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Impact of Static VAR Compensator in Stability and Harmonics Mitigation for Real Time System with Cogeneration

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Abstract

Main objective of the paper is to study the impact of SVC on stability and enhancing the power quality for a real time industrial system. Modified RK method is used for transient stability analysis and detailed frequency modeling is used for harmonic analysis. Real time system of 3.5 MTPA Steel plant at Raichur in Karnaraka, India with Electric Arc Furnace and Laddle Refining Furnace are considered for study. ETAP 12.6 software is used to simulate both transients and harmonic analysis. Harmonic study is performed with sinusoidal source non linear loads and Non sinusioidal source non linear loads. SVC performance when the non sinusoidal source is also verified to have the practical meaning. For Transient stability enhancement the controller tuning fault at 11V and 33KV bus is verified.

Keywords: Non-sinusoidal Source, Power Quality, SVC, Transient Stability Enhancement

1. Introduction

Cogeneration in process industries are becoming more and more popular because of better energy efficiency, cheaper power generation, better reliability of power etc. However this cogeneration also posses many drawbacks to power system engineer in-terms of steady state and transient state operations. Transient stability is one such very important parameter which has to be considered while designing cogeneration power plants[1,2]. Arc furnaces and variable frequency drives are quite common in these process industries which collapse the power system voltage and current wave shape[3]. Conventionally filters are used to eliminate or minimize the harmonic. However the transient stability of the cogeneration is still a concern. This Paper discusses the application of SVC to improve the transient stability while mitigating the harmonics.

Facts devices are power electronics based device that provides control of one or more transmission system parameters such as terminal bus voltage and relative phase angle between transmission line ends[4,5]. SVC typically consists of TCR (Thyristor Controlled Reactor), a TCS (Thyristor Switched Capacitor). This configuration can be tuned to minimize the losses at the most operating point. Transient stability evaluation focuses on the reactive power flow of the power system in response to a fault[6–10]. In transient stability prediction, the progress of the power system transient due to occurrence of disturbance is to be monitored. The key factor in transient stability prediction is based on the convergence and divergence of transient swings[11].

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The problem is formulated as the insertion of SVC in real time system that is to be analyzed using ETAP simulation software for enhancing the transient stability, SVCs, with an auxiliary injection of a suitable signal, can significantly improve the dynamic stability and performance of a power system. Reference[12] presented the fundamental analysis of the application of SVC for enhancing the power system stability. Also, the enhancement of low frequency oscillation damping via SVC has been analyzed[13–16]. The SVC enhances the system damping of local as well as inter-area oscillation modes. New Algorithm is introduced for voltage control for multi machine system is described[27]. Reference[17] studied the nonlinear model interaction in stressed power systems with multiple SVC voltage support. Harmony search algorithm is developed for SVC controller tuning[28]. It is observed that SVC controller can significantly influence nonlinear system behavior especially under high-stress operating conditions[18–20]. The general representation of SVC is represented in the Figure 1[21].

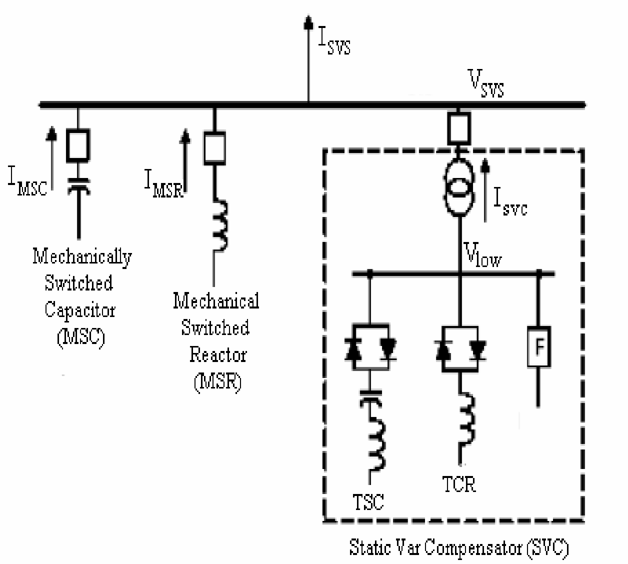

Figure 1. SVC employing TSC and TCR.

