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Damping Power System Oscillations with Controller using STATCOM

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Abstract

The paper presented here outlines an approach to design a damping controller, which is used for providing the pulses to the gates of the energy storage based type static synchronous compensator (STATCOM). The energy storage type STATCOM is one of the A.C. transmission system devices, which are also known as FACTS devices. It is an advanced flexible device, which controls the injection and absorption of both active and reactive power to the power system. Integrating an energy storage system into a FACTS device helps to provide much-needed flexibility for mitigating transmission-level power flow problems. It also provides a better power oscillations damping. The control strategy is carried out using a proportional-integral controller. The desired model is implemented in MATLAB Simulink using a sim power system toolbox. Power oscillations are introduced in the power system, and their effects on the power system generator's and load's current-voltage with and without the use of STATCOM are shown in the Simulink waveform. The simulation results and waveforms are used to verify the effectivity of the proposed control method to provide power oscillation damping.

Keywords - *Static synchronous compensator (STATCOM), energy storage, power oscillation damping (POD), flexible ac transmission devices (FACTS).*

I. INTRODUCTION

Power systems may become increasingly vulnerable with the growing complexity of power grid interconnections to the low-frequency oscillations[1],[4]. Power systems are being forced to operate at or closer to their stability limits. This trend is caused as the electrical energy demand is increasing day by day enormously. On the other hand, investment installed in transmission infrastructure and energy market deregulation is limited[2]. The emergence or worsening of low-frequency oscillations is one of the manifestations of this stability reduction[3],[4]. A noticeable increase in the number of events involving these oscillations is reported by some power systems[4]. Generally, these power system oscillations are mitigated or eliminated or damped by using power system stabilizers (PSS)[1],[8]. The stabilizer injects a supplementary signal to the excitation system of the synchronous generator to which it is connected[1],[3],[4]. This supplemental signal is generated using only local measurements. This method limits its effectiveness for system-wide damping control. Therefore, to achieve the damping control of power system oscillations without losing power system stability, another approach is needed.

In power transmission systems that are heavily bulk according to the present scenario, power electronics-based controllers are frequently used. They are called Flexible AC Transmission System (FACTS) devices[1],[2],[3],[4]. These flexible networks provide help to delay or at least minimize the need to build more transmission lines and power plants. This step taken by fact devices enables neighbouring utilities and regions to exchange power economically and reliably and supply adequate power to the consumers. These devices can be shunt connected or series connected[6],[8]. STATCOM is one of the shunts connected FACTS devices. The circuit diagram of STATCOM and its working principle is further explained in this paper.

The simulation model of the proposed project is implemented by making use of a transmission line system, two machine models and a STATCOM controller. MATLAB version R2015a is used for modelling the system. Simulation is performed, and various waveforms of the power system, load, and compensator are obtained.

II. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

The static synchronous compensator, also known as STATCOM, is a shunt connected FACTS device[1],[7]. The tool generates a balanced set of three-phase sinusoidal voltages at the fundamental frequency along with a rapidly controllable amplitude and phase angle. Various topologies can be used to implement it[1],[5].

When the power system dynamic stability is considered, the STATCOM provides better damping characteristics than the SVC[7],[8]. The reason behind this is that STATCOM can transiently exchange active power with the power system[1],[7].

STATCOM functions as a shunt-connected synchronous voltage source with the facility of converter-based var generation[1],[7],[8]. If STATCOM is equipped with an energy storage element at its dc terminal, it possesses an ability to exchange real power from the system[2]. In other words, it can absorb as well as total supply management as well as reactive power in an appropriate amount by equipping it with energy storage[1],[2].

A schematic diagram of the STATCOM is shown in figure 1.

