Modeling and Simulation of a Distribution STATCOM(1) using Simulink's Power System Blockset

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Abstract - **This paper presents a study on the modeling of a STATCOM (Static Synchronous Compensator) used for reactive power compensation on a distribution network. The power circuits of the D-STATCOM and the distribution network are modeled by specific blocks from the Power System Blockset while the control system is modeled by Simulink blocks. Static and dynamic performance of a ±3 Mvar D-STATCOM on a 25-kV network is evaluated. An "average modeling" approach is proposed to simplify the PWM inverter operation and to accelerate the simulation for control parameters adjusting purpose. Simulation performance obtained with both modeling approaches are presented and compared.**

I. INTRODUCTION

Electricity suppliers are. nowadays concerned about the quality of the power delivered to customers. With the developments of power electronics- several solutions have been proposed to compensate for the fluctuations observed on the distribution networks in order to ensure highest possible power quality for the customers [2].

These "Power Quality Devices" (PQ Devices) are power electronic converters connected in parallel or in series with the lines and the operation is controlled by a digital controller [1]- [2]- [3]- [4]. The interaction between the PQ device and the network is preferably studied by simulation. The modeling of these complex systems that contain both power circuits and control systems can be done on different bases- depending on the trade-offs that we are ready to accept and on the degree of accuracy of what we want to study (switching in power converter or controller tuning). The modeling abstraction degree in these systems can be thus adapted to the study requirements.

In this paper- two approaches to model a distribution STATCOM (Static Synchronous Compensator) are considered and evaluated- that is "device modeling" and "average modeling". Both modeling approaches take advantage of Simulink and Power System Blockset to implement in the same diagram the power circuit and control system. The models are described and the simulation results are presented. They will be then compared.

II. DESCRIPTION OF THE D-STATCOM OPERATION

In distribution networks- the STATCOM (Static Synchronous Compensator) is a shunt device that regulates the system voltage by absorbing or generating reactive power.

Fig. 1 shows a simplified diagram of a STATCOM connected to a typical distribution network represented by an equivalent network.

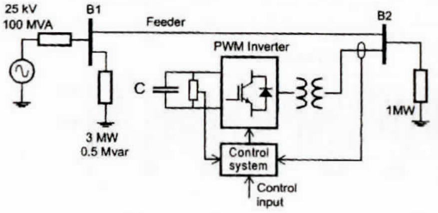

Fig. 1 Simplified diagram of a D-STATCOM connected to a distribution network.

The STATCOM consists mainly of a PWM inverter connected to the network through a transformer- The de link voltage is provided by capacitor C which is charged with power taken from the network. The control system ensures the regulation of the bus voltage and the de link voltage.

The D-STATCOM function is to regulate the bus voltage by absorbing or generating reactive power to the network- like a thyristor static compensator. This reactive power transfer is done through the leakage reactance of the coupling transformer by using a secondary voltage in phase with the primary voltage (network side). This voltage is provided by a voltage-source PWM inverter. The D-STATCOM operation is illustrated by the phasor diagrams shown in Fig. 2. When the secondary voltage (V_D) is lower than the bus voltage (VB)' the D-STATCOM acts like an inductance absorbing reactive power from the bus. When the secondary voltage (V_D) is higher than the bus voltage (VB)' the D-STATCOM acts like a capacitor generating reactive power to the bus. In steady state- due to inverter losses the bus voltage always leads the inverter voltage by a small angle to supply a small active power.

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1. Reactive power measurement and control devices

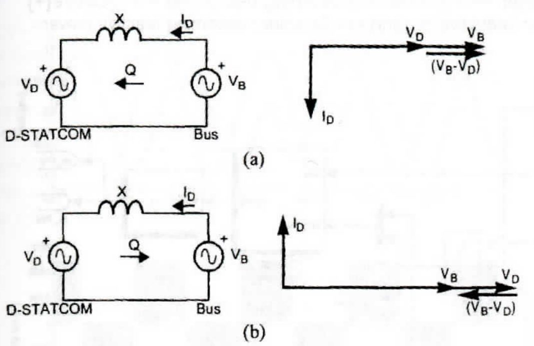


Fig. 2 D-STATCOM operation
(a) Inductive operation- (b) Capacitive operation

The STATCOM has several advantages as compared to "conventional" Static Var Compensator (SVC) using thyristors. It is faster- can produce reactive power at low voltage- does not require thyristor-controlled reactors (TCR) or thyristorswitched capacitors (TSC)- and does not produce low order harmonics.

