Simulation and Performance Analysis of SSSC with Power Oscillation Damper Controller

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Abstract— In modern electric power system. The Massive use of the nonlinear and time varying devices has led to distortion of voltage and current waveforms. As a consequence, recently the issue of power quality has become important at both electric utility and end users of electric power. Power engineers consider rising power quality and giving certain power at the lowest cost in a major situation. This Achievable solutions to power distribution have been recommended by the use of, a number of power electronic based devices for enhanced power quality. Distribution Static Compensator (SSSC), Distribution Voltage Regulator (DVR), Unified Power Quality Compensator (UPQC), Battery Energy Storage System (BESS), HVDC Light are few of the prominent custom power devices employ at distribution level. This paper present the model of a static synchronous series compensator (SSSC) with an additional controller, power oscillation damper (POD) to reduce harmonic distortion and decrease clearing time of inter area oscillations to improve power quality. This paper proposed modeling and simulation has been analysis on MATLAB/Simulink software The simulation result show that, The power system oscillation are damped out rapidly with the use of power oscillation damper. The performance of the system is simulated for Linear and Motor load.

Keywords: Programmable Sourse, SSSC, BESS, POD Controller, Motor Load. MATLAB/Simulink

I. Introduction

The use of alternating current circuits in electrical power system has been a common practice nearly since the very inception of the interconnected power network As a consequence, recently the issue of power quality has become important. Both electric utility and end users of electric power are becoming increasingly concerned about the quality of electric power. The term “power quality” [1] [2] has been used to describe the variation of the voltage, current and frequency on the power system beyond a limit. Power engineers consider rising power quality and giving certain power at the lowest cost a major situation. Achievable solutions to power distribution difficulties have been recommended in the form of a number of power electronic based devices for enhanced power quality. Distribution Static Compensator (SSSC), Distribution Voltage Regulator (DVR), Unified Power Quality Compensator (UPQC), BESS, HVDC Light are few of the prominent custom power devices employ at distribution level.

The Distribution Static synchronous Compensator (SSSC) [3] [4] is a chief member of the FACTS family of power electronic based controllers. It has been studied for many years, and is probably the most widely used FACTS device in present's power systems. The SSSC voltage and reactive power compensation are normally related through with the magnetic of the D-SSSC. This traditional power flow framework of the SSSC neglects the impression of the high frequency effects and the switching diagnostics of the power electronics on the active power losses and the reactive power insertion.

The SSSC has appeared as a hopeful device to offering not only for voltage sag reduction but also for a host of other power quality solutions such as voltage stabilization, flicker suppression, power factor correction, and harmonic control.

SSSC is a Series device that produces a balanced 3-Φ voltage or current with capability to control the magnitude and the phase angle. Generally, the SSSC configuration consists of a typical 12-pulse inverter arrangement, a dc energy storage device. A coupling transformer linked in Series with ac system and connected control circuits.

The simulation results show the enhancement in power flow. These methods are tested in MATLAB SIMULINK model of D-SSSC with the POD controller which is used for the improvement of power Quality at distribution end.

II. Facts Devices

The AC transmission system has different limits classified as stationary limits and dynamic limits. These inherent power system limits restrict the power deal, which guide to the beneath utilization of the active transmission resources. Conventionally, fixed or mechanically switched Series and series capacitors, reactors and synchronous generators were being used to solve much of the difficulty. Though, there are limitations as to the use of this conventional equipment. Wanted performance was not being able to attain efficiently. Wear and tear in the mechanical apparatus and sluggish response were the heart of the trouble.

