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Enhancement of Power System Quality Using Static Synchronous Compensation (STATCOM)

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Abstract

Power generation and transmission is a complex process, that's required many auxiliaries components for control, saving the stable system and to decrease the power losses. Power quality is extremely significant because of the impacts the electric power industry and the non-linear loads, that directly affect the power system quality. Flexible AC Transmission System (FACTS) devices consider the optimum components that's consider an electronic device based on the types of the voltage or power level either, it's a Gate Turn-Off thyristors (GTO) or Insulated Gate Bipolar Transistor (IGBT). Static Synchronous Compensator (STATCOM) module can be operated with the power system by the fed or absorb the reactive power. The three-level STATCOM topology is considered instead of the two-level STATCOM, as it is suitable for the high-voltage application. This paper discusses the reactive power compensation to obtain the voltage regulation in the power system by using STATCOM design, this discussion can to simulate by MATLAB/Simulink software to obtain the steps for operation and control on the STATCOM to enhance the power system quality.

Keywords: *FACTS, STATCOM, Voltage Sag, MATLAB and Power Quality.*

1. Introduction

Power quality is often defined as the electrical network's capability to deliver a clean and stable power supply. That's constantly available, has a pure noise-free sinusoidal wave shape, and is always within voltage and frequency tolerances. To improve the performance of ac power systems, its require to manage the reactive power in an efficient way and this is known as reactive power compensation. There are two aspects to the problem of reactive power compensation: load compensation and voltage support. Load compensation consists of improvement in power factor, balancing of real power drawn from the supply, better voltage regulation, etc. of large fluctuating loads. Voltage support consists of reduction of voltage fluctuation at a given terminal of the transmission line. Two types of compensation can be used: series and shunt compensation. These modify the parameters of the system to give enhanced VAR compensation. In recent years, static VAR compensators like the STATCOM have been developed [1]. These quite satisfactorily do the job of absorbing or generating reactive power with a faster time response and come under Flexible AC Transmission Systems (FACTS).

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This allows an increase in transfer of apparent power through a transmission line, and much better stability by the adjustment of parameters that govern the power system i.e. current, voltage, phase angle, frequency and impedance. Leading in recent years, flexible alternative current transmission systems (FACTS) devices are one of the most effective ways to improve power system operation controllability and power transfer limits. Through the modulation of bus voltage, phase shift between buses, and transmission line reactance, the FACTS devices can cause a substantial increase in power transfer limits during steady state [2]. These devices are an addition to normally steady-state control of a power system but, due to their fast Controller Design of STATCOM for Power System Stability Improvement, the FACTS can also be used for power system stability enhancement through improved damping of power swings. The real power flow with primary function of FACTS devices can be regulated to reduce the low frequency oscillation and enhance power system stability. Recently, several FACTS devices have been implemented and installed in practical power systems [2-4]. STATCOM is a member of the FACTS family that is connected in shunt with the system as shown in Fig.1. From the viewpoint of the power system dynamic stability, the STATCOM provides better damping characteristics than the SVC. It is able to exchange transiently reactive power with the system, it can improve oscillation stability better than SVC [5-6]. The STATCOM is based on the principle that a voltage source inverter generates a controllable AC voltage source behind a transformer-leakage reactance hence, that the voltage difference across the reactance can produce active and reactive power exchange between the STATCOM and the transmission network. Several trials have been reported in the literature of dynamic models of STATCOM in order to design suitable controllers for power flow, voltage and damping controls [4-7].

