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Enactment of HBMMC five-level inverter based D-STATCOM using robust controllers

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ABSTRACT

This paper provides the results of a concerted investigation into developing a robust voltage controller for the modular multilevel converter (MMC) used in the D-STATCOM. The simplicity of the half bridge (HB) sub-module, along with the fact that it has minimal conduction losses, led to its adoption in the MMC. For the purpose of controlling the HB MMC switches, an enhanced modulation strategy based on the phase disposition (PD) scheme has been implemented. In the presence of nonlinear load conditions, the converters are experiencing difficulties with the DC voltage balancing. The sliding mode controller (SMC) is utilized so that the DC voltage can be maintained in a balanced state. Performance characteristics including active power, reactive power, dc voltage control and THD are shown and compared. For the purpose of simulating the indicated methodology, MATLAB/Simulink is the tool of choice.

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1. INTRODUCTION

The expansion of both the population and the economy over the course of the preceding decade has resulted in a meteoric rise in the demand for electricity. Power that is both high-quality and reliable is very necessary for the long-term growth and prosperity of any nation. These days, a significant number of renewable energy sources, abbreviated as RES, are being connected to the distribution grid in order to ensure reliability and satisfy the current demand for electrical energy.

Harmonics are produced in distribution grids by non-linear loads such as control hardware gear known as adjustable speed drives (ASD), switched mode power supplies (SMPS), and data processing equipment, as well as by enormous motor starters, lightning and switching surges, and other similar phenomena. The negative repercussions of these power quality (PQ) issues include increased power losses in the distribution systems, interference with the communication systems, increased power losses in the distribution systems, and increased neutral currents that are excessively high and cause the electrical equipment to overheat. All of these issues are problematic. As a result, corrective actions are required in order to attain high standards of reliability in the power supply. Earlier researchers suggested using passive filters, which are comprised of inductors and capacitors tuned for a particular frequency, are used to reduce these power quality problems. However, these filters have the limitations of being bulky in size, involving in series and parallel resonance, requiring a high rating, and necessitating proper reactive power coordination.

Active power filters are implemented as a solution to the issues described above. When these components are used in power distribution systems, they are referred to as custom power devices or CPDs for short. Power electronic converters were utilized in order to bring about the creation of specialized power devices such as D-STATCOM [1]–[7], dynamic voltage restorer (DVR), and unified power quality conditioner (UPQC).

In the literature, many switching control strategies for custom power devices such as ramp comparison controller, hysteresis current control, and adaptive hysteresis control are discussed. The carrier-based pulse width modulation (PWM) is the most widely utilized of these due to its simplicity, high dynamic response, and adaptability. Hence, carrier-based phase disposition (PD) PWM is adopted for the control of switches. Through the use of this method; it is possible to realize relocatable and financially efficient D-STATCOM devices. Modular multilevel converters are recently popular in this area due to its competitive benefits such as superior modularity, uncomplicated scalability, and a low voltage and current specification requirements for the power valves. It also has excellent output performance, which is of a high quality. Therefore, for the sake of this research, modular multilevel converter (MMC) [8]–[11] will serve as the D-STATCOM application of choice. The adopted HB MMC have advantages including Lowest component count and low cost compared to full bridge (FB) MMC.

2. METHOD

Figure 1 depicts the intended block diagram. The proposed block includes both the PD PWM [12]–[16] controller and the DC voltage link controller [17]–[20], both of which are used to manage the MMC [21]–[27] DSTATCOM of DC voltage link and insulated-gate bipolar transistors (IGBTs). The connection between DSTATCOM and PCC is described as being in shunt. In order to perform load balancing, power factor correction, and harmonic filtering, it supplies filter current (i_{comp}) at the point of common coupling (PCC). Figure 1 is a diagram that depicts the block diagram of a compensated system that makes use of DSTATCOM. Utilizing three phase five level modular multilevel converter (MMC) allows for the regulation of the filter current (i_{comp}) that is flowing via the interface inductor (L_{comp}). A DC storage capacitor, abbreviated as C, is what makes the operation of MMC possible. This capacitor is responsible for keeping a constant voltage across DC-link [28]–[32]. Both the resistance and the inductance of the source are represented by the symbols (R_s) and (L_s) respectively.

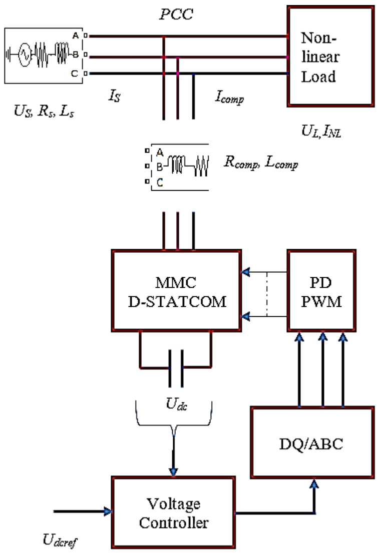

Figure 1. Proposed configuration

The capabilities of the DSTATCOM compensation system are determined by the parameters that are chosen, such as the DC link voltage (U_{dc}), the interface inductance (L_{comp}), and the DC link capacitance (C). The level of U_{dc} is kept at the maximum value of line voltage (U_{lm}), which is maintained at all times. At the point of common coupling, the filter currents i_{comp_a}, i_{comp_b}, and i_{comp_c} that are injected. The size of C is determined by the length of the transients that occur within the system. It is necessary to generate reference currents in order to control the current flowing via custom power devices and, as a result, to compensate for the flow of load current. When attempting to calculate the reference currents, the instantaneous symmetrical component theory is the methodology of choice.

The instantaneous source voltage is written as (1).

$$U_{sa}(t) = U_m \sin \omega t$$
$$U_{sb}(t) = U_m \sin\left(\omega t - \frac{2*\pi}{3}\right)$$
$$U_{Sc}(t) = U_m \sin\left(\omega t - \frac{4*\pi}{3}\right) \quad (1)$$

From Figure 1, the non-linear load current including source/grid current and MMC current is written as (2).

$$I_{NL}(t) = I_s(t) + I_{comp}(t) \quad (2)$$

It is recommended that the peak voltage of the system's phase be at least two times higher than the minimum voltage of the dc bus. The voltage of the dc bus can be determined using the (3).

$$U_{dc} = \frac{2\times\sqrt{2}\times U_{L-L}}{\sqrt{3}\times m} \quad (3)$$

Where, U_{L-L} represents the root-mean-square line-line voltage and 'm' denotes the modulation index.

The switching frequency (f_s), current ripple (i_{cr} (*p-p*)), and MMC input voltage (U_{dc}) are three factors that have a role in the choosing of the ac inductance ($L_f$or L_{comp}). The filter inductance is calculated using in (4).

$$L_{comp} = \frac{\sqrt{3}\times m\times U_{dc}}{I_{NLph}\times a\times f_s\times i_{cr(p-p)}} \quad (4)$$

Where, 'm' represents the modulation index, 'a' represents the overload factor =1.2, 'U_{dc}' represents the dc voltage, and '$i_{cr\,(p-p)}$' represents the expected ac line current distortion of 5%. The immediate amount of energy that is accessible to the D-STATCOM when transients occur is what determines the value of the dc capacitor, also known as *C*. The idea of energy conservation is put into practice, and the resulting equation can be found in (5).

$$0.5U_{dcref}\left[U_{dcref}^2 - U_{dc1}^2\right] = 3 \times U(aI)t \quad (5)$$

Where (U_{dcref}, U_{dc1}, *a*, *U*, *I*) are the dc bus reference voltage, DC bus minimum voltage, overloading factor, phase voltage, phase current, and DC bus recovery time, respectively.

In order to show competitive results, this work makes use of a variety of voltage controllers, all of which are depicted in Figure 2. The block diagram of SMC is depicted in Figure 2. The mathematical expression for sliding mode voltage controller is given in (6) and (7).

$$u(t) = \frac{C}{k} sgn(\varphi) \quad (6)$$

$$\varphi = k * (0.5CU_{dc\_ref}{}^2 - 0.5CU_{dc}{}^2) \quad (7)$$

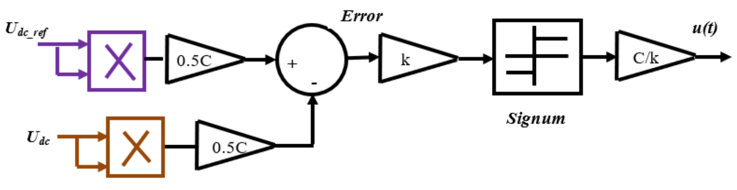

Figure 2. SMC controller

Figure 3 depicts a structure that is constructed on a sub-module that is a three-phase half-bridge. Additionally, this structure is shown to be constructed. If you search for it in the MMC, you will find that this construction is made available. The many switching states that correspond to them are listed in Table 1, which contains the information. Research has been conducted in recent years to investigate whether or not MMCs and DSTATCOMs that are based on MMCs are effective in resolving power quality concerns such as harmonics, imbalanced dc voltages, and reactive power correction. The findings of this research have been brought to light in recent years. In an effort to determine whether or not MMCs and DSTATCOMs that are based on MMCs are effective, this investigation has been carried out in order to find out.

