Proceedings of 4th RIT Post Graduates Conference (RIT PG Con-18)
NOVATEUR PUBLICATIONS
JournalNX- A Multidisciplinary Peer Reviewed Journal (ISSN No:2581-4230)
April, 13th, 2018

POWER QUALITY ENHANCEMENT IN ARC FURNACE ENVIRONMENT

Nupur Laxman Mali,
Student member, IEEE, M. Tech (Electrical Power System), Department of Electrical Engineering, Rajarambapu Institute of Technology, Islampur, 415414, India Email id: nupurlmali@gmail.com

Dr. V. N. Kalkhambkar,
Member, IEEE Associate Professor, Department of Electrical Engineering. Rajarambapu Institute of Technology, Islampur, 415414, India.
Email id: vaiju.kalkhambkar@ritindia.edu

Abhijeet Shete,
Director technical, Sharda Electronics & Co. J-32, MIDC kupwad, Sangli, india.
Email id: abhis@shardacapacitor.com

***Abstract* - Electrical power quality defines the health of power system which includes voltage and current quality, a reliability of power supply and maintaining sinusoidal nature of waveform. Voltage flickers and fluctuations, poor power factor and harmonics are the most common power quality issues in steel producing plants because of it contains Electric Arc Furnace (EAF), electrical drives and welding machines. Non-linear characteristics of EAF are the major source of power quality issues that include reactive power consumption, harmonic production and system unbalance. Static VAr compensator (SVC) is one of the efficient FACTS devices to overcome these power quality problems. In this paper, Operating principle and control strategy of Thyristor Controlled Reactor - Fixed Capacitor (TCR-FC) are described briefly. TCR-FC type of SVC is used in proposed work for reactive power compensation, reduction of voltage fluctuations and harmonic mitigation. The SVC model is simulated in MATLAB software and results are observed.**

Keywords – Power Quality, Harmonic, Reactive power, EAF, SVC, TCR-FC, Passive filters

I. INTRODUCTION

Nowadays, power quality issues are more important in power system. Power quality is defined as a steady supply of voltage within prescribed range, steady ac frequency near rated value and smooth waveform. However, with increased load demand, power electronic equipments and automation in industrial processes create disturbance in the ideal power quality issues [1]. These disturbances includes Voltage variation, over frequency, under frequency, harmonic and transient, oscillations.

The various dynamic loads such as electric drives, furnaces, rolling mills and spot welding machines absorb heavy reactive power for their operation. These loads are major source of power quality problems in terms of harmonic, large reactive power, voltage flicker and fluctuation [2]. Therefore System losses and system cost increases. For improving the industrial power supply quality some useful standards are developed by IEEE [3-5]. To meet these standards and overcome power quality problems various types of devices are used such as synchronous condenser, fixed reactor or fixed capacitor, FACTS devices [6], active and passive filters [7].

Proposed work is carried out in steel industry. Steel plants production is based on Electrical Arc Furnace (EAF) for smelting and refining of scrap material. EAF is a nonlinear and time varying load. It demands large fluctuating reactive power. Therefore EAF is responsible for producing power quality problems in form of harmonics, poor power factor, voltage sag and swell, and flickers and fluctuations [8]. To remove these power quality problems SVC plays a vital role over other devices due to it produced required reactive power [9, 10]. Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR) type SVC is considered in proposed work to mitigate harmonics and reactive power compensation.

In this paper, Impact of SVC on power Quality problems which is produced by steel plant is studied. Section II introduces proposed a scheme, SVC, and nonlinear load (furnace) operation. The basic principle of operation of TCR-FC type SVC is explained briefly in section III. Control strategy for firing angle variation is described in section IV. Section V carries out simulation results to demonstrate the effectiveness of SVC.

II. PROPOSED METHODOLOGY

The block diagram of proposed scheme for reactive power compensation and harmonic elimination is shown in Fig 1. It consists of power source, non-linear load for representing EAF, Static VAr compensation (SVC) and firing delay angle controller to control reactive power output of SVC. Combination of TCR and FC is used for rapidly controlling of reactive power and harmonic mitigation.

