Design and Analysis of STATCOM for Reactive Power Compensation using Three Phase Multilevel Inverter

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Abstract - This paper proposes the concept of reactive power compensation with the aid of STATCOM (static synchronous compensators) and three phase multilevel inverter. The classification of multilevel inverters under three major types which are H-bridge inverter, flying capacitors-based inverter and diode clamped multilevel inverter. Among these multilevel inverters, the diode clamped type is stressed in this paper due to its capability to process 3-phase output in the absence of any input. Here the reactive power is compensated using 7-level based multilevel inverter with diode clamps are made utilizing the capacitors banks, diodes and switches which would therefore abates the voltage stresses and harmonics resulting in higher efficiency of the power system. Besides the functioning of multilevel inverter, STATCOM is also utilized to improve the regulation of reactive power flow and thereby, enhances the stability under transient condition of a power system. Subsequently, the compensated seven level output is procured by the sinusoidal PWM technique.

Keywords - STATCOM, Multilevel Inverter, Reactive Power, FACTS Devices, THD

1. Introduction

The major disturbances in power system are due to power quality and power grid instability. These power quality issues are due to harmonic distortion, high switching frequency, voltage sag, voltage swell, transient oscillation etc., Due to integration of renewable energy with non-renewable resources under the name of distributed generation is supporting the grid system by providing stability of grid system with multiple loads. The increment usage of power electronics-based components leads to develop power quality issues in main grids. FACTS devices are utilized to curb the major disadvantages in the power system. Mostly it is made classified into two major groups namely, controller with thyristor-based and controller with voltage source inverter (VSI). The existing and advancement in FACTS controllers are attained and they are shunt connected controllers includes thyristor controlled with braking resistor (TCBR), static Var compensators (SVC), static synchronous compensators (STATCOM), thyristor switched capacitors (TSC), thyristor-controlled reactors (TCR). The controllers that are connected in series includes thyristor-controlled series reactor (TCSR), thyristor-controlled series compensators (TCSC), static synchronous series compensators (SSSC), thyristor switched series capacitors (TSSC) and Interline power flow controllers (IPFC) are combined series-series controllers. The shunt controllers which are combined in series include Thyristor controlled phase angle regulators (TCPAR), Unified power flow controllers (UPFC) and TCPST. Among the above various type of controllers STATCOM is stressed in this paper which has more advantages of improving poor power factor, transient stability and diminishing voltage stress in the power system. In general, it is made adopted to improve the transmission line capacity by minimization of damping oscillation in high transmission system. It also plays a vital role in wind farm in order to overcome the loss of generation in grid side under the critical fault which occurs in transmission line. Due to advancement and enhancement, it founds application in industrial domain for stability control by adequate reactive power compensation. Advancement in power electronics design paved way for multilevel inverters, where it supports and made an important role in efficiency, to regulate grid voltage, to manage the real and reactive power flow in transmission system. FACTS controlled by multilevel are provide reliability and robustness to the grid system under disturbances. Whereas multilevel inverter also attains some additional features in minimization of harmonic content, improve the voltage profile, supports to condense voltage drop, function under moderate switching frequency with more reliable with above features multilevel inverter are made adopted in FACTS devices. In addition to that, STATCOM made utilized with diode clamp based multi-level inverter is preferred to attain improved performance. The specific intention behind employing the diode clamped multi-level inverter is due to its capability of processing the 3-phased output without any input requirements and its efficiency is notably higher when operating at fundamental frequency. The levels of

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the inverter are cascaded up to 7 levels as it is known that the voltage stress and harmonics diminishes by upgrading the levels of inverters. Though, the higher and lower switching frequencies can be used in the functioning of the inverter, operating at lower switching frequencies increase the effectiveness and minimizes the losses of the system. Thus, operating at reduced switching frequency is preferred. Moreover, the operation of rotating synchronous compensators (generators) and STATCOM is analogous to each other. Therefore, it has high speed operation compared to generators. The proposed system is made simulated and evaluation are made using MATLAB platform. The simulation using PWM technique is done to attain the remunerated voltage and current by the use of seven level inverter.

2. Operation of Static Compensator and Multilevel Based Diode Clamped Inverter

![Circuit diagram of seven level diode clamped inverter](image)

Multiple power converter topology is made interfaced with multilevel inverter are being proposed. Among them all proposed topology modular based structure arrangement is made studied for efficiency improvement [1]. In this juncture new technique 7-level based multi-inverter are designed. Figure 1 indicates the structure of the proposed 7-level diode clamped multilevel inverter [2]. The six capacitors C1, C2, C3, C4, C5, C6 shown in the above figure are used to separate the dc bus voltage into seven different levels. It operates in seven modes to produce the output. The seven modes are VDC, 2VDC/3, VDC/3, 0, -VDC/3, -2VDC/3, VDC.

