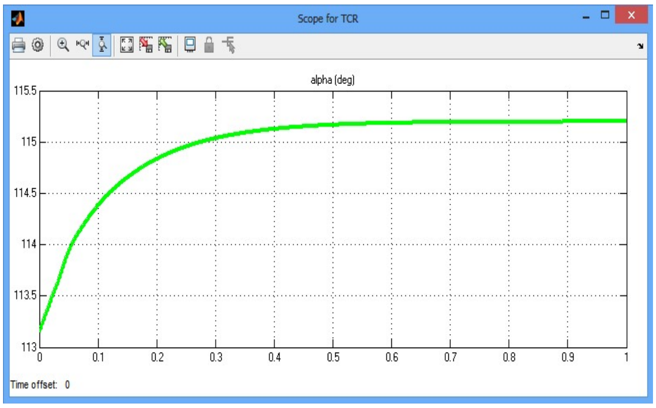

Figure14. Simulation Results of Alpha for TCR

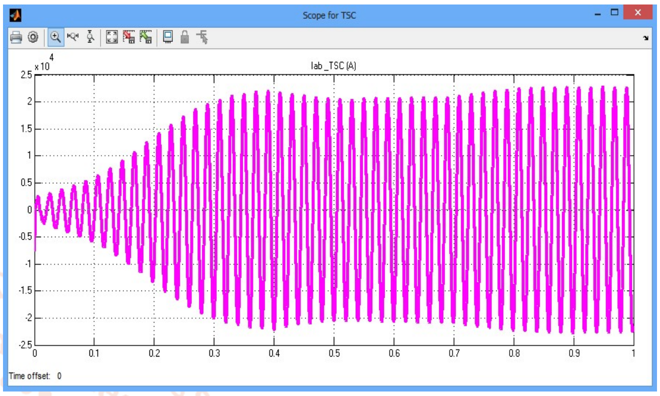

Figure15. Simulation Results of Voltage for TSC

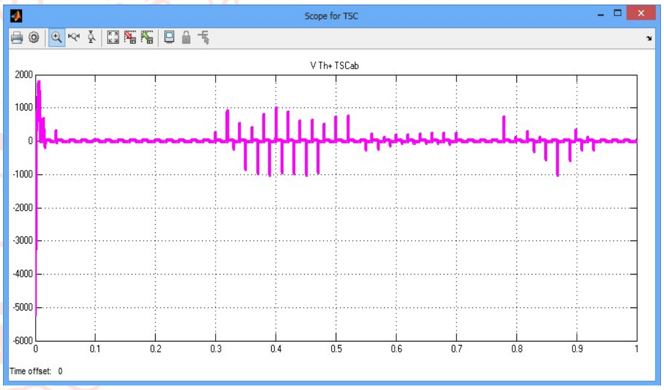

Figure16. Simulation Results of Thyristor Voltage for TSC

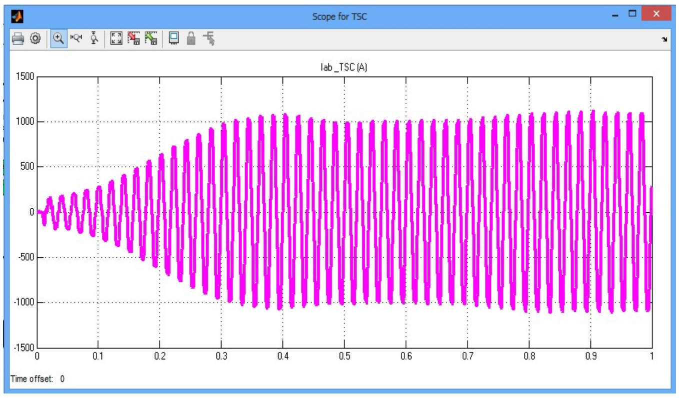

Figure17. Simulation Results of Current for TSC

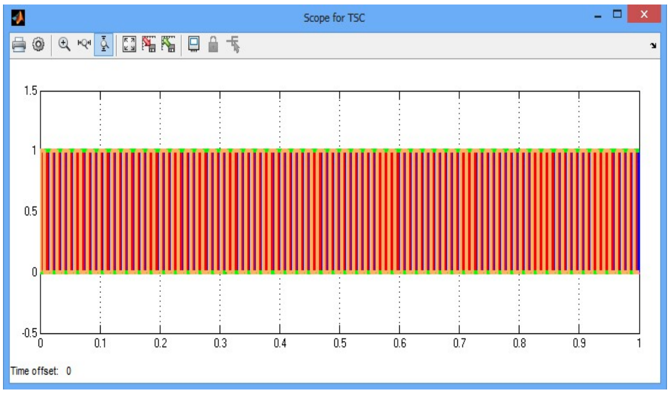

Figure18. Simulation Results of Pulses for TSC

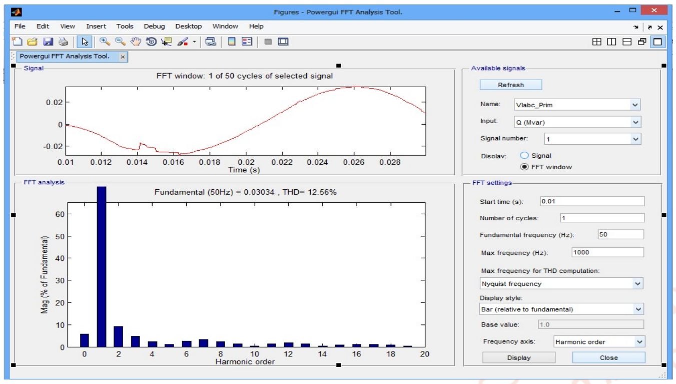

Figure19. Total Harmonic Distortion of EAF after Using SVC

Moreover, simulation results for TCR are shown in Figure 12, Figure 13 and Figure 14. And then, Figure 15, Figure 16, Figure 17 and Figure 18 are simulation results for TSC. From the simulation results of Figure 19, the percentage of total harmonic distortion (THD) is 12.56%. It is not existing within acceptable level by comparing IEEE Standard 519. So, depending on the harmonic spectrum, the passive filters designed are low pass filter tuned