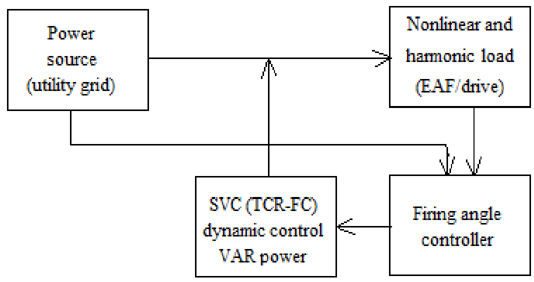


Fig.1. Block diagram of proposed scheme

A. SVC (Static VAr Compensator)

To improve power system quality and stability various types of FACTS devices are used [6]. These are series controller and shunt controller. SVC is one of the shunt controller FACTs devices which are able to provide controlled and variable reactive power leading, lagging or combination of both. SVC's are used to control dynamic and steady state system voltages, improve transient stability, correct power factor, reduce voltage flicker and fluctuation at industrial arc furnaces, damping oscillation, and reduce sub synchronous resonances[11]. SVC consists of following main parts and their combination Fig 2:

i. Thyristor controlled Reactor (TCR) which is generally operated with fixed capacitor (TCR-FC).
ii. Thyristor switched reactor (TSR)
iii. Thyristor switched capacitor (TSC)
iv. Combination of TCR and TSC (TCR-TSC)

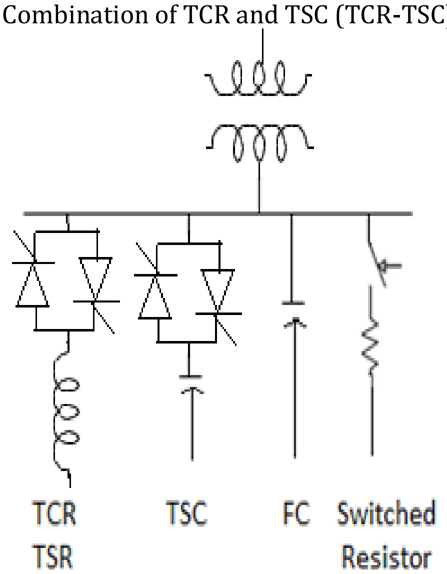


Fig.2. Different types of SVC

TSR and TCR both are shunt connected thyristor controlled reactors. Output of TSR is controlled in stepwise manner that is 'completely on' or 'completely off', whereas output of TCR is controlled by controlling firing angle. TSC operates similar as TSR, but capacitor is present instead of reactor. The reactance of TSC is varied by thyristor switch that is either fully connected or fully disconnected. With different combinations of these components, SVC fulfills variable reactive power requirement.

B. Nonlinear load (EAF)

Many power quality problems are produced because of industrial nonlinear loads. Due to varying impedance, current drawn by these loads is non sinusoidal. EAF is an unbalanced, nonlinear and time varying load. Many factors are involved in the furnace operation such as electrode position, electrode arm control scheme, supply voltage, operating reactance and the materials used for smelting and refining. EAF operation is divided into three distinct steps; striking (boring), melting, and refining. During the striking stage, the electrode is lowered with the help of hydraulic actuator system to maintain the stable arc. Then at melting stage a maximum no of buckets of scrap material are added into the furnace. The pieces of steel create momentary short circuits at secondary side of the furnace transformer. Therefore arc characterizes are changed and causes fluctuation in current. The refining period is further divided in several stages. During the refining stage, a long arc is produced. The arc currents are more uniform during the refining period hence, less impact on the power quality problems. This Arc current is also responsible to create harmonic problem.

Single line diagram of proposed work is represented in Fig. 4. The model consists of the source, source impedance (Z), arc furnace, power transformer and distribution transformer, and Static VAr compensator. Furnaces are strong source of harmonics and inter harmonics as well as it draws large reactive current and disturbed the power quality of system. [12]. Shunt connected SVC is used to improve the power quality of EAF.