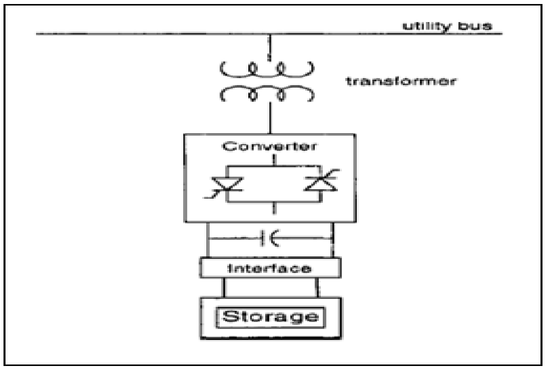

Fig.1: Schematic diagram of STATCOM

It can be seen from the figure that STATCOM is connected to the utility bus, i.e., ac system through a transformer [5],[6]. The transformer acts as a coupling medium. The STATCOM is connected to a dc-link capacitor[2]. D.C. Capacitor is used to supply constant D.C. voltage to the voltage source converter. It is further connected to energy storage via an interface like a chopper for the exchange of active power[2].

III. PRINCIPLE OF OPERATION OF STATCOM

This is now to understand how the STATCOM works. As can be seen from the figure above, source V1 represents the output voltage of the STATCOM. In case of reactive power demand increases in the power system, STATCOM increases its output voltage V1 while maintaining the phase difference between V1 and V2 to zero (it shall be noted here that there always exist a small phase angle between V1 and V2 to cater for the leakage impedance drop in the interconnecting transformer) [1],[4],[7]. As for V1 > V2, reactive power flows from STATCOM to the power system. Thus STATCOM, supplies reactive power and acts as a reactive power generator.

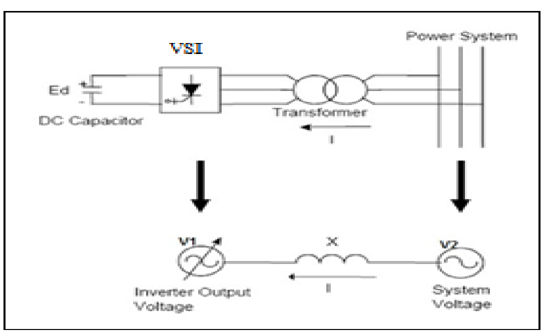

Fig.2: Operating principle of STATCOM

Again, if the voltage of the power system increases due to load thrown off, STATCOM reduces its output voltage V1 and, therefore, absorbs reactive power to stabilize the voltage to average value[5]. The above mode of Operation of STATCOM is called Voltage Regulation Mode[5]. But as we know, every equipment has its limitations, so STATCOM must also have some limitation of supplying or absorbing reactive power. Yes, there exists a limitation, and this limitation is imposed by the current carrying capacity of force commutated devices like IGBT, GTO. [4]. Therefore, if the Operation of STATCOM reaches its limitation, it does not further increase or decreases its output voltage V1 somewhat; it supplies or absorbs fixed reactive power equal to its limiting value at a fixed voltage and current and acts as a constant current source. This mode of Operation of STATCOM is called VAR Control Mode[2],[3]. Thus from the above discussion, it is concluded that the Operation of STATCOM can be classified into two modes[7]:

1) Voltage Regulation Mode
2) VAR Control Mode

Figure 3 below well explains the above two modes of Operation of STATCOM.

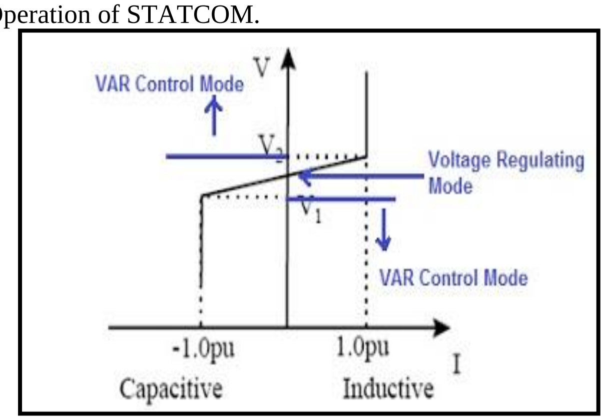

Fig.3: Capacitive and inductive mode of Operation of STATCOM

The integration of energy storage allows the STATCOM to inject and/or absorb active and reactive power simultaneously[3]. Because of this facility, STATCOM provides additional benefits and improvements in the system.