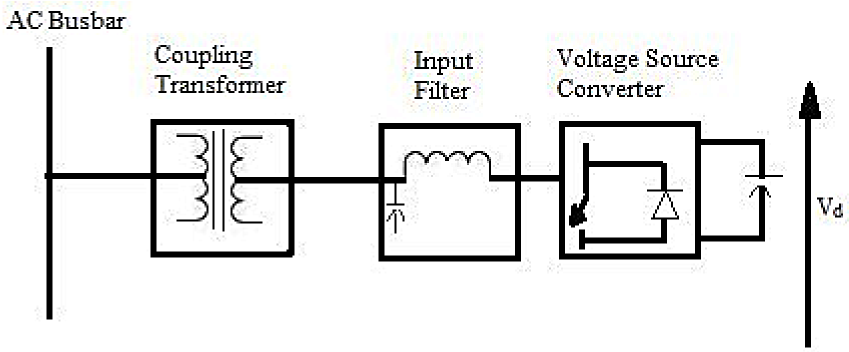

Fig. 1. Basic STATCOM design

2. STATCOM Operation and Control

One of the many devices under the FACTS family, a STATCOM is a regulating device which can be used to regulate the flow of reactive power in the system independent of other system parameters. STATCOM has no long term energy support on the dc side and it cannot exchange real power with the ac system. In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to these disturbances [7-9]. A STATCOM consists of a three-phase inverter (generally a PWM inverter) using SCRs, MOSFETs or IGBTs, a D.C capacitor which provides the D.C voltage for the inverter, a link reactor which links the inverter output to the a.c supply side, filter components to filter out the high frequency components due to the PWM inverter. From the d.c. side capacitor, a three phase voltage is generated by the inverter. This is synchronized with the a.c supply [7-10]. The link inductor links this voltage to the a.c supply side. This is the basic principle of operation of STATCOM.

2.1 Phase angle control

In this case the quantity controlled is the phase angle δ. The modulation index "m" is kept constant and the fundamental voltage component of the STATCOM is controlled by changing the DC link voltage. By further charging of the DC link capacitor, the DC voltage will be increased, which in turn increases the reactive power delivered or the reactive power absorbed by the STATCOM. On the other hand, by discharging the DC link capacitor, the reactive power delivered is decreased in capacitive operation mode or the reactive power absorbed by the STATCOM in an inductive power mode increases [7-10]. By making phase angle δ negative, power can be extracted from DC link. If the STATCOM becomes lesser than the extracted power, Pc in becomes negative and STATCOM starts to deliver active power to the source. During this transient state operation, Vd gradually decreases. Fig. 2 shows the phasor diagrams which illustrating power flow between the DC link in transient state and the ac supply.

For a phase angle control system, the open loop response time is determined by the DC link capacitor and the input filter inductance. The inductance is applied to filter out converter harmonics and by using higher values of inductance; the STATCOM current harmonics is minimized. The reference reactive power (Qref) is compared with the measured reactive power (Q) [7-10]. The reactive power error is sent as the input to the PI controller and the output of the PI controller determines the phase angle of the STATCOM fundamental voltage with respect to the source voltage. To simulate the STATCOM equations, its can represent the shunt voltage source of the three-phase E_{VR}, also, V_K is the magnitude of the bus voltage to determine the reactive power flow, and the V_{VR} is the VSC output fundamental voltage [10]. The principle operation of the STATCOM module is given by a source coupled in parallel to the node with series impedance ($Y_{VR} = G_{VR} + jB_{VR}$), the expression current supplied to the bus system as:

$$I_{VR} = Y_{VR}\, E_{VR} - Y_{VR} V_K \tag{1}$$

In addition, the reactive power is expressed as:

$$Q_{VR} = V_{VR}^2 B_{VR} - V_{VR} V_K [G_{VR} \cos(\delta_{VR} - \theta_K) - B_{VR} \sin(\delta_{VR} - \theta_K)] \tag{2}$$

Where, δ_{VR} and θ_K are the voltage phase angles. For V_{VR}>V_K, the controller generates reactive power and consumes reactive power when V_{VR}<V_K.

