# Solving the grid overvoltage caused by connected PV systems: DSTATCOM based on MMC as exemplary EMC solution

***Abstract*** **– With the expansion of installing photovoltaic cells at residential units. The low voltage distribution system became facing a new challenge concerning the stability of the distribution network. This problem became associated with sudden flickers. Overvoltage followed by under voltage due to the uncontrolled connection/disconnection of the photovoltaic units. This paper introduce a Distribution Static synchronous shunt compensator based on modular multilevel converter as a solution to regulate the overvoltage and give the distribution network more stability.**

***Index Terms – Distribution Static synchronous shunt compensator, DSTATCOM, Modular multilevel converter, MMC, Overvoltage, Photovoltaic, PV.***

## I. Introduction

Fossil fuel based generation plants have been the basic generation source for a lot of decades. However, nowadays it became used extensively which made the world storage of fossil fuel decreasing significantly. Also, there is environmental problems associated with using fossil fuel for generation plants such as air pollution, $CO_2$ emissions and the adverse effects on global warming [1]. This has increased the interest to use renewable energy as it is an eco-friendly solution. Photovoltaic (*PV*) became widely adopted at large scale at residential customers or as a generation farms connected to supply the gird [2]. This is due to the fact that it depend on sunlight only, can be easily implemented and the ability to reduce transmission and distribution system losses [3]. Also, in order to meet the sustainability and climate change goals, most of the European Union countries supported the installation of *PV* cells [4]. With this extensive installation of *PV*s some problems aroused regarding the stability of the grid. This problem happened because lot of residential customers became injecting power to the grid to make profits [2, 3]. Due to diversity and simultaneous generation from customers. Overvoltage became occurring on both low and medium voltage grid [3]. This problem caused interruption of customers, islanding operation, disconnection of *PV* inverters. This problem caused an electromagnetic compatibility (EMC) which is defined by standards such as IEC TR 61000-2-14:2006, IEC 61173 and IEEE 1862-2014. There has been some classical solutions such as increasing the distribution cables sizes or using ultra long cables but those solutions are costly and infeasible [5]. Other previously proposed solution were using static VAR compensators or on line tap changers [6, 7]. However, those solutions has drawbacks such as lack of dynamic operation, long time response which make them unable to match the voltage fluctuation caused by the instant *PV* penetration [3]. Controlled real and reactive power production is considered as an efficient solution for power regulation as it has high influence on the low voltage distribution cables due to the fact that low voltage cables have high *R/X* ratio [2. 3]. Because of this, distribution static synchronous shunt compensator (DSTATCOM) is considered as an efficient solution to compensate the overvoltage through reactive power control [8, 9]. DSTATCOM has fast dynamic response and has a light weight compared to online transformers. However, the capacitors used at the *DC* bus are bulky. Therefore, using modular multilevel converter (MMC) will overcome this problem as it will distribute the *DC* voltage across the small modules capacitors [10].

This paper presents DSTATCOM based on MMC used to regulate the reactive power. The DSTATCOM is connected at the 11 kV medium voltage and utilized to compensate up to 5 MVAR injected by loads at both medium and low voltage networks. The *d-q* theory is used to control the power injection of the DSTATCOM as this method is simple and efficient [9]. For giving a proper MMC operation, capacitors sorting algorithm is utilized with phase disposed pulse width modulation (PDPWM) [10, 11]. The system switching frequency is 2 kHz. Section II presents the network structure and the proposed system structure. Section III presents the used control system. While section IV shows the obtained simulation results using Matlab/Simulink.

## II. Network And Proposed System Structure

As presented in figure 1, the system network consists of 11kV grid source connected to two loads through a 5 km PI section feeder. The grid *R/X* is 7. The loads are connected at 11 kV and 380 V. The DSTATCOM is connected at the 11 kV level.

