IJEASM

International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 4 Issue 4, April 2023

DSMPI Controller Based on a Dual-function PV-ECS Integrated to 3P4W Distribution Grid for Active Power Quality Improvement

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Abstract: *In this paper a PVA integrated VSI is connected to three phase four wire system which acts are both harmonic filter and also distribution generation during PVA OFF time ie. active power transfer and power quality (PQ) enhancement at the point of interaction (POI). The PV-ECS system comprises of a solar photovoltaic array and a voltage source inverter (VSI), supplying active power (during daytime) to the distribution grid and connected single-phase and three-phase loads. A three-phase magnitude-phase locked loop (3M-PLL) method is utilised to extract and estimate fundamental term of load currents and an incremental conductance algorithm is applied for maximum power point tracking. To demonstrate its effectiveness, the system is modelled and its performance is simulated on MATLAB with replacement of the PI controller with DSM-PI controller for better settlement of source currents. The new controller reduces the disturbances and oscillations faster with variable Kp and Ki values helps in reduction of harmonics.*

Keywords: *PV Array, Hysteresis current controller, MPPT Controller, PI Controller, DSMPI controller, PLL.*

1. Introduction

The development of solar photovoltaic-energy conversion systems (PV-ECS) on the terraces of commercial and industrial buildings has been proven to be a key strategy for establishing urban sustainability. The Indian government announced its intention to install grid-connected PV-ECS with a capacity of roughly 40 GW by the end of 2022. This is projected to lower the cost of solar photovoltaic (PV) systems and bring them closer to grid parity. [1]
Numerous control strategies can also be used to minimise harmonics, keep accurate power distribution, restrict negative sequence voltage components, as well as improve the stability in PV-Grid connected systems in attempt to solve the influence of nonlinear as well as unbalance mixed loads on output of voltage source inverters. In the power generating, transmission, as well as distribution networks, power quality issues are critical difficulties. Distributed generation is defined as renewable energy sources (RES) integrated at the distribution level (DG). [2]
The utility is concerned about the increased prevalence of intermittent renewable energy sources in distribution systems, which could endanger network stability, voltage regulation, as well as power-quality (PQ) issues. As a result, DG systems must adhere to stringent technical and regulatory frameworks in order to assure the overall network's safety, reliability, and efficiency. [3]

Solar PV Array

Energy is one of the most attractive alternatives, as it contributes significantly to global economic growth. Numerous causes, such as urbanisation, modernization, and the growth of the human population, have resulted in a significant increase in global energy demand. Energy consumption in wealthy countries is expanding at a rate of 1% per year, whereas in developing countries it is increasing at a rate of 5% per year. Nowadays, all the world countries' believe that the renewable energy is the alternative solution instead of using the traditional energy types. Solar energy considers one of the most important types among all renewable energy types that for the advantages which are clean, carbon-free and the availability. [4]
The basic building block of a solar panel is the solar cell. Several low voltage PV cells (~0.5 V) connected in series (to produce high voltage) and in parallel (to produce high current) form a module. While solar panels are comprised of multiple modules, the terms solar module and solar panel are often used interchangeably. Panels connected in

parallel-series configurations form arrays as shown in Fig. 1.

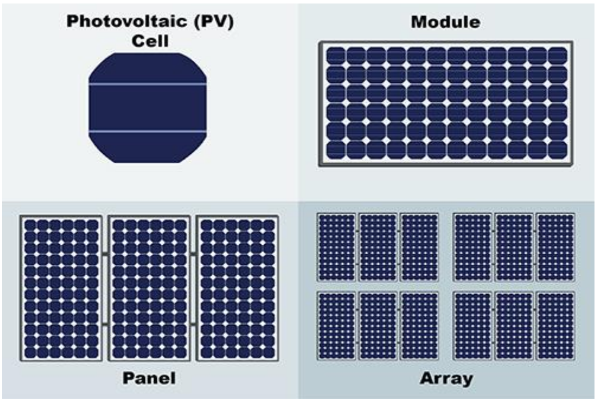

Figure 1 PV Array

A solar cell is a forward biased PN junction diode. It works in response to the voltage generated in exposure to visible radiation. To obtain the I-V curve generated from a single cell, it can be modelled as a current source. A diode is attached across the terminals of the current source to construct the equivalent circuit. When the solar cell is exposed to light, its behavior can be modelled as:[5]

$$I = I_{pv} - I_D$$

Where, I_{pv} is the photo generated current and I_D is the Shockley diode equation.

