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Simulation and Modeling of 24-Pulse STATCOM in EMTDC/PSCAD Program in Order to Regulate Voltage and Dynamic Stability Improvement

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Abstract: This study starts from the proof of Low Frequency Oscillation (LFO) and then points out that there are many ways to study the LFO including its rejection measures. Also in this study one control system is planned in order to regulate voltage at common coupling point (PCC) in where STATCOM is installed. This research present a single-machine infinite-bus system with one static synchronous compensator (STATCOM) asymmetrically installed as a current source. Together with a classical generator model, the simplest power equation is obtained to give direct and clear physical concepts on synchronizing and damping torque factors. According to the primary equations, some basic issues, such as the relationship of voltage gain control and damping control, operating conditions, and the installation of STATCOM, are investigated in this research. Then, with assistance of proportional controller for voltage regulation and damp control, the digital simulation indicate the necessity of control of STATCOM in damping power system oscillations and supplying regulated voltage support.

Key words: Low Frequency Oscillation (LFO), power system, STATCOM, voltage regulation

INTRODUCTION

If one looked back the history of power system since its evolution, operation engineers faced with transient instability problem and researchers struggled to find counter measures to overcome it (Hochgraf and Lasseter, 1998; Schauder and Mehta, 1993) . Transient instability problem, considered as part of the phase angle related problem, is defined as the ability of power system to maintain synchronism when subjected to large disturbances. When the system faces large disturbances such as large load increase, loss of tie lines, loss of generating units, maintaining constant electrical speed among all the generators were challenging as some machines speed up while some other slow down to adjust to post disturbance situation (Reed *et al*., 2000). If there is no control mechanism to keep the speeding up or slowing down generators.

Within the allowable speed limits, there is a good chance that these generators would fall out of the grid by losing synchronism. Hence, fast exciter or Automatic Voltage Regulators (AVR) was introduced in the systems one of the remedial measures to solve the problem (Sensarma *et al*., 2001). The introduction of fast AVR was able to give the "coarse adjustment" to keep electrical speed of synchronous generators within the limits and successful in maintaining synchronism by controlling the first swing (Akagi and Fujita, 2007). However, the fast AVR could not do the "fine adjustment" to control oscillation in the speed. Then, Power System Stabilizer (PSS) was introduced in generator to give that fine adjustment to damp out power oscillations that are referred to as electromechanical or Low Frequency Oscillations (LFO) (Gutierrez *et al*., 2000). Fast load voltage regulation is required to compensate for time varying loads such as electric arc furnaces, fluctuating output power of wind generation systems, and transients on parallel connected loads (e.g., line start of induction motors). Reactive power compensation is commonly used for flicker mitigation and load voltage regulation. Due to their high control bandwidth, Static Compensators (STATCOMs) based on three phase pulse width modulated converters, have been proposed in Ref (Jintakosonwit *et al*., 2002; Inzunza and Akagi, 2005). For effecting fast control, the STATCOM is usually modeled using the dq axis theory for balanced three phase systems, which allows definition of instantaneous reactive current.

In this study simultaneously low frequency oscillation damping and regulation of output voltage of power system with considering STATCOM is analyzed and studied. PSCAD/EMTDC is implemented in order to simulate STATCOM with two control blocks for investigate the effect of STSTCOM on damping low frequency oscillations and regulation voltage.

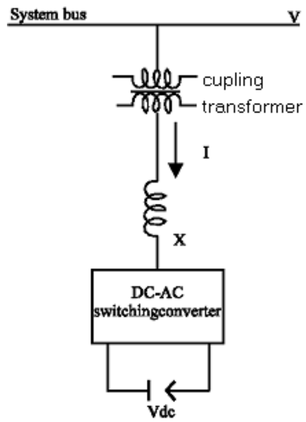

Fig. 1: Basic schematic of STATCOM

Low frequency oscillation: The ability of synchronous machines of an interconnected power system to remain synchronism after being subjected to a small disturbance is known as small signal stability that is subclass of phase angle related instability problem (Padiyar and Kulkarni, 1997). It depends on the ability to maintain equilibrium between electromagnetic and mechanical torques of each synchronous machine connected to power system. The change in electromagnetic torque of synchronous machine following a perturbation or disturbance can be resolved into two components:

- A synchronizing torque component in phase with rotor angle deviation
- A damping torque component in phase with speed deviation