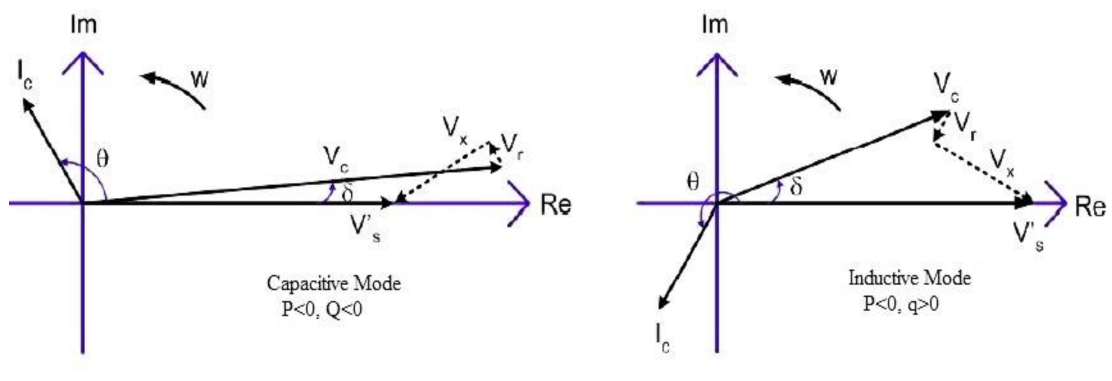

Fig 2. Phasor diagrams for illustrating power flow between the DC and AC

3. STATCOM simulation

Depending on the power rating of the STATCOM, different technologies are used for the power converter. High power STATCOMs (several hundreds of Mvars) normally use GTO-based, square-wave voltage-sourced converters (VSC), while lower power STATCOMs (tens of Mvars) use IGBT-based (or IGCT-based) pulse-width modulation (PWM) VSC. The Static Synchronous Compensator (Phasor Type) block of the FACTS library is a simplified model, which can simulate different types of STATCOMs. . Due to low frequencies of electromechanical oscillations in large power systems (typically 0.02 Hz to 2 Hz), this type of study usually requires simulation times of 30–40 seconds or more[10-12].

The STATCOM model described in this example is rather a detailed model with full representation of power electronics. It uses a square-wave, 48-pulse VSC and interconnection transformers for harmonic neutralization. Fig. 3 Shows the STATCOM module and Fig. 4 Control Circuit on 100 Mvar STATCOM on a 500 kV Power System, this type of model requires discrete simulation at fixed type steps (25 µs in this case) and it is used typically for studying the STATCOM performance on a much smaller time range (a few seconds). Typical applications include optimizing of the control system and impact of harmonics generated by converter [12].