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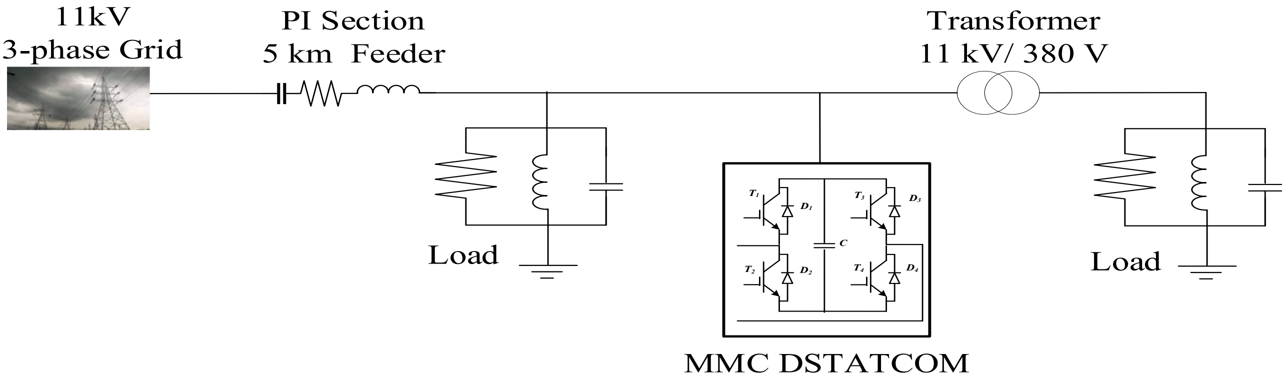



Figure 1. Network structure

The structure of the three phase six arms MMC used for DSTATCOM is presented in figure 2. For creating an equilibrium system the voltage across the SMs is decided based on equation 1.

$$V_{SM} = V_{dc}/N \tag{1}$$

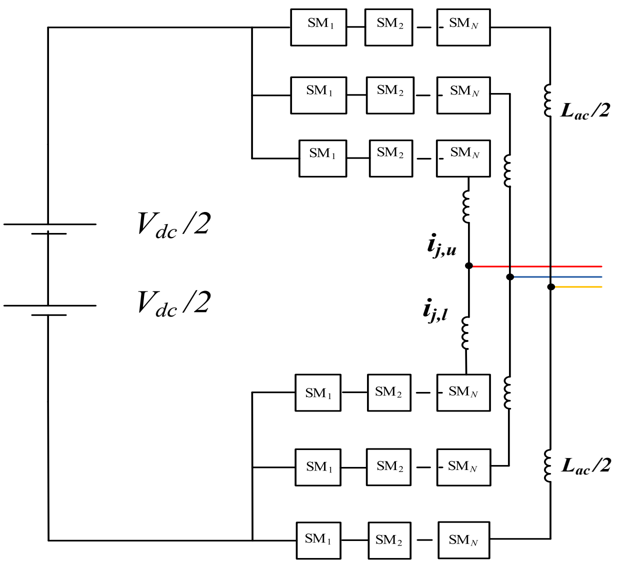



Figure.2 DSTATCOM power injector structure.

The voltage of upper and lower arms is calculated form the equations 2 and 3

$$v_{ju} = \ v_{ac} + \frac{v_{dc}}{2} \tag{2}$$

$$v_{jl} = -v_{ac} + \frac{v_{dc}}{2} \tag{3}$$

Where, $j \in \{a,\ b,\ c\}$

From equation 2 and 3 the phase and *DC* voltages can be calculated as presented in equation 4 and 5 respectively [10].

$$v_{j,ph} = \frac{v_{ju} - v_{jl}}{2} \tag{4}$$

$$v_{DC} = v_{ju} + v_{jl} \tag{5}$$

Full bridge converter is utilized as submodule (SM). The possible non-faulty operations of full bridge converter are presented in figure 3 [12].

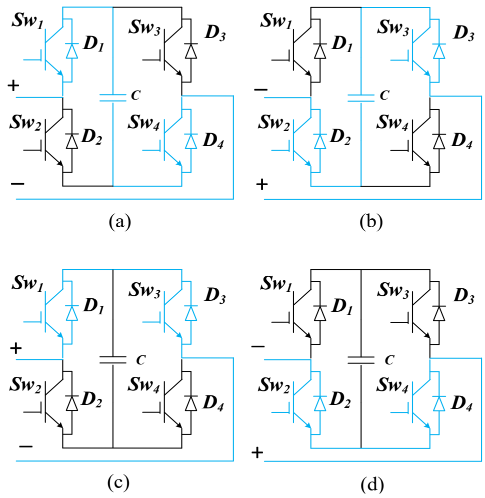



Figure.3 Full bridge converter non-faulty operation states (a) Charging, (b) Discharging, (c) & (d) Bypassing.

## III. DSTATCOM Control System

The proposed system control algorithm is presented in figure 4. In order to identify the instantaneous active and reactive power equations 6 & 7 are used [9].

$$p = v_{sd}i_d + v_{sq}i_q = \ v_{sd}i_d \tag{6}$$

$$q = v_{sd}i_q - v_{sq}i_d = \ v_{sd}i_q \tag{7}$$

Owing to equation 5, The *DC* mean voltage is

$$\bar{v}_c = \frac{v_{a,ph} + v_{b,ph} + v_{c,ph}}{3} \tag{8}$$

The *d-q* currents references are calculated from equation 9 and 10 while the *d-q* voltages references are deducted from equation 11.

$$i_d^* = K_1\ (v_c^* - \ \bar{v}_c) \tag{9}$$

$$i_q^* = \frac{q_{ref}}{v_{sd}} \tag{10}$$

$$\begin{bmatrix} v_d^* \\ v_q^* \end{bmatrix} = \frac{1}{3}\left(\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} - \begin{bmatrix} 0 & -\omega L_{ac} \\ \omega L_{ac} & 0 \end{bmatrix} \cdot \begin{bmatrix} i_d \\ i_q \end{bmatrix} - K_2 \begin{bmatrix} i_d^* - i_d \\ i_q^* - i_q \end{bmatrix} - \frac{K_2}{T_2}\int \begin{bmatrix} 0 \\ i_q^* - i_q \end{bmatrix} dt\right) \tag{11}$$

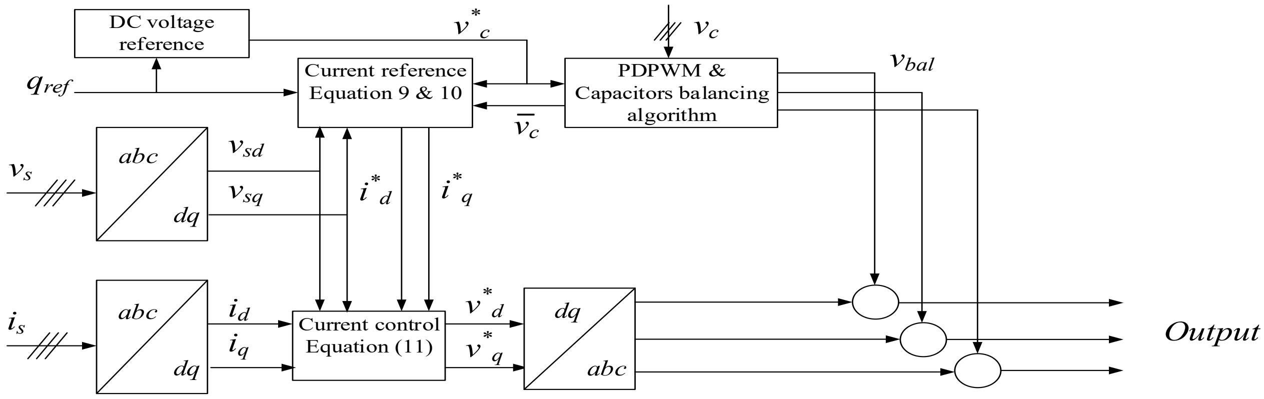



Figure 4. DSTATCOM control scheme.

At equation 11, the first two parts are used to eliminate the supply voltage and the voltage across the MMC inductor. The last two parts form the *PI* controller for the *d-q* axis [9]. For proper MMC SMs operation, PDPWM is used. In PDPWM carriers are in phase but with different offsets depending on the number of modules per arm as presented in equation 12 [12]. Figure 5 shows four PDPWM carriers waveform.

$$offset = \frac{1}{N} \qquad (12)$$

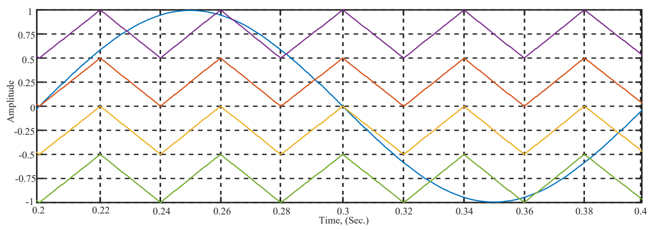



Figure 5. Four PDPWM carriers.

For balancing the voltages of the SMs capacitors, sorting algorithm is adopted. This algorithm depend on measuring the voltages of SMs and the arm currents to identify the charging/ discharging states before choosing which sorted SMs need to be activated. Figure 6 shows the algorithm flowchart [11].

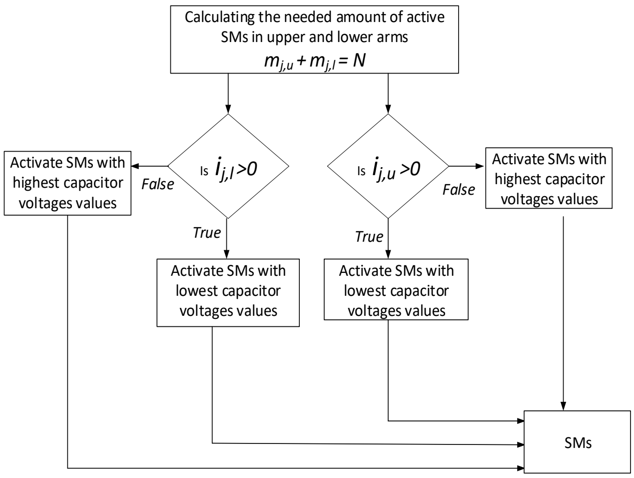


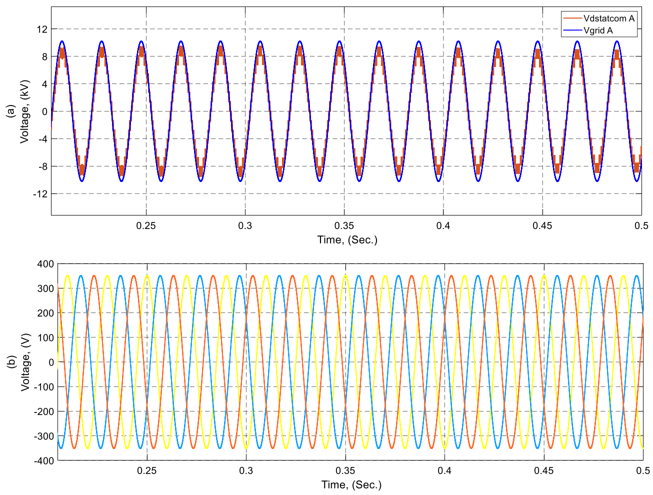

Figure 6. Sorting technique flowchart.

## IV. Simulation Results

MATLAB/SIMULINK program is used to study the DSATCOM performance when an overvoltage occur. The system parameters are presented in table I. The loads values are the measurements at the point of common coupling for medium and low voltage grid and their reactive power changes from the steady state to the over voltage state.

Table I: Network and DSTATCOM parameters.

| | |
|---|---|
| $v_s$ | 11 kV |
| *R/X* | 7 |
| Transmission line impedance | R: Positive sequence= 0.1153 Ω/km<br>Zero sequence= 0.413 Ω/km<br>L: Positive sequence= 1.05e-3 H/km<br>Zero sequence= 3.32e-3 H/km<br>C: Positive sequence= 11.33e-009 F/km<br>Zero sequence= 5.01e-009 F/km |
| Transformer | 15 MVA<br>11 kV/380 V |
| Low voltage load | 5 MW , 0-3 MVAR |
| Medium voltage load | 7 MW, 0-2 MVAR |
| *N* | 4 |
| $C_{sm}$ | 1 mF |
| $L_{ac}$ | 1.2 mH |
| $f_{sw}$ | 2 kHz |
| $v_c$ | 2 kV |



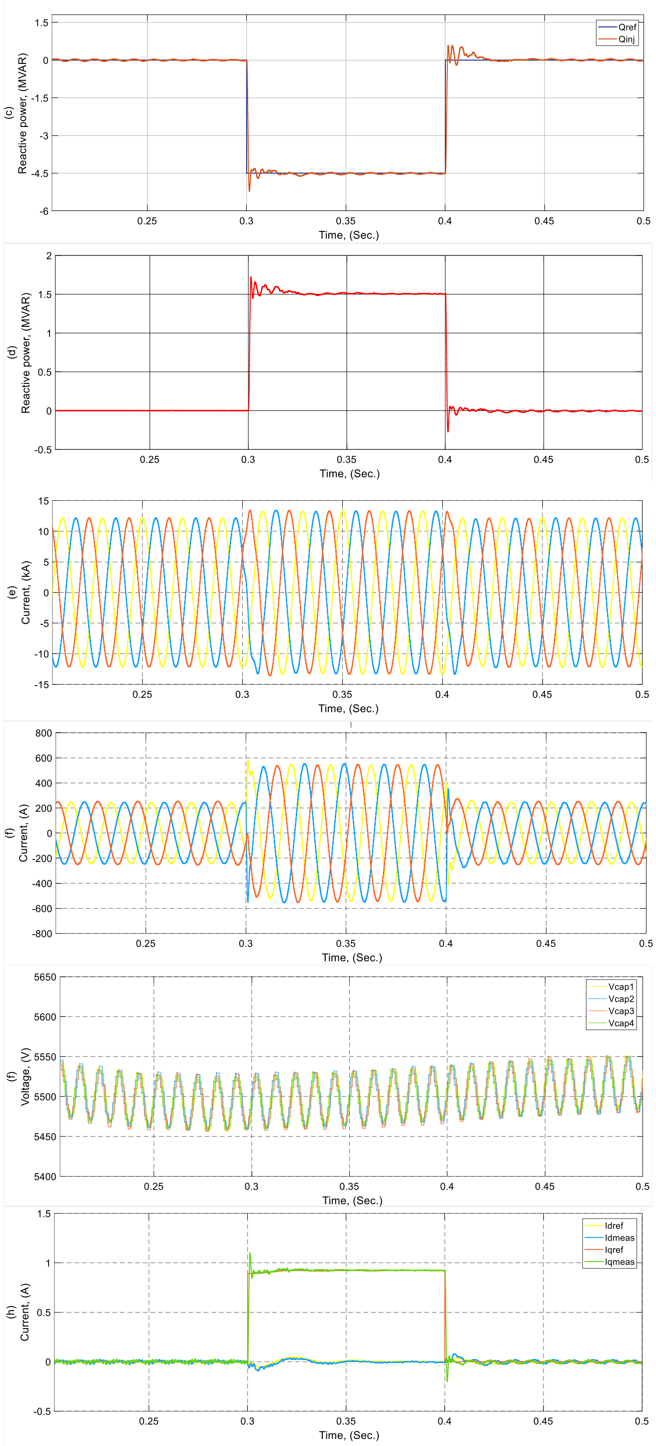



Figure 7. System performance under steady state and during over voltage occurrence (from 0.3 to 0.4 Second), (a) DSTATCOM and grid voltage, (b) Grid voltage at low voltage grid side, (c) Reference and DSTATCOM injected reactive power, (d) Load reactive power, (e) Current at the low voltage grid, (f) Current at the medium voltage grid, (g) Voltage of arm SMs & (h) The *d-q* reference and measured currents.

Figure 7 shows the network components operation at steady state and during the over voltage event which take place between 0.3-0.4 second. Figure 7a shows both the grid voltage and the DSTATCOM at the medium grid level while figure 7b shows the voltage at the low grid level. Figure 7c and 7d shows the DSTATCOM injected reactive power to compensate the loads resultant capacitive reactive power. Figures 7e & 7f shows the currents at the low voltage level and medium voltage level respectively. Figure 7g shows the balanced MMC SMs voltages for single arm. Figure 7h shows the *i-q* currents for giving the DSTATCOM the proper values to regulate the reactive power. From figure 7 it can be seen that the DSTATCOM is able to dynamically compensate the reactive power and maintain the voltage steady during the occurrence of overvoltage.

## V. Conclusion and Future Work

In this paper, a study on the performance of the DSTATCOM based on MMC was conducted. The dynamic response of the DSTATCOM made it able to trace the grid voltage and instantaneously compensate the overvoltage by injecting an opposite reactive power value. The presented results showed the effective compensation for voltage at both medium and low voltage levels. This make the connected inverters don't cause any EMC problems with the grid on low and medium voltage levels. Future work of this study will be studying the energy management, apply the DSTATCOM system on radial and ring networks with defining critical buses and use optimization energy flow algorithms.

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