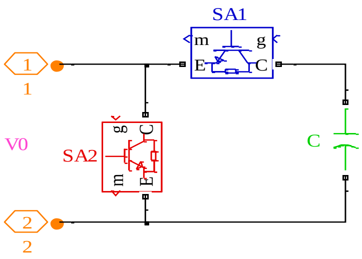

Figure 3. Half bridge sub-module configuration [8]

Table 1. Switching half-bridge submodule (HB SM)

Mode	S_{A1}	S_{A2}	Output voltage
1	1	0	V_0
2	0	1	0

3. RESULTS AND DISCUSSION

The simulation used to test the proposed configuration, which can be seen illustrated in Figure 1, is carried out here, and the results of the test are reported. MATLAB Simulink was used to create a simulation of the proposed MMC-DSTATCOM [33]–[35] arrangement, which can be seen in Figure 1. First, a simulation is run on the proposed system using the PI controller. The power (apparent, active and reactive), pf and total harmonic distortion (THD) were measured at 6,340 VA, 6,233 W, 1,160 VAR, 0.9831 and 4.91% respectively. The outputs of the device are depicted in Figures 4(a)-4(h) respectively. The simulation specifications are enumerated in Table 2.

In second scenario, a simulation is run on the proposed system using the fuzzy logic controller (FLC). The power (apparent, active and reactive), pf and total harmonic distortion (THD) were measured at 6,359 VA, 6,259 W, 1,122 VAR, 0.9843 and 4.91% respectively. The outputs of the device are depicted in Figures 5(a)-5(h) respectively.

In third scenario, a simulation is run on the proposed system using the SMC. the power (apparent, active and reactive), pf and total harmonic distortion (THD) were measured at 6,379 VA, 6,314 W, 909 VAR, 0.9898 and 4.74% respectively. the outputs of the device are depicted in Figures 6(a)-6(h) respectively. The performance parameters are listed in Table 3. From this table it is observed that the SMC control has given good results compared to PI and FLC controller. The value of THD using SMC is 4.74% which is best compared to PI and FLC.

Table 2. Model considerations

Description	Value
3-Ø supply/grid voltage, L_s and R_s	415 V (r.m.s), 200 mH and 0.01 Ω
Non-linear load	3- Ø diode bridge with R-L load
Switching frequency	5000 Hz
U_{dcref}	700 V
Capacitor, C	3300 µF

Table 3. Performance comparison

Parameter		PI	FLC	SMC
S (VA)		6340	6359	6379
P (W)		6233	6259	6314
Q (VAR)		1160	1122	909
PF		0.9831	0.9843	0.9898
i_{sa} (A)		8.903	8.918	8.909
Source current	I_{h5}	1.09	1.15	1.35
harmonics	I_{h7}	2.10	1.75	1.77
(% values)	I_{h11}	1.63	1.76	1.46
	I_{h13}	1.52	1.62	1.22
	I_{h17}	1.10	1.0	1.40
	THD	4.91	4.91	4.74

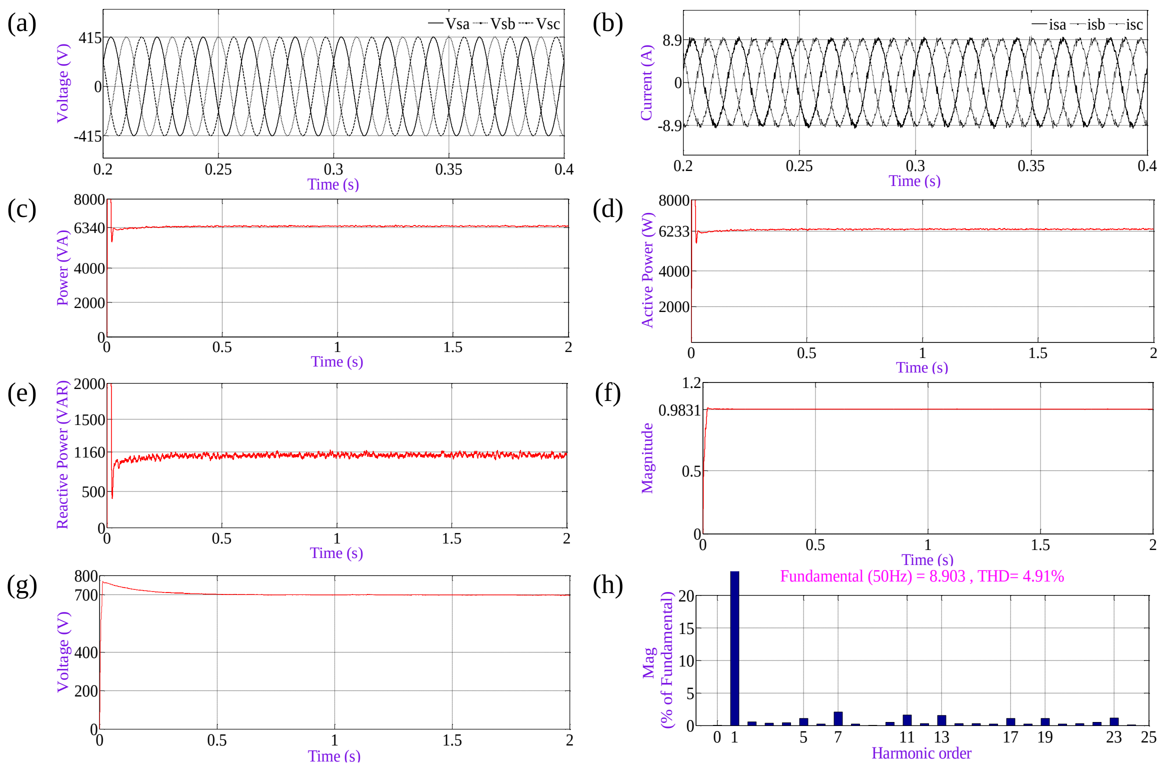

Figure 4. Responsive signals using PI controller and a five-level HBMMC-DSTATCOM of (a) source voltage, (b) source current, (c) apparent power, (d) active power, (e) reactive power, (f) power factor, (g) DC voltage, and (h) harmonic spectrum of source current