| Voltage | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 |
|---------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| 0       | 0  | 1  | 0  | 1  | 0  | 1  | 0  | 1  | 0   | 1    | 0    | 1    |
| Vdc     | 1  | 1  | 0  | 0  | 0  | 1  | 0  | 1  | 0   | 1    | 0    | 1    |
| 2Vdc    | 1  | 1  | 0  | 0  | 1  | 1  | 0  | 0  | 1   | 0    | 1    | 0    |
| 3Vdc    | 1  | 1  | 0  | 0  | 1  | 1  | 0  | 0  | 1   | 1    | 0    | 0    |
| -Vdc    | 0  | 1  | 0  | 1  | 0  | 1  | 1  | 1  | 0   | 0    | 1    | 1    |
| -2Vdc   | 0  | 1  | 0  | 1  | 0  | 1  | 0  | 0  | 0   | 1    | 1    | 1    |
| -3Vdc   | 0  | 0  | 1  | 1  | 0  | 0  | 1  | 1  | 0   | 0    | 1    | 1    |

Table 1: Switching Sequence

Table 1 shows the switching sequence from s1 to s12. The switches s1 and s2 are required to be switched ON for the voltage level VDC/2 and for the voltage across VAO=VDC. The voltage of C2 is blocked such that voltage across S1 and S2 is balanced by D1. The voltage across VAO is direct current and VAN is alternating current. If the output is pulled out between A and 0 then the circuit operates as a DC-to-DC converter (chopper) which consists of three output voltage levels they are VDC, VDC/2, and 0. The above is the operation of seven level diode clamped multilevel inverter [3]. Whereas the proposed method has some merits and demerits when it is made compared with other existing methods, although it provides effective and simple topology in configuration with existing PWM technique under balanced capacitor charging. It also enriches supports in terminal voltage maximization using step up transformer with couple capacitors [4].

3. Simulation Schematic and its results

The diode clamped multilevel inverter using STATCOM for reactive power compensation is simulated using the MATLAB software [5]. With the help of simulation compensated voltage and current is shown with help of PWM technique [6].
Figure 2 represents the simulation model that links the subsystems present in the diode clamped multilevel inverter to the load. In the above diagram, the source of alternating current is directly connected to the load and then double line to ground fault is injected (L-L-G) and with the help of diode clamped inverter the reactive power is compensated which reduces the voltage stress and improves the transient stability of the system. The inverter level is cascaded up to 7 levels [7]. Therefore, the voltage stress and harmonics diminishes as by upgrading the levels of inverters. The multilevel inverter is used for its high-power applications and improves the efficiency of the system [8].

The performance of system and its stability are tested by creating external fault [9]. It is made tested under LLG fault conditions. Figure 3 is the waveform during the injection of the double line to ground fault. The waveform in fig.3 shows the distortion in the source side voltage and current and also it is clear that one phase is low in magnitude due the impact of LLG fault during the particular duration [10].

The designed controller provide compensation signal to overcome above faulted condition [11]. The controller tunes the system and provide the compensated voltage and current. Figure 4, demonstrates the waveform of compensated current and voltage [15-18] after simulation variant with time. It briefly shows in the above waveform that the time interval is between 0.25 and 0.3sec

The above Figure 5 represents the Current Total Harmonic Distortion (THD) in the Voltage source inverter (VSI). It is noted from the simulation that the VSI has about 31.01% THD which is an ample amount of THD level which means it causes excess current that in turn results in increased power loss in the core of the distribution transformers and neutral conductors [12],[13]. Therefore, the diode clamped multilevel inverter is preferred.

The above Figure 6 denotes current THD of the diode clamped multilevel inverter. The degree of THD in voltage source inverter (VSI) is 31.07%. The THD level in diode clamped multilevel inverter is diminished to 19.43%.
Figure 7 and Figure 8 represents the waveform of the output voltage of single level H-bridge inverter and seven level diode clamped multilevel inverter respectively. In the Figure 7, the output voltage of H-bridge inverter is 150 V DC and the output voltage of diode clamped multilevel inverter is nearly 100 V DC which is represented in the Figure 8.

Figure 9 and Figure 10 represents the voltage waveform of the switches s1 and s2 of both single level H-bridge multi-level inverter and 7 level diode clamped multilevel inverter (DCML) respectively. From Fig. 9., it is understood that voltage at switch S1 of the H-bridge inverter is 150 VDC and from Fig 10., we infer that the voltage at switch s1 of the seven level diode clamped inverter is 32.5 VDC. From this comparison, we conclude that the voltage stress in diode clamped multilevel inverter with seven level is comparatively less than the cascaded H-bridge multilevel inverter [14].

The voltage waveform represented in the Figure 11. denotes that voltage stress of switch S2 has been reduced in diode clamped multilevel inverter to that of the voltage in the single level H-bridge inverter.

Figure 12. exhibits the 7 stage of multilevel inverter signal, where it can be able to visualize the 7 stages in each range of wave form. The above signal made helps to mitigate the harmonics content in existing systems, when we made increased number of stage in multilevel inverter resulted in mitigation of harmonics content, similarly it can be achieved by multiple switching which in turn develop switching losses [15]. So it is essential to keep stage level to 7 in order to attain effective mitigation in harmonics.

4. Conclusion
The compensation of the reactive power using STATCOM is designed and analysed. STATCOM is used because of its lower cost and active compensation of the
reactive power flow using multilevel inverter topology in the grid system. The voltage and current compensation of DCML inverter under 7 level is attained and results where exhibits the improved performance in harmonics elimination. The output of the STATCOM with DCML inverter is simulated and analysed completely. Therefore, Diode clamped multilevel (DCML) inverter is best opted reactive power compensation and it is much preferable because of its ability to produce three phase output in the absence of giving any input.

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