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Harmonic Reduction of a Single Stage Grid-Connected Photovoltaic System Using PSCAD/EMTDC

Seshankar.N.B, Nelson Babu.P, Ganesan.U

Department of Electrical & Electronics Engineering,
Valliammai Engineering College,
Kattankulathur, Chennai

***Abstract*— Whenever Photovoltaic (PV) power system is connected to the grid it creates a lot of problem such as overvoltage at the point of common coupling (PCC), reverse power flow and the presence of harmonics in the system. In this project a detailed analysis of the modeling method for photovoltaic (PV) arrays and power controller in a single stage grid connected PV system (SSGCPS) is proposed. The detailed model of PV arrays and the power controller are designed under PSCAD/EMTDC environment. Also to that reverse power flow and harmonics are eliminated. The diode blocks the reverse current flow through the PV array. The harmonics reduction filter eliminates the harmonic components other than the fundamental electrical frequency. The simulation results show that the simulation models can reflect characteristics and functions of the actual physical device accurately and can be used to the design and research of big-power PV system.**

***Index Terms*— detailed model of PV arrays, MPPT, power control, SSGCPS**

I. Introduction

The modern, power distribution grid is undergoing a significant change with the connection of a large number of small capacity distributed generation (DG) units such as photovoltaic (PV) systems, energy storage systems, and in some cases, wind turbines. Small scale PV systems (0-10 kW) are the type of renewable energy DG units that are mostly connected to the power distribution grid. The majority of small scale PV systems are domestic roof-top type installations and are generally single-phase systems. Rebates and concession schemes that were introduced by the government for installing small scale PV systems along with price reductions in PV panels and power electronic converter systems, are the main reasons for the increased number of grid-connected small scale PV systems in the power distribution grid.

SSGCPS has advantages such as simple topology, low cost, etc. However, this kind of system has only one stage of power conversion and all the control objectives need to be considered simultaneously, such as MPPT, synchronization with the utility voltage and harmonics reduction for output current [1]. Then the complexity of control strategy is increased. Modeling and simulation is an essential part in system design and application to ensure satisfactory operation and optimize controller. PSCAD/EMTDC is an industry standard simulation tool for studying the transient behavior of electrical apparatus and networks

II. THE CONFIGURATION OF SSGCPS

Figure 1 presents a typical configuration of a three phase SSGCPS. The system consists of a PV array, a diode, a dc-link capacitor, a voltage source inverter (VSI), a harmonic reduction filter, a step-up transformer and power grid [4]. DC power generated from the PV array charges the dc-link capacitor. The grid connection inverter turns the dc into ac power, which has a sinusoidal voltage with the same frequency as the utility grid. The diode blocks the reverse current flow through the PV array. The transformer steps up the VSI voltage to the nominal value of the power grid and providing electrical isolation between the PV system and electric network. The harmonics reduction filter eliminates the harmonic components other than the fundamental electrical frequency.

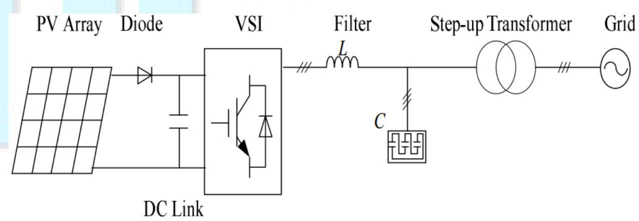

Fig.1. A typical configuration of a three phase SSCGPS

III. CIRCUIT ORIENTED PV ARRAY MODEL

PV cell can be represented by the equivalent electrical circuit shown in fig 2. 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 Id and the shunt-leakage current I_{sh}. The series resistance R_s represents the internal resistance to the current flow, and depends on the p-n 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 Rs can decrease the PV output significantly.