Lack of sufficient synchronizing torque results in "aperiodic" or non-oscillatory instability, whereas lack of damping torque results in low frequency oscillations. Low frequency oscillations are generator rotor angle oscillations having a frequency between 0.1-2.0 Hz and are classified based on the source of the oscillation (Chen and Joos, 2000). The root cause of electrical power oscillations are the unbalance between power demand and available power at a period of time. In the earliest era of power system development, the power oscillations are almost non observable because generators are closely connected to loads, but nowadays, large demand of power to the farthest end of the system that forces to transmit huge power through a long transmission line, which results an increasing power oscillation (Ogata, 1997; Lehn and Iravani, 1998). The phenomenon involves mechanical oscillation of the rotor phase angle with respective to a rotating frame. Increasing and decreasing phase angle with a low frequency will be reflected in power transferred from a synchronous machine as phase angle is strong coupled to power transferred. The LFO can be classified as local and inter-area mode. Local modes are associated with the swinging of units at a generating station with respect to the rest of the power system (Moreno *et al*., 2002). Oscillations occurred only to the small part of the power system. Typically, the frequency range is 1-2 Hz.

24-pulse converter and the basic control of the STATCOM: Figure 1 shows the STATCOM connection to a utility bus. The GTO inverter shown in the figure consists of several six step voltage sourced inverters. These inverters are connected by means of a multi-winding transformer to a bus. The use of several inverters reduces the harmonic distortion of the output.

There are various types of dc-ac converter topologies that can be employed in the STATCOM, such as two level, three level and PWM converters (Dolezal and Tlusty, 2001) .Since two level, multipulse converters can be implemented easily and full the STATCOM requirements, they are widely used in STATCOM applications Besides they are the most economical type of dc-ac converters (Preville, 2001). For digital simulation purposes, a two level, 24-pulse converter was modeled. The details can be found in Refs 1 and 5. The phase displacement of two consecutive 6-pulse converters is 15. Figure 2 shows the digital simulation of a 24-pulse converter using PSCAD .The STATCOM is connected to the bus (with voltage Vs) through a coupling transformer with resistance and reactance of Rs and Xs, respectively. In the power circuit of the STATCOM, the converter has either a multi-pulse and/or a multilevel topology.

With three-level converter topology the magnitude of the ac output voltage of the converter can be changed by varying the dead angle b with fundamental switching frequency. The ac output voltage of the converter is shown in Fig. 3.

DC-bus voltage control and PWM method: A critical issue in this hybrid active filter is the dc-bus voltage control. The dc bus consists of a single capacitor charged from the power supply. During operation, the active filter may absorb an amount of active power into, or release it from, the dc capacitor. Excessive active power absorption will increase the dc-bus voltage, and may damage the active filter. The strategy used to control the dc-bus voltage is based on active power control. According to the D- Q theory, a dc component in the D-Q coordinates corresponds to active power. No direct axis current on the D-Q coordinates flows in the LC filter. Thus, the active power is controlled by adjusting the quadrature axis component. The direct axis is set to zero. Figure 4 shows a block diagram for the dc bus voltage control. The dc-bus voltage is detected and compared with a reference, amplifying the error signal by a control gain