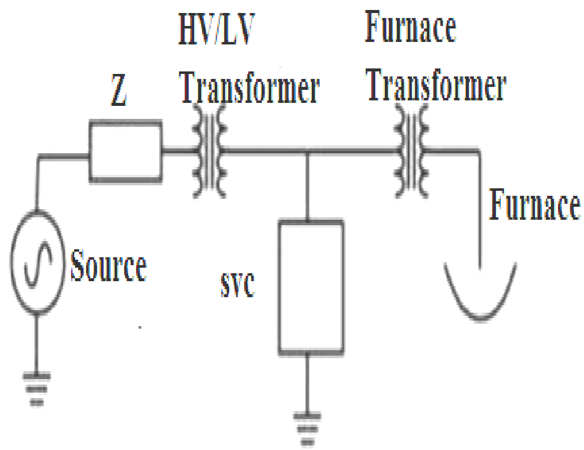


Fig.3. Single line diagram of proposed work

III.THEROTICAL BACKGROUND OF (TCR-FC)

TCR-FC type SVC is used in proposed work for reactive power compensation and harmonic mitigation. This provides required reactive power by controlling reactor where fixed capacitor connected with the series reactor is responsible to mitigate dominant harmonics as shown in Fig.4.

A. Principle of Operation of TCR-FC-

The TCR-FC type VAr compensator generator consists of a variable reactor (controlled by delay angle α) and a fixed capacitor as shown in Fig. 4. The reactor current can be controlled from maximum value to zero by changing the firing angle delay [13]. The range of firing angle 'α' of TCR extends from 90^o to 180^0. When thyaristor is completely closed (α= 90^o) current reaches the highest value in the reactor and when α = 180^0, thyristor valve is switched off completely and the current reaches the lowest value. A basic TCR consist of an anti-parallel connected pair of thyristor valves in series with reactor. The TCR acts like a variable susceptance. Variations in the firing angle, alpha changes the susceptance and consequently, the fundamental current component which is shown by equation (1),

$$i_L(t) = \frac{1}{L}\int_{\alpha}^{\omega t} v(t)dt = \frac{v}{\omega L}(\sin \omega t - \sin \alpha) \qquad (1)$$

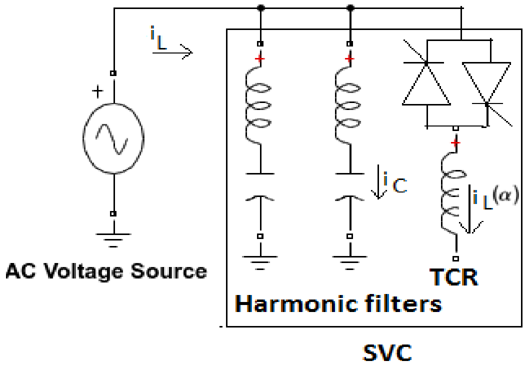


Fig.4. TCR-FC type SVC

Then Fundamental reactor current is carried out from above equation,

$$i_{LF}(\alpha) = \frac{v}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right) \qquad (2)$$

susceptance of TCR,

$$B_L(\alpha) = \frac{1}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right) \qquad (3)$$

Fixed capacitor and its series inductor are tuned at particular frequency to provide low impedance path for a dominant harmonics.

IV. CONTROL SCHEME

SVC can generate required reactive power by varying firing pulse of TCR [14]. Therefore this control system is used to generate appropriate firing pulses as well as fast and dynamic control operation of reactive power compensation. Fig.5. shows control system for SVC. This system is divided into four parts.

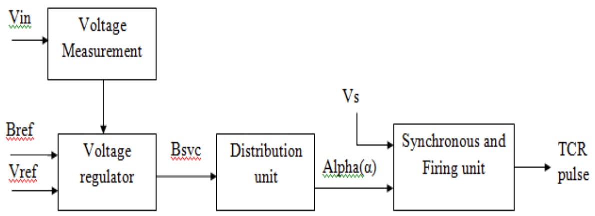


Fig.5. Control scheme for TCR-FC

i) Voltage measurement

Voltage measurement measures the positive-sequence primary voltage. This unit is driven by a Phase-locked loop (PLL) is used to continuously changing frequencies and phases according with measured input signal. Basically PLL consists of variable frequency oscillator and phase detector.

