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PowerFlow Control of Grid Connected PV System using STATCOM

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Abstract: ***In this project, a solar energy with FACTS controller is presented. The proposed inverter is placed between the PV panel and the grid to regulate active and reactive power transfer to the grid. The capacitor will be charged from the solar source through a boost converter. The voltage obtained by using a boost converter will be applied to the STATCOMs Inverter. The work of this project is to introduce a new ways to increase the penetration of renewable energy into the distribution systems. This STATCOMs is capable of supplying variable reactive power. Thus the different bus systems with Inverter based STATCOMs will be simulated and the results will be presented.***

Keywords: Photovoltaic system, Multilevel inverter (MLI), STATCOM, Powerflow model, Total Harmonics Distortion (THD).

1. Introduction

In the proposed control strategy, the concepts of the inverter and the STATCOM have been combined to make a new inverter, which possesses FACTS capability with no additional cost. Role of power electronics in distribution systems has greatly increased recently. The power electronic devices are usually used to convert the nonconventional forms of energy to the suitable energy for power grids, in terms of voltage and frequency. A Photovoltaic (PV) cell is a semiconductor device that directly converts the energy of solar radiation into electric energy. In general, an element that converts sunlight into electricity is called a PV device. The fundamental PV device is the PV cell, while a set of connected cells form a panel or module. As an array either a module or a set of modules can be considered. To provide an introduction into the photovoltaic solar energy and to present a brief introduction to the behaviour and functioning of the PV devices, without the intention of providing in-depth analysis of the PV phenomenon and the semiconductor physics.

2. Photovoltaic System

A photovoltaic system, also photovoltaic power system, solar PV system, PV system or casually solar array, is a power system designed to supply usable solar power by means of photo voltaic. It consists of an arrangement of several components, including solar panels to absorb and directly convert sunlight into electricity, a solar inverter to change the electrical current from DC to AC, as well as mounting, cabling and other electrical accessories to set-up a working system. It may also use a solar tracking system to improve the system's overall performance or include an integrated battery solution, as prices for storage devices are expected to decline. Strictly speaking, a solar array only encompasses the ensemble of solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized as balance of system (BOS). PV systems range from small, roof-top mounted or building integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts. Nowadays, most PV systems are connected to the electrical grid, while standalone or off-grid systems only account for a small portion of the market
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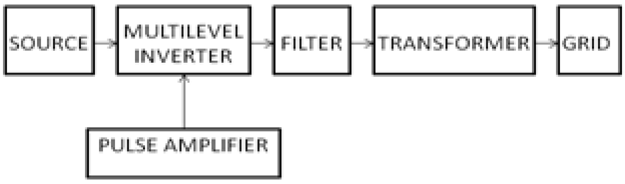

Figure 1: Complete configuration of the proposed inverter with FACTS capability.

A photovoltaic system converts the sun's radiation into usable electricity. It comprises the solar array and the balance of system components. PV systems may be built in various configurations: Grid-connected optionally using a battery storage Off-grid without battery (array-direct) Off-grid with battery storage, optionally converting to AC Besides these basic configurations, PV systems can be categorized by various aspects, such as, building integrated vs. rack-mounted systems, residential vs. utility systems, distributed vs. centralized systems, roof-top vs. ground-mounted systems, tracking vs. fixed-tilt systems, new construction vs. retrofitted systems. Other distinctions may include, systems with micro inverters vs. central inverter, systems using crystalline silicon vs. thin film technology, and systems with modules from Chinese vs. European and US-manufacturers.

2.1 Powerflow Model

The STATCOM is a FACTS controller based on voltage sourced converter (VSC). A VSC generate a synchronous voltage of fundamental frequency, controllable magnitude and phase angle. If a VSC is shunt-connected to a system via a coupling transformer, the resulting STATCOM can inject or absorb reactive power to or from the bus to which it is connected and thus regulate the bus voltage magnitude [4]. This STATCOM model is known as Power Injection Model (PIM) or Voltage Source Model (VSM). Steady state modelling of STATCOM within the Newton-Raphson method in rectangular co-ordinates is carried out as follows: The Thevenin equivalent circuit representing the fundamental frequency operation of the switched-mode voltage sourced converter and its transformer $V_{STC}=V_K+Z_{SC}*I_{STC}$ (2.1) is expressed in Norton equivalent form