for 2nd order harmonic frequency. The subsystem named shunt filter consists of 2nd harmonic frequency. Based on the design carried out the filter component value are L= 16mH, C= 25 μF and R= 0.83 Ω.

X. SIMULATION OF ELECTRIC ARC FURNACE WITH SVC (TCR-TSC) AND PASSIVE FILTER

The status of source voltage and current waveforms after using SVC and passive filter are shown in Figure 21. And, the condition of load voltage and current waveforms after using SVC are shown in Figure 22.

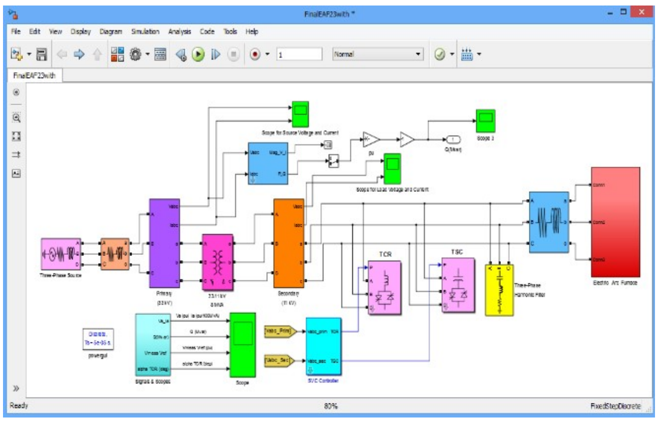

Figure20. Simulink Block Diagram of EAF after Using SVC and Passive Filter

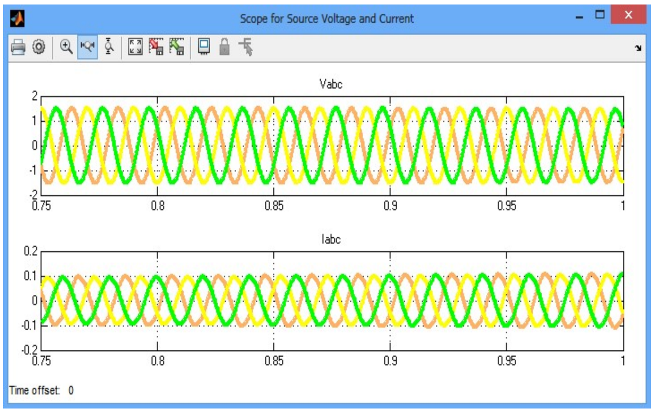

Figure21. Simulation Results of Source Voltage and Current after Using SVC and Passive Filter

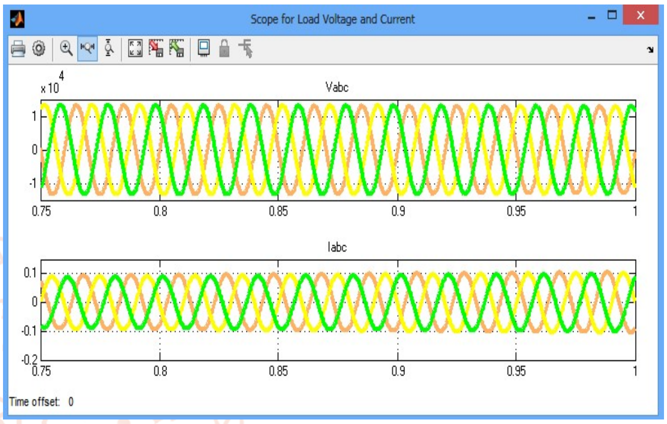

Figure22. Simulation Results of load Voltage and Current after Using SVC and Passive Filter

As shown in Figure 21 and Figure 22, voltage and current waveforms change to smooth by the effectt of SVC and passive filter installation.