III. MODELING THE D-STATCOM USING THE SIMULINK'S POWER SYSTEM 8LOCKSET

As seen above- a D-STATCOM is a power electronic system with a complex control system. Modeling the D-STATCOM including the power network and its controller in Simulink environment requires "electric blocks" from the Power System Blockset [5] and control blocks from Simulink library. We consider here a ±3Mvar D-STATCOM connected to a 25-kV distribution network.

Figure 3 shows a Simulink diagram which represents the DSTATCOM and the distribution network.

The feeding network is represented by a The venin equivalent (bus 81) followed by a 21-km feeder which is modeled by a pi-equivalent circuit connected to bus 82. At this bus- a 3MW load is connected. A 25-kV/600V transformer and a I MW variable load are connected to bus B2 by a 2-km feeder.

The D-STATCOM output is coupled in parallel with the network through a step-up 2.5125-kV ~- Y transformer. The primary of this transformer is fed by a voltage-source PWM inverter consisting of two IGBT bridges. A filter bank is used at the inverter output to absorb harmonics. A 10000 µ.F capacitor is used as de voltage source for the inverter.

A PWM pulse generator with a carrier frequency of 1.68 kHz is used to control both IGBT bridges. The modulation scheme used is of sinusoidal type.

The controller diagram is shown in Fig. 4. It consists of several subsystems: a phase-locked loop (PLL)- two measurement systems- a current regulation loop- a voltage regulation loop- and a de link voltage regulator.

The PLL is synchronized to the fundamental of the transformer primary voltage to provide the synchronous reference (sinωt and cosωt) required by the abc-qd transformation. The measurement blocks "Vmes" and "Imes" compute the d-axis and q-axis components of the voltages and currents.

The inner current regulation loop consists of two proportional-integral (PI) controllers that control the d-axis and q-axis currents. The controllers outputs are the voltage direct-axis and

