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Improved Multi-String Inverter –Based STATCOM for High-Power Applications

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ABSTRACT

This Paper presents a comparative study between Cascaded Multi-level Inverter based STATCOM and Multi-String Multi-level Inverter based STATCOM and finally concludes on the possible design and implementation of the Multi-String Inverter based STATCOM for High Power applications. This conceptual design addresses the Voltage stability of the STATCOM inverters during unbalance conditions, Maximum percentage of sag voltage that can be compensated, Maximum swell voltage that can be absorbed by the STATCOM. A New control strategy is also proposed where the DC source of the inverter is controlled; rather controlling the inverter switching pulses as in any conventional system. Though this system may seem to insist more on the usage of coupling transformers, when compared to modern transformer less STATCOMs, this proposed method seems to be more economical and stable when compared to reference [1]. The THD analysis of the proposed system is also addressed for a comparative study using MATLAB SIMULINK.

Keywords: Multi-String multilevel inverter, power quality (PQ), static compensator (STATCOM).

I. INTRODUCTION

The recent developments in the industrial power sector as well as domestic sectors calls for a huge power transfer from sources which are located at a very large distances like cross country transmission system or elsewhere. It also demands for the addressing on issues which involve power quality, system reliability and stability. The large penetration of renewable sources, which are in uncertain and highly variable by nature as effective means of power generation has arisen new challenges to existing power networks. Nonlinear loads such as single phase ac tractions systems make the network to operate under undesired conditions [i.e., distorted, uncontrolled reactive power (VAR)], restricting the maximum active power transfer and significant unbalance enforcement [1].

The rapid development of the power electronics industry on the other hand has opened up opportunities for improving the operation and management of power system networks via flexible ac transmission. New developments are evolved in a perpetual manner in order to enhance the power electronic devices and their configurations to solve the new challenges ahead in a effective manner. Devices such as STATCOM have already proved their reliability and robustness in overcoming the problems caused due to grid overloading. The STATCOM as a reactive power source to increase the voltage profile of a power system network is well addressed in various papers. As an additional enhancement this paper takes a new perspective on the application of STATCOM for high power applications.

The drawbacks in a conventional STATCOM used for high power applications is that the Switching pulses of the Inverter is changed frequently, i.e., the STATCOM converter is operated in rectifier mode during Swell conditions in the grid, hence the reactive power is observed by the capacitor in the STATCOM. During sag condition the converter is operated in Inverter mode in ordered to enable the capacitor to discharge and hence allowing the capacitor to inject the reactive power into the grid, thus increasing the grid voltage profile. Hence this varying operation of the converter control causes a complexity in the whole control process of the converter itself.

Moreover the complexity extends to a new level during unbalanced voltage conditions; the symmetry of the grid voltage is lost when there is a phase unbalance in one of the phases. The control feedback signal tapped from the segregated phases of the grid starts to see swell of voltage in two of the phases and sag of voltage in one of the phase. Hence there will be a mixture of control signals which forces the converter to act in inverter mode for one of the phase and in inverter mode for two of the phases, hence causing miss-fire of the switches and leading to instability and collapse of the inverter.

A new method is proposed in reference [1] and [2] which suggests in maintaining the control signals of the inverter as completely open loop thus maintaining only one mode of operation i.e., in inverter mode only, hence ensuring the stability of the inverter during all operation conditions. The capacitor of the STATCOM is replaced by a controlled stiff DC source. The voltage of the DC source is varied by the control signal. Thus the DC source voltage is increased when there is sag condition in the grid. During swell condition the DC source voltage is reduce to negative, hence switching off all the switching devices of the inverter. Now the bleeder devices connected across the switches acts as load and absorbs reactive power from the grid hence reduces the swell voltage.

This paper discusses about the two effective types of inverters that can be used in the method of STATCOM control. The Cascaded Multilevel inverter and the Multistring inverters are considered for a comparative study and hence proposing an improved version of the Multistring inverter to be used in STATCOM for high power applications.