ii) Voltage regulation

Voltage Regulator uses a PI regulator to regulate primary voltage at the reference voltage. A voltage droop is incorporated in the voltage regulation to obtain a V-I characteristic with a slope. Operating point of SVC changes from fully inductive to capacitive value with system voltage.

iii) Distribution system

Distribution Unit uses the primary susceptance B_{svc} computed by the voltage regulator to determine the firing angle α of TCR. The firing angle α as a function of the SVC susceptance B_{svc} is implemented by a look-up table from the equation (3)

iv) Synchronous and Firing unit

Firing unit gives firing pulse to each phase of TCR. This is accomplished by the firing pulse generator circuit which produces the necessary gate pulse for the thyristors to provide the reactive current. This unit consists of PLL for synchronize gate pulse with peak value of system voltage.

V. RESULTS AND DISCUSSION

For designing, analysis and modeling of SVC measurement are done at EAF. According to these measured data, required parameters have been calculated and the effectiveness of SVC is observed.

A. Measurement carried out at EAF

- Connected Load - 550 KW
- Voltage – 550V
- Fundamental frequency – 50Hz

For power quality analysis required data is available from above power analyzer readings as described in Fig.6. Table 1 represents summary of harmonics present at furnace. By analyzing all data 5^{th} and 7^{th} order of harmonic is dominating. This order of harmonic is reduced by connecting passive filter which is tuned at particular frequency

Harmonic measurement at R phase

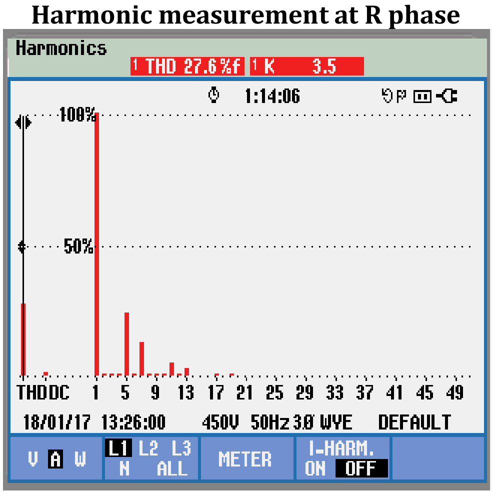


Fig.6. Power analyzer's readings

Designing of FC-TCR

1. Fixed capacitor

Total reactive power requirement - Q MVAR

Source voltage -V

Dominating harmonics - 5^{th}, 7^{th}

$$Qnet = Vs^2/X_1 \qquad (4)$$

Then

At resonance frequency $X_{L2} = X_{c2}$

$X_{L1} * h = X_{C1} / h$, $X_{L1} = X_{C1} / (h)^2$

Then,

$X1 = X_{C1} - X_{L1} = X_{C1} - X_{C1} / (h)^2 = ((h)^2 - 1) X_{C1} / (h)^2$

From X_{C1} and X_{L1}, we can find value of c and L

$X_{C1} = 1/ (2\pi f C)$, $X_{L1} = (2\pi f L)$

2. TCR

By controlling firing angle, current through TCR changes as equation (3). Therefore, reactive power of TCR changed. Value of inductor is depends on reactive power and to control overvoltage in system value.

B. Simulation result

1. Harmonics mitigation

MATLAB/simulink model is developed for 5th and 7th order of harmonics mitigation. Fig.7. shows the three phase voltage and current waveform of harmonic load. This is the disturb waveform containing 5th and 7th order of harmonics.

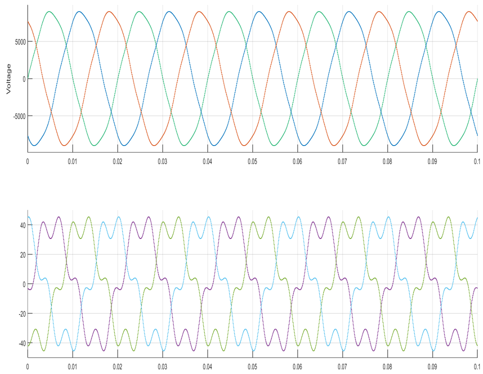


Fig.7. Voltage and Current waveform (Without filter)

After connecting LC passive filter tuned with resonant frequency, pure sinusoidal waveform is achieved. It is illustrate in Fig.8. This LC filter provide low impedance path for particular dominant harmonics and improve sinusoidal waveform.