2. System Description

This paper considers a 5 MTPA real time steel plant in India for transient stability analysis. Considering the demand of more than 30 MW, the system is fed by a 220 kV grid supplied by state electricity board. 220 kV system voltage is step down to a 110 kV by using 2 x 100 MVA, 220/110 kV step down transformer. 110 kV overhead transmission line with ACSR conductor length of 3 kms is used to transfer the power to the steel industry. Main and transfer bus scheme is used in 110 kV substation. Major loads in the industry are Electric Arc Furnace (EAF), Ladle Refining Furnace (LRF), Rolling mill are connected at 33 kV and it is derived from the 110 kV bus through 35 MVA, 110/33 kV transformer. Since arc furnace is connected at 33 kV, there exists a huge harmonics. To reduce the Total Harmonic Distortion (THD) at point of common coupling PCC, single tuned passive filters are used.

35 MW cogeneration is also available to meet the industrial demand. Some of the auxiliary loads are connected in the 11kV bus. For power factor improvement, Capacitor with Automatic Power Factor Corrected equipment (APFC) is used. This real time system is modeled using ETAP simulation software and the corresponding single line diagram is shown in Figure 11.

3. Modeling of SVC

The SVC improves the system damping of local as well as inter-area oscillation modes. SVC model shown in Figure 2 used to improve the transient stability of the real time system considered, has been modeled in ETAP[22–25].

4. Modeling of Real Time System

The generator is connected to the transformer of 40/45 MVA, 110/11 kV, ONAN/ONAF with 12.5 percent impedance on its own base. This transformer has an OLTC with 17 taps (-15% to 7.5%). Major loads like Electric Arc Furnace (EAF), Ladle Refining Furnace (LRF) and Rolling mill are highly fluctuating in nature and hence considered with one dedicated transformer of 35/40 MVA, 110/33 kV, ONAN/ONAF with 10% impedance on 40 MVA base. This transformer has an OCTC with 9 taps (-15% to 5%).

Other additional auxiliary supply for process, power plant, lighting loads and small power loads are grouped together and fed from 11 kV via 15 MVA, 110/11 kV, ONAN with 10% impedance on its own base. This transformer also has an OCTC with 9 taps (-15% to 5%). The system uses 220 kV, 110 kV, 33 kV, 11 kV, 6.6 kV and 415 V systems for the efficient operation. Generator data (X_q'', X_d, T_{do}', H) considered is given in Table 1.