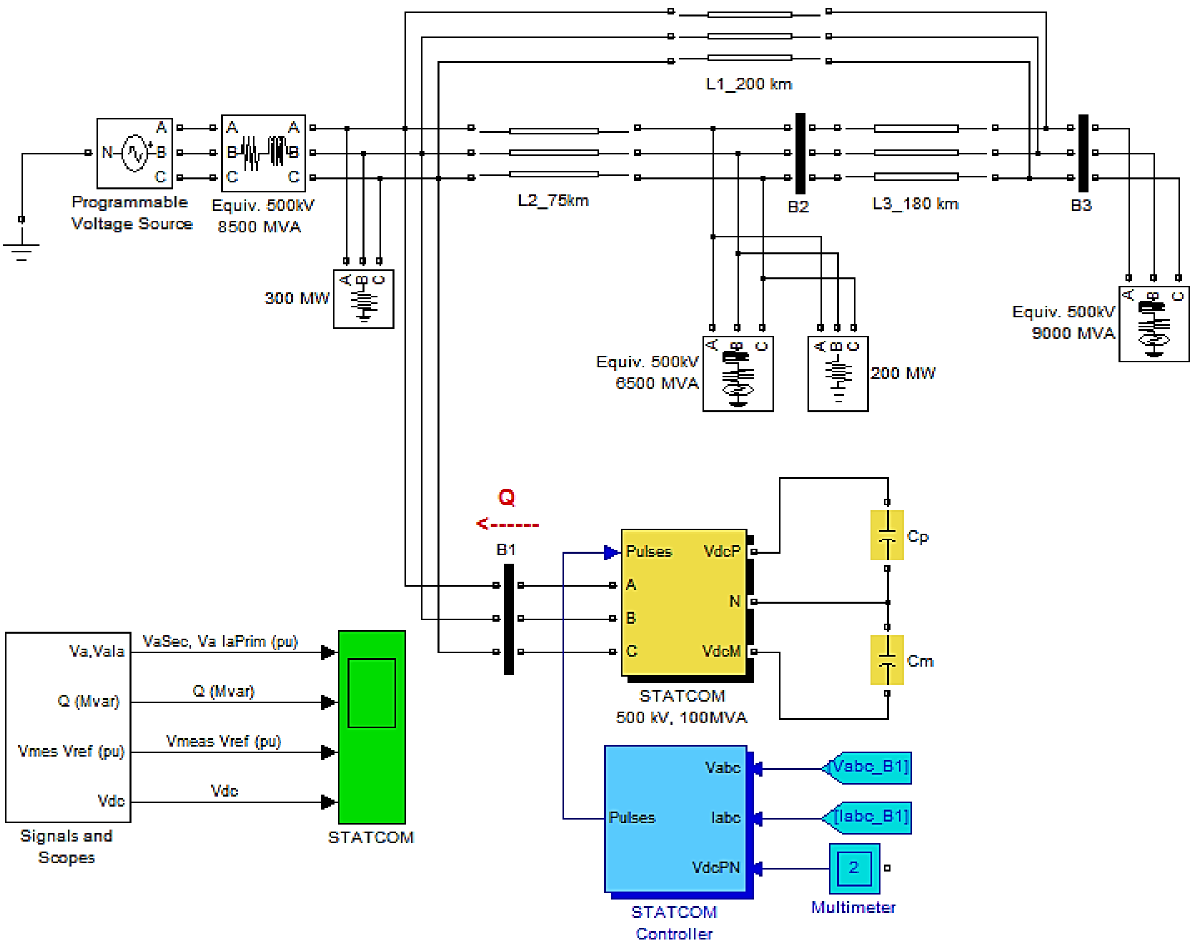

Fig. 3. Model of the 100 Mvar STATCOM on a 500 kV Power System

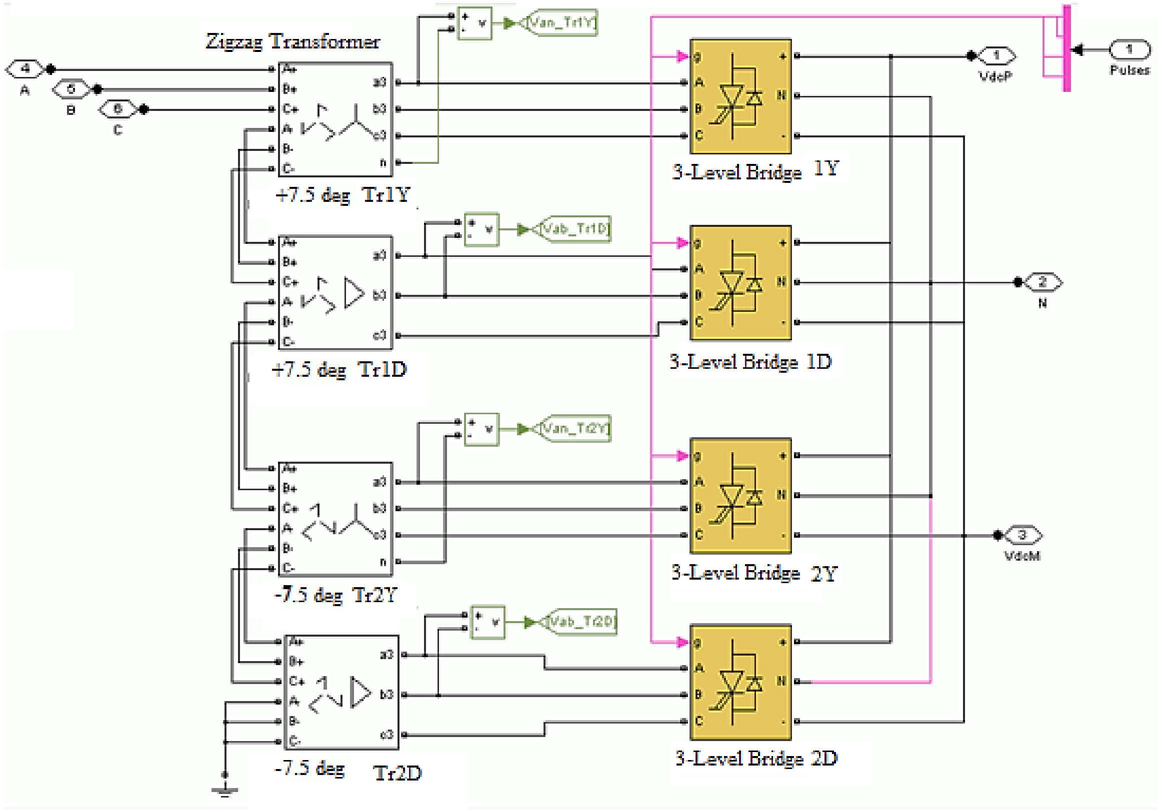

Fig. 4. Control Circuit on 100 Mvar STATCOM on a 500 kV Power System

Except for the 23rd and 25th harmonics, this transformer arrangement neutralizes all odd harmonics up to the 45th harmonic. Y and D transformer secondaries cancel harmonics 5+12n (5, 17, 29, 41,...) and 7+12n (7, 19, 31, 43,...). In addition, the 15° phase shift between the two groups of transformers (Tr1Y and Tr1D leading by 7.5°, Tr2Y and Tr2D lagging by 7.5°) allows cancellation of harmonics 11+24n (11, 35,...) and 13+24n (13, 37,...). Considering that all 3n harmonics are not transmitted by the transformers (delta and ungrounded Y), the first harmonics that are not canceled by the transformers are therefore the 23rd, 25th, 47th and 49th harmonics. By choosing the appropriate conduction angle for the three-level inverter (σ = 172.5°), the 23rd and 25th harmonics can be minimized. The first significant harmonics generated by the inverter will then be 47th and 49th. Using a bipolar DC voltage, the STATCOM thus generates a 48-step voltage approximating a sine wave.

Fig. 5 shows the waveforms Illustrating STATCOM Dynamic Response to System Voltage Steps. PLL (phase locked loop) synchronizes GTO pulses to the system voltage and provides a reference angle to the measurement system. Measurement System computes the positive-sequence components of the STATCOM voltage and current, using phase-to-dq transformation and a running-window averaging. Voltage regulation is performed by two PI regulators: from the measured voltage Vmeas and the reference voltage Vref, the Voltage Regulator block (outer loop) computes the reactive current reference Iqref used by the Current Regulator block (inner loop). The output of the current regulator is the α angle which is the phase shift of the inverter voltage with respect to the system voltage. This angle stays very close to zero except during short periods of time, as explained below. A voltage droop is incorporated in the voltage regulation to obtain a V-I characteristics with a slope (0.03 pu/100 MVA in this case). Therefore, when the STATCOM operating point changes from fully capacitive (+100 Mvar) to fully inductive (-100 Mvar) the SVC voltage varies between 1-0.03=0.97 pu and 1+0.03=1.03 pu.

Firing Pulses Generator generates pulses for the four inverters from the PLL output (ω.t) and the current regulator output (α angle). To explain the regulation principle, let us suppose that the system voltage Vmeas becomes lower than the reference voltage Vref. The voltage regulator will then ask for a higher reactive current output (positive Iq= capacitive current). To generate more capacitive reactive power, the current regulator will then increase α phase lag of inverter voltage with respect to system voltage, so that an active power will temporarily flow from AC system to capacitors, thus increasing DC voltage and consequently generating a higher AC voltage. As explained in the preceding section, the conduction angle σ of the 3-level inverters has been fixed to 172.5°. This conduction angle minimizes 23rd and 25th harmonics of voltage generated by the square-wave inverters. Also, to reduce noncharacteristic harmonics, the positive and negative voltages of the DC bus are forced to stay equal by the DC Balance Regulator module. This is performed by applying a slight offset on the conduction angles σ for the positive and negative half-cycles. The STATCOM control system also allows selection of Var control mode (see the STATCOM Controller dialog box). In such a case, the reference current Iqref is no longer generated by the voltage regulator. It is rather determined from the Qref or Iqref references specified in the dialog box.