$$I_{STC}=I_N-Y_{SC}V_K \tag{2.2}$$

Where $I_N=Y_{SC}V_{STC}$

In these expressions, Vk represents bus k voltage and VSTC represents the voltage Source inverter. NI is the Norton's current while STCI is the inverter's current. Also, ZSC and YSC are the transformer's impedance and short-circuit admittance respectively. The STATCOM voltage injection VSTC bound constraints is as follows $V_{STC\ MIN} \le V_{STC} \le V_{STC\ MAX}$ (2.3)

Where VSTCmin and VSTCmax are the STATCOM's minimum and maximum voltages. The current expression in (2.2) is transformed into a power expression by the VSC and power injected into bus k as shown in equations (2.4) and (2.5) respectively.

$$S_{STC} = V_{STC}I^*_{STC}=V^2_{STC}Y^*_{SC}-V_{STC}Y^*_{SC}V^*_K \tag{2.4}$$

$$S_K=V_KI^*_{STC}=V_{STC}Y^*_{SC}V^*_K-V^2_KY^*_{SC} \tag{2.5}$$

2.2. Electrical Equivalent Circuit

PV cell can be represented by the equivalent electrical circuit. The circuit parameters are as follows. The current *I* at the output terminals is equal to the light-generated current I_l, less the diode current *I*d and the shunt-leakage current I_{SH} The series resistance R_S represents the internal resistance to the current flow, and depends on the pn junction depth, impurities, and contact resistance. The shunt resistance R_{SH} is inversely related to the leakage current to ground. In an ideal PV cell, R_S = 0 (no series loss), and $R_{SH}= \infty$ (no leakage to ground). In a typical high-quality 1 in.2 silicon cell, R_S varies from 0.05 to 0.10Ω and R_{SH} from 200 to 300Ω. The PV conversion efficiency is sensitive to small variations in R_S, but is insensitive to variations in R_{SH}. A small increase in R_S can decrease the PV output significantly [3].

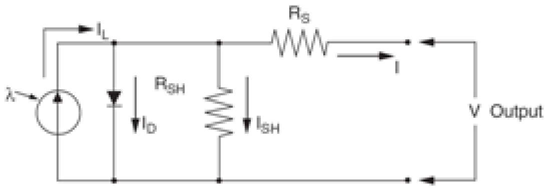

Figure 2: Equivalent circuit of PV module showing the diode and ground leakage currents

In the equivalent circuit, the current delivered to the external load equals the current I_L generated by the illumination, less the diode current I_D and the shunt leakage current I_{SH}. The open-circuit voltage V_{OC} of the cell is obtained when the load current is zero, i.e., when I = 0, and is given by the following:

$$V_{OC} = V + IR_{SH} \tag{2.6}$$

The diode current is given by the classical diode current expression:

$$I_d = I_D\left[e^{\frac{QV_{OC}}{AKT}} - 1\right] \tag{2.7}$$

Where
I_D = the saturation current of the diode
Q = electron charge = 1.6×10^{-19} C
A = curve-fitting constant
k = Boltzmann constant = 1.38x 10^{-23}J/°K
T = temperature on absolute scale °K
The load current is therefore given by the expression:

$$I = I_L - I_D\left[e^{\frac{QV_{OC}}{AKT}} - 1\right] - \frac{V_{OC}}{R_{SH}} \tag{2.8}$$

3. Simulation and Results

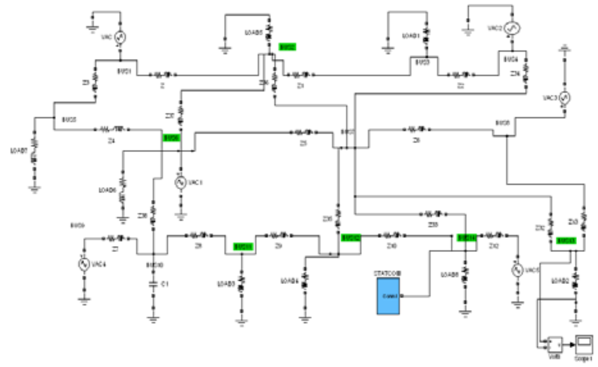

Figure 3: multibus system with statcom

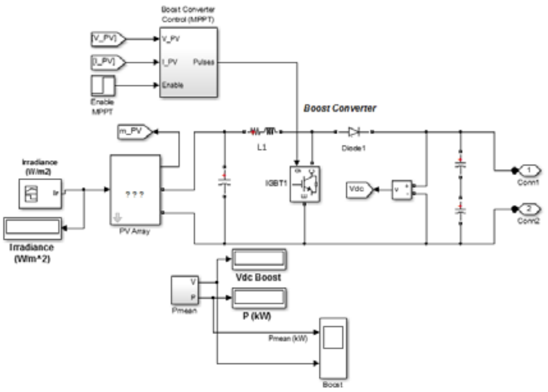

Figure 4: PV source

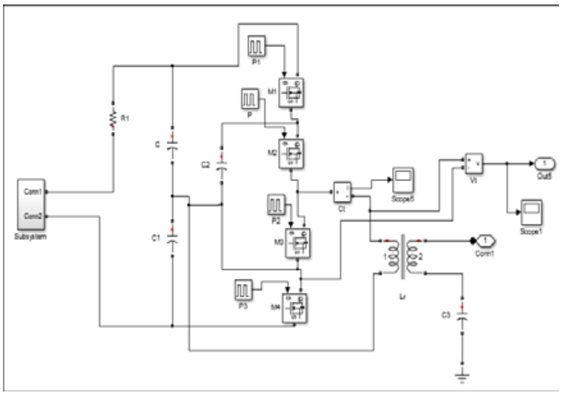

Figure 5: simulation of 3level inverter

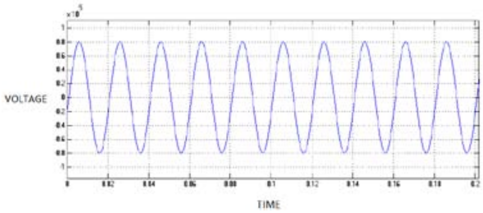

Figure 6: load voltage across bus11

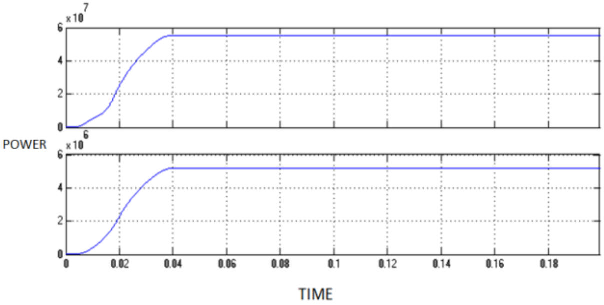

Figure 7: Real and Reactive power across bus11

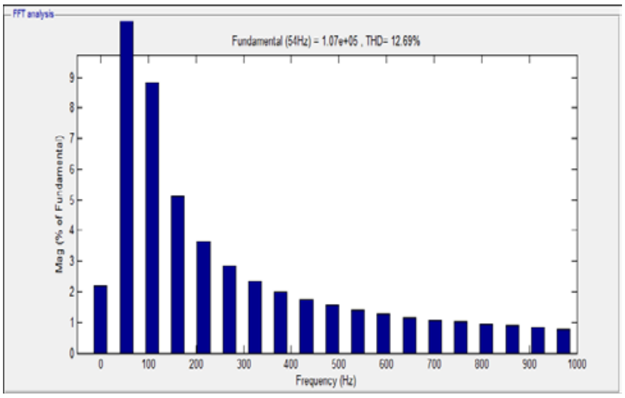

Figure 8: FFT Analysis

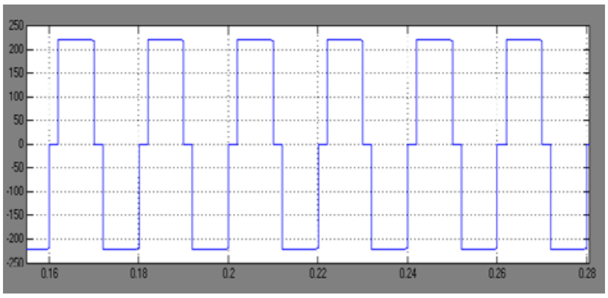

Figure 9: Output voltage waveform

3.2 Simulation of 5 Level Inverter

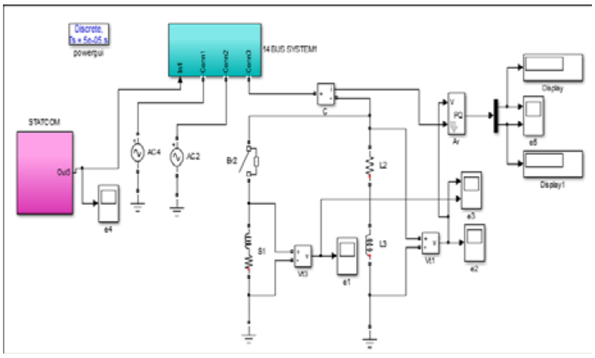

Figure 10: simulation of 5level invereter

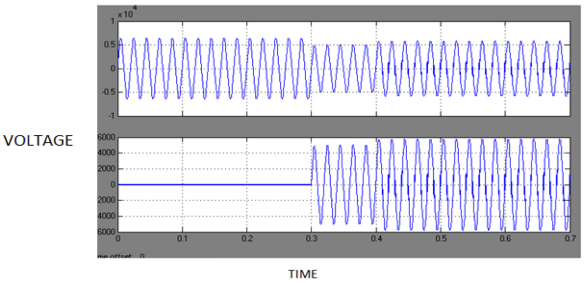

Figure 11: Load1 and Load2 voltage

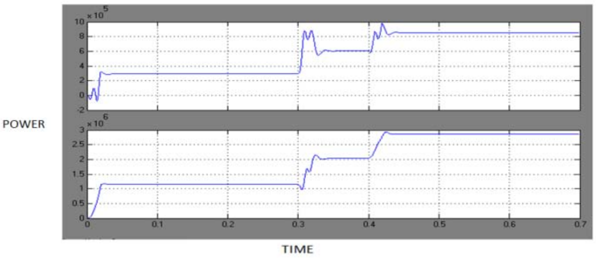

Figure 12: Real and Reactive power

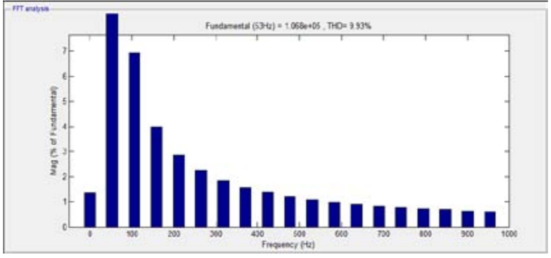

Figure 13: FFT Analysis

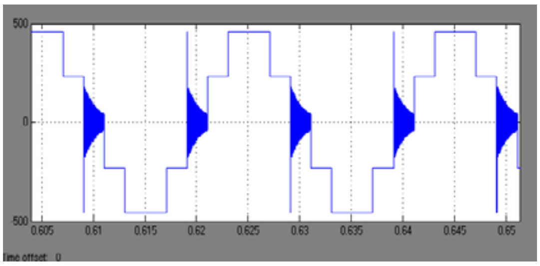

Figure 14: output voltage waveform

3.3 Simulation of 9 Level Inverter

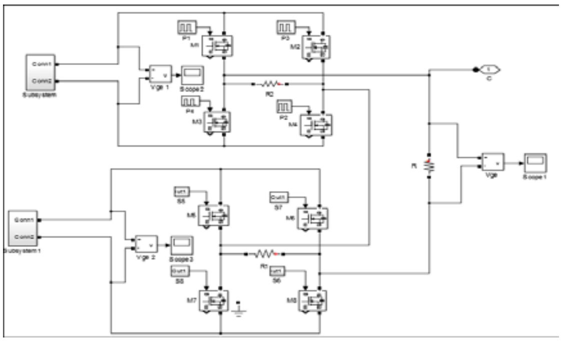