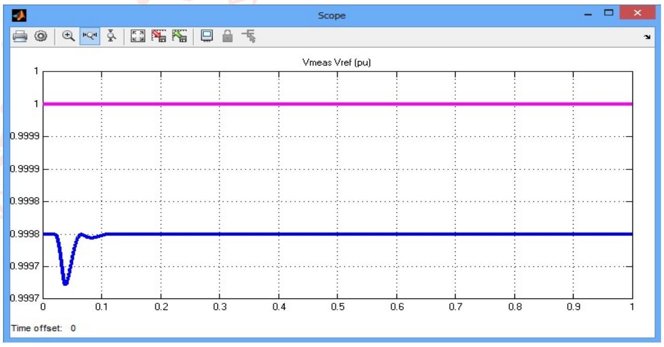

Figure23. Simulation Results of EAF after Using SVC and Passive Filter

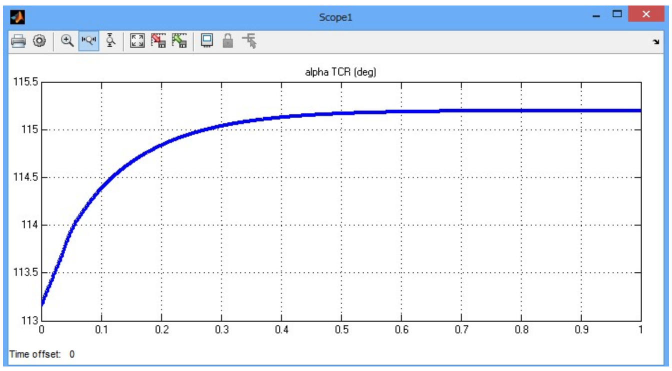

Figure24. Simulation Results for EAF after Using SVC and Passive Filter

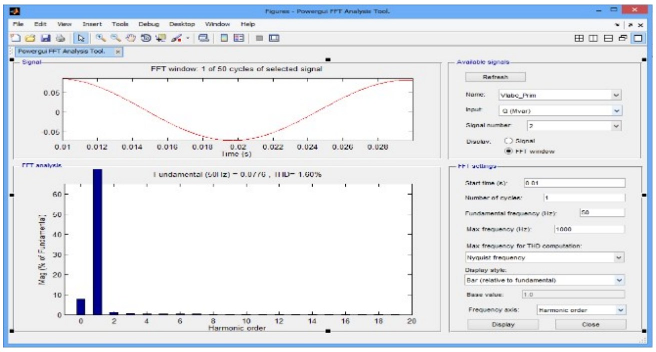

Figure25. Total Harmonic Distortion of EAF after Using SVC and Passive Filter

From the simulation results, Total Harmonic Distortion of electric arc furnace is reduced to 1.60% shown in Figure 25. By comparing the IEEE standard value, Total Harmonic Distortion exists within acceptable level. After simulation of electric arc furnace with SVC and passive shunt filter, the combine results of Total Harmonic Distortion percentage before and after SVC and passive shunt filter are presented in Table I.

Table I. Comparisons of THD with Different Schemes for EAF

Matlab Simulink Model	Total Harmonic Distortion, THD (%)
Before Using SVC	67.60 %
After Using SVC	12.56 %
After Using SVC and Filter	1.60%

And then, comparison of THD is shown in Figure 26. To demonstrator the performance of these passive filter with TCR and TSC for electric arc furnace load, these are modeled in MATLAB environment along with SIMULINK and power system block set toolboxes. It has been shown that before the use of SVC for electric arc furnace, the percentage of total harmonic distortion (THD) is 67.60 %. And then, after the use of SVC for electric arc furnace, the percentage of total harmonic distortion (THD) is 12.56 %. Finally, after the use of the combination of SVC with passive filter, it is clear that the total harmonic distortion of electric arc furnace is 1.60 %.

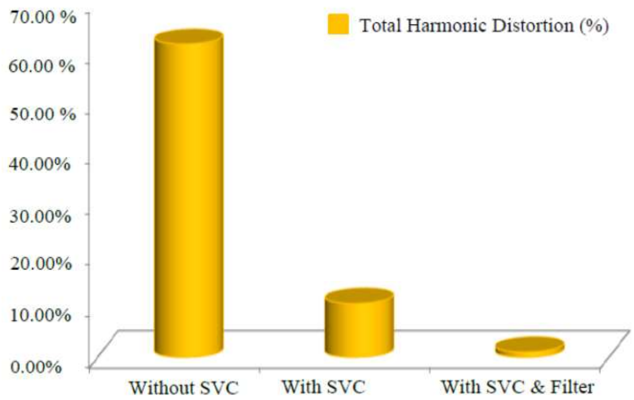

Figure26. Percentage of Total Harmonic Distortion

XI. CONCLUSIONS

This paper provides a detailed description of a modern, TCR-TSC type Static Var Compensator installed on Electric Arc Furnace (EAF) in iron and steel mill. The SVC is a controller for voltage regulation and for maintaining constant voltage at a bus. SVCs are used to improve voltage regulations, improve power factor, reduction of voltage and current unbalances, etc. A model has been developed in MATLAB/SIMULINK and simulated to verify the results. Simulation results were obtained before and after the use of SVC. From the analysis of simulation data, THD is 67.60 % before using SVC is reduced to 12.56 % after using SVC for electric arc furnace. And then, THD is reduced to 1.60 % after using SVC and passive filter for electric arc furnace.

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