II. POWER SYSTEM NETWORK

Fig. 1 shows the power system model considered in this paper. The Power system network considered is a 33kV network with a long transmission line. The 33kV is stepped down to 415V via a power transformer and feds a 1.5MW non-linear load. The STATCOM is connected at the point of common coupling near the load. The coupling transformer of the STATCOM is rated at 5500V/33kV, 6MVA. The STATCOM is connected at the primary side of the coupling transformer.

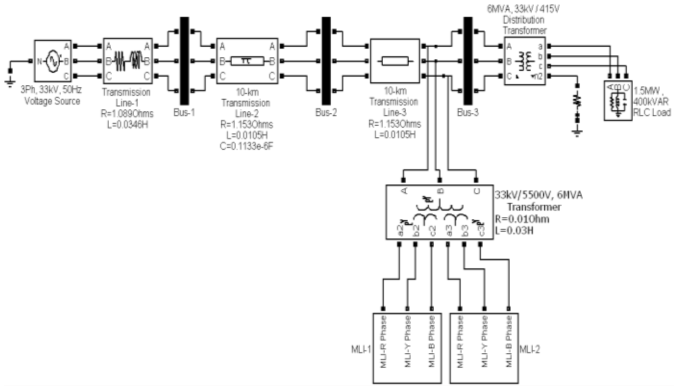

Figure 1: Power system model

Though the modern STATCOM configuration studies suggests the method of having a transformerless STATCOM for HV applications, in order to remove the burden of transformer cost, it has its own drawbacks, i.e., the switches required in such transformerless configurations are HV Switches which are difficult to control and the operating and replacement costs are high, moreover they require separate filter units in order to filter their harmonics. Hence the advantages of having a coupling transformer is that it itself acts as a harmonic filter, moreover the switches can also be operated at low voltages hence reduced cost and complexity.

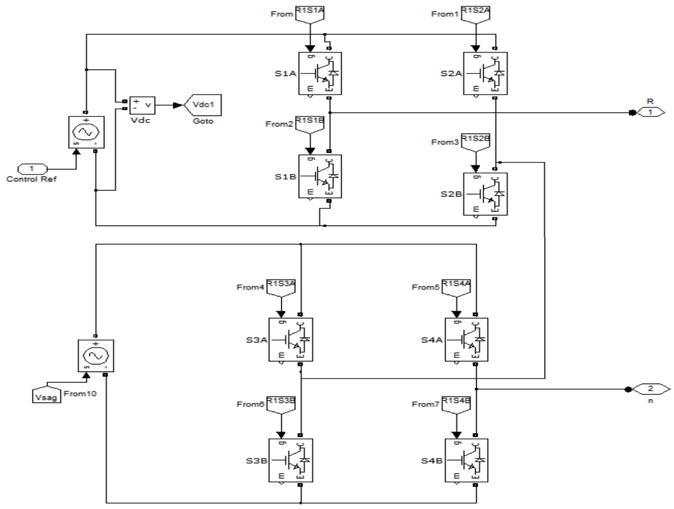

Figure 2: Cascaded five-level inverter (MLI-1/2).

The fig-2 and fig-3 shows the circuit configuration of one of the three phases (R-Phase) used in the STATCOM Multilevel inverter (MLI-1 or MLI-2). Fig-2 represents the Cascaded Multilevel Inverter and fig-3 represents the Multi-String Multilevel Inverter.

These single phase configurations are connected in star configuration in order to achieve a three phase inverter as shown in fig-4. The line inductors indicated in fig-4 are smoothing inductors to reduce spikes that occur during voltage overlapping condition during sag compensation.