Figure 15: Simulation of 9level inverter

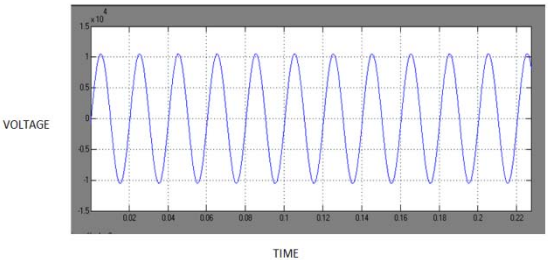

Figure 16: Load voltage across bus 11

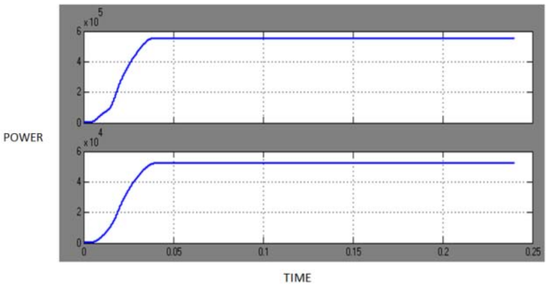

Figure 17: Real and Reactive power across bus11

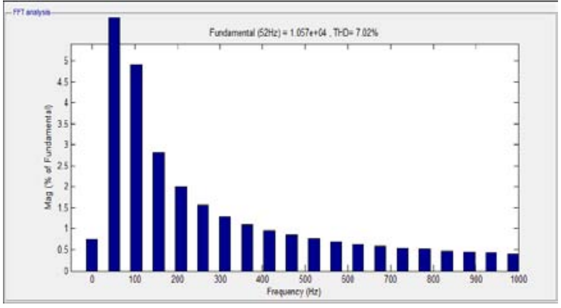

Figure 18: FFT Analysis

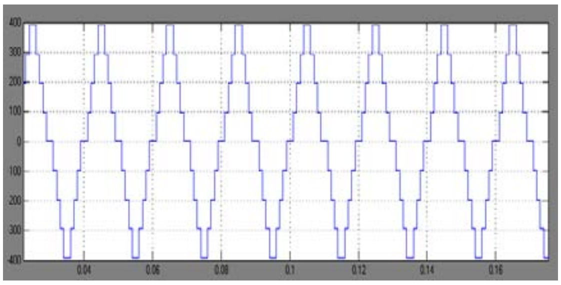

Figure 19: Output voltage waveform

4. Result and Discussion

This project has presented Design and Implementation of an 3Level, 5Level, 9Level Inverter with FACTS Capability for Distributed Energy Systems Simulation results are obtained, showing a good agreement with the theoretical analysis. The simulation results for an 9-level inverter are presented in MATLAB/Simulink. THD is minimum with 9level inverter based STATCOM. Sag is mitigated using STATCOM.To validate the simulation results, a scaled prototype of the proposed 9-level inverter with STATCOM capability is built and tested. Practical results show good performance of the proposed control strategy even in severe conditions.

Table 1: Datas Obtained from Simulation for Various Level of Inverter

Types of inverter	THD
Three level	12.9%
Five level	9.93%
Nine level	7.02%

The simulation results for an 9-level inverter are presented in MATLAB/Simulink. THD is minimum with 9level inverter based STATCOM.

Table 2: Parameters Used for the Simulation

Parameter	Value
L_{line}	15 mH
R_{line}	1 Ohm
L_{filter}	5 mH
Primary voltage	110 KV
Secondary voltage	130 KV
Load active power	50 KW
Load reactive power	34.8 kVAR
Target PF	0.90
Switching frequency	2 kHz

5. Conclusion

In this paper, the concept of a new multilevel inverter with FACTS capability for small-to-mid-size solar installations is presented. The proposed system demonstrates the application of a new inverter with FACTS capability in a single unit without any additional cost. Replacing the traditional renewable energy inverters with the proposed inverter will eliminate the need of any external STATCOM devices to regulate the PF of the grid. Clearly, depending on the size of the compensation, multiple inverters may be needed to reach the desired PF.

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