IV. PULSE WIDTH MODULATION

A modulation technique used to encode a message into a pulsing signal is the pulse-width modulation (PWM) technique. This modulation technique can be used to encode information for transmission. However, its primary use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors[9],[10].

The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is compared to the off periods, the higher the total power supplied to the load[9],[13]. Duty Cycle is a measure or duration of when the modulated signal is in its "high" state. It is generally expressed as the percentage of the signal period where the signal is considered on[13].

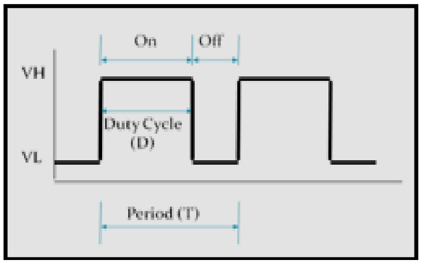

Fig.4: Waveform showing duty cycle with ON and OFF period

The switching frequency of PWM has to be much higher than what would affect the load, i.e. the device that uses the power, which is to say that the resultant waveform perceived by the load must be as smooth as possible[9],[10],[15]. The rate or frequency at which the power supply must switch can vary greatly depending on load and application.

The carrier-based PWM (sine-triangle PWM or SPWM) techniques and the space vector based PWM techniques are the two PWM schemes for multi-level inverters which are used on a large scale [13],[15].

In sinusoidal pulse width modulation (SPWM), the technique, two signals, one of them is modulating, and the other is carrier signal, are compared[9]. The Modulating signal is a reference signal which is taken as sinusoidal, and the other signal, which is carrier wave, is triangular. Gating pulses are produced by comparing the two signals mentioned above, and the width of each pulse is varied in proportion to the amplitude of the sinusoidal wave[10],[11]. The inverter output frequency is determined by the frequency of the reference signal[11]. The reference peak amplitude handles the control of the modulation index and the root mean square (RMS) value of the output voltage[15].

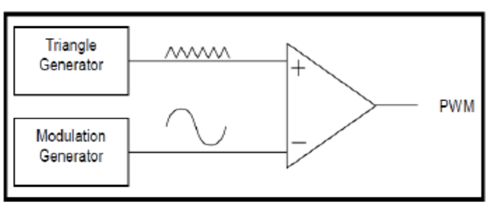

Fig.5: Block Diagram of SPWM Technique

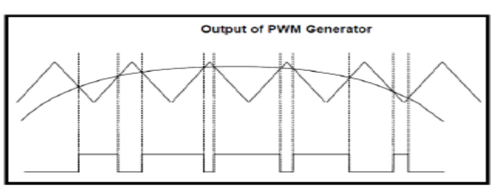

Fig.6: Output of SPWM Generator

Space vector modulation is a PWM control algorithm which we call space vector pulse width modulation. It is used for multi-phase A.C. generation. In this technique, the reference signal is sampled regularly[10]. After each sample, for the appropriate fraction of the sampling period, non-zero active switching vectors adjacent to the reference vector and one or more of the zero switching vectors are selected. This is done to synthesize the reference signal, i.e. sinusoidal signal, as the average of the used vectors[10],[13].

A three-phase VSI generates eight switching states. Out of these eight switching states, six states are active, and two are zero states. These vectors form a hexagon, as shown in figure 7[11],[13]**.** It can be seen from the figure that it consists of six sectors spanning 60° each. The reference vector represents the three-phase sinusoidal voltage. It is generated using SVPWM by switching between two nearest active vectors and zero vector[13].

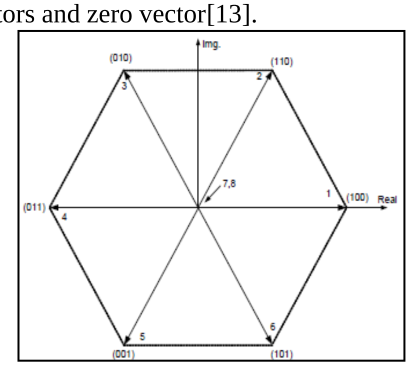

Fig.7: Phase voltage space vectors

V. MATLAB SIMULATION MODEL

A simulation model is designed in MATLAB version R2015a for analyzing the working of STATCOM with energy storage whose gate pulses are controlled by a proportional-integral controller using space vector pulse width modulation technique. It is shown in the following figure 8.

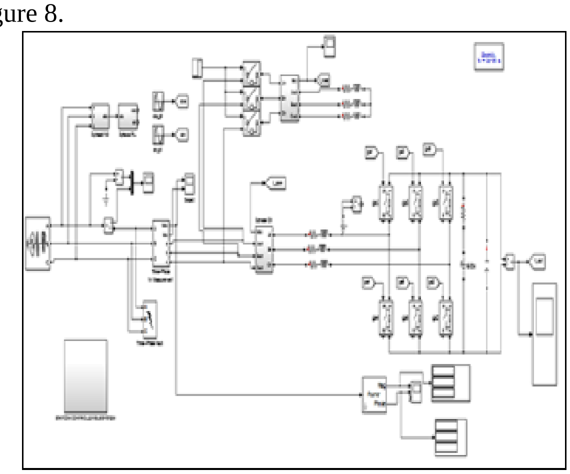

Fig.8: MATLAB simulation model of STATCOM with energy storage for damping power system oscillations

The specification of various parameters of the different MATLAB Simulink library blocks used in the model are listed as follow:

1) Three-phase source:-

A three-phase source of 200 KVA ratings is internally connected in star with the ground. It has the specification of the following parameters:

Phase to phase rms voltage = 240*√3 V;

Frequency = 50 Hz;

Three-phase short circuit level at a base voltage (V.A.) = 200 KVA;

Base voltage = 240*√3 V;

X/R Ratio = 7.

2) Three-phase fault:-

A 3 phase fault is introduced in between the source voltage and the STATCOM. Fault can be of any type, such as L.G., L.L., LLG, LLL. It has the following specifications :

Fault resistance = 0.001 ohm;

Transition time = Fault start time 0.4 sec and fault end time 0.6 sec ;

Snubber resistance = 1 MOhm.

3) Breaker (1 phase):-

Circuit breakers are incorporated in the model. Specifications are as follow:

Breaker resistance = 0.01 ohm;

The initial state of breaker = Open;

Closing time = 0.2 sec;

Snubber resistance = 1 MOhm.

4) Series RLC load :-

One star connected RLC load is conncted to the power system. It has following specifications :

Resistance = 12.218 ohm ;

Inductance = 0.038889 H ;

Capacitance = 1 microFarad .

5) Ideal switch:-

It is controlled by a gate signal parallel with a series R.C. snubber circuit.

Initial resistance = 0.001 ohm ;

Initial state of switch = open ;

snubber resistance = 0.1 MOhm .

The controller block in the model is a subsystem consisting of a current reference generator, P.I. controller and two-level space vector pulse width modulation. This subsystem is shown in figure 9.

Various blocks of controller subsystem are given below:

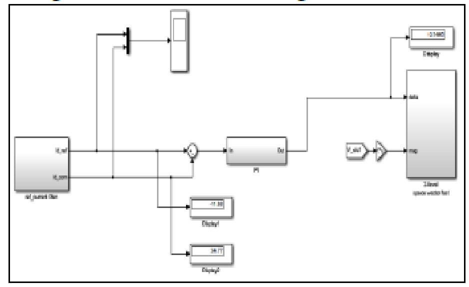

Fig.9: Controller subsystem

1)Reference current generator:- It has two subsystems blocks of load current and compensator current again. Load current and compensator current ABC components are converted into stationary q-d axis components, which are further converted into revolving QE-de axis components. It is shown in figure 10.

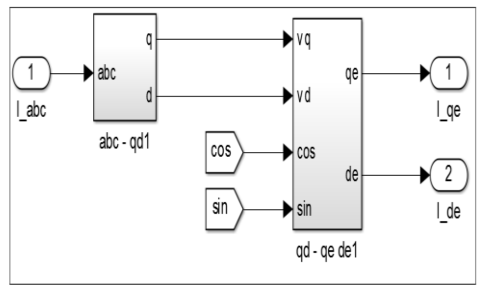

Fig.10: Reference current generator block

2) P.I. controller: - The proportional-integral controller has one input and one output. Its block diagram is shown in figure 11.

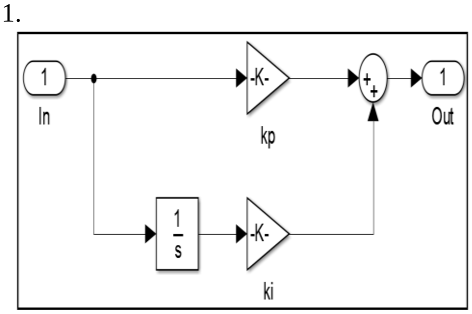

Fig.11: P.I. controller block

The d-axis components of load current and compensator current are compared, and the result is given as input to the P.I. controller. This controller has a proportional gain of Kp = 0.0005 and an integral gain of Ki = 0.005. Input is multiplied by gain Kp and 1/s times gain Ki, and both are added. The result gives the output of the P.I. controller.

3) Two-level space vector subsystem:- Figure 12

Shows the subsystem for two level space vector pulse width modulation. This block makes various calculations for giving pulses to the gates of the STATCOM for its desired Operation.

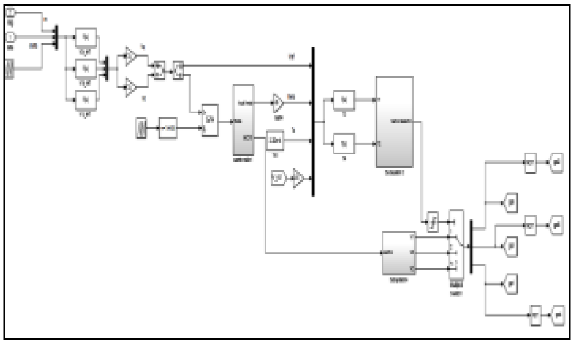

Fig.12: Two-level space vector subsystem

4) Sector selector subsystem:- As the name suggests, this subsystem performs operations for selecting a particular sector in which the reference voltage vector operate. Diagram for the same is shown in figure 13.

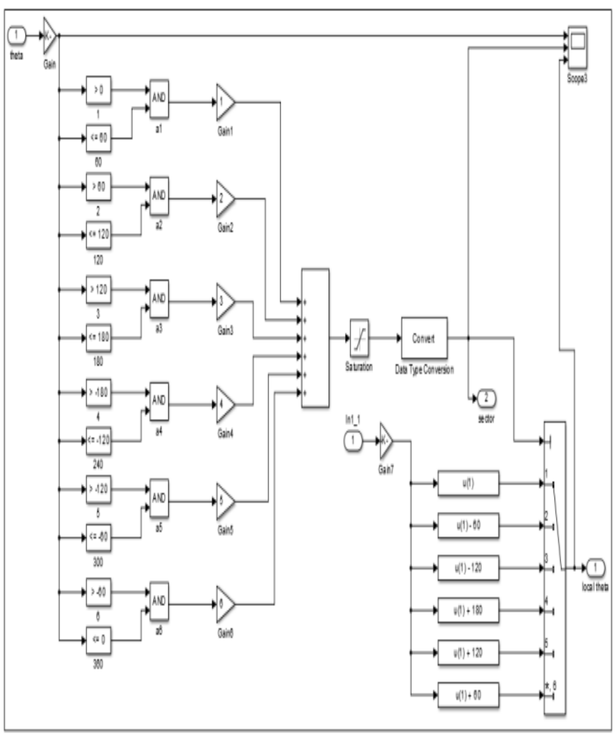

Fig.13: Sector selector subsystem

5) Multiport switch subsystem:- It is another subsystem of the two-level space vector pulse width modulation. It consists of a multiport switch. It determines which of several inputs to the block passes to the output. The block bases this decision on the value of the first input. The first input is the control input, and the remaining inputs are the data inputs. The value of the control input determines which data input passes to the output. It is shown in following figure 14.

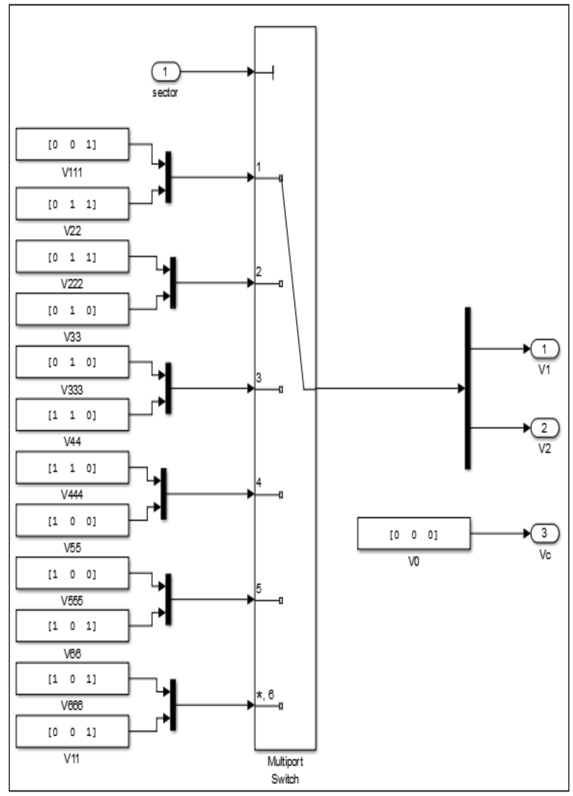

Fig.14: Multiport switch subsystem

VI. MATLAB SIMULATION RESULTS

Star connected inductive and capacitive load is connected to the system at 0.2 seconds, and a line-to-ground L.G. fault is introduced in the system between phase “a” and ground at 0.4 seconds. The fault is cleared at 0.6 seconds. Various simulation waveforms are obtained as follow:

A. Results showing a system for Inductive Load during L.G. Fault condition

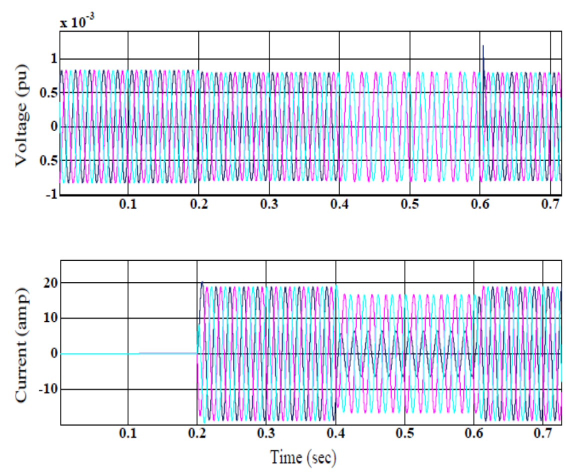

Fig.15: Power system three-phase voltage and current waveform during L.G. fault condition and inductive load without STATCOM