As a result of today’s power electronics technologies, new devices capable of providing control of one or more of the transmission and distribution system parameters have been developed. The definition of FACTS device given by the IEEE is “a power electronics based system and other static equipment that provide control of one or more AC transmission and distribution system parameters to enhance controllability and increase power transferability” [5] There was better requiring for the substitute technology made of solid state devices with quick response characteristics. They require was extra fuelled by universal reformation of electric utilities, rising environmental and efficiency regulations and difficulty in realization authorize and accurate of technique for the construction of overhead transmission lines. This, jointly with the development of Thyristor switch (semiconductor gadget), opened the gate for the growth of power electronics devices known as Flexible AC Transmission Systems (FACTS) controllers. The path from historical Thyristor based FACTS controllers to present state of the skill voltage source converters based FACTS controllers, was ready possible due to fast advances in high power semiconductors devices. The FACTS devices have main purposes of power flow regulation, power loss reduction, power oscillation damping, cost reduction and transmission routes power flow control [6]. The of FACTS devices has many advantages that are listed below,

- Control of Power flow
- Rise of transmission capability
- Increase the loading capability
- Reactive power compensation with controllers
- System security
- Provides greater flexibility
- The problem of voltage fluctuation and flickers can be reduced
- Reduce the reactive power flows [7]
- Improve the stability of power system [8]

III. TYPE OF FACTS DEVICES

In common, FACTS devices can be divided into four types.

A. Series Connected FACTS Devices:

Series FACTS devices might be variable impedance, such as capacitor, reactor, etc. or power electronics based variable source of chief frequency, sub synchronous and harmonic frequencies (or a blend) to provide the desired requirement. In principle, every series FACTS devices insert voltage in series with the transmission line. A series FACTS device can effectively used for controlling the power flow [9]

B. Static synchronous series compensator (SSSC):

Static Synchronous Series Compensator (SSSC) [10] is single of the main series FACTS devices. SSSC is a solid state voltage source inverter inserts an approximately sinusoidal voltage, of variable magnitude in series with the transmission line. The injected voltage is approximately in quadrature with the line current. A little part of the injected voltage, which is in phase with the line current, provides the losses in the inverter. Mainly of the injected voltage, which is in quadrature with the line current, emulates an inductive or a capacitive reactance in series with the transmission line. This emulated variable reactance, inserted by the injected voltage source, influences the electric power flow through the transmission line.

C. Operating Principle:

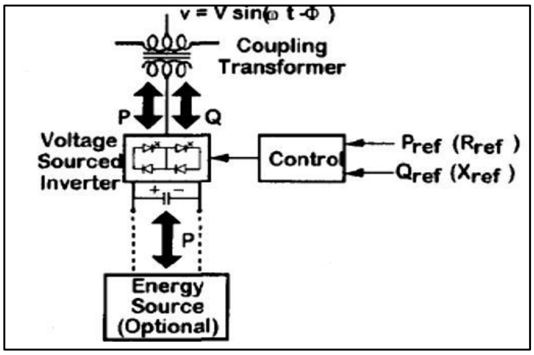

Fig. 1: Block diagram of Stat Synchronous Series Compensator

IV. PRINCIPLE OF SSSC

D-SSSC is to suppress voltage variant and control reactive power in phase with system voltage. It can compensate for inductive and capacitive currents linearly and continuously. Figure 5.2 shows the vector diagram at the basic frequency for capacitive and inductive modes and for the transition state from capacitive to inductive and vice versa. The terminal voltage (Vbus) is equal to the sum of the inverter voltage (Vvsc) and the voltage across the coupling transformer reactive VL in both capacitive and inductive modes. I denote that if output voltage of D-SSSC (Vvsc) is in phase with bus terminal voltage (Vbus) and Vvsc is greater than Vbus, D-SSSC provides reactive power to system. And if Vvsc is smaller than Vbus, D-SSSC absorbs reactive power from power system. Vbus and Vvsc have the same phase, but in reality they contain a little phase difference to component the loss of transformer winding and inverter switching, therefore absorbs some real power from system. Figure 2 is SSSC vector diagrams, which illustrate inverter output voltage VI, system voltage VT, reactive voltage VL and line current I in association with magnitude and phase δ. Figure 2(a, b) explain how VI and VT generate capacitive or inductive power by controlling the magnitude for inverter output voltage VI in phase with each other. Figure 2 illustrate D-SSSC produces or absorbs real power with VI and VT having phase ±δ. The shift from inductive to capacitive mode occurs by charging angle δ from zero to a negative value. The active power is transferred fromthe AC terminal to the DC capacitor and reasons of the DC link voltage to increase The active and reactive power might be expressed by the subsequent equations:

$$P = (V_{bus}V_{vsc}/X_L) \sin \delta$$

$$Q = (V_{2bus}/X_L) - (V_{bus}V_{vsc}/X_L) \cos \delta$$

In several practical SSSC there are losses in the transformer windings and in the converter switches. These losses use active power from the AC terminals. Consequently, a tiny phase variation at all times is present between the VSC voltage and the AC system voltage. A review of the power interactions between the SSSC and the AC system as a purpose of the D-SSSC output voltage Vvsc and the AC system voltage Vbus.

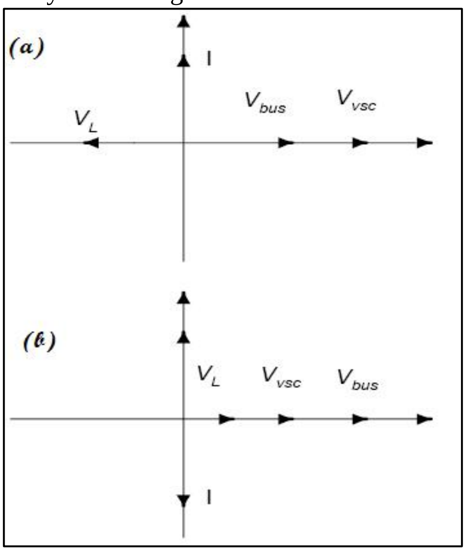

Fig. 2: Vector diagram of SSSC (a) Capacitive mode and (b) Inductive mode

V. DESCRIPTION OF CONTROL STRATEGY

The majority used control techniques involve instantaneous reactive power theory (p-q theory), synchronous reference frame theory, indirect current control theory etc. The current control theory employing hysteresis rule based carrier-less PWM current control is valuable and easy. To understand this, a current controlled voltage source inverter is used as a D-SSSC. One power oscillation controller is used to control the dc link voltage and helps to pick up power-factor to unity.

A. p-q Method:

Instantaneous reactive power theory has been published in 1984. Based on this theory, the so-called "p-q method" was applied successfully in the control of AHF. Zero-sequence component is neglected in this method, and because of that the p-q method is not accurate when the 3-Φ system is distorted or unbalanced.

B. d-q Method:

Based on the park transformation, the d-q method came. The three-phase load current can be decomposed in positive-sequence, negative sequence and zero-sequence component. The current in the d-q frame and can be transformed from the positive sequence and negative sequence using a PLL (phase locked loop). The division of the AC and DC components can be obtained across a low-pass PHF. The reference current signal can be achieved by the AC element in d-q frame through a counter transformation.

C. Control Block Diagram of POD

POD gives supplementary input signal to AVT for damping the network oscillations. Generally bus voltage, line current, real and reactive power from the bus is the enforced input signals [11]. For maintaining the damping, there is necessary for POD to give electrical torque component which is in phase to speed of rotor diversion (dwr).

POD subsist of distinct blocks, gain block finds the magnitude of power oscillations confer to its gain value. Washout block shows high pass filter and assure at normal state outcome of POD is zero. Phase compensating block gives the adequate phase lead properties for compensating the phase lag betwixt the input of exciter and torque of alternator. Time constant block manage the proper time lag for controllers. POD block diagram is shown in Fig.3.

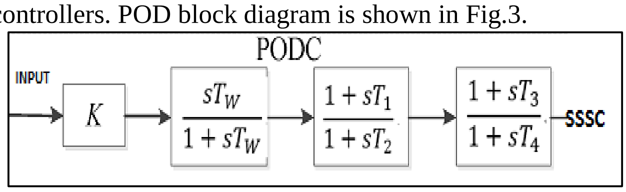

Fig. 3: Block diagram of POD

VI. SIMULATION MODEL

The model consist of two substations (M1 &M2)and one main load center at bus3.M1 substation is rated as 2100MVA it shows six machine of each rating of 350MVA and M2 is rated as 1400MVA exhibiting four machine each rating 350MVA .load center near about 2200MW. The SSSC connected in series with line L1 and input to the POD controller from bus voltage (B2) and line current (L1). .The SSSC is rated as 100 MVA is placed at bus B1 in series with line L1 and it is able to implant up to 10% of the nominal network voltage. The reference implanting voltage is intent by power oscillation damping (POD) controller whose outcome is linked with reference input voltage of SSSC. The voltage at bus B2 and current through a line L1 are the inputs of POD controller.

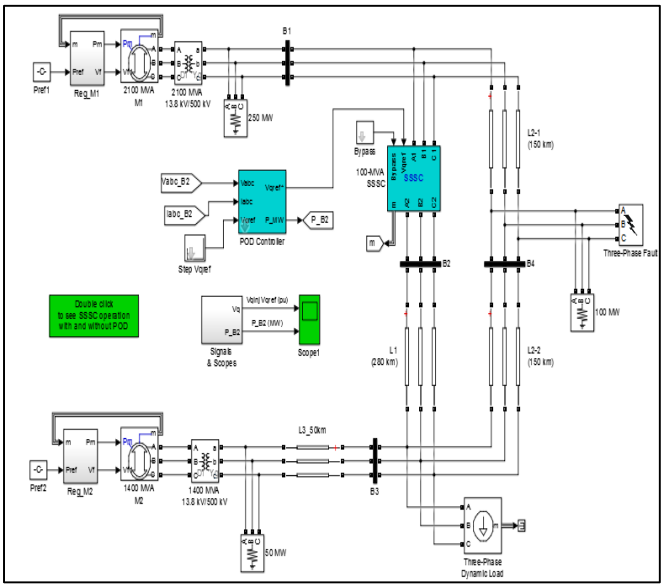

Fig. 4: Model of SSSC with POD

Nominal Power (Pn)– 3730 VA, Voltage (line -line) (Vn)– 338 Vrms, Frequency (Fn) – 50 Hz , Stator Resistance (Rs) – 1.115 ohm and Inductance (Lls)– 0.005974 H, Rotor Resistance (Rr`)-1.083 ohm and Inductance (Llr`)- 0.005974 H, Mutual Inductance (Lm)- 0.2037 H, Inertia (J) –0.02 Kgm2 , Friction Factor (F) – 0.005752 N.M.S. , Pole Pair (p) – 2,Lc= 5mH, Rc = 0.1Ω, hb=0.5A, C1=5000F, Rl = 1000 Ω, P = 0.43, I = 0.15, D = 0.

VII. RESULT AND DISCUSSION

Fig.5 shows result with power oscillation damper OFF. The first graph display between Vqref signal and measured injected voltage by the SSSC. And the second graph display active power flow on line L1 measured at bus2 (B2).for ground fault

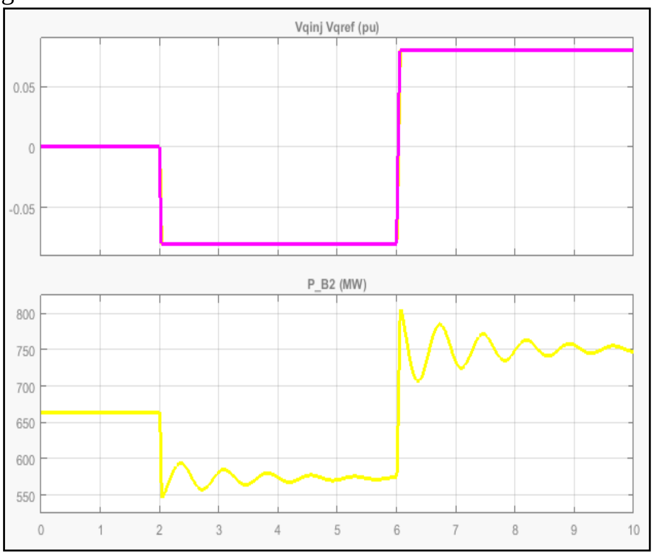

Fig. 5: SSSC inductive and capacitive mode POD OFF

Fig. 6 shows the result with power oscillation damper ON for ground fault. We can see that the SSSC with a POD controller is a very effective tool to damp power oscillation.

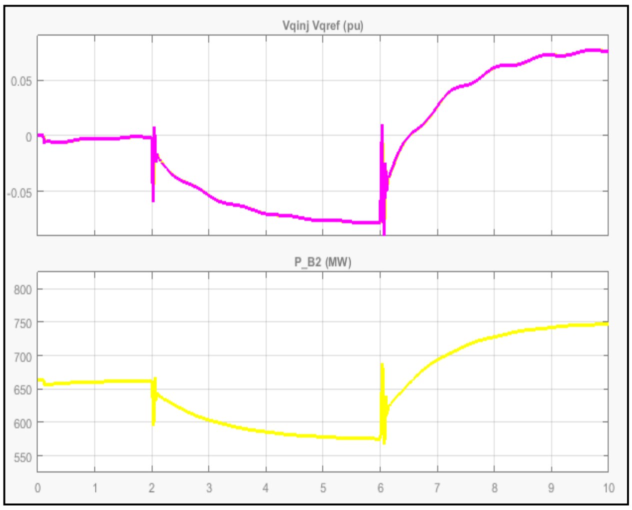

Fig. 6: SSSC inductive and capacitive mode POD ON

From the fig.7 [(a),(b),(c),(d)],it is shows that the simulations for both POD status ON and OFF. At 2 sec SSSC is switched to inductive mode and at 6 sec to capacitive mode. It can be easily seen that there is a significance difference between oscillations damping foe both cases. SSSC operation is therefore more efficient with POD controller

In graph the X-axis shows simulation time and Y-axis shows the real and reactive power respectively.