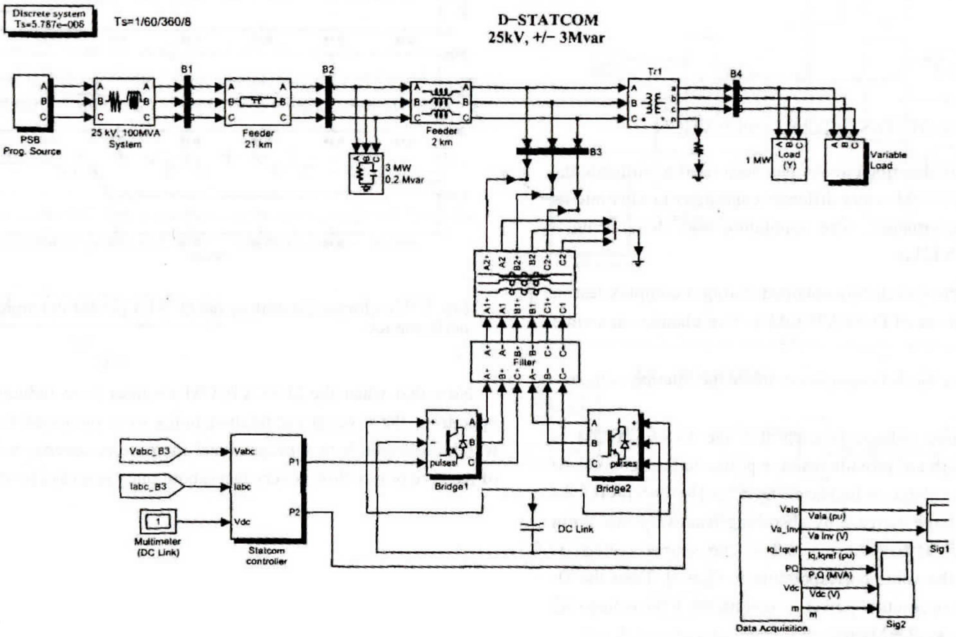
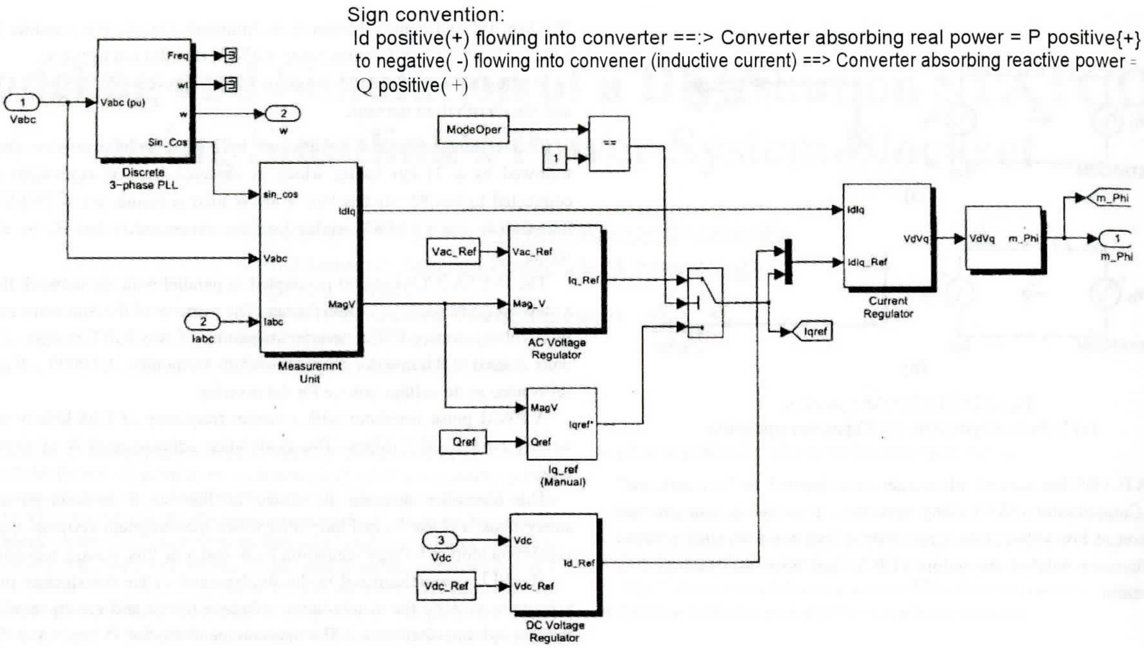


Fig. 3 Simulink diagram representing the D_STATCOM and the distribution network.



Sign convention:
Id positive(+) flowing into converter ==:> Converter absorbing real power = P positive{+}
to negative(-) flowing into convener (inductive current) ==> Converter absorbing reactive power =
Q positive(+)

Fig. 4 D-STATCOM control system

quadrature-axis components (V d and V q) that the PWM inverter has to generate. The V d and V q voltages are converted into phase voltages Va' Vb' Vc which are used to synthesize the PWM voltages.

The network bus voltage is regulated by a PI controller which produces the I_q reference for current controller. The I_d reference comes from the de link voltage regulator which maintains the DC link voltage constant.

IV. SIMULATING THE D-STATCOM OPERATION

The Simulink diagram described above has been used to simulate the operation of the D-STATCOM under different conditions to illustrate its static and dynamic performance. The simulation was done using a discrete step time (T- = 5.8I1s).

Figs. 5 and 6 show the waveforms obtained during a complex test in which the dynamic response of D-STATCOM to step changes in source voltages is observed.

The *PSB Prog. Source* block is used to modulate the internal voltage of the 25-kV source.