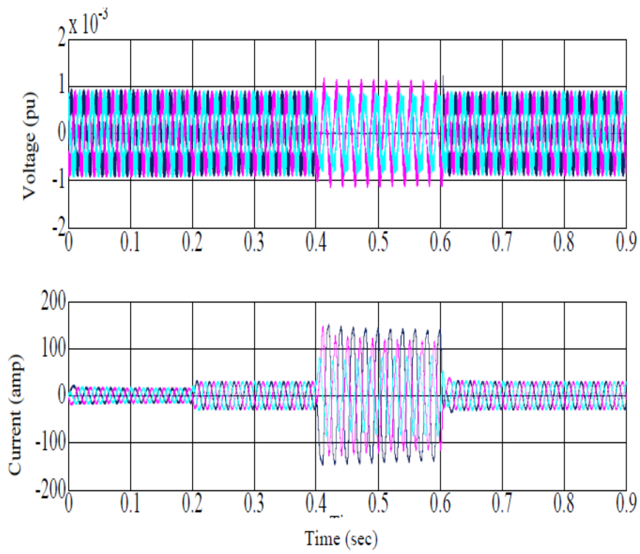

Fig.16: Power system three-phase voltages and current waveform during L.G. fault and inductive load on power system with energy storage device based STATCOM

Figure 15 shows the power system without STATCOM, where it can be observed that transient in voltage is there at time 0.6 seconds, which is removed by connecting STATCOM in the system, as shown in figure 16. The current in figure 15 was zero until 0.2 seconds at which load is connected in the system, whereas the current in figure 16 started flowing from the start.

B. Results showing a system for Capacitive Load during L.G. Fault condition

Similarly, waveforms for the capacitive load can be obtained as below.

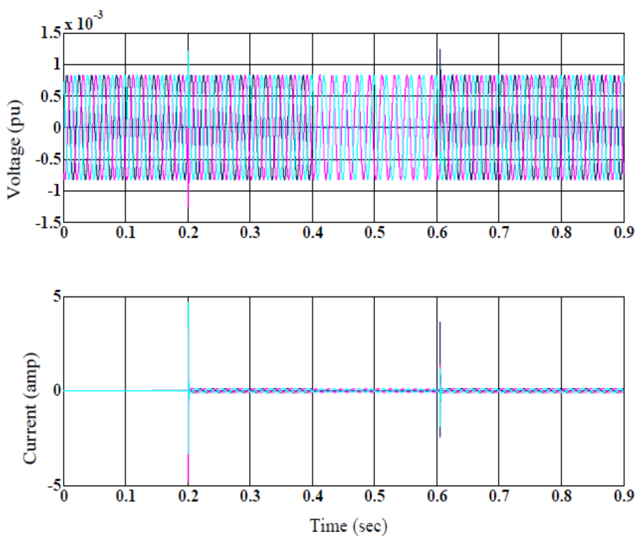

Fig.17: Power system three-phase voltage and current waveform during L.G. fault condition and capacitive load without STATCOM

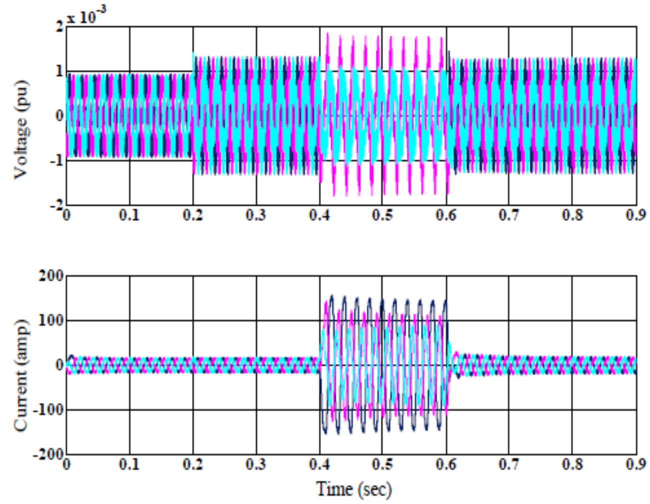

Fig.18: Power system three-phase voltages and current waveform during L.G. fault and capacitive load on power system with energy storage device based STATCOM

Thus, the above waveforms show that power oscillations can be damped out with the help of STATCOM.

VII. CONCLUSION

This paper deals with the adaptive view for designing a power oscillations damping controller using STATCOM. Simulation is carried out for conditions with and without the static synchronous compensator. Thus, the facts device is used to obtain smooth waveforms. In future, we can use several new technologies for controlling the pulses of STATCOM. Renewable energy sources can also be integrated with the device.

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