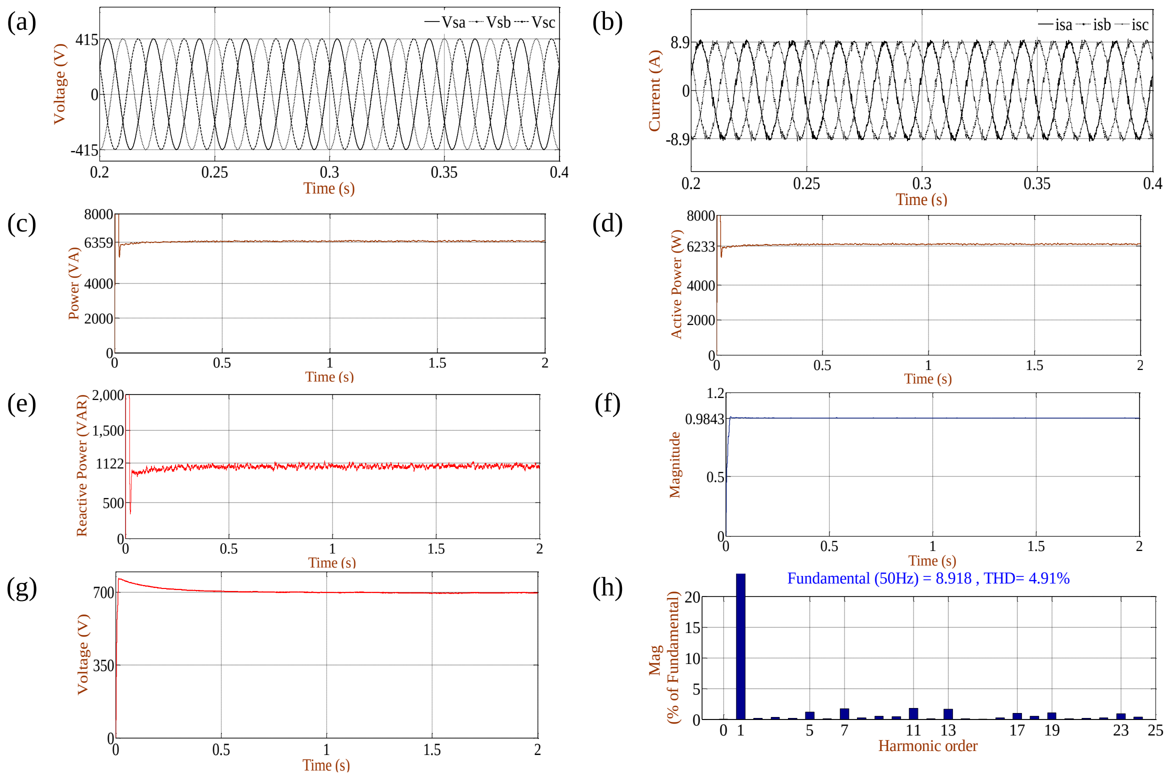

Figure 5. Waveforms of responses obtained through the use of five-level HBMMC-DSTATCOM with FLC of (a) source voltage, (b) source current, (c) apparent power, (d) active power, (e) reactive power, (f) power factor, (g) DC voltage, and (g) harmonic spectrum of source current

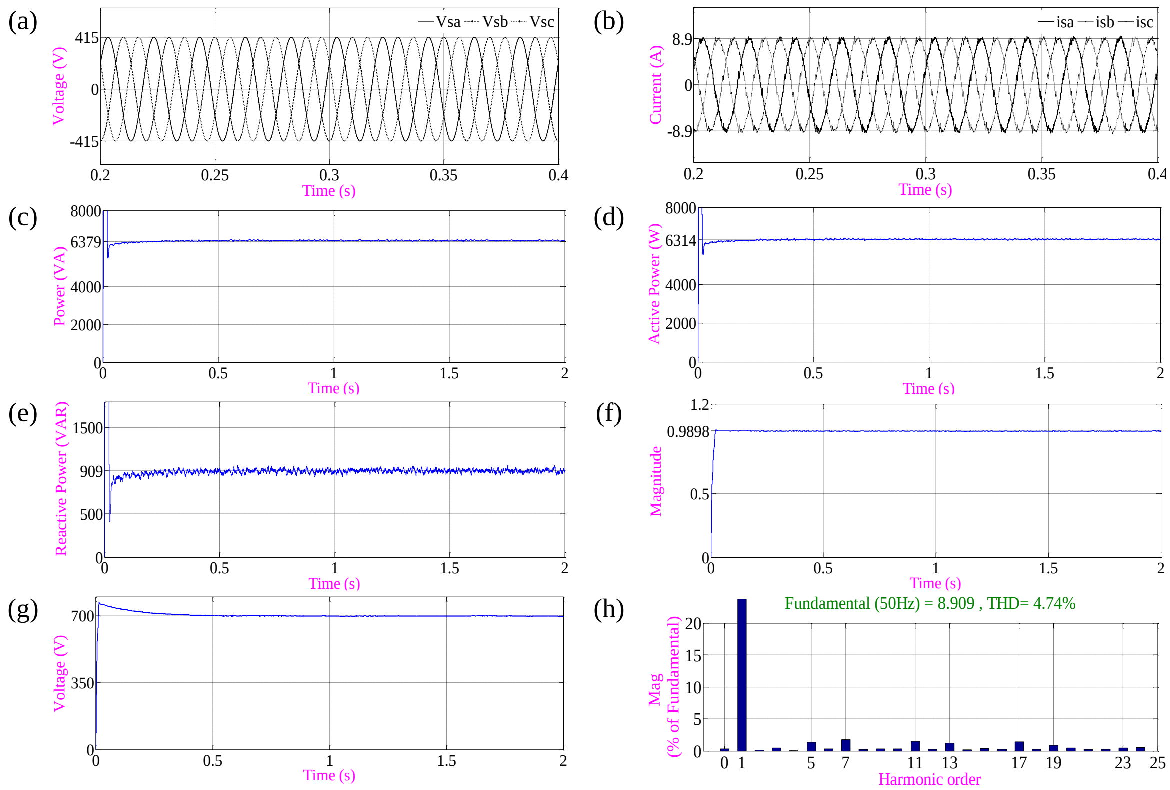

Figure 6. Waveforms of responses obtained through the use of five-level HBMMC-DSTATCOM with SMC of (a) source voltage, (b) source current, (c) apparent power, (d) active power, (e) reactive power, (f) power factor, (g) DC voltage, and (h) harmonic spectrum of source current

4. CONCLUSION

A sliding mode control technique was used for the reparation of reactive power, harmonics, and voltage regulation for this system. The results of this technique's application to the analysis of the performance of MMC-based DSTATCOM have been presented. The THD of the source/grid current is lower than the limit that is prescribed by the IEEE-519 standard. It has been established that the performance of DSTATCOM and its control algorithm is effective for reactive power compensation as well as the elimination of harmonics when applied to nonlinear loads.

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