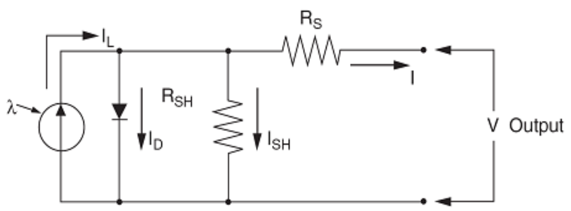

Fig.2 Equivalent circuit of PV module showing the diode and ground leakage currents

In the equivalent circuit, the current delivered to the external load equals the current IL generated by the illumination, less the diode current Id and the shunt leakage current Ish. The open-circuit voltage Voc of the cell is obtained when the load current is zero, i.e., when $I = 0$, and is given by the following:

$$V_{OC} = V + IR_{SH} \qquad (1.1)$$

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

$$I_d = I_D\left[e^{\frac{QV_{OC}}{AKT}} - 1\right] \qquad (1.2)$$

Where
I_D = the saturation current of the diode
Q = electron charge = 1.6×10^{-19} C
A = curve-fitting constant
k = Boltzmann constant = $1.38\text{x } 10^{-23}$J/°K
T = temperature on absolute scale °K

The load current is therefore given by the expression:

$$I = I_L - I_D\left[e^{\frac{QV_{OC}}{AKT}} - 1\right] - \frac{V_{OC}}{R_{SH}} \qquad (1.3)$$

IV. MAXIMUM POWER POINT TRACKING

The amount of maximum power that can be extracted from the PV array at a given time is a function of the solar irradiance and the ambient temperature. Since the solar irradiance and the ambient temperature is continuously changing, an MPPT algorithm is necessary to track the MPP. Among the available MPPT algorithms, perturb and observe (P&O) method and the incremental conductance (InC) method are two well-known MPPT algorithms. The P&O method has been identified as a simple but a slow tracking MPPT algorithm. Further, under rapid variations of solar irradiance the P&O method can fail [2]. The InC method performs well under rapid variations of solar irradiance [3]. Hence in the developed simulation model of the PV system, the InC method is used.

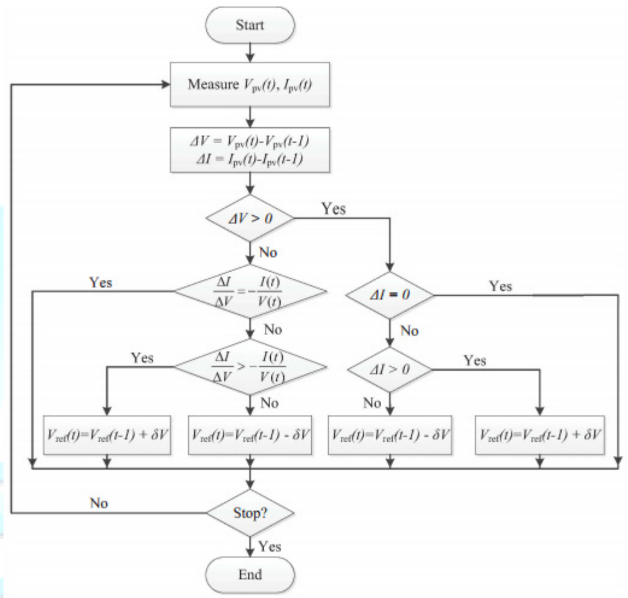

Fig.3.The flow diagram of MPPT

The flowchart of the InC algorithm is shown in Fig.3. In the flowchart t and (t -1) indicate the current sample time and the previous sample time, ΔV and ΔI are differences in two consecutive samples of the output voltage and the current at the PV array output respectively, Vref(t) is the voltage of the MPP that is found by the InC algorithm at the end of a iteration and δV is the amount of voltage that is added/subtracted to/from Vref(t -1) in the process of finding MPP after each iteration.