At starting- the source voltage is such that the D-STATCOM is inactive. It does not absorb nor provide reactive power to the network. At t = 0.125 s- the source voltage is increased by 6%. The D-STATCOM compensates for this voltage increase by absorbing reactive power from the network (Q = +2.7 Mvar). At t = 0.2 s- the source voltage is decreased by 6% from the value corresponding to Q = 0. Then the D-STATCOM must generate reactive power to maintain a 1 pu voltage (Q changes from +2.7 Mvar to -2.8 Mvar).

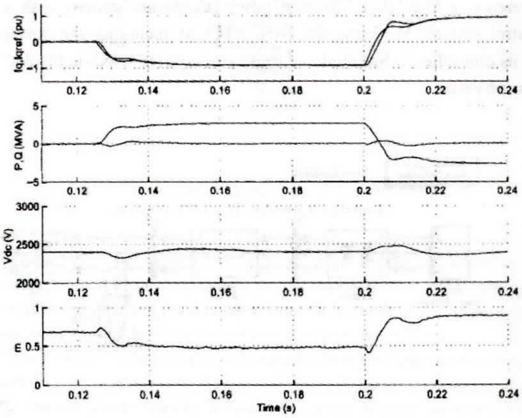


Fig. 5 Waveforms illustrating the D_STATCOM dynamic performance.

Note that when the D-STATCOM changes from inductive to capacitive operation- the inverter modulation index m is increased from 0.48 to 0.87 which corresponds to a proportional increase in inverter voltage. Reversing of reactive power flow is very fast (about one cycle) as shown in Fig. 6.

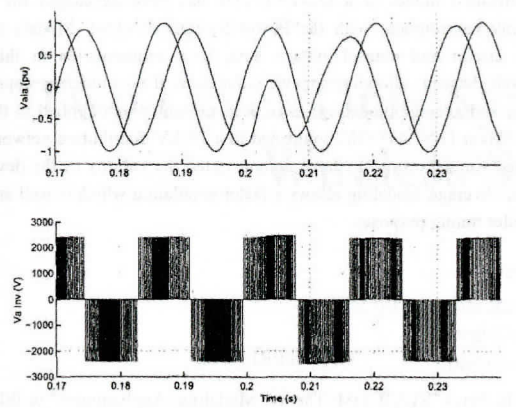


Fig. 6 Voltage and current waveforms during the change from inductive to capacitive operation at t = 0.2 s.

V. AVERAGE MODELING TO ACCELERATE THE SIMULATION

The above simulation uses a detailed model of the inverter that includes the switching of the inverter power switches. This model requires a very small computing time step to well represent the PWM waveforms (T- = 5.8 us)- The simulation time is thus fairly long. If we are not interested to represent the chopping of the PWM waveforms- we can use instead a voltage source having the same average value computed upon a chopping period (111680 in this case). By using this "average model"- we can simulate the system operation with a larger step time resulting in a simulation time reduction.

The "average model" can be built based on the energy conservation principle. As shown in Figure 7- the instantaneous power must be the same on the DC side and the AC side of the inverter (assuming an ideal inverter):

$$V_{dc}I_{dc} = v_a i_a + v_b i_b + v_c i_c \tag{1}$$

The DC current in the DC-link capacitor can be then computed from the measured AC instantaneous power and the DC-link voltage V_{dc} as:

$$I_{dc} = \frac{v_a i_a + v_b i_b + v_c i_c}{V_{dc}} \tag{2}$$

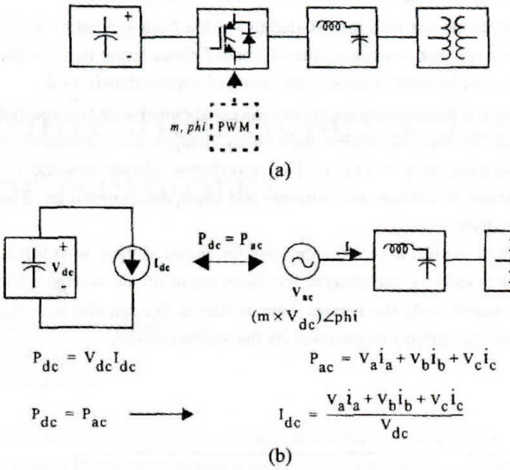


Fig. 7 Average modeling technique
(a) Detailed model (PWM)- (b) Average model.