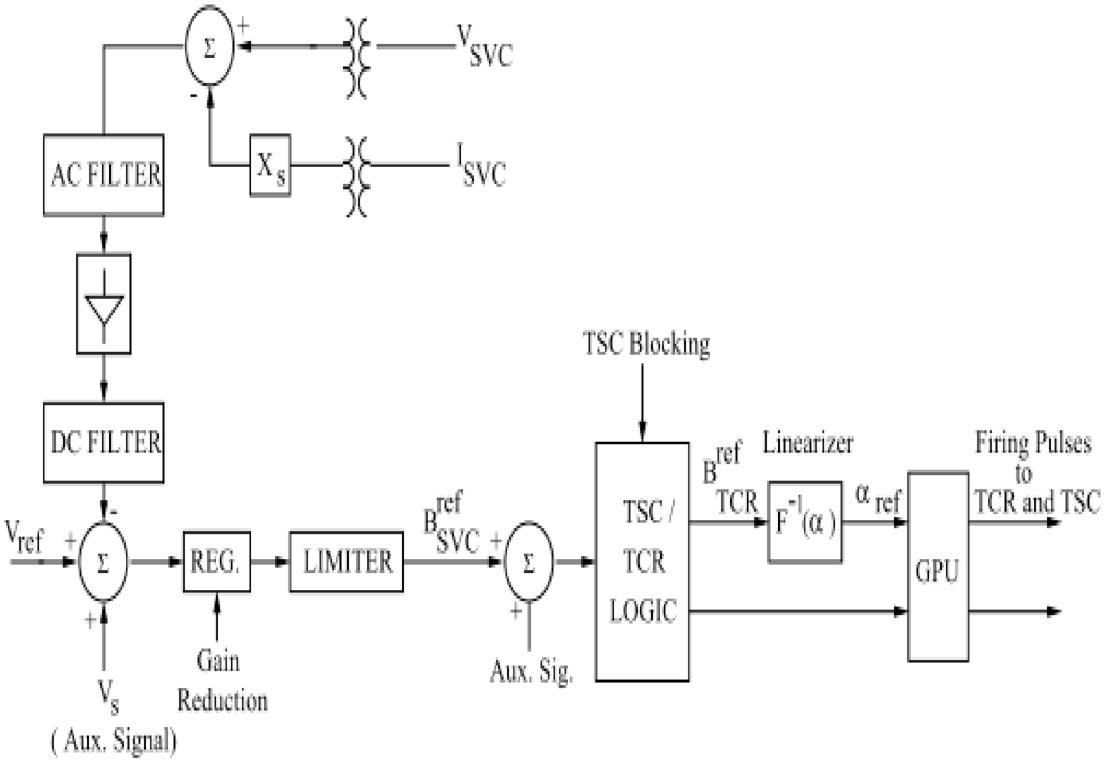

Figure 2. Modelling of SVC.

Table 1. 35 MW Generator Parameters

Variable	Description	Data
	MVA rating	43.75
	MW rating	35
	Rated voltage in kV	11
R_a	Armature resistance in p.u.	0.004593
X_2	Negative sequence reactance in p.u.	0.149
X_0	Zero sequence reactance in p.u.	0.066
X_d	Direct axis reactance in p.u.	2.036
X_d'	Direct axis transient reactance in p.u.	0.237
X_d''	Direct axis sub - transient reactance in p.u.	0.185
X_q	Quadrature axis reactance in p.u.	1.8

Variable	Description	Data
X_q'	Quadrature axis transient reactance in p.u.	0.33
X_q"	Quadrature axis sub – transient reactance in p.u.	0.1678
T_{do}'	Direct axis open circuit transient time constant in p.u.	4.902
T_{do}"	Direct axis open circuit sub – transient time constant in p.u.	0.017
T_{qo}'	Quadrature axis open circuit transient time constant in p.u.	0.533
T_{qo}"	Quadrature axis open circuit sub – transient time constant in p.u.	0.1
H	Inertia constant (Generator + Exciter)	3
	Winding connection	Y grounded through NGT

Transformer data (rated MVA, rated HV/LV voltage, % impedance) considered is given in Table 2.

Table 2. Transformer Data

Rated MVA	Rated HV/LV	% impedance
100	220/110	10
40	110/33	10
45	11/110	12.5
6.3	11/6.6	7.15
15	110/11	10
1.25	11/0.433	6
3	11/0.433	6
0.5	11/0.433	6
6.3	11/6.9	6
0.315	11/0.433	6

Detailed system modeling is of prime importance for carrying out any system study. The block diagrams of Automatic Voltage Regulator (AVR) shown in Figure 3 have been modeled using ETAP for 35 MW generator. The parameter related to the TG and AVR are listed in Table 3 and 4 respectively. The modeling of real time system is represented in Figure 11.

Modeling of Turbine Governor data considered for analysis is given in Table 3.

Table 3. Turbine Governor Data for 35 MW Generator

Variable	Description	Data
σ	Droop	0.05
Pmax	Maximum power limit	1.0
Pmin	Minimum power limit	0.1
Cmax	Rate of valve opening	0.1
Cmin	Rate of valve closing	-1.0
T1	Phase compensation 1	0.1
T2	Phase compensation 2	0.3
T3	Servo time constant	0.4
Thp	HP section time constant	0.26