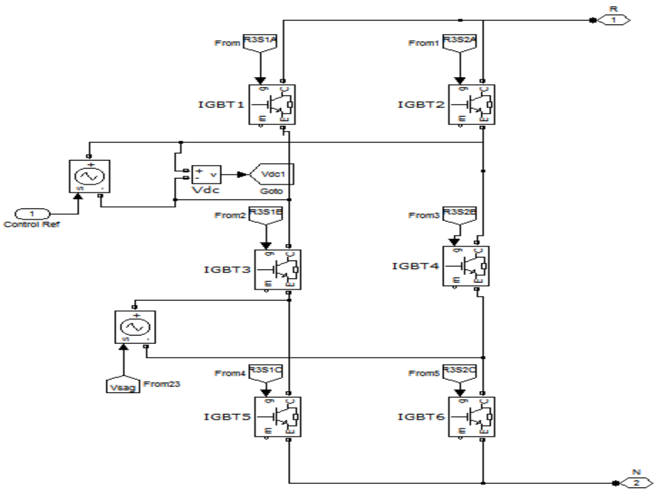

Figure. 3: Multi-String five-level inverter (MLI-1/2).

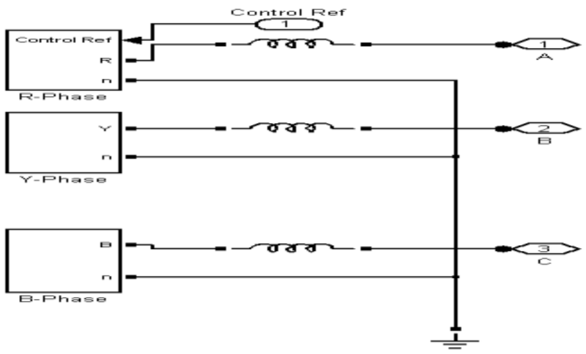

Figure 4: Simulink model of the proposed Multilevel Inverter (RYB Phases connected – MLI-1/2).

The Multilevel inverters are connected in cascade arrangement via the LV side of the coupling transformer as shown in fig-5.

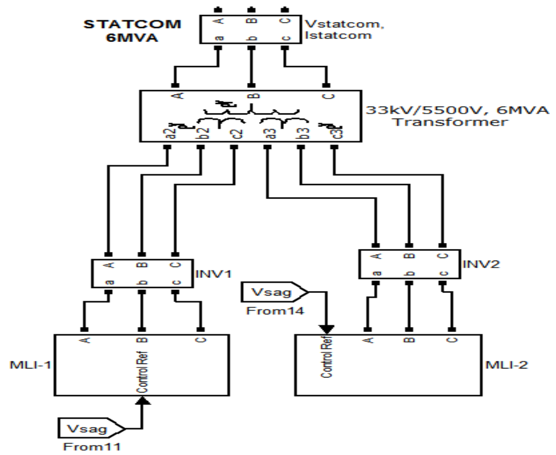

Figure 5: Cascaded arrangement of Multilevel Inverters MLI-1 and MLI-2 via LV side of the Coupling Transformer.

III. STATCOM CONTROLLER

The Fig.6 shows the Control circuit topology for the multilevel inverter (MLI-1 and MLI-2) voltage source Vdc. The STATCOM Voltage Magnitude controller compares the grid voltage magnitude with a reference voltage magnitude and generates the difference as an error signal. This error signal is amplified by a gain and is given as control input to the STATCOM inverter controlled DC voltage source

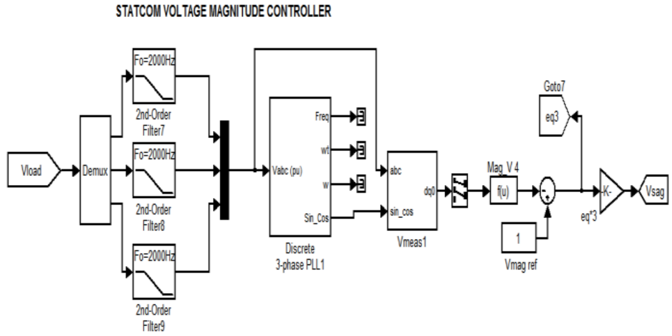

Figure 6: STATCOM Voltage Magnitude Controller.

The STATCOM Voltage magnitude controller is modeled based on the below equation (1).