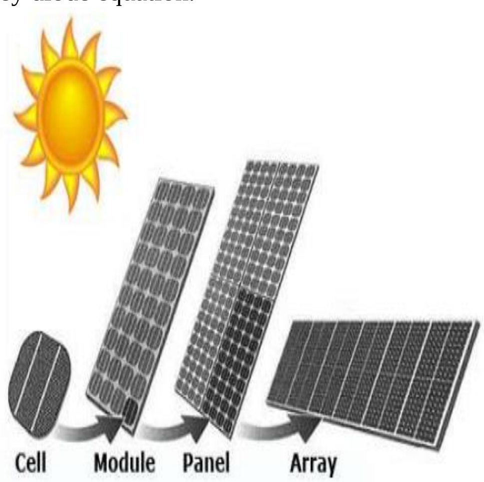

Figure 2 Building blocks of a solar PV system

PV systems generate DC electricity. However, there are significant discrepancies between the power generated by solar modules and the public electrical utility (grid) interconnection requirements. Since the grid system, and nearly every home electronic device, is designed to work with AC electricity, dc-ac converters (also known as inverters) must be included in the power conditioning system. Fig. shows a block diagram of a grid-interactive PV system.[6]

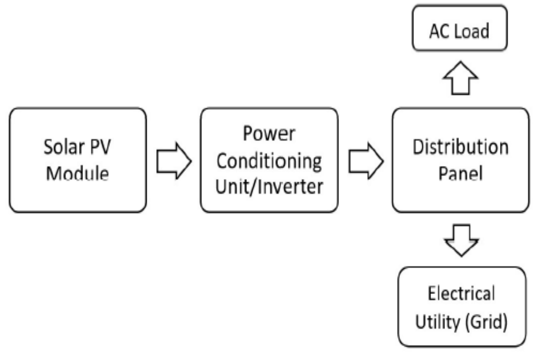

Figure 3 Block diagram of a grid-connected photovoltaic system.

2. P4W grid-integrated PV-ECS

The schematics and block diagram of 3P4W grid-integrated PV-ECS are shown in Fig.4

The system utilises a solar PV array, an insulated gate bipolar transistor based four-leg VSI with a DC link capacitor (C_{dc}), an interfacing inductance (L_f), a ripple filter, a 3P4W grid having a source impedance (Z_s) and connected single-phase or three-phase nonlinear or linear loads. The ripple filters are used to reduce the excessive noise generated by VSI operation. In addition, interface inductance (Lf) role is to attenuate the ribs that may be found in the VSI currents. The control method of a suggested single-stage PV-ECS solar grid is illustrated in Fig.5 The adoption of one-stage topology lowers the number of PV-ECS components, thereby decreasing losses and improving efficiency. The control method includes two major components: (i) InC-based MPPT control and (ii) 3M-PLL-based switching control of VSI.

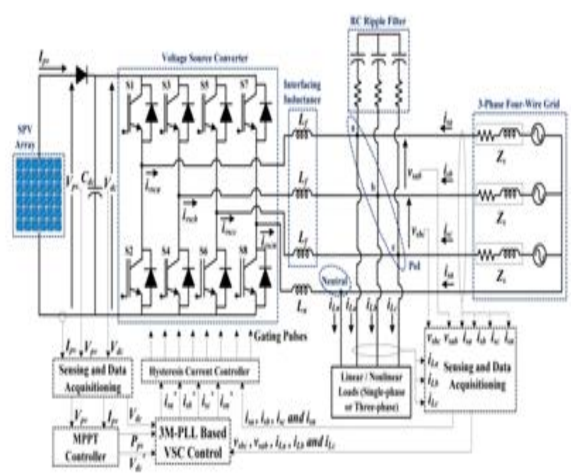

Fig. 4 Structure diagram of 3P4W grid-connected PV-ECS

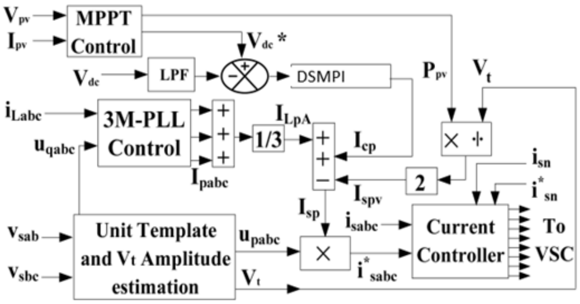

Fig. 5 Control scheme for 3P4W grid-tied PV-ECS

Phase Magnitude-Phase Locked Loop (3m-Pll)

Phase Locked Loop

A phase-locked circuit (PLL) is an electronic circuit containing an oscillator driven by tension or voltage that adapts continuously for the input signal frequency. PLLs are used for generating, stabilizing, modulating, demodulating, filtering or recovering a signal from a "noisy" channel of communication, which interrupts data.
PLLs are often used in wireless or radio frequency (RF) applications, particularly Wi-Fi routers, walkies, TVs and mobile telephones.[2]
A phase-locked loop is a closed-loop feedback control circuit which is frequency- as well as phase-sensitive at its simplest. PLL is a system made of both analogue and digital components — linked in a configuration of "negative feedback." Consider an extensive operational amplifier circuit (op amp) similar.[5]
A PLL consists of three key components:

- Phase detector (sometimes referred to as the phase comparator): compares the two-signal phases and produces a voltage according to the phase difference. It multiplies the reference input and the oscillator output controlled by the voltage.
- Controlled voltage oscillator: produces a sinusoidal signal which roughly corresponds to the centre frequency supplied by the low passenger filter.