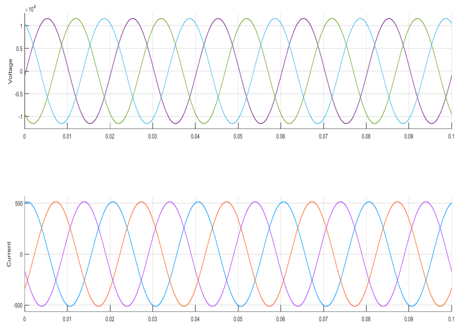
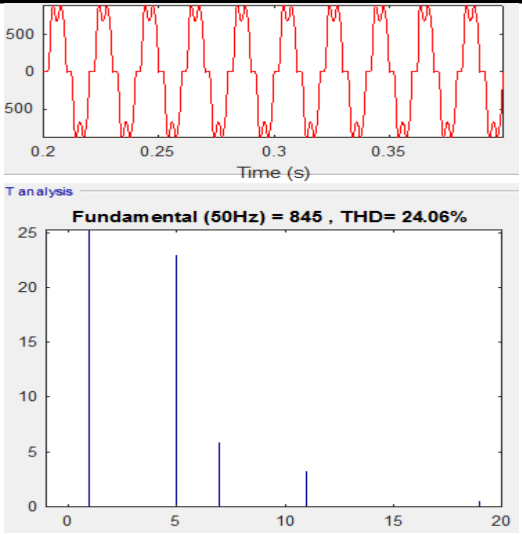
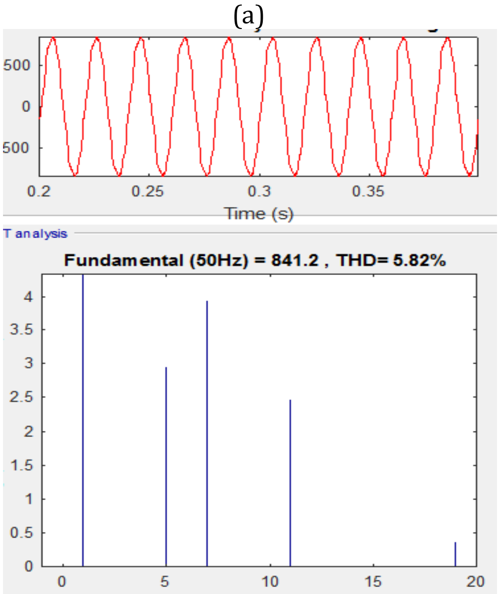


Fig.8. Voltage and current (with filter)

Total harmonic distortion of current is also shown in Fig.9. by using FFT analysis. Before connection of passive filter THD of current waveform is 24.067% and after connecting filter THD is reduced to 5.82%. It's shows that after connecting passive filters level of THD is reduced up to standard limit.



(a)

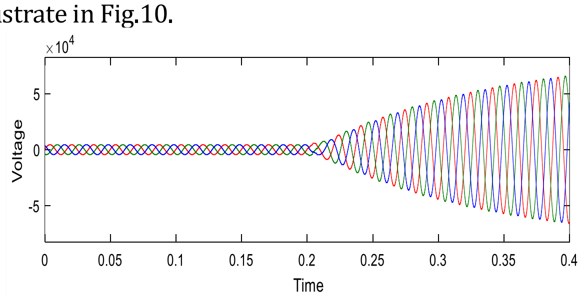


(b)

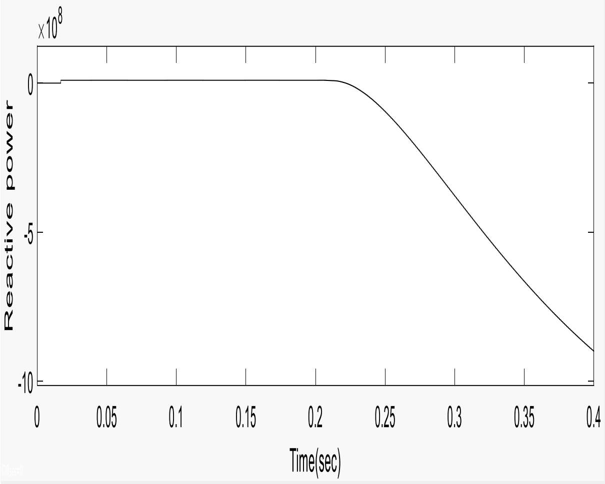
Fig.9. FFT Analysis (a) with filter (b) without filter

