Reactive Power Control of A 220kv Transmission Line Using PWM Based Statcom with Real Time Data Implementation

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Abstract-Static Synchronous Compensator (STATCOM) is the best device for reactive power compensation and power system stability. In this paper a novel STATCOM model is proposed. The STATCOM model used in this paper used a control algorithm. Pulse Width Modulation technique (PWM) is implemented with control algorithm for the generation of the gating pulses for IGBTs Installed in the Voltage Source Inverter (VSI). The STATCOM model is implemented in a 220KV existing transmission line located in Multan for reactive power compensation. The model is simulated in MATLAB/Simulink software and results are compared with the existing system. The results of STATCOM are compared with the capacitor which is already installed in the transmission system.

Keywords- STATCOM, Control Algorithm, PWM, VSI, MATLAB

I.INTRODUCTION

In recent past the demand of electrical energy has increased drastically which causes lots of problems for the power system stability. This will suggest that the electrical power system should be more flexible, reliable, accurate and should have faster response time. The transmission line is the major part of electrical system having high voltage and supply bulk amount of electricity from power generating ends to the substations that are located near to the population areas. Transmission and distribution system normally have the losses in between 6% to 8% [i].During past years the increased demand of electrical energy have created problems like reactive power deficiency, power transfer capability and power system stability. Severe blackouts happened in the recent past due to transient stability problems[ii-iii]. So for the improvement of transient stability many solutions have been provided which includes superconducting faults current limiters [iv-v], superconducting magnetics energy storage units[vi-viii] and thyrsitor controlled braking resistors [ix]. These solutions have the disadvantage of rigidity and slower reponse time.

Flexible AC transmission system (FACTS) devices are the most viable option for the power system performance, transient stability and reactive power compensation [x]. FACTS devices include TSC (Thyristor Switched Capacitor),SSSC (Static Synchronous Series Compensator) ,TCR (Thyristor Controlled Reactor), TCSC (Thyristor Controlled Series Compensator),SVC (Static VAR Compensator) and STATCOM (Static Synchronous Compensator). FACTS devices are implemented using power electronics converters and thyristors for reactive power compensation and to improve power system stability[xi-xiii].The FACTS devices are categorized by series and shunt connected compensators. Series compensators include Thyristor Switched Capacitor, Static Synchronous Series Compensator, Thyristor Controlled Reactor and Thyristor Controlled Series Compensator. And shunt compensators include Static VAR compensator and static synchronous compensator [xiv].

STATCOM is considered to be one of the best devices for reactive power compensation, transient stability improvement, better voltage support capability, better power transfer capability and have faster response time. Moreover, a STATCOM does not need thyristor-switched capacitors (TCS) or thyristor-controlled reactors (TCR) and it does not generate harmonic order distortions [xv-xvi]. A STATCOM model is connected to the 230KV transmission line for the improvement of transient stability and reactive power compensation of the system. This model is implemented with the help of PID controller along with feedback signals to control the firing angle of the converter [xvii]. STATCOM model is used for the power system improvement in [xviii-xix].A comparison is made between SVC and STATCOM of the same ratings for the shunt compensation and proves STATCOM gives better results [xx, xxi].

II.PROBLEM STATEMENT

Now a days demand of electricity is increased a lot due to this reason an existing electrical system is require transferring more power than its standard ratings. This problem can be overcome by simply installing new transmission lines. But this solution is not a best solution. This solution obviously will increase the cost of the system and also will take much time for the installation. And another important factor which comes into existence is the environmental impacts of the transmission system which has to be installed. We have to provide other solutions for this problem.

Due to high demand of electricity voltage of the system decreases which will increase the demand of high current. High current will in return damage the transmission line conductors. And also the reactive power of the system will increase exponentially. Severe blackout happens due to these reasons in the past.

To maintain the reactive power balance in transmission line FACTS devices are installed. And amongst the FACTS devices STATCOM controllers provide better performance for system stability and reactive power compensation. STATCOM controllers provide leading and lagging reactive power, faster response time and improve transient stability of the system.

In this paper a 220KV transmission line known as Multan Samundri-1 transmission line is modeled in MATLAB/Simulink. The line already provided with capacitor banks for reactive power compensation which is an older technique. A STATCOM controller is implemented for this transmission line in MATLAB/Simulink. A comparison will be made between STATCOM response and capacitor bank response for reactive power compensation.

III.STATCOM

A STATCOM is one of the most promising devices for improvement of power system stability. STATCOM may have many topologies, for most practical applications it uses DC to AC converter also known as Voltage Source Inverter (VSI). A STATCOM mainly consists of Voltage Source Inverter, DC capacitor, link reactor and filter components.Voltage source inverter thyristors, MOSFETs or IGBTs. The essential hypothesis of VSI is to create an arrangement of contorllable 3-phase yield voltages/currents at the fundamental frequency of the AC line voltage from DC source voltage, for example, a charged capacitor or any DC energy supplying device. By adjusting the phase angle and magnitude of the output current and voltage, the system can provide active as well as reactive power between AC and DC buses, and stabilize AC bus voltage.

The performance of a STATCOM for reactive power compensation is directly related to the performance of VSI, and VSI is directly linked with the control techniques. Amongst many ways of controlling techniques of VSI pulse width modulation (PWM) and hysteresis current control are the famous ones.

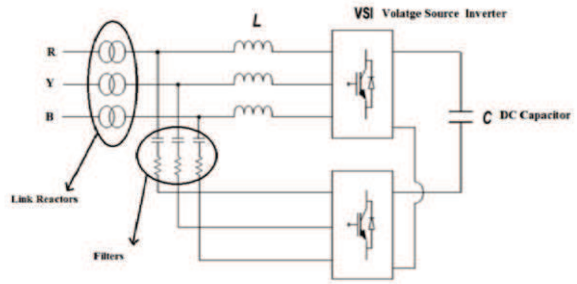

Fig. 1 Basic STATCOM Block

A. PWM STATCOM

PWM voltage control of STATCOM presents the control of three phase output voltage and phase angle with respect to the voltage of transmission line, thus controlling output current indirectly. In STATCOM PWM is done by comparing a high frequency triangular carrier wave with the sinusoidal waveform which in turn creates the desired gating pulses for the IGBTs. The gating signal just controls the switching of the VSI and exchange the active/ reactive power to the power system. There are many ways of generating the gate pulses. In this paper a control technique is developed for PWM for gating signals.

B. Control Block Methodology

The control signals of gate pulses are generated with the help of current computations. Figure 3 shows a single line diagram of current computations for the generation of gating pulses. The reference voltage V_s is multiplied with power factor angle and pass through a bandpass filter. V_{dc} is the DC bus voltage which subtracted from a reference voltage V_{dc*} and pass through a PID controller and generates the current I_{sm*}.

The unit vectors are used for wave shaping. Subtraction of PID controller current with source currents gives source reference currents(I_{sR*},I_{sY*},I_{sB*}). Subtraction of source reference currents with load currents(I_{LR},I_{LY},I_{LB}) gives the command currents (I_{cR*},I_{cY*},I_{cB*}). The difference resulting from I_{cR*},I_{cY*},$I_{cB*}$and I_{cR},I_{cY},I_{cB} pass through a low pass filter set at 10kHz.The output is the compare with the triangular carrier wave and produce sinusoidal PWM. SPWM is very effective for reducing switching losses of IGBTs.

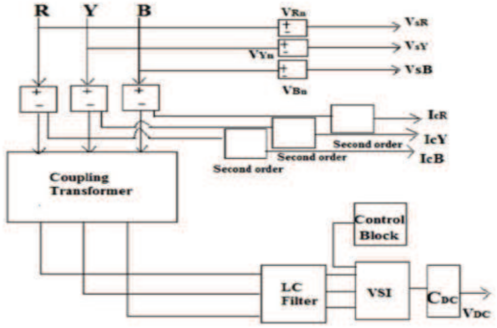

Fig. 2. STATCOM MATLAB Model

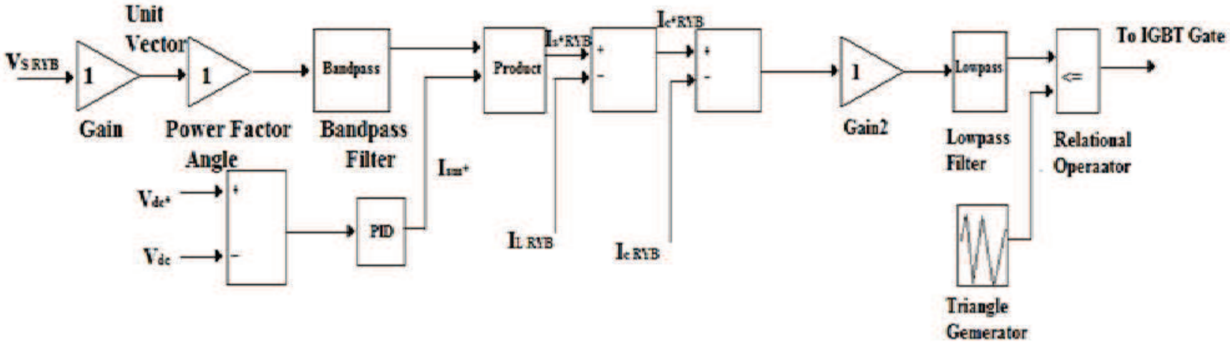

Fig. 3. Single Line Diagram of Control Methodology

C. Mathematical Modeling

The mathematical expressions for the control algorithm are given below.The equations for the three-phase Source Reference Currents (SRC) are given as:

$$I_{SR}* = I_{sm}* \times U_{SR} \tag{1}$$

$$I_{SY}* = I_{sm}* \times U_{SY} \tag{2}$$

$$I_{SB}* = I_{sm}* \times U_{SB} \tag{3}$$

Where,

$$U_{SR} = \frac{v_{RS}}{V_S} \tag{4}$$

$$U_{SY} = \frac{v_{SY}}{V_S} \tag{5}$$

$$U_{SB} = \frac{v_{SB}}{V_S} \tag{6}$$

Here v_{SR}, v_{SB} and v_{SB} are peak phase voltages.V_S is the peak source voltage it can be calculated as:

$$V_S = \frac{2}{3}\sqrt{v_{SR}^{\ 2} + v_{SY}^{\ 2} + v_{SB}^{\ 2}} \tag{7}$$

The value of *SRC* ($I*_{sm}$) is calculated through the PID controller. At nth instant the output of PID controller is given below:

$$Z_{0(n)} = Z_{0(n-1)} + K_{pdc}\{v_{dce(n)} - v_{dce(n-1)}\}K_{idc}v_{dce(n)} \tag{8}$$

$$Z_{0(n)} = I_{sm}* \tag{9}$$

In equation (8) $K_{idc}K_{pdc}$ are considered to be the integral and proportional gains of PID controller. $v_{dce(n-1)}$ is the error signal and $Z_{0(n-1)}$ is the output of PID controller at instant (n - 1). vdce(n) is the DC error signal at the instant n .$Z_{0(n)}$ is the required output for calculating the SRC.

The DC error signal can be calculated by taking the difference between the reference DC voltage $v*_{dc(n)}$ and the sensed DC voltage v_{dc} of DC bus capacitor.

$$v_{dce(n)} = v_{dc(n)}* - v_{dc(n)} \tag{10}$$

After the calculation of *SRC* the difference between SRC and measured load currents yields the active filter currents as:

$$i_{CR}* = i_{SR}* - i_{lR} \tag{11}$$

$$i_{CY}* = i_{SY}* - i_{lY} \tag{12}$$

$$i_{CB}* = i_{SB}* - i_{lB} \tag{13}$$

The error Active Filter current is obtained by taking the difference of reference currents and the measured Active Filter current i.e.

$$i_{CRe} = i_{CR}* - i_{CR} \tag{14}$$

$$i_{CYe} = i_{CY}* - i_{CY} \tag{15}$$

$$i_{CBe} = i_{CB}* - i_{CB} \tag{16}$$

The error currents of active filter will pass through a low pass filter and after that it is compared with carrier triangular wave of frequency 10 kHz then following things happen:

If,
i_{cRe} < carrier wave magnitude
{The upper Switch of IGBT is turned on}
Else if,
i_{cRe} > Carrier wave magnitude
{The lower switch of IGBT is turned off}
End.

D. System Under Study

A 220KV transmission line is taken into account. The line is installed in Multan and is known as Multan Samudri-1 transmission line. This system is implemented in MATLAB/Simulink program to study the STATCOM and capacitor behavior on the specified line. A single line diagram of the system is shown in figure 4. Two loads are connected to transmission system. One load is of 300MW and given the step of 0.2seconds and the other load is of 350MW and will connect after a 0.5 seconds interval. The behavior of capacitor and STATCOM is studied when these two loads are connected to the system.

E. Simulation Results

The simulation results are represented by the Fig. 5-12. Initially the sytem shows its response before 0.2 second. After 0.2 second capacitor or STATCOM is connected to the system and after 0.5 second the other load is connected to the system and shows the system response. Figure 5 and figure 6 shows the voltage waveforms of capacitor and STATCOM. As shown in figures initially before 0.2 second the the system is unstable and there is no sinusoidal response as the system requires some compensation. After 0.2 second when capacitor is connected to the system the system voltage stabilizes and become sinusoidal. After 0.5 second the voltage remains the same as when the second load is connected to the system. So, voltage waveform is constant which shows that the system implemented is stable. When STATCOM is connected to the system it also shows the same response as in the case of capacitor it is because of the fact that the voltage have no influence on the reactive power which satisfies the condition of system's performance. The Fig. 7-8 shows the current waveforms of the system when capacitor and STATCOM are connected to the system. Figure 7 shows the reponse of capacitor. Initially before 0.2 second the system response is very unstable when capacitor is connected at 0.2 second the system currents requirement decreses as capacitor starts supplying the current.

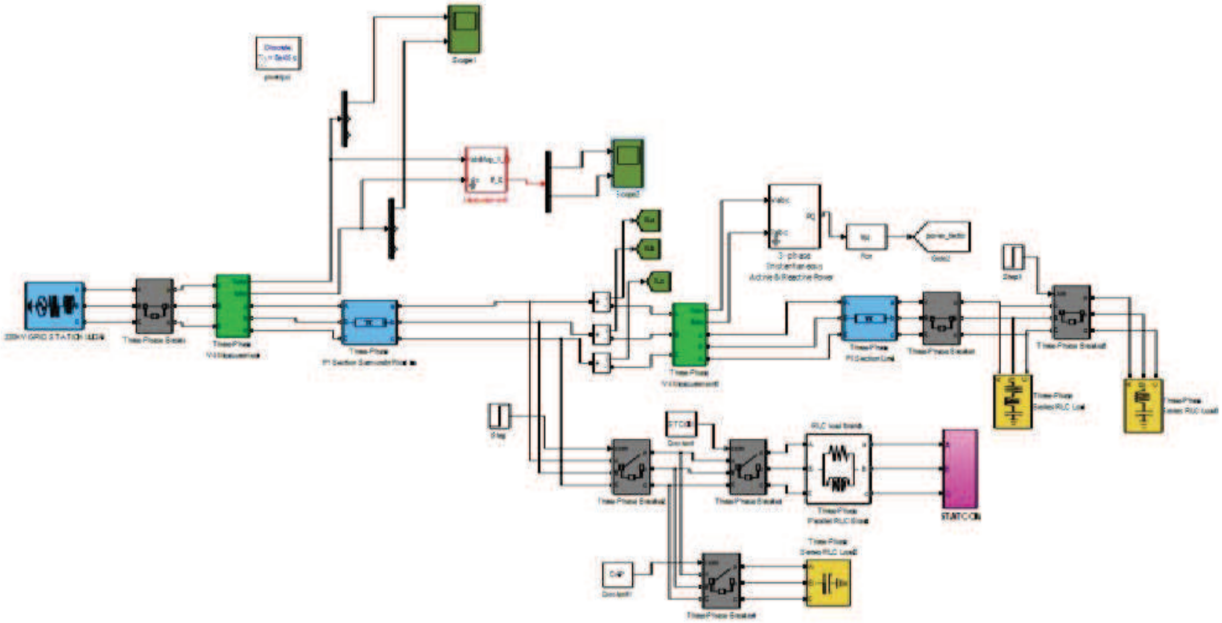

Fig. 4. MATLAB/Simulink Model of 220KV Transmission line with Capacitor and STATCOM Implementation

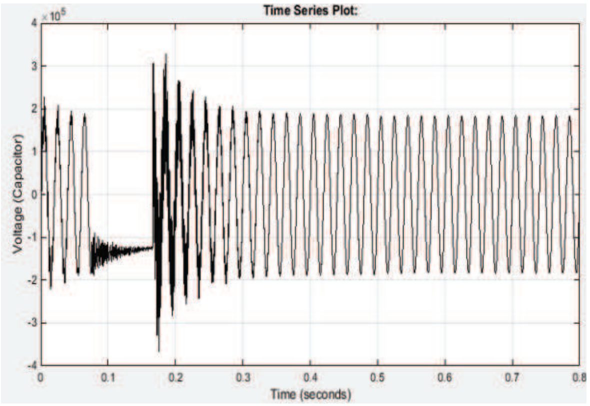

Fig. 5. Voltage of System when Capacitor is Connected

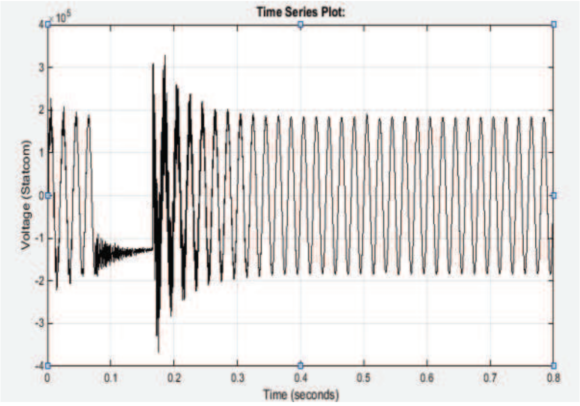

Fig. 6. Voltage of the System when STATCOM is connected

But when the second load is connected to the system at 0.5 second the system's current increses which in turn increase the reactive power of the system.

Fig. 8 shows the response of the STATCOM. At 0.2 second the STATCOM is connected to the system and STATCOM supplies the current. The wavform shows the response of the current waveform as the current requirement is decreased. At 0.5 second the other load is connected to the system which should increase the current demand of the system but it does not happen as the STATCOM supplies the current itself and the syetm's current requirement is decresed which shows that STATCOM stabilizes the system.

In Fig. 9-10 the active power of the system is shown when capacitor and STATCOM are connected the system under consideration.

As shown in Fig. 9-10 the active power remains the same for capacitor as well as for STATCOM. This shows that the system implemented is stable.