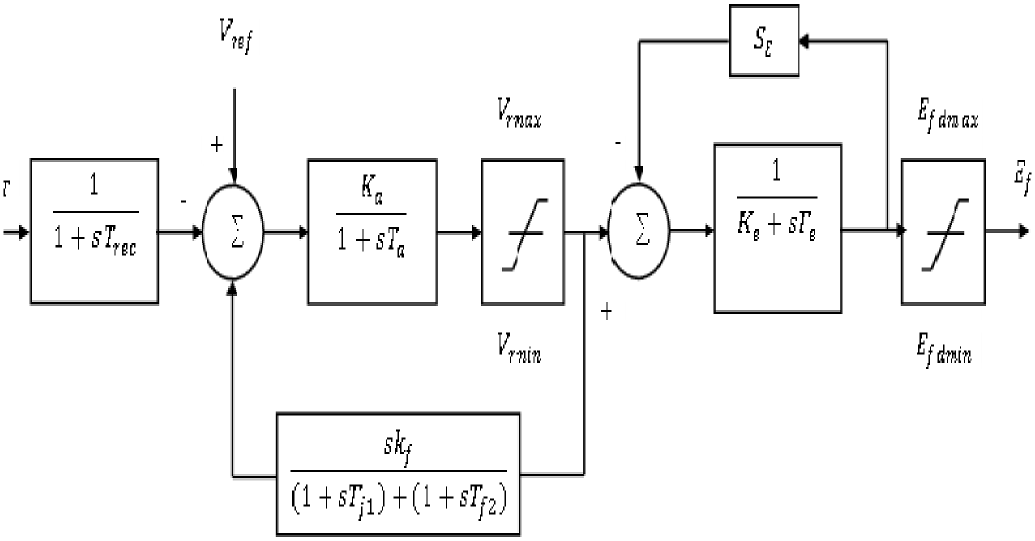

Figure 3. Block diagram of AVR for 35 MW Generator.

Table 4. AVR Data for 35 MW Generator

Variable	Description	Data
T_{rec}	Input rectifier time constant in s	0.02
T_a	Amplifier time constant in s	0.02
T_e	Exciter time constant in s	0.6
T_{f1}	Regulator stabilizing circuit time constant1in s	1.0
T_{f2}	Regulator stabilizing circuit time constant2 in s	0.1
k_a	Amplifier gain	100
k_e	Exciter gain	1.0
K_f	Regulator stabilizing circuit gain	0.01
V_{se1}	Saturation function at 0.75 times maximum field voltage	0.4
V_{se2}	Saturation function at maximum field voltage	0.7
V_{rmax}	Maximum amplifier voltage	4.3
V_{rmin}	Minimum amplifier voltage	-4.3
Ef_{dmax}	Maximum field voltage	4.3
Ef_{dmin}	Minimum field voltage	0

5. Studies Performed

Load flow analysis is needed to initialize the power system so that further transient study can be carried out. Various cases of load flow analysis, Grid Nominal Voltage, Maximum and Minimum Grid Voltage and Peak Demand, Average Demand and minimum demand are studied. Voltage profile, Losses, Equipment loading are compared for all the cases. Studies are repeated after including SVC.

Transient stability study has been carried out based on the initial condition obtained using load flow analysis. The details of SC studies considered for analysis is given in Table 5.

Table 5. Details of SC Studies

System studies	Without SVC	With SVC
Three phase fault	33 kV bus	33 kV bus
	11 kV bus	11 kV bus
Single phase fault	33 kV bus	33 kV bus
	11 kV bus	11 kV bus

Critical clearing time is the comparative parameter for three phase faults and rotor angle oscillation is comparative parameter single phase fault. The ETAP software is used to simulate the real time system yield validated results.

THD is sum of ratio of all harmonic frequency except fundamental to fundamental frequency. Voltage harmonic distortion is sum of ratio of all voltage harmonic frequency except fundamental to fundamental voltage frequency.

THD for voltage is given by equation (1).

$$\%V_{THD} = \frac{\sum_{h=2}^{n} \sqrt{V_h}^2}{V_1} \times 100\% \quad (1)$$

Current harmonic distortion is the sum of ratio of all current harmonic frequency to fundamental current frequency.

THD for current is given by equation (2).

$$\%I_{THD} = \frac{\sum_{h=2}^{n} \sqrt{I_h}^2}{I_1} \times 100\% \quad (2)$$

6. Simulation Result

To simulate the real time system, models have been developed for each element and implemented in the dedicated power system simulation tool ETAP which provides the ability to simulate load flow study, short circuit study, Harmonic study and transient events in the same software environment. The ETAP simulation tool therefore has a dedicated model for generators which take into account, the current displacement in the rotor, slip and short circuit analysis curves. Also models of synchronous machines, transformers, bus bars, grid models, transmission lines etc are provided.

6.1 Transient Analysis

6.1.1 Without SVC

Without SVC, the three phase fault occur in the 33 kV bus, the critical clearing time of the system is analyzed and the Figure 4 shows the stability of the system for the critical clearing time of the system is 357 ms. When the time exceeds the 357 ms the system move to unstable operation is described in the Figure 5.

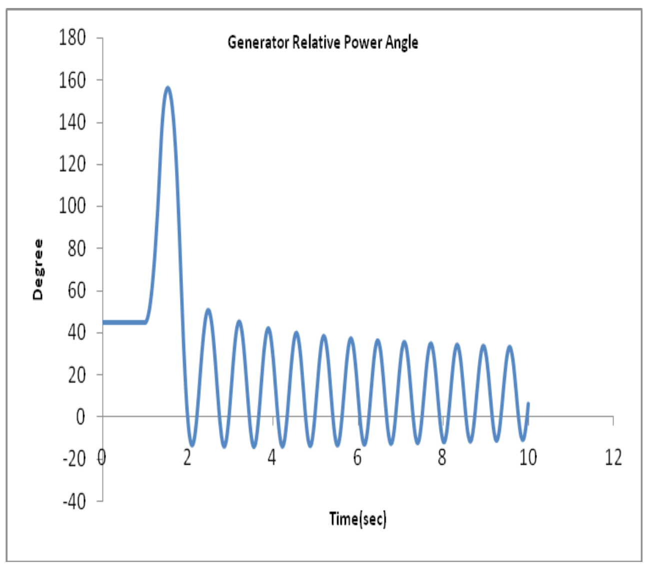

Figure 4. Power angle curve for the generator without svc.

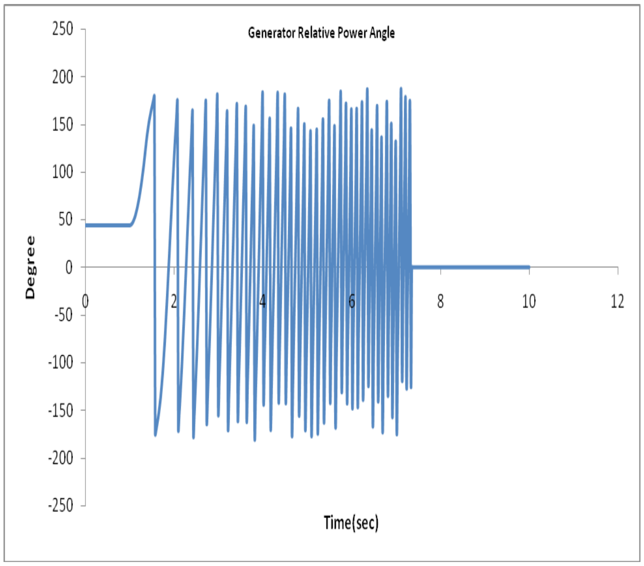

Figure 5. Unstable operation of the system without svc.

6.1.2 With SVC

The SVC is placed at 33 kV bus and fault is created at the 11 kV bus and 33 kV bus and the simulation results were produced here. SVC at 33 kV bus slightly improves the transient stability by reducing the oscillation represents in the Figure 6. The ability of the SVC at 33 kV bus significantly contributes the reactive power and improve the voltage profile of the 110 kV, 33 kV and 11 kV bus as well as improves the stability of the system respectively. The critical clearing time of the system is increased while SVC is connected.

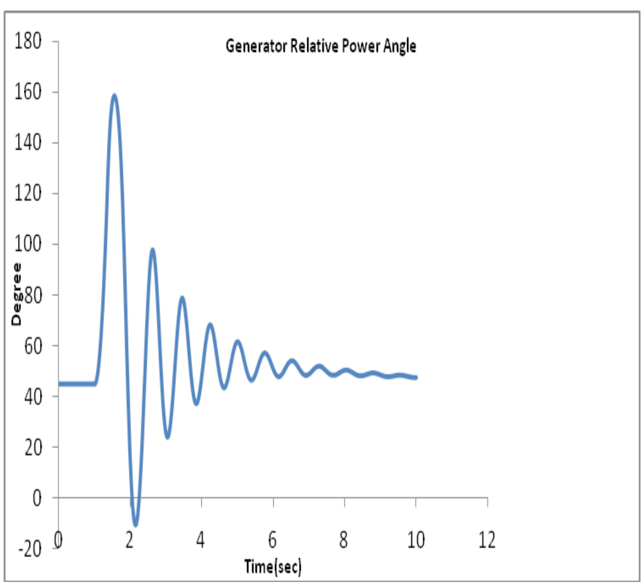

Figure 6. Swing curve of the generator.

The impact of the SVC in the system for three phase fault is, the critical clearing time is increased but in the single phase fault the oscillation of the swing curve is reduced is represented in Figure 7 & 8. The impact of the SVC in the stability of the system is represented in Table 6.

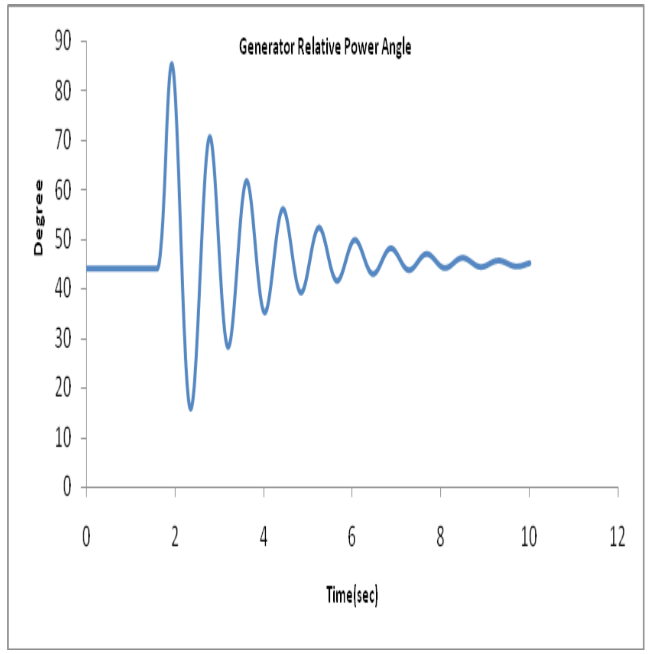

Figure 7. Swing curve of the generator without SVC.

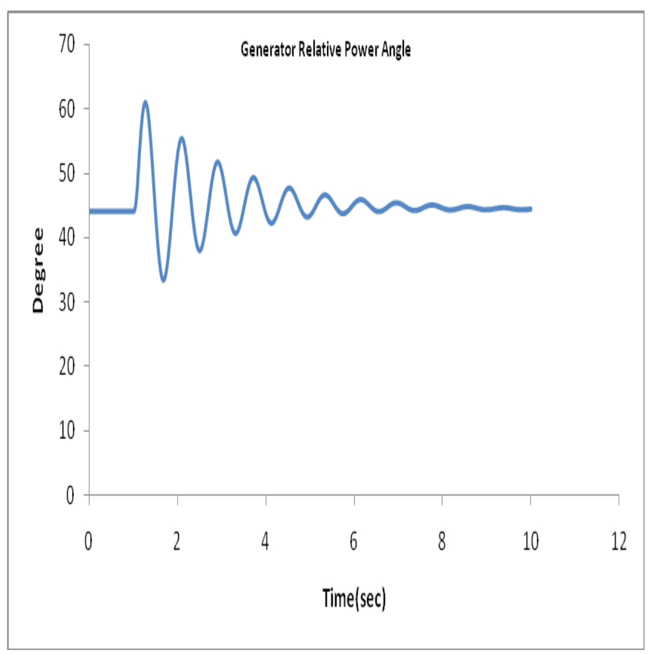

Figure 8. Swing curve of the generator with SVC.

Table 6. Impact of SVC in Stability of the System

System studies	Without SVC	With SVC
Three phase fault	33 kV bus (355 ms)	33 kV bus (357 ms)
	11 kV bus (359 ms)	11 kV bus (361 ms)
Single phase fault	33 kV bus Maximum Rotor angle - 110	33 kV bus Maximum Rotor angle - 62
	11 kV bus Maximum Rotor angle - 88	11 kV bus Maximum Rotor angle - 52

6.2 Harmonic Analysis

IEEE standard 519-1992, IEEE suggested Practices and a necessity for Harmonic Control in Electrical Power Systems gives the level of voltage harmonics in the Point of Common Coupling (PCC), as per this standard we limit the harmonics at PCC.

When the EAF and LAF presents in the real time system are switched on, it injects the harmonics to the supply; hence supply is affected due to this injected harmonics in PCC.

Here SVC is modeled and placed at the point of common coupling, by running the simulation the THD is limited to 2.37 percent which is lower than the THD limit recommended by IEEE standard 519. Figure 9 represents the voltage at PCC without SVC. Figure 10 represents the power quality improvement with the presence of SVC.

6.2.1 Without SVC

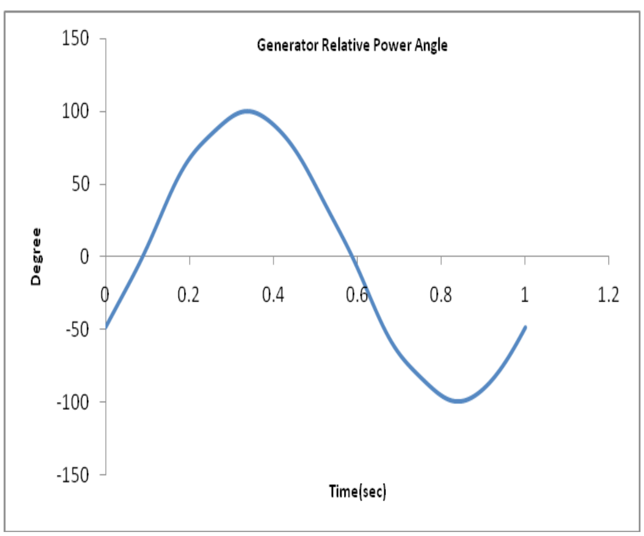

Figure 9. Voltage waveform of the Bus-1 without SVC.

6.2.2 With SVC

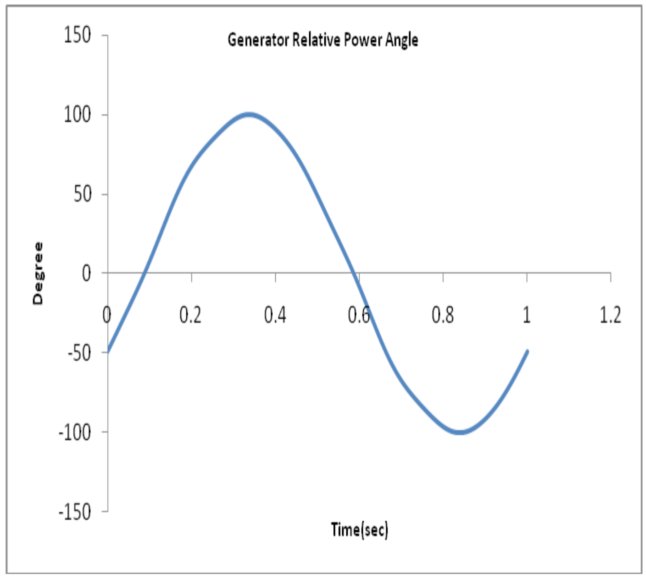

Figure 10. Voltage waveform of the Bus-1 with SVC.

With SVC & Without SVC comparison of is given in Table 7.

Table 7. Comparison results of THD with and without SVC

Bus	WithOUT SVC	With SVC
Bus-1	3.97 THD	2.53 THD
BUS-18	18.56	10.17

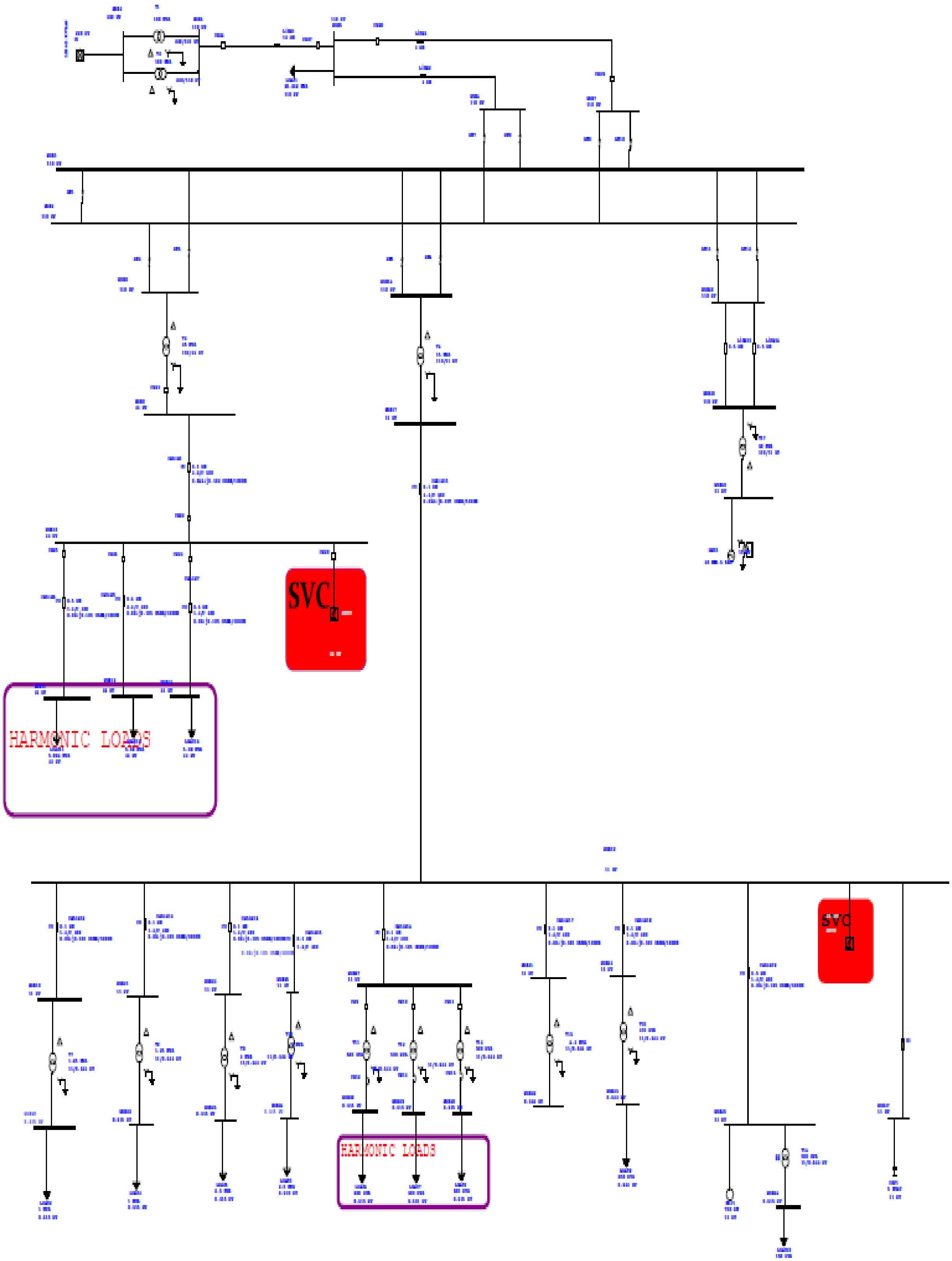

Figure 11. Single line diagram of industrial power system.

7. Conclusion

Modeling of real time system with SVC is presented. SVC is modeled using ETAP for enhancing the transient stability of the system. From the transient stability analysis, SVC at 33 kV Bus improves the voltage profile of the real time system for the three phase fault and single line to ground fault. SVC also suppresses the harmonics and reduces the THD at PCC below IEEE 519 limits. SVC improves the transient stability for three phase faults by improving the critical clearing time and reduces the oscillation for single line to ground fault.

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