A. Controller Equations:

STATCOM Voltage Magnitude Controller

$e_q*3=1-sqrt(V_d*V_d+V_q*V_q)$ (1)

IV. SIMULATION SYSTEM PARAMETERS

TABLE I

SYSTEM PARAMETERS

S. No	Description	Value	Units
1	Rated Power	6	MVA
2	Transformer voltage rating	33/5.5	kV
3	AC supply frequency, f	50	Hz
4	Inverter dc source voltage limits, Vdc	0-6000	V
5	Transformer leakage reactance, Xl	0.03	H
6	Transformer resistance, R	0.01	Ohm
5	Switching frequency	1200	Hz

The system configuration shown in Fig. 1 is considered for simulation. The simulation study is carried out using MATLAB/ SIMULINK. The system parameters are given in Table I.

The following are the scenarios subjected to the simulation:

- The Source voltage is initially set at 1pu at 33kV base.
- Sag of 15% (i.e., 0.85pu) is created in the load voltage from the time 0.1 to 0.2secs.
- A Swell of 10% (i.e., 1.1pu) is created in the load voltage from the time 0.2 to 0.3secs.
- Sag of 10% (i.e., 0.9pu) is created in the load voltage from the time 0.3 to 0.4secs along with an unbalanced loading of 10% in R-Phase.
- The load voltage is reset to 1pu at the time of 0.4secs and the simulation is stopped at 0.5secs.

The load voltage waveform is observed for variations, as the expected result shall be a uniform load voltage waveform of 1pu without any abrupt fluctuations in the load voltage waveform as indicated in the source voltage scenarios.

V. RESULTS AND DISCUSSION

A. STATCOM Controller Output

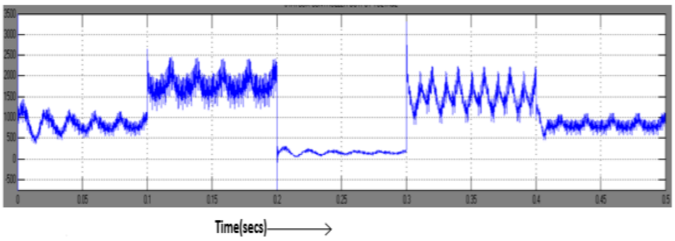

Figure.7: MATLAB Simulation output- STATCOM Voltage Magnitude Controller Output.

B. Cascaded Multilevel Inverter based STATCOM:

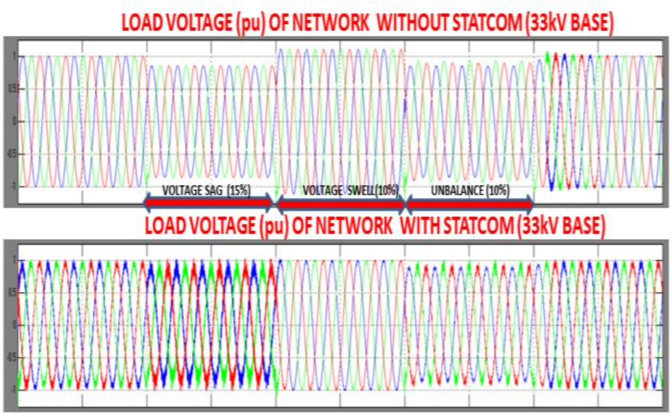

Figure. 8: Grid Voltage profile at the Point of Common Coupling – Cascaded Multilevel Inverter

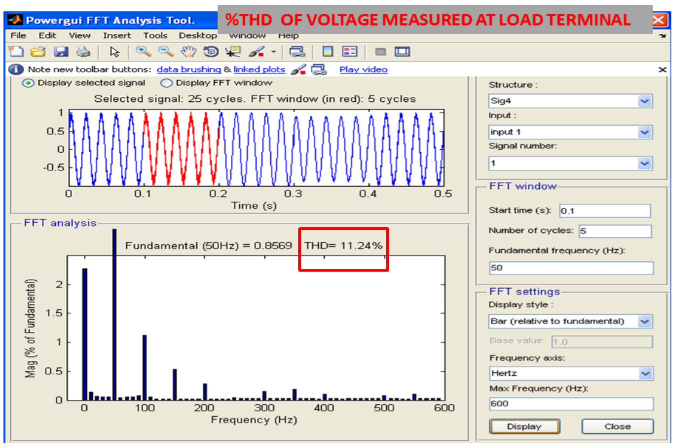

Figure.9: MATLAB Simulation output- Fast Fourier Transform analysis of Output waveform indicating the Total Harmonic Distortion (THD) in the Load voltage waveform – Cascaded Multilevel Inverter

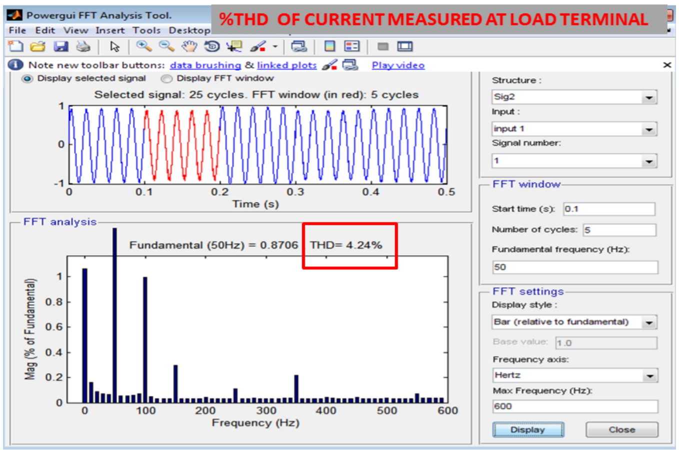

Figure.10: MATLAB Simulation output- Fast Fourier Transform analysis of Output waveform indicating the Total Harmonic Distortion (THD) in the Load current waveform– Cascaded Multilevel Inverter

C. Multistring Multilevel Inverter based STATCOM:

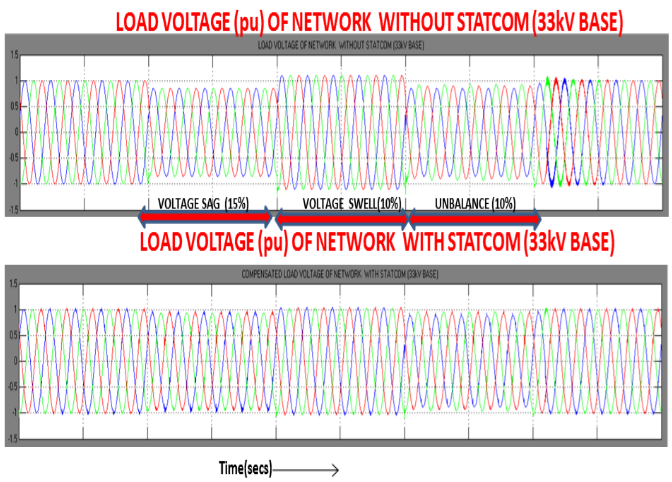

Figure. 11: Grid Voltage profile at the Point of Common Coupling – Multistring Multilevel Inverter

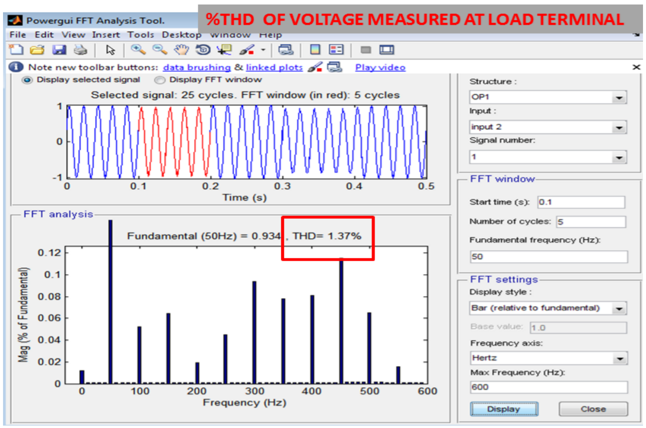

Figure.12: MATLAB Simulation output- Fast Fourier Transform analysis of Output waveform indicating the Total Harmonic Distortion (THD) in the Load voltage waveform – Multistring Multilevel Inverter

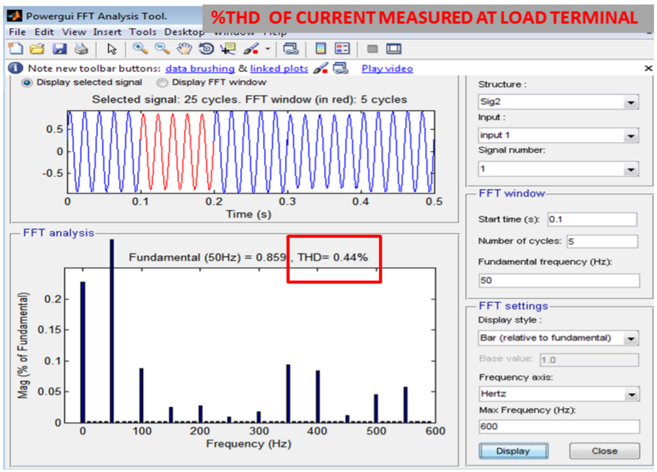

Fig.13. MATLAB Simulation output- Fast Fourier Transform analysis of Output waveform indicating the Total Harmonic Distortion (THD) in the Load current waveform – Multistring Multilevel Inverter

D. **Simulation Result Observations**

1) STATCOM Controller Output: The fig-7 shows the output waveform of the STATCOM Voltage Magnitude controller. It can be clearly understood that the response of the controller to Sag, Swell and Unbalanced conditions is prompt as discussed in section-III of this paper.

2) Cascaded Multilevel Inverter based STATCOM: The fig-8 gives the comparison between the grid voltage disturbances without STATCOM and with STATCOM. It is observed that the grid voltage profile is almost 1(pu) for all voltage disturbances. It is to be noted that the voltage waveform of fig-8 has more distortions during sag conditions. The voltage stability of the STATCOM is also high during unbalance voltage conditions.

The fig-9 indicates the Total Harmonic distortion of voltage waveform which is about 11.24%. The fig-10 indicates the Total Harmonic distortion of current waveform which is about 4.24%.

3) Multi-String Multilevel Inverter based STATCOM: The fig-11 gives the comparison between the grid voltage disturbances without STATCOM and with STATCOM. It is observed that the grid voltage profile is almost 1(pu) for all voltage disturbances. It is to be noted that the voltage waveform has very less distortions for all voltage conditions when compared to fig-8. The voltage stability of the STATCOM is also high during unbalance voltage conditions. The fig-12 indicates the Total Harmonic distortion of voltage waveform which is about 1.37% which is much lower when compared to fig-9 i.e., 11.24%. The fig-13 indicates the Total Harmonic distortion of voltage waveform which is about 0.44% which is much lower when compared to fig-10 i.e., 4.24%. It is evident from the above observations that the THD value measured at the load voltage is much less in both the inverter cases when compared to THD value of 22.54% as reported in reference [1].

VI. CONCLUSION

This Paper presents a comparative study on the MATLAB SIMULINK simulation results high power STATCOM which employs Voltage magnitude control for both Cascaded Multilevel Inverter and Multistring Multilevel Inverter. It is found from the above simulation result observations that the Improved Multistring Multilevel Inverter is best suitable configuration for High Power STATCOM Applications. Moreover the number of switches used is less when compared with Cascaded Multilevel inverter, hence the cost is also less and the switching losses are also low. The MATLAB/SIMULINK based simulation results confirm the feasibility and effectiveness of the proposed approach to regulate the load voltage using the improved Multi-String inverter based STATCOM.

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