2. Reactive power compensation with SVC

Model of SVC is developed in MATLAB / simulink for observing dynamic response of TCR with system voltage. Fig.10. At t = 0.2 s heavy inductive load is disconnected from the system and voltage is start to increases as illustrate in Fig.10.



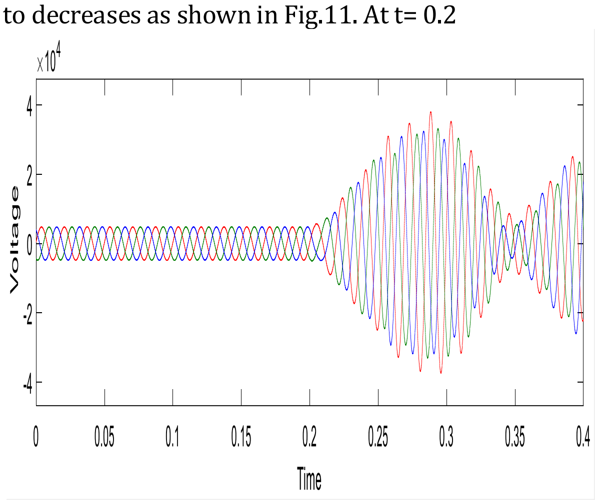
(a)



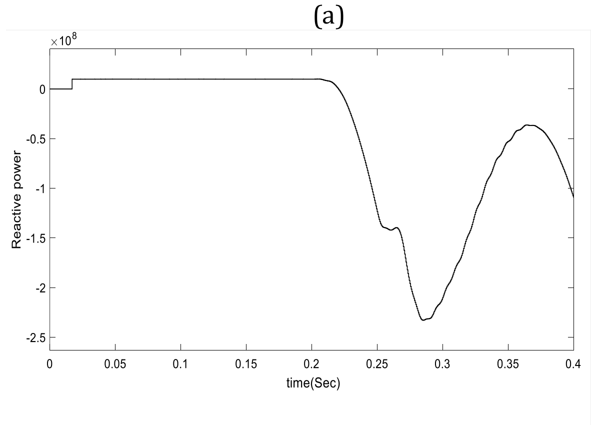
(b)

Fig.10. without SVC (a) voltage (b) reactive power

If the SVC is connected into system then it is absorbed the increasing reactive power and increased voltage is start to decreases as shown in Fig.11. At t= 0.2



(a)



(b)

Fig.11. with SVC (a) voltage (b) reactive power

TCR pulses are shifted by changing firing angle from 180^0 to 90^0. Therefore current in TCR also changes according to firing angle. As shown in Fig.12. TCR is responsible to reduce voltage fluctuation. When per unit voltage is start to increases TCR is fired and reactive power is absorbed by reactor. Therefore system voltage is start to decreases.