V. POWER CONTROLLER

Figure 4 shows the electrical configuration of PV inverter for grid connection

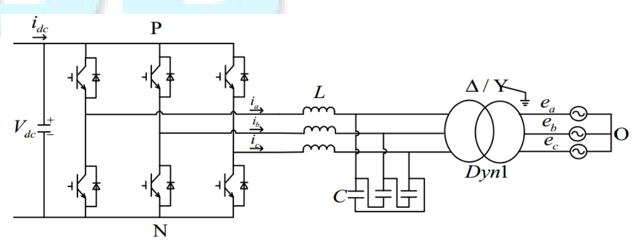

Fig.4.The electrical configuration of PV inverter for grid connection

Figure 5 presents the control system diagram of SSGCPS.

The control system includes a MPPT controller and a power controller, and the power controller consists of measurement and calculation, voltage control, current control and PWM generate four units [4]

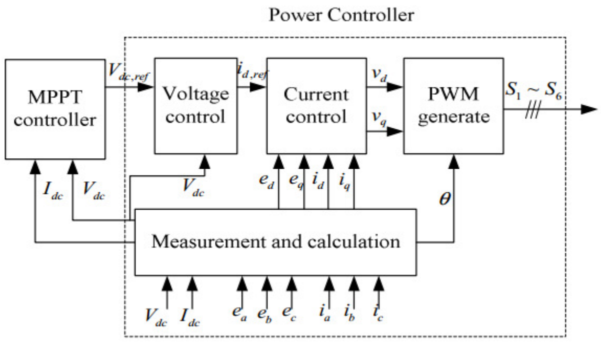

Fig.5.The control system diagram of SSGCPS

Measurement and calculation: The sensors detect the PV array output current (Idc) and output voltage (Vdc) to use for MPPT. More important is that this unit senses the three phase grid voltage (ea, eb, ec) and three phase inverter current (ia, ib, ic), and calculates grid voltage (ed, eq) , inverter current (id, iq) in the rotating frame, and reference phase angle θ

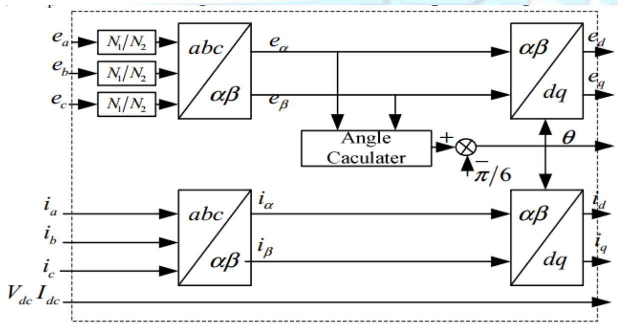

Fig.6.The measurement and calculation unit

Voltage control: the control target of this unit is stabilizing the dc-link voltage. The MPPT controller generates the desired value of dc-link voltage (Vdc,ref), to be compared to the actual value Vdc. The error between the two values is processed as (id,ref) through a proportional-integral (PI) controller.

Current control: The objective of this unit is making the inverter current id and iq track the target current, id,ref and 0, respectively. The controller compares the reference and actual values of the d-axis and q-axis current components and generates the desired values, vd and vq, for the d-and q-axis components of the inverter voltage. Figure 7 shows the voltage control and current control unit.

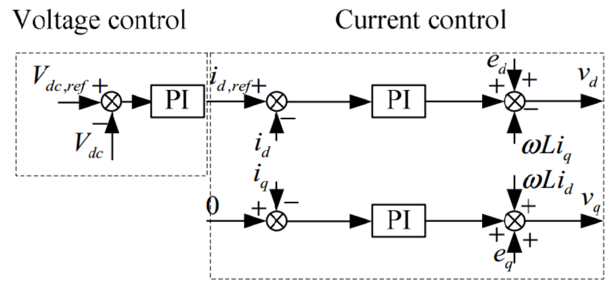

Fig.7.The voltage control and current control unit

PWM generate: The objective of this unit the controller uses the d-axis and q-axis components of the inverter voltage (vd and vq) and phase angle θ to generate 6 PWM pulses S1~S6 for the controlling of VSI.

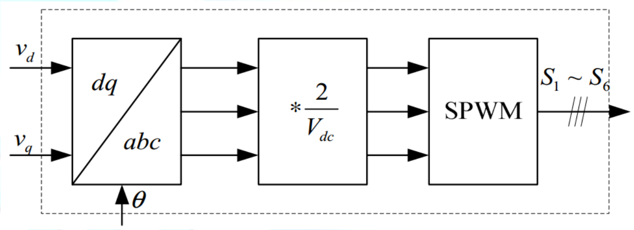

Fig.8.The PWM generate unit

VI. RESULTS AND DISCUSSION

A. *The electromagnetic transient model*

According to the modeling method for PV arrays, MPPT controller and the power controller, the electromagnetic transient model of SSGCPS is established under PSCAD/EMTDC environment. Figure 9 shows this model.

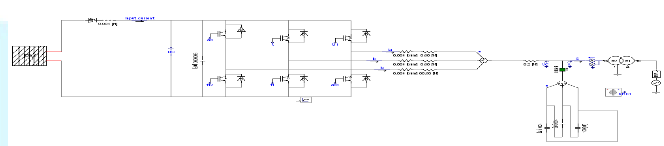

Fig.9.The electromagnetic transient model of SSGCPS

B. *The simulation results*

Pulse width modulation (PWM) is a method where the switched voltage pulses are produced for different output frequencies and voltages. A typical modulator produces an average voltage value equal to the reference voltage within each PWM period. PWM provides a way to decrease the Total Harmonic Distortion (THD) of load current. The THD requirement can be met when the output of a PWM inverter is filtered since the unfiltered output of a PWM based inverted will have a relatively high distortion. Figure 10 shows PWM Pulse Generation.

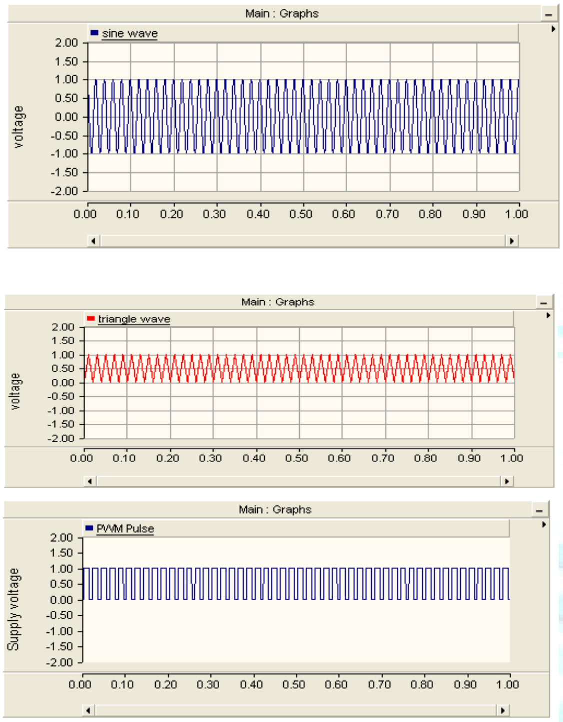

Figure.10. PWM pulse Generation

Harmonics are electric voltages and currents that appear on an electric power system as a result of non-linear electric loads. Harmonic frequencies in the power grid are a frequent cause of power quality problems. Harmonic components should be reduced as much as possible. To perform the harmonic analysis on the inverter, the PSCAD measurement circuitry created can be seen in Figure 11

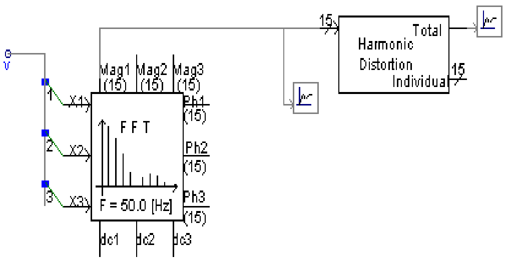

Figure.11. FFT and THD Blocks in PSCAD

From the same steady state test started from a snapshot taken during the run, Figure 11 and Figure 12 respectively shows the output voltage and current waveforms and their corresponding THD levels at the PCC for a short time segment during the run. Similarly Figure 13 and 14 respectively shows the THD value for with and without harmonic reduction filter.

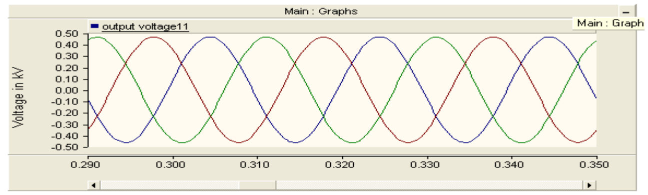

Figure.11.Output Voltage Waveform

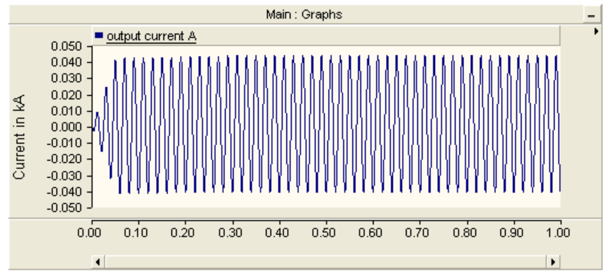

Figure.12. Output Current waveform for Phase A

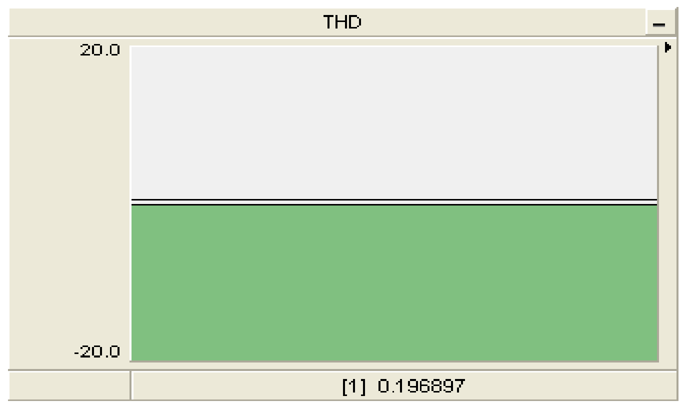

Figure.13. THD value with Harmonic Reduction Filter

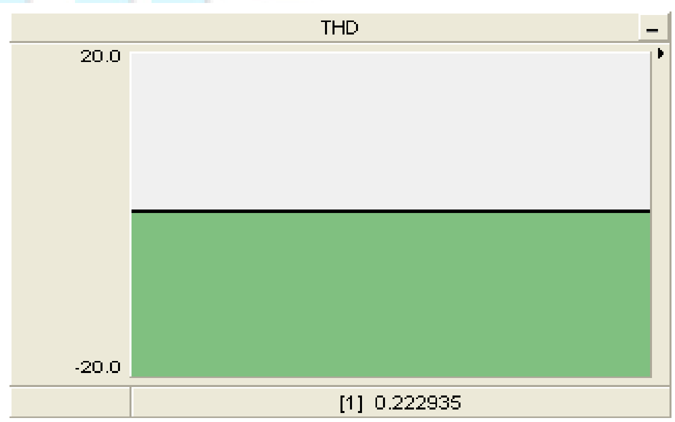

Figure.14. THD value without Harmonic Reduction Filter

VII. CONCLUSION

This paper makes a detailed analysis of the modeling method for PV arrays, MPPT controller and the power controller in SSGPS. Based on this method, the electromagnetic transient model of a 100kW SSGCPS is established. The simulation results show that the simulation model can reflect characteristics and functions of the actual physical device accurately and can be used to the design and research of big-power PV system.

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