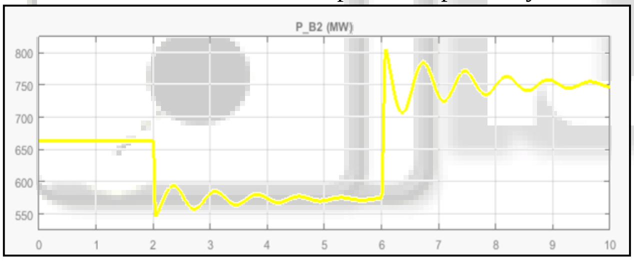

Fig. 7: (a) POD OFF

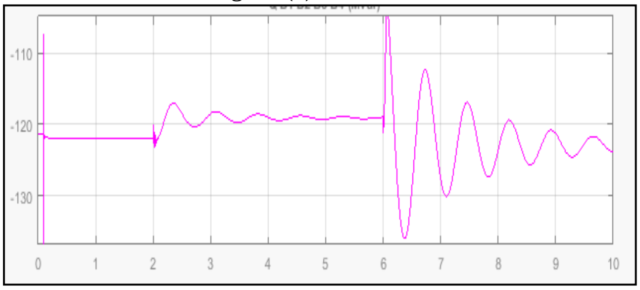

Fig. 7: (b) POD OFF

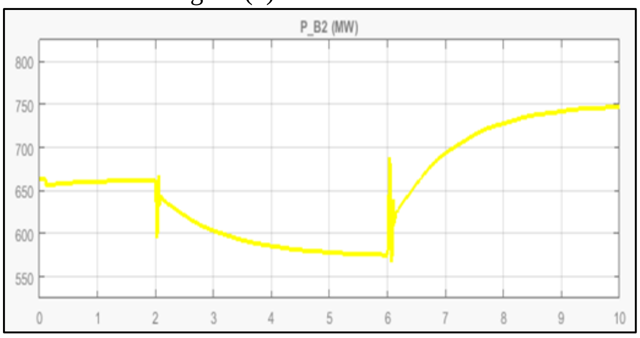

Fig. 7: (c) POD ON

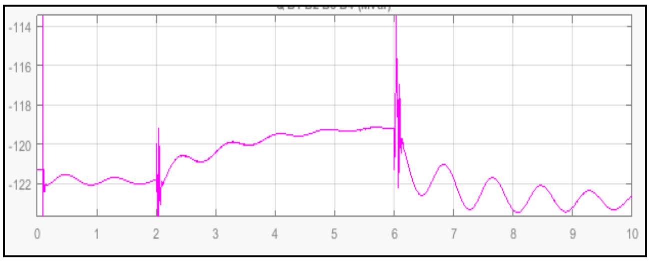

Fig. 7: (d) POD ON

From fig.8 it is seen that, three phase fault occurred at 1.33 sec. the fault duration is 10 cycle. It can see that with OPD ON oscillation are damp in less than a second but without POD ON the oscillation are continue and settling time is greater than 5 second.

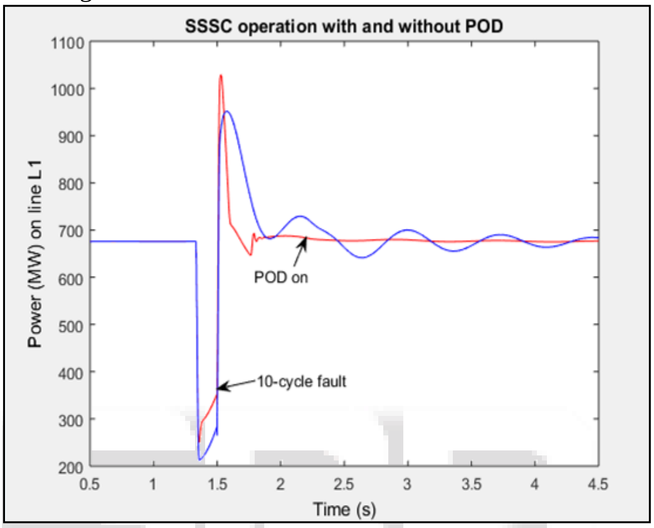

Fig. 8: fault analysis with and without SSSC-POD

VIII. Conclusions and Future Work Conclusion

- A model of SSSC has been developed in MATLAB environment using Power System Block-set. The performance of the developed model is tested under a wide variety of loading conditions.
- It is found that SSSC is capable of minimizing the harmonics and reactive power compensation.
- Indirect current control technique has been applied over the sensed and reference supply currents for SSSC and it has been found to be a simple technique. Only one controller is required to regulate terminal voltage and thus reduces computation effort.
- The control algorithm of the SSSC is flexible and has been tested for power quality improvement for linear as well as nonlinear and Induction motor loads.
- D-SSSC is able to reduce harmonics in voltage at PCC and supply currents to less than 5% IEEE 519 standards. SSSC reduces harmonics in load current to a large extent and provides quality power.

A. *Future Implications*

- The simulation has been carried out in MATLAB/SIMULINK environment and power factor is unity for supply voltage and current.
- To analyze the effect of non-linear loads, linear loads and Motor loads on Distribution system when feeding a generation with wind and solar.

- Modeling of reactive power theory and compare results with ICCT.
- To Study and Simulation of Fuzzy and ANN based controller on behalf of PI controller.
- In a future work, the obtained simulation results will be compared with experimental results, to be measured in a developed D-SSSC prototype.

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