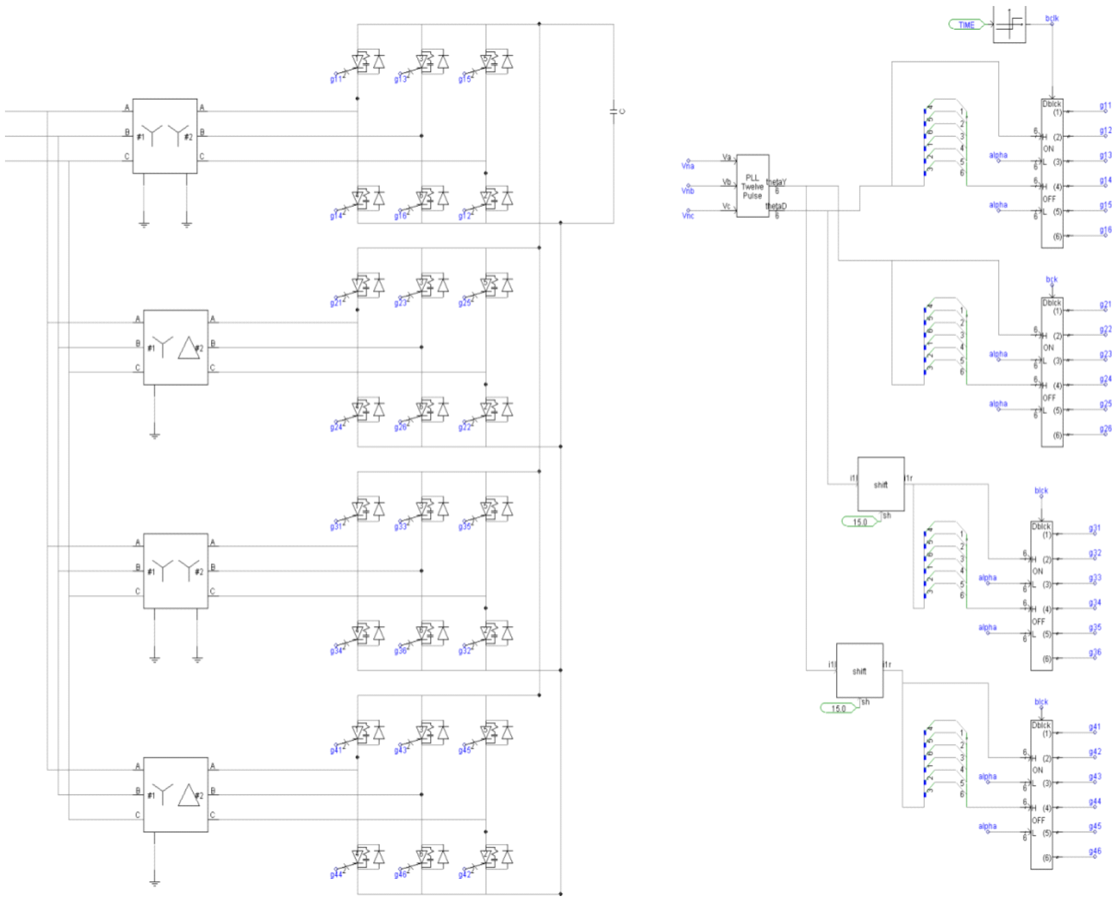

Fig. 2: Simulation 24-pulse converter in PSCAD/EMTDC prigram

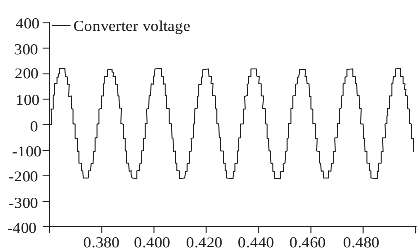

Fig. 3: Twenty-four pulse converter waveforms

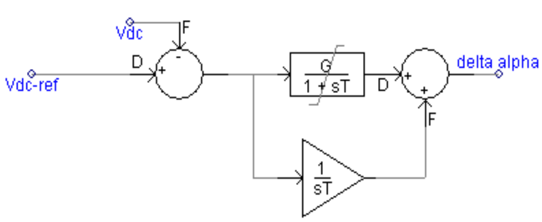

Fig. 4: The control block for regulation of dc voltage of capacitor

of 0.12. A limiter is included in the dc-bus control loop. It is designed to ensure a smooth transient response and to avoid sudden increments or decrements in the dc-bus voltage. It is also designed to prevent the control loop from numerical saturation in the control signals. The limiter is set to ±2.5 V in the digital controller which corresponds to 25% of the maximum control signal. For a 40-V dc-bus voltage, the maximum dc-bus control signal corresponds to a ±10 V peak-to-peak fundamental voltage for the inverter.

Terminal voltage controller: AC voltage controller regulates the voltage of terminal according to requested reference that it accomplishes through changing of converter output voltage magnitude.input signal for auxiliary damping stabilizer. The terminal voltage controller is introduced in Fig. 5.

Stability analysis with STSTCOM for LFO: To demonstrate the effect of the power system strength on the STATCOM stability, an exact digital simulation, using the 24-pulse converter of Fig. 2, was performed by

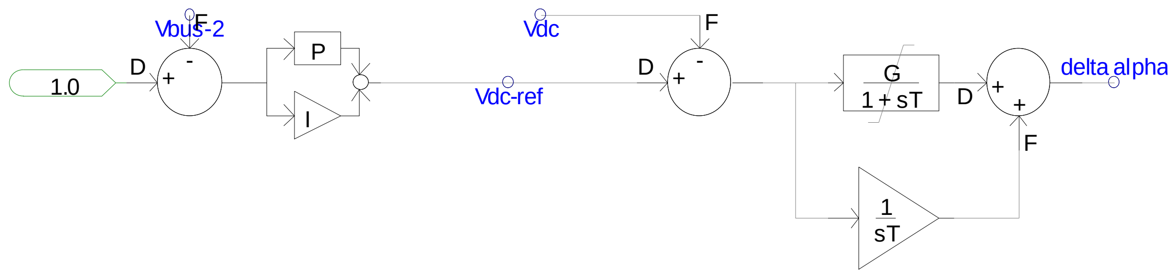

Fig. 5: The control block of alternative voltage output of STSTCOM

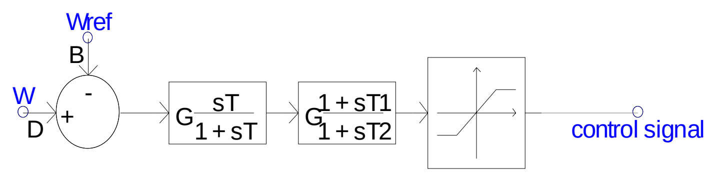

Fig. 6: Control loop of STSTCOM for damping LFO

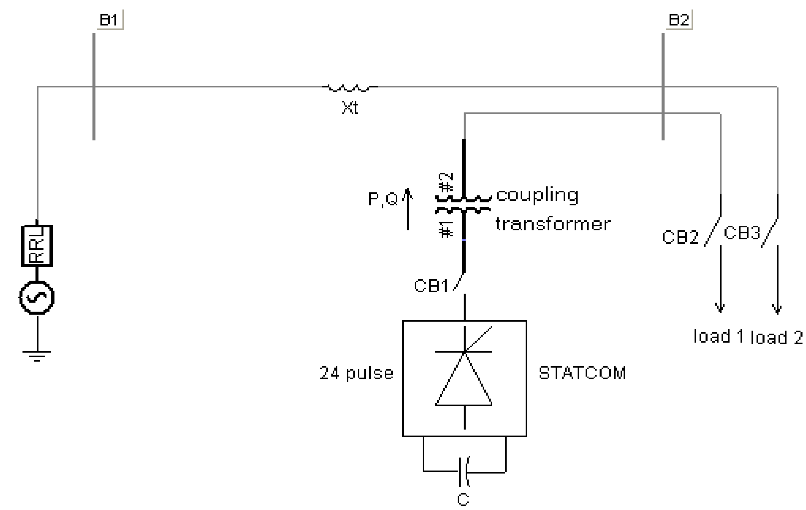

Fig. 7: Test power system to illustrate regulation voltage with STSTCOM

EMTDC/PSCAD. The voltage regulator parameters are and the regulation slope is 24.3 V/A. Power systems and STATCOM parameters are given in Appendix. The STATCOM is connected to bus B2 at Sec, while both loads are in the power system. It regulates the bus voltage to 0.97 pu. At Sec, load 1 is rejected and only loads 2 with high impedance remains. Although the STATCOM has a fast and stable response for the strong system, it exhibits oscillations for the weak power system. The proposed damping stabilizer of STATCOM is shown in Fig. 6. This stabilizer has a structure similar to PSS. In this stabilizer T1' and T2' are the stabilizer input and output signals respectively. This stabilizer is used to create an additional damping signal for STATCOM.

RESULTS AND DISCUSSION

Figure 7 shows the single line diagram of the simulated power system with the STATCOM. The power system is represented by a single machine nfinite-bus system and the system has an installed STATCOM in transmission line as shown in Fig. 8. The STATCOM is used at the middle point in transmission line for voltage regulation and power oscillations damping. The system is modeled for low frequency oscillations studies and the liberalized power system model is used for this purpose. The digital simulation results for voltage regulator output STATCOM voltage phase displacement, dc capacitor voltage, and B2 bus voltage are shown in Fig. 9-15.