Fig. 8 shows the Simulink implementation of the inverter's average model. On the AC side- the inverter is modeled as three controlled voltage sources which are determined by three voltages V_{abc} from the control system. On the DC side- it is modeled by the *DC link model.* In this model- a capacitor (represented by an integrator) is charged by a DC current source

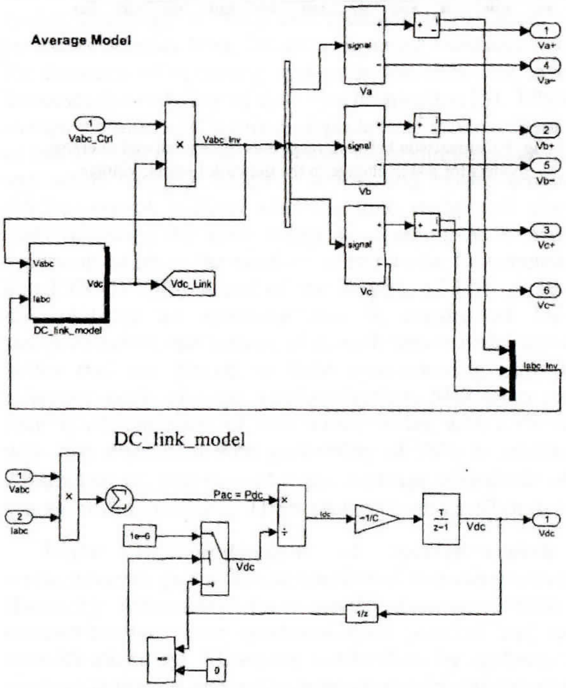


Fig. 8 Simulink diagram of the PWM inverter average model.

with value computed as shown in (2). A *Switch* block is used to avoid a division by zero at starting when the capacitor has no charge.

The same dynamic test with the detailed model has been applied to the D-STATCOM average model using a time step size 8 times larger than for the detailed model. The simulation time is thus reduced approximately by 8.

Fig. 9 shows a comparison between waveforms obtained with average and detailed models for the case where the system changes from inductive to capacitive operation at t = 0.2 s. The waveforms shown are the D-STATCOM phase A voltage and current- and the q-axis current Iq. The waveforms are quite identical for both models except for the inverter output voltage waveforms. In the detailed model- we can observe the chopping of the dc voltage while in the average model- only the average value is shown. We can also note that the dynamics of the currents is preserved by the average model.

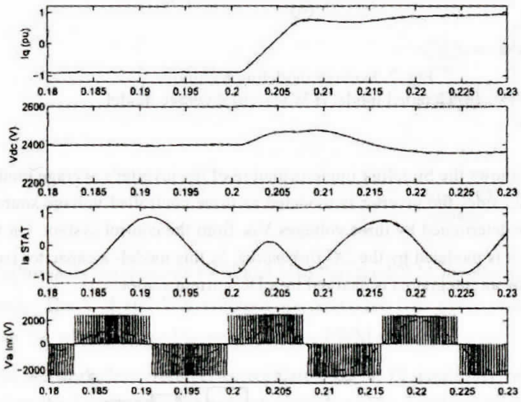


Fig. 9 Comparison between responses of detailed and average models for a step change in the network internal voltage.

VI. CONCLUSION

A detailed model of a D-STATCOM has been developed for use in Simulink environment with the Power System Blockset. Models of both power circuit and control system have been implemented in the same Simulink diagram allowing smooth simulation. Two modeling approaches (device and average modeling) have been presented and applied to the case of a ±3Mvar D-STATCOM connected to a 25-kV distribution network. The obtained simulation results have demonstrated the validity of the developed models. Average modeling allows a faster simulation which is well suited to controller tuning purposes.

VII. REFERENCES

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