Low-pass filter: a kind of loop filters which smoothens and flattens the signal to make it more DC-like by slowing the high-frequency alternating current (AC) component of the input signal.

3. Methodology

DSMPI Controller

The gains are locked to a certain value in a conventional PI controller. Differently the value of the DSM-PI controller is continuously altered by mistake.

This DSM-PI controller monitors Kp and Ki's proportional and integrated gains and thus minimizes the reaction time. The primary benefit of this system is that the speed reaction time is decreased by reducing oscillations and perturbations.

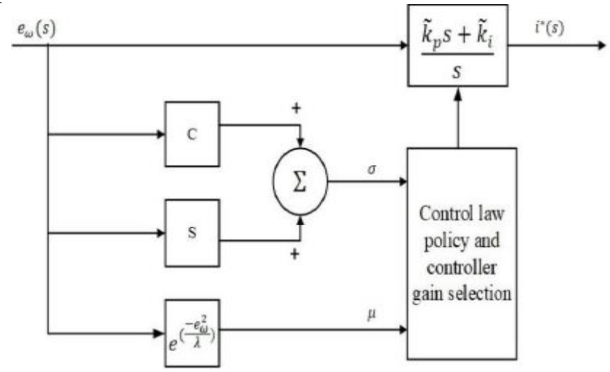

Figure 6 DSM-PI control scheme block diagram

Therefore, the DSM-PI controller accelerates the speed response and causes reduced oscillations and perturbations. [8]

4. Results and Discussion

For validation of the proposed 3M-PLL-based control algorithm applied to 3P4W grid-integrated PV-ECS, simulations are performed on MATLAB software using FFT Analysis toolbox.

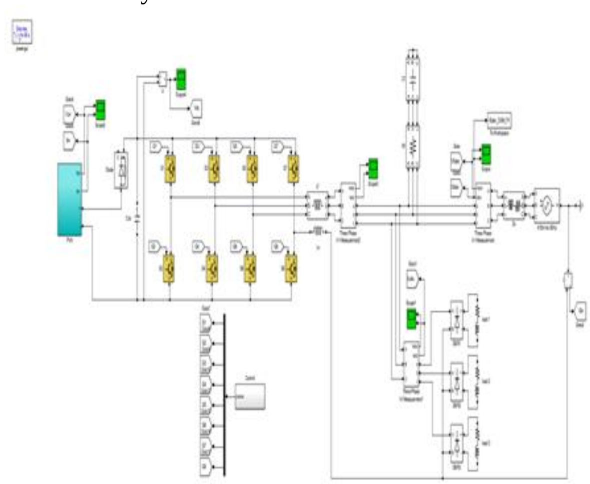

Figure 7 PVA connected to 3P4W grid with non-linear loads

The above is the test system modeling of the proposed system with 3P4W grid operating at 415V 50Hz connected to three individual non-linear loads. At PCC the PVA four legged VSI is connected for injection of active power and harmonic compensation. The internal control of the proposed VSI model is shown below. As seen the controller used Incremental conduction MPPT for estimation of reference DC voltage Vdc ref. The reference current signals are generated using 3M-PLL module and unit template Vt amplitude estimator module.

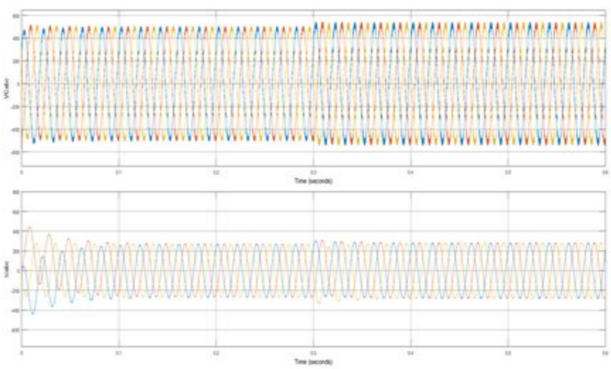

Figure 8 Source voltage and currents

The above are the source voltages and currