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Study, Mathematical Modeling And Simulation Of New Generation STATCOM

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ABSTRACT

Modeling and simulation of Fixed Capacitor new generation Static synchronous compensator STATCOM for power system stability. New generation STATCOM based on modular multilevel converter (MMC) for power system stability enhancement and improvement of power transfer capability have been presented in this paper. The Modular Multilevel Converter (MMC) represents an emerging topology with a scalable technology making high voltage and power capability possible. First, we obtain mathematical modeling and find output voltage and current of MMC. Secondly, we obtain power flow results and then real power, reactive power, output current and output voltage profiles have been studied for an uncompensated system and then compared with the results obtained after compensating the system using new generation STATCOM. All simulations have been carried out in MATLAB/SIMULINK environment.

Keywords : *FACTS, real and reactive power, STATCOM, MMC and stability.*

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1 INTRODUCTION

Modern power system is complex and it is essential to fulfil the demand with better power quality. Advanced technologies are nowadays being used for improving power system reliability, security and profitability and due to this power quality is improved. Voltage stability, voltage security and power profile improvement are essential for power quality improvement. To achieve optimum performance of power system it is required to control reactive power flow in the network. Construction of new transmission lines and power stations increase the problem of system operation as well as the overall cost. Regulatory limitation on the expansion of system network has resulted in reduction in stability margin thereby increasing the risk of voltage collapse [1]. Voltage collapse occurs in power system when system is faulted, heavily loaded and there is a sudden increase in the demand of reactive power. Voltage instability in power system occurs when the system is unable to meet the reactive power demand. Reactive power imbalance occur when system is faulted, heavily loaded and voltage fluctuation is there. Reactive power balance can be regained by connecting a device with the transmission line which can inject or absorb reactive power based on system requirement [2].One of the most important reactive power sources is FACTS (Flexible A.C transmission system) device. FACTS may be defined as a power electronic based semiconductor device which can inject or absorb reactive power in a system as per requirement. This device allows “Flexible” operation of an AC system without stressing the system. In this paper, performance of new generation STATCOM based on modular multilevel converter (MMC) are analyzed. The MMC technology provides a high degree of flexibility in converter design and station layout and it is built up by identical, but individually controllable submodules. Therefore the converter can act as a controllable voltage source, with a large number of available discrete voltage steps. Power electronic controllers were first introduced in HVDC transmission for improving power flow and system stability. The benefits of employing FACTS are many: improvement of the dynamic and transient stability, voltage stability and security improvement, less active and reactive power loss, voltage and power profile improvement, power quality improvement, increasing power flow capability through the transmission line, voltage regulation and efficiency of power system operation improvement, steady state power flow improvement, voltage margin improvement, loss minimization, line capacity and loadability of the system improvement [3].

2 Basic Description And Mathamatical Modeling Of Statcom And New Generation STATCOM

2.1 STATCOM:

STATCOM is a static synchronous generator operated as a shunt-connected static VAR compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. The STATCOM, like its conventional counterpart, the SVC, controls transmission voltage by reactive shunt compensation. It can be based on a voltage source and current source converter. Figure 2.1(a) show a one line diagram of STATCOM based on voltage source converter.

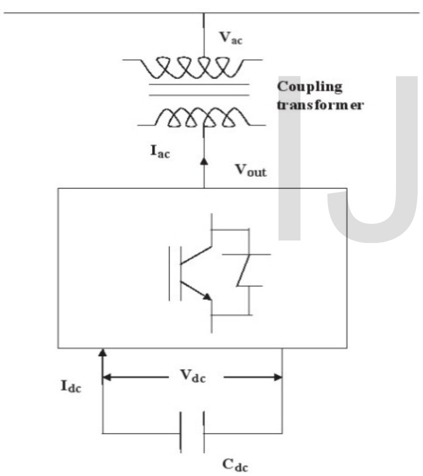

Figure 2.1(a). STATCOM based on voltage source converter

A combination of STATCOM and any energy source to supply or absorb power called static synchronous generator (SSG). Energy source may be a battery, flywheel, superconducting magnet, large dc storage capacitor etc[4].

2.2 New generation STATCOM

New generation STATCOM uses voltage source converter (VSC) technology based on modular multilevel converter (MMC) design. The MMC provided a nearly ideal sinusoidal shaped waveform on the AC side. Therefore, there is only little-if any-need for high-frequency filtering and no need for low order harmonic filtering and it also provided low switching frequencies, which reduced losses.

The MMC is a scalable technology. The voltage level determines the number of submodules needed, and the technology can be used up to the highest transmission voltages [8]. The configuration is without series connection of semiconductor switches, and hence problems with simultaneous switching are irrelevant. Losses are lower than for two-level and three-level VSCs, about 1 % per converter [6]. The low losses are obtained by low switching frequency in each submodule and low voltage across each switch [5]. However, as the submodules are switched at different points in time, the effective switching frequency of the converter is high, giving a low harmonic distortion [7].

A MMC with two-level half-bridge submodules requires twice the number of switch of to a two-level VSC of the same rating. For a MMC with two-level full-bridge submodules, the need for IGBTs is twice as high as with half-bridge submodules [8]. The MMC has no DC link capacitance, but one capacitor in each submodule and these capacitors require both large voltage capacity and large capacitance. The result of many semiconductor switches and capacitors with high ratings is a heavy and bulky circuit, giving a converter that is less compact than the classical VSC, but still more compact than the LCC [8].

The MMC with two-level half-bridges cannot block fault currents during a DC pole to pole fault. With two-level full-bridge submodules the MMC is capable of suppressing the fault current and therefore no AC breaker opening is needed [8]. It can be discussed whether this advantage is large enough to defend the increased number of semiconductors. As both vendors delivering MMC solutions uses two-level half bridges [9, 6], only this solution will be described in the following.

An advantage with MMCs compared to classical VSC is that the $\frac{dv}{dt}$ on the AC side is reduced as the voltage steps at the terminals are smaller. The MMC structure and the submodule circuit show in below:

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Figure 2.2 (a) The MMC Structure

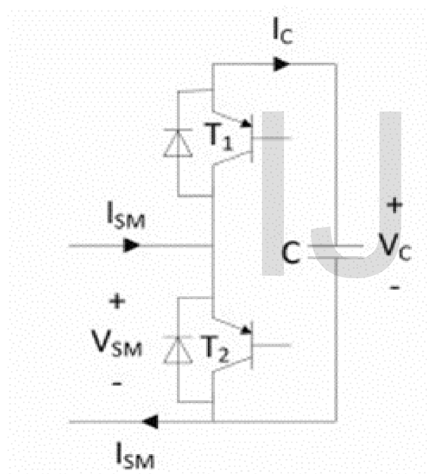

Figure 2.2 (b) The Submodule Circuit

The mathematical modeling of MMC:

Using thyristors, the only controllable parameter is the firing angle, and therefore modelling of the LCC is quite straight forward. For VSC schemes using series connected IGBTs, all the series connected switches are either conducting or blocking. This is utilized in the modelling by defining the share of time the switches are on, the duty ratio [9]. This method cannot be applied for MMCs as some submodules in the multivalve are inserted while others are bypassed. The selection of which submodule to insert or bypass is made on basis of measurements of the capacitor voltages [5]. The capacitor voltages must be kept in a narrow band and this is done through the submodule selection algorithm, using the knowledge of whether a capacitor will charge or discharge given the present current direction. The following circuit model is developed assuming infinite switching frequency in the converter and infinitive number of submodules per multivalve. These assumptions are made in order to enable the development of a continuous model [10].

Using Kirchhoff's current law in Fig.

$Iu + I_l = Iv$ (3)

$Iu = I_{s1} + I_{abc}$ (4)

$I_l = Is2 + Iabc$ (5)

Put equation 4 and 5 in equation 3 gives:

$Iv = Is1 + Iabc + Is2 – Iabc$

$= Is1 + Is2$ (6)

The difference between the two multivalve currents is:

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$Iu-Il = Is1 + Iabc – (Is2-Iabc)$

$= Is1- Is2 + 2Iabc$ (7)

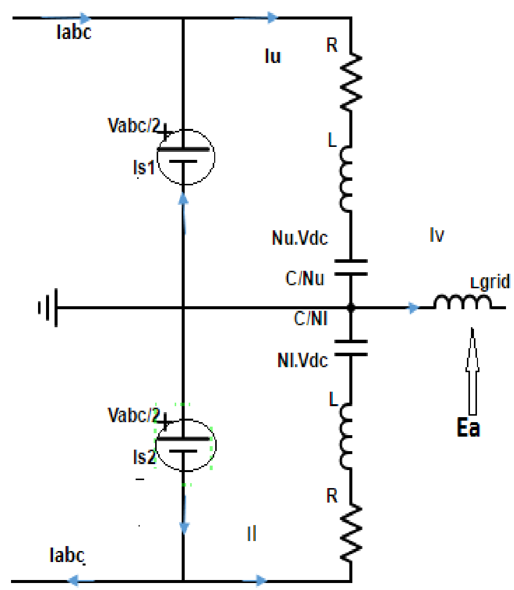

Figure 2.2(c) Continuous Equivalent of a Phase Leg

If the converter consists of N submodules per multivalve, and n_m = 0 means that all the N submodules are bypassed, while n_m = 1 means that all N submodules are inserted, then the available voltage in a multivalve m, i.e. sum of all the inserted capacitor voltages, is given as:

$$V_{Cm} = n_m . V_{dc} \quad (8)$$

Where m = u,l

The sum of the two insertion indexes should be kept equal to 1, as an insertion in one multivalve corresponds to a bypassing in the other multivalve in the phase, expressed mathematically as:

$$Nu + N_l = 1 \quad (9)$$

Using Kirchhoff's voltage law in Fig.3.2(c)

$$\frac{Vabc}{2} - Nu.V_{dcu} - Ea - (RIabc + L\frac{dIabc}{dt}) - Lgrid.\frac{dIv}{dt} = RIs1 + L\frac{dIs1}{dt} \quad (10)$$

$$\frac{-Vabc}{2} + N_l . V_{dcl} - Ea + RIabc + L\frac{dIabc}{dt} - Lgrid\frac{dIv}{dt} = RIs2 + L\frac{dIs2}{dt} \quad (11)$$

Assuming that:

$$I_{s1} = I_{s2} \quad (12)$$

Combining this assumption with the fact that Ea = Ea in equations (10) and (11) gives:

$$Vabc - Nu.V_{dcu} - N_l V_{dcl} = 2(RIabc + L\frac{dIabc}{dt}) \quad (13)$$

In the perfectly balanced case Vdcu=Vdcl=Vabc. This shows that the circulating current is a result of not perfectly balanced multivalve voltages. If the deviation from Vabc is zero, the steady state value of Iabc will also be zero. Using the assumption in equation (12) on equation (6) gives:

$$I_{s1} = I_{s2} = \frac{Iv}{2} \quad (14)$$

And using the assumption on equation (7) gives:

$$Iabc = \frac{Iu - Il}{2} \quad (15)$$

Using that $\frac{Vabc}{2} = \frac{Vabc}{2}$ in equations (10) and (11) gives:

$$R(Iu+I_l) + L\frac{d(Iu+Il)}{dt} + 2Lgrid\frac{dIv}{dt} + 2Ea = N_l.V_{dcl} - Nu.V_{dcu} \quad (16)$$

L' can be defined as:

$$L' = L/2 + Lgrid \quad (17)$$

Inserting from equation (3):

$$Ea = 0.5(N_l.Vdcl - Nu.Vdcu) - (R/2)Iv - L'\frac{dIv}{dt} \quad (18)$$

Here Ea are Output AC voltage, Vabc are DC pole to pole voltage, V_{dcu} are Sum of capacitor voltages, upper multivalve; V_{dcl} are Sum of capacitor voltages, lower multivalve; Iu are Current in the upper multivalve, I_l are Current in the lower multivalve, Iv are Output AC current, Iabc are Circulating current, Nu are Insertion index, upper multivalve and N_l are Insertion index, lower multivalve.

Equation (18) shows that the output voltage, Ea, is only dependent on the output current, Iv, and the difference between the two multivalve voltages $Nu.V_{dcu}$ and $N_l V_{dcl}$ [17].

3 Performance Analysis Of Statcom AND New Generation statcom

3.1 Uncompensated system model

The basic transmission (11kV) model of an uncompensated system show in below figure 3.1(a)

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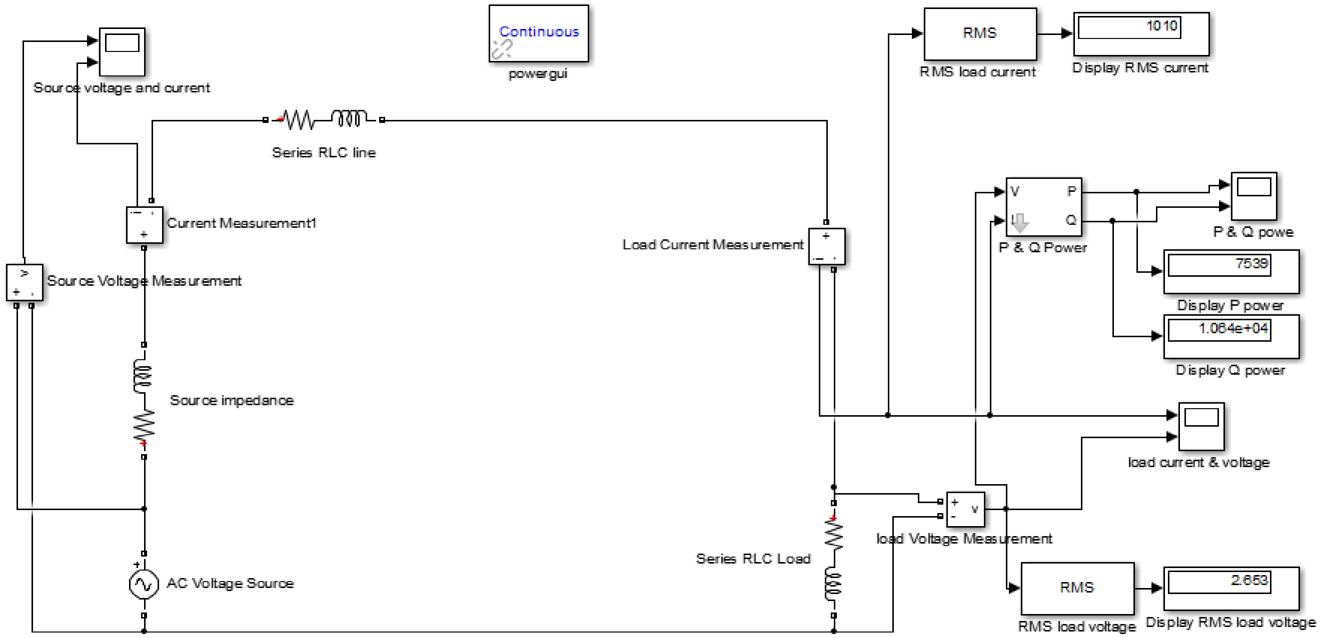

Figure 3.1(a) Basic transmission (11kV) model of an uncompensated system

This model consists of current measurement block, voltage measurement block, real and reactive power block and scopes. 11kv voltage is supplied from the AC voltage source to the system. Source impedance (0.01+0.001) Ω, Line impedance (5+0.023) Ω and load is kept constant at 25MW and 50MVAR for the above transmission line model. Simulation is done using MATLAB/SIMULINK. Current measurement block is used to measure the instantaneous source and load current flowing through the transmission line, Voltage measurement block is used to measure the source and load voltage. Real and reactive power in load side is measured using active and reactive power measurement block. Scopes display results after simulation. Above model provides three scopes: one displays the source voltage (V) and source current (I), second one displays real (P) and reactive (Q) power and third one displays load voltage (Vo) and load current (Io) after simulation. Real and reactive power flows obtained after simulation are shown in below:

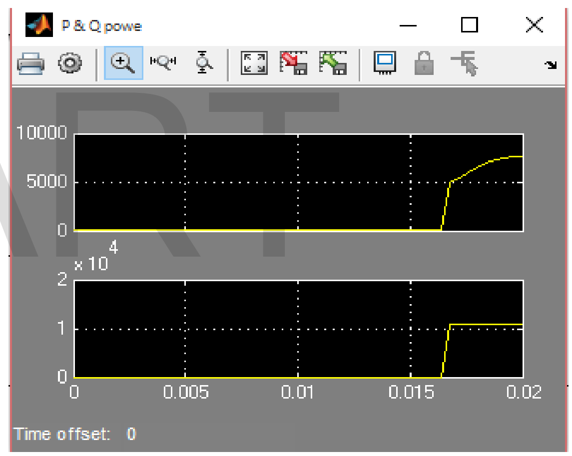

Figure 3.1(b). Real and Reactive power flow

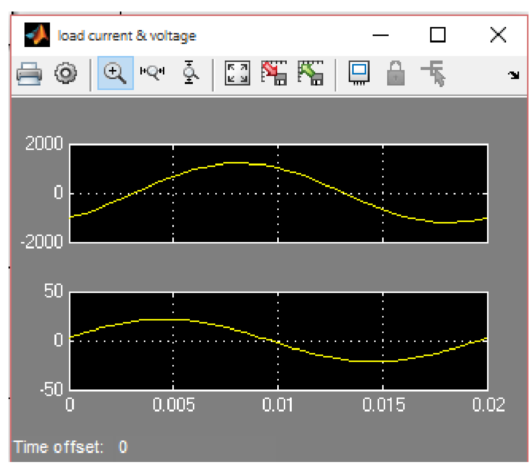

Figure 3.1(c). Load current and voltage

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3.2 new generation STATCOM compensated system

The basic transmission (11kV) model of new generation STATCOM based on MMC compensated system show in below figure 3.2(a)

The below figure 3.2(a) shows the compensated model of new generation static synchronous compensator based on MMC. The model is compensated for a particular value of capacitance (350µF) plots for real power (P), reactive power (Q), load voltage (Vo), load current (Io) and STATCOM current to system are shown below:

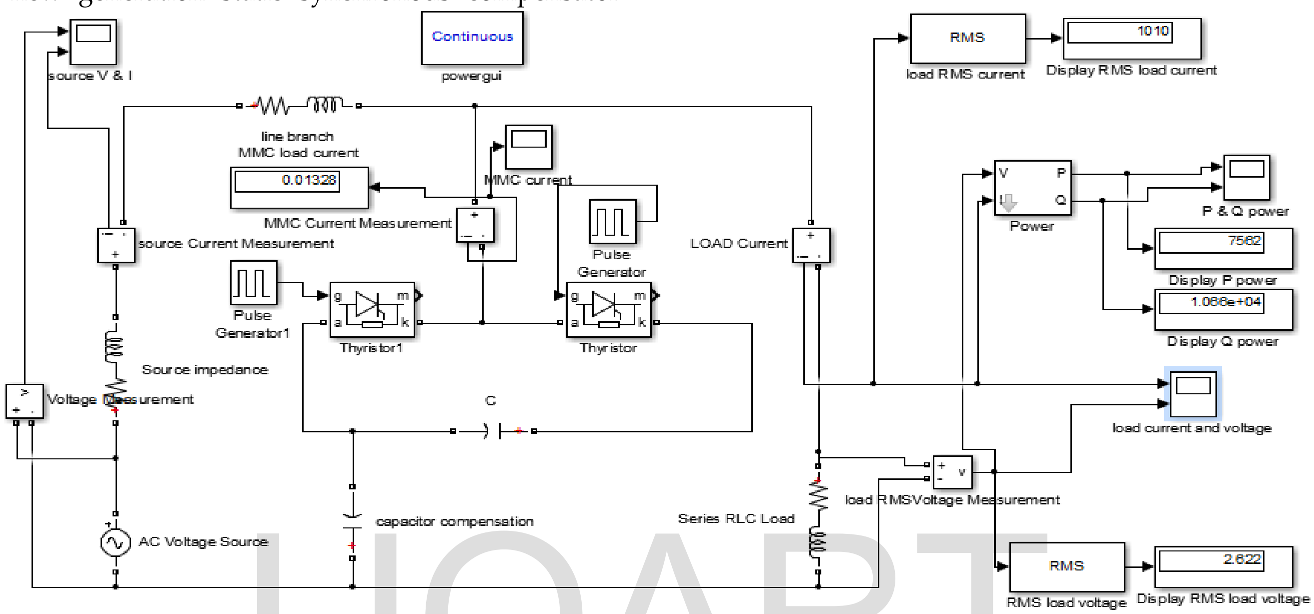

Figure 3.2(a) Basic transmission (11kV) model of new generation STATCOM compensated system

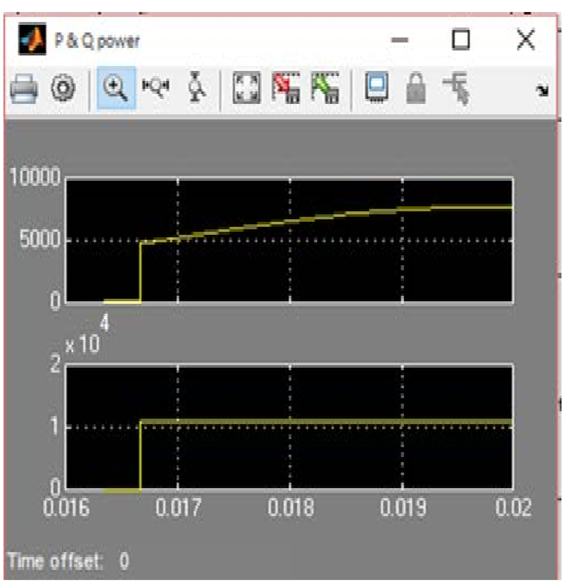

Figure 3.2(b) Real and Reactive power flow

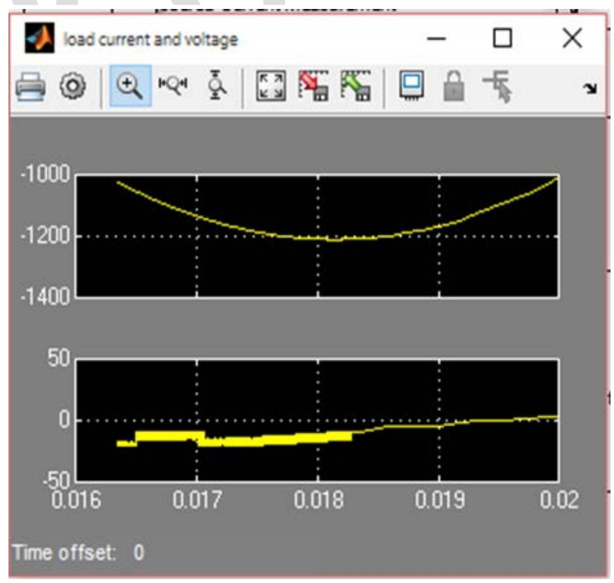

Figure 3.2(c) Load current and voltage

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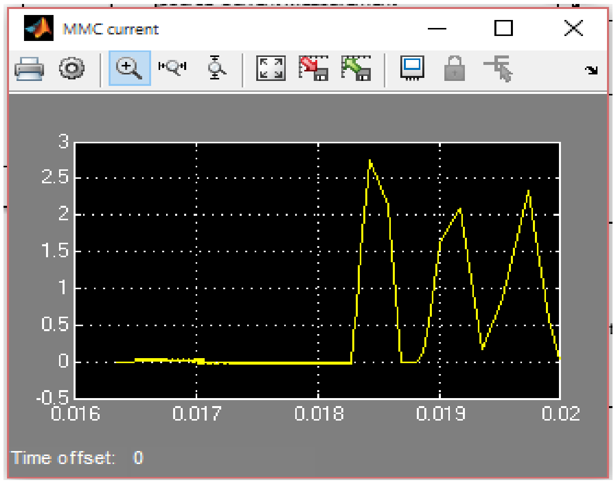

Figure 3.2(d) MMC current to system

4 Result And Discussion

For a particular value of capacitance (350 μF) and simulation time 0.2 sec. the real and reactive power, load voltage and load current variation with new generation STATCOM compensation system are tabulated below:

OUTPUT QUANTITY	WITHOUT compensation	New generation STATCOM compensation
RMS load current(A)	1010	1010
RMS load voltage(V)	2.653	2.622
Real power(MW)	7373	7562
Reactive power(MVAr)	1.064e+04	1.066e+04

Table4. Variation of power flow with different compensation system

From the above table we can see real and reactive power increases with the introduction of capacitance. But, it is also noted that compensation with new generation STATCOM base on MMC technology give +/- value up to four submodule circuit compare to STATCOM.

Capacitor design for new generation STATCOM:

The Thevenin equivalent is deduced using the trapezoidal integration method. V_C is the voltage across the capacitor and I_C the current through it show in figure 4 give below

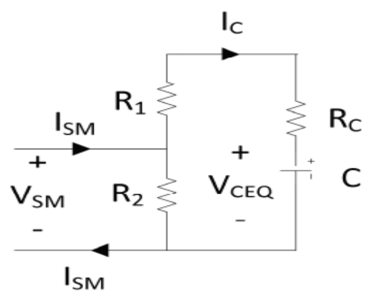

Figure 4: Sub-module Thevenin Equivalent

$V_C(t) = \int_0^t \left(\frac{1}{C}\right).dt$

$V_C(t)=V_C(t- \Delta T) +1/2C(I_C(t-\Delta T)+I_C(t)).\Delta T$ .. (19)

The capacitor is first calculated based on the wrost case where the STATCOM compensates for strong unbalance currents.

$C = T/2R_c$ … .. (20)

In balance conditions, the active power exchanged between the STATCOM and the grid (P_{SM}) is given by question(21):

$P_{SM} = V_C*I_C = V_C.C.\frac{dVc}{dt} = \frac{3}{2}.Vsm * Ism$ (21)

where Vc is the capacitor voltage, I_{SM} the capacitor current, V_{SM} phase to neutral voltage peak value and I_{SM} the active current peak value.

By integrating (21), over a time interval [0, Δt], one obtains (eq. 22):

$C*(V^2c\ (\Delta t)-V^2o) = 3*V_{SM}*I_{SM}*\Delta t$

Where Vo is the capacitor voltage at t=0

Then the following active current(ISM) can be supplied by the STATCOM

$I_{SM} = 2C * \frac{|V^2c(\Delta t)-V^2o|}{3*Vsm*\Delta t}$ (22)

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Advantage of new generation STATCOM based on MMC over conversional STATCOM

There are following same advantage are given bellow

- Harmonic performance:
  - ✓ Due to the MMC technology, the degree of harmonic generation emission is quite small.
- Operational advantage:
  - ✓ A very high level of system availability, thanks to the redundancy of power modules.
  - ✓ Minimized maintenance and service requirements
- Network stabilization:
  - ✓ High dynamic performance: very fast response time
  - ✓ Excellent under voltage performance: highly efficient voltage support
- Economical benefits:
  - ✓ MMC with low switching frequencies means reduced losses
  - ✓ Fewer components translate into less time and cost demands for planning, engineering, construction, and commissioning.

5 Conclusion

MATLAB/SIMULINK environment is used for this comparative study using model and simulate of STATCOM and new generation STATCOM connected to a simple transmission line. The mathematical modelling of MMC has been presented. The MMC for new generation STATCOM mathematical modelling needs to be done differently to account for the fact that some submodules are inserted while others are bypassed. Assumptions were made to enable development of a continuous mathematical model. The MMC has the same advantages as two-level and three-level VSCs, d axis and q axis control can be done independently. This paper presents performance analysis and an elaborate comparison between their performances. Power flow and voltage profile are seen to improve with the compensating devices. Results, show that in case of MMC based compensation, reactive power flow improved. The modular concept make new generation STATCOM uniquely adaptive without compromising on performance, construction time and cost effectiveness.

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