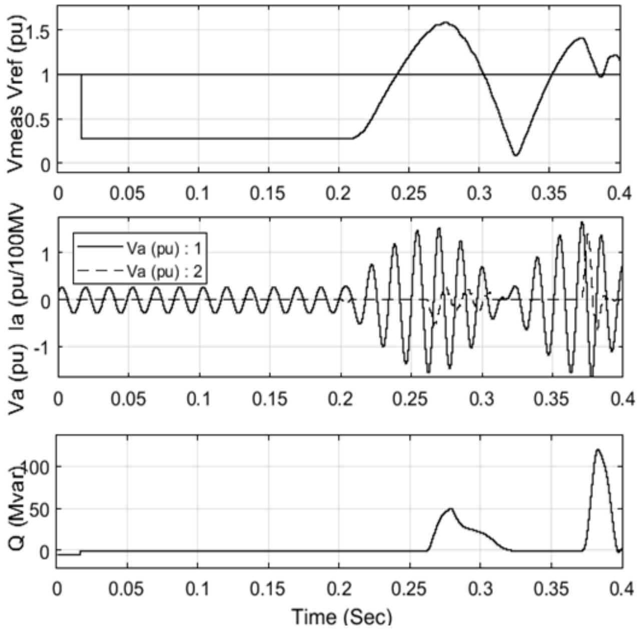


Fig.12. TCR current and voltage

As the simulation results showed, it is clear that the proposed SVC model and its control system able to provide required reactive power and mitigate dominant harmonics from system. By doing FFT analysis THD is reduced up to IEEE standards and improve waveform nature.

VI. CONCLUSION

SVC successfully compensates the dynamical variation in reactive power and suppresses dominant harmonics which is presented in different operating condition in steel plants. The variation of reactive power by varying firing angle is studied with the help of control scheme of SVC. The range of reactive power control can be increased by using the combination of thyristor-controlled reactor and fixed capacitor banks. It is also observed that harmonics can be mitigated by the combination of fixed capacitor and series inductor passive filter tuned with resonant frequency to provide low impedance path for dominant harmonics. In this paper, this LC passive filter effectively suppresses 5^{th} and 7^{th} order of harmonics. Therefore SVC with passive filter improves power quality of steel plant.

REFERENCES

1. M.H.J. Bollen, "Review-What is power quality?", Electric Power Systems Research, vol-66, PP-5-14, 2003
2. Ambra Sannino, Jan Svensson, Tomas Larsson, "Review-Power electronic solutions to power quality problems", science direct Electric Power Systems Research, Vol-66 PP:71-82, 2003
3. IEEE standard 519-1992, "IEEE Recommended practice and requirements for harmonic control in electrical power systems"
4. IEEE Std 141-1993, "IEEE Recommended practice for electric power distribution for industrial plants"
5. IEEE Std 1459-2002, "IEEE Recommended practice for measurement and limits of voltage fluctuations and associated light flickers on ac power systems.
6. Gaurav singh J. Rajput, "Use Of Facts Device For Improving Power Quality In Industry", International Journal of Electrical

Engineering & Technology, Volume 8, Issue 1, January-February 2017, pp. 38–44,

7. Gonzalez Damian A., McCall, John C. “Design of Filters to Reduce Harmonic Distortion in Industrial Power Systems,” IEEE Transactions on Industry Applications, vol. IA-23, pp.505-511, 1987
8. Özgül Salor, Burhan Gültekin, Serkan Buhan, Burak Boyrazo˘glu, Tolga ˙Inan, Tevhid Atalık, Adnan Açık, Alper Terciyanl, “Electrical Power Quality of Iron and Steel industry in Turkey”, IEEE transactions on industry applications, vol. 46, no. 1, February 2010.
9. Albrecht wolf, Manoharan Thamodharan, "Reactive power reduction in three-phase electric arc furnace", IEEE Transactions on industrial electronics, vo1.47, no.4, pp 729-33, Aug.
10. Samu Hosono, Masao Yano, Shunichi Yuya, Satoru Sueda, “Suppression and Measurement of arc furnace flicker with a large Static VAr Compensator”, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-98, No.6 Nov./Dec. 1979
11. Yi-Kuan Ke, Pei-Hwa Huang and Ta-Hsiu Tseng, “Performance Measurement of Static Var Compensators in Distribution System’’, SICE Annual Conference, Taiwan. Vol.2, No. 6. 21 August 2010.
12. Thomas J. Dionis, Sam Morell, Thomas L. Mank, “Installation, Startup and Performance of a Static VAr Compensator for an Electric Arc Furnace Upgrade”, IEEE Transactions on Industry Applications, July 2017
13. Miller T.J. Reactive Power Control in Electric Systems. John Willey & Sons: New York, 1982
14. H. Samet and M. Parniani, “Predictive method for improving SVC speed in electric arc furnace compensation,” IEEE Trans. Power Del., vol. 22, no. 1, pp. 732–734, Jan. 2007.