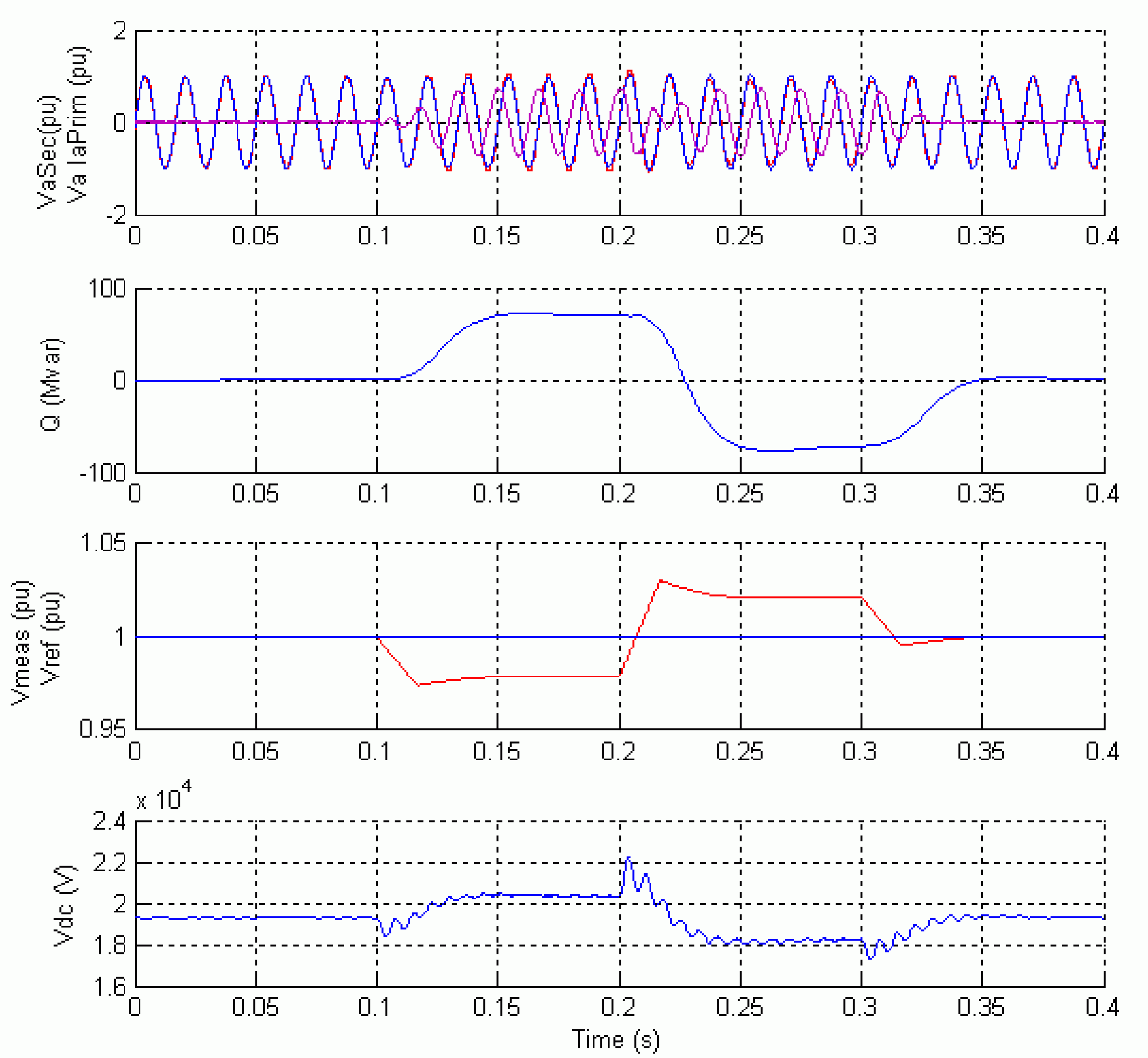

Fig. 5. Waveforms Illustrating STATCOM Dynamic Response to System Voltage Steps

Initially the programmable voltage source is set at 1.0491 pu, resulting in a 1.0 pu voltage at bus B1 when the STATCOM is out of service. As the reference voltage Vref is set to 1.0 pu, the STATCOM is initially floating (zero current). The DC voltage is 19.3 kV. At t=0.1s, voltage is suddenly decreased by 4.5% (0.955 pu of nominal voltage). The STATCOM reacts by generating reactive power (Q=+70 Mvar) to keep voltage at 0.979 pu. The 95% settling time is approximately 47 ms. At this point the DC voltage has increased to 20.4 kV. Then, at t=0.2 s the source voltage is increased to1.045 pu of its nominal value. The STATCOM reacts by changing its operating point from capacitive to inductive to keep voltage at 1.021 pu. At this point the STATCOM absorbs 72 Mvar and the DC voltage has been lowered to 18.2 kV. Observe on the first trace showing the STATCOM primary voltage and current that the current is changing from capacitive to inductive in approximately one cycle. Finally, at t=0.3 s the source voltage in set back to its nominal value and the STATCOM operating point comes back to zero Mvar. Fig. 6 and Fig. 7 zooms on two cycles during steady-state operation when the STATCOM is capacitive and when it is inductive. Waveforms show primary and secondary voltage (phase A) as well as primary current flowing into the STATCOM. When the STATCOM is operating in capacitive mode (Q=+70 Mvar), the 48-pulse secondary voltage (in pu) generated by inverters is higher than the primary voltage (in pu) and in phase with primary voltage. Current is leading voltage by 90°; the STATCOM is therefore generating reactive power. On the contrary, when the STATCOM is operating in inductive mode, secondary voltage is lower than primary voltage. Current is lagging voltage by 90°; the STATCOM is therefore absorbing reactive power.

Finally, at look inside the Signals and Scopes subsystem you will have access to other control signals. Notice the transient changes on α angle when the DC voltage is increased or decreased to vary reactive power. The steady-state value of α (0.5 degrees) is the phase shift required to maintain a small active power flow compensating transformer and converter losses.

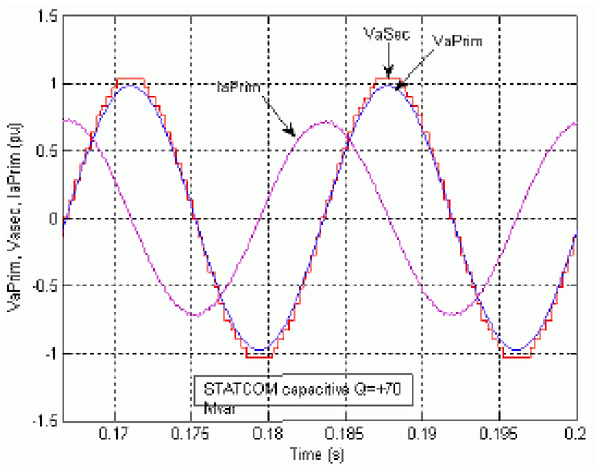

Fig. 6. Steady-State Voltages and Current for Capacitive Operation

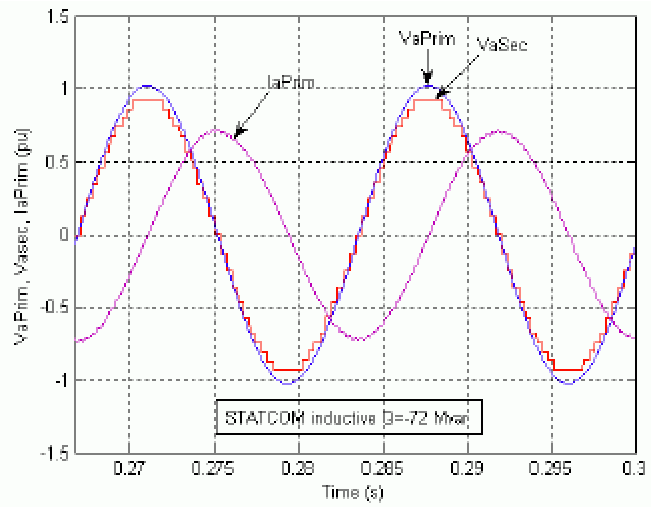

Fig. 7. Steady-State Voltages and Current for Inductive Operation

Conclusion

A STATCOM is build with Thyristors with turn-off capability like IGBTs. The static line between the current limitations has a certain steepness determining the control characteristic for the voltage. The advantage of a STATCOM is that the reactive power provision is independent from the actual voltage on the connection point. To better understand the functioning of the STATCOM, an analysis of active and reactive power has been presented in this paper. Generally the STATCOM is designed to compensate the reactive power and several disturbances at the voltage level. Therefore, it can simultaneously compensate voltage sag and swell by injecting or absorbing a reactive current through the transformer. The performance for power quality and balanced network operation can be improved much more with the combination of active and reactive power.. As a result, a new interpretation of the compensation phenomena for a voltage sag or swell has been presented in this paper to improve the power system quality.

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