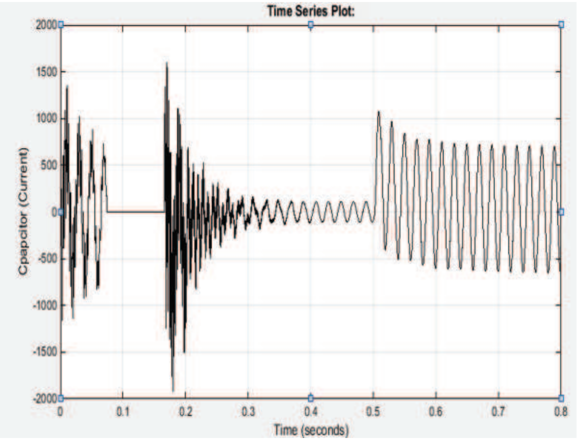

Fig. 7. Current of the System when Capacitor is Connected

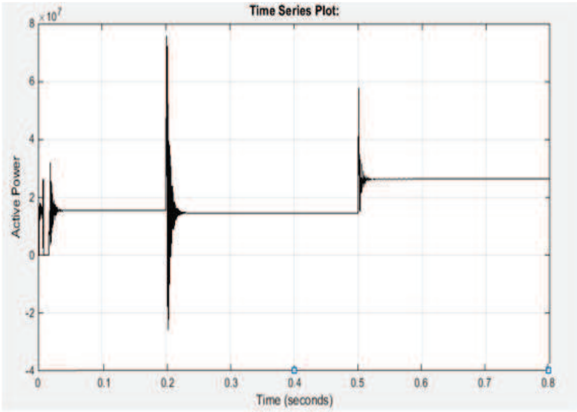

Fig. 8. Active Power of the System when Capacitor is Connected

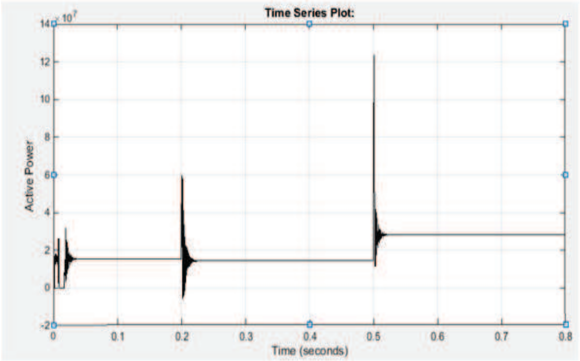

Fig. 9. Active Power of the System when STATCOM is Connected

Now the wavefoems of reactive power are shown in Fig. 11-12. As shown in Fig. 11 when capacitor is connected to the system at 0.2 second the capacitor compensates the system's reactive power. But when the second three phase load is connected to the system at 0.5 second the system's reactive power increases as the capacitor is not suitable for variable loads. Capacitor shows the disadvantage of fixed compensation in this case. So, capacitor will never be used for variable loads.

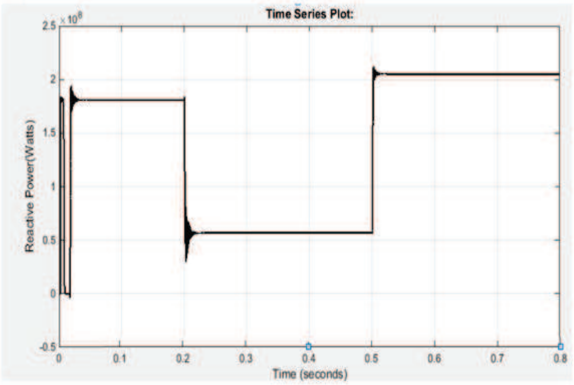

Fig. 10. Reactive Power of System when capacitor is connected

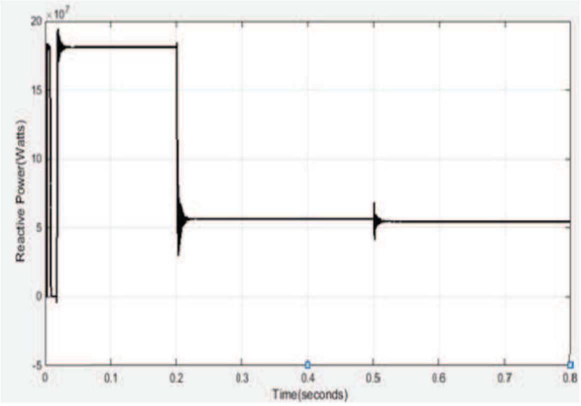

Fig. 11. Reactive Power of System when STATCOM is connected

Fig. 12 shows the response of reactive power when STATCOM is connected to the system at 0.2 second. After 0.2 second the STATCOM compensates the reactive power of the system and decreases the reactive power demand of the system. When the second load is connected to the system at 0.5 second the STATCOM try to reduce the reactive power demand of the system again. And the reactive power of the system remains nearly constant for both the loads as STATCOM is used for variable loads. So these results shows that the STATCOM is the best device for reactive power control and system stability.

IV. CONCLUSIONS

The results of simulation revealed that a STATCOM behaves better in reducing harmonics as compared to existing installed capacitor in the transmission system. The voltage and current waveforms also indicate that a STATCOM is better in maintaining the system's current and voltage sinusoidal waveforms. Moreover, the result of active power show that the system implemented is stable and provides better voltage regulations. From our results of all available waveforms, we can conclude that the STATCOM is the best choice for the reactive power compensation and power system stability for the transmission line under study. And furthermore, STATCOM can be implemented to the other transmission lines having the problem of reactive power compensation.

APPENDIX

Two Loads: Active Power: 300 MW and 350 Mw, Freq: 50 Hz, Phase to Phase Nominal voltage
Transmission Line:220KV, Line Length 196Km, Conductor ACSR(Zebra), Positive Sequence Impedance (0.06774 + j0.40211) Ω/km, Zero Sequence Impedance (0.22623 + j1.1653) Ω/km, Positive Sequence Resistance (0.0677 Ω/km),Zero Sequence resistance (0.22623 Ω/km)Positive Sequence Inductance (1.28 mH/km), Zero sequence Inductance (3.709 mH/km), Positive Sequence Capacitance (12.74 nF/km),Zero Sequence Capacitance (7.751 nF/km)
STATCOM Parameter: 220KV, ±150MVAR, R=0.3 , L= 0.33, C_{dc}=300 mF, V_{dc}= 2.5KV , V_{ref}=1.0

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