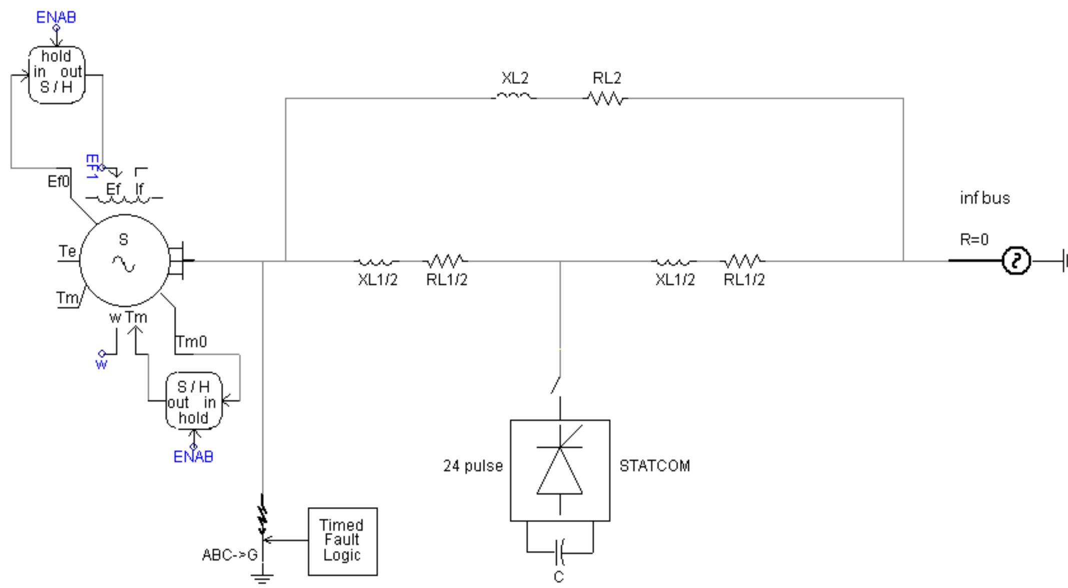

Fig. 8: Single machine power system interconnceted to inf.bus

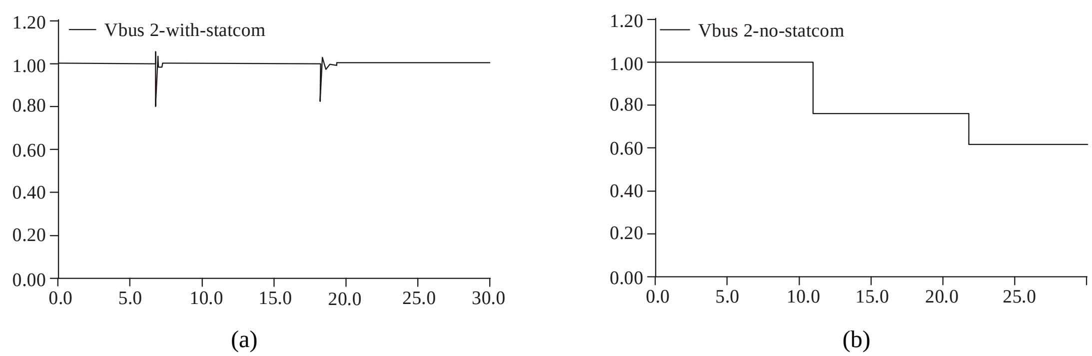

Fig. 9: Voltage at PCC, (a) without STSTCOM, (b) with STATCOM

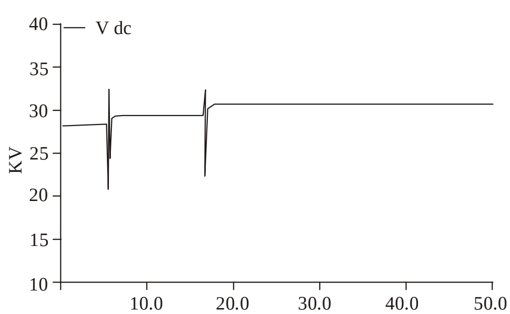

Fig. 10: Dc voltage capacitor variation in terms of load of system

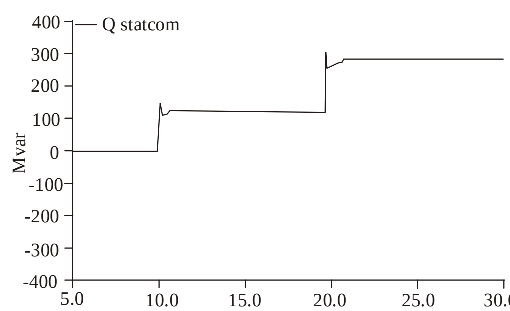

Fig. 11: Ariation of reactive power of STSTCOM in versus load of system

Figure 9 shows the voltage at PCC without STSTCOM and with STATCOM.

Figure 10 shows DC voltage capacitor variation in terms of load of system. Figure 11 presents variation of

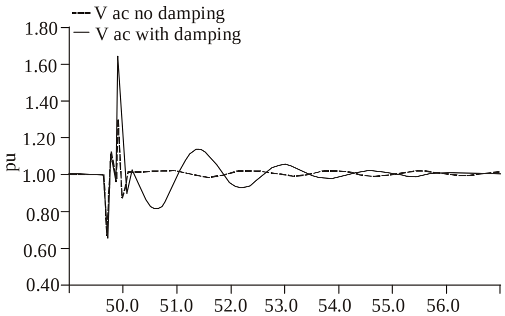

Fig. 12: Variation of STATCOM output voltage for damping LFO

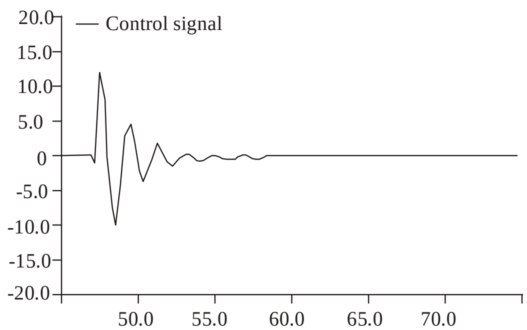

Fig. 13: Variation of control- signal STSTCOM for damping LFO

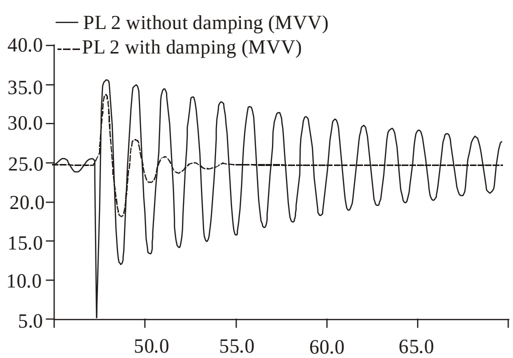

Fig. 14: Angular velocity variation with and without damoing block

reactive power of STSTCOM in versus load of system. Figure 12 represents variation of STATCOM output voltage for damping LFO. Figure 13 indicates variation of control- signal STSTCOM for damping LFO. Figure 14 shows Angular velocity variation with and without damoing block. Figure 15 presents power flow in transmission line variation with and without damoing block.

CONCLUSION

The modeling of a STATCOM for power system applications is presented in this study. In this study the damping of low frequency oscillation and voltage regulation when STSTCOM is installed in system is analyzed. Some types of controllers are developed and compared. One of the main advantages of these approaches is that the nearly linear behavior of the STATCOM response enables linear control methods to be effectively employed. This allows a wide range of design strategies to be explored with linear tools, while a nonlinear simulation need only be applied during the final stages of design to substantiate the control. In this research, the power system is represented by a single machine infinite-bus system and the system has an installed STATCOM in transmission line has been considered. The STATCOM is used at the middle point in transmission line for voltage regulation and power oscillations damping. The system is modeled for low frequency oscillations studies and the liberalized power system model is used for this purpose.

The digital simulation results for voltage regulator output STATCOM voltage phase displacement, dc capacitor voltage, and B2 bus voltage are evaluated and discussed in this study. Also for beeter intustan the effect of block control of voltage regulator and power system stabilizer, the voltage at PCC without STSTCOM and with STATCOM, DC voltage capacitor variation in terms of load of system, variation of reactive power of STSTCOM in versus load of system.,variation of STATCOM output voltage for damping LFO, variation of control- signal STSTCOM for damping LFO, Angular velocity variation with and without damoing block and power flow in transmission line variation with and without damoing block are obtained and discussed.

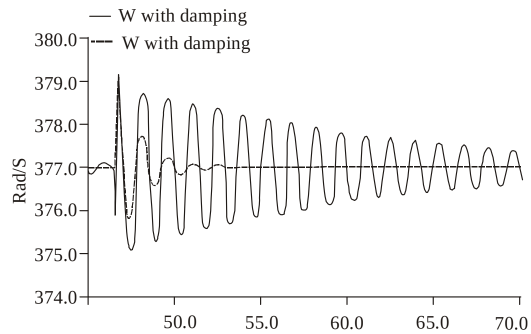

Fig. 15: Power flow in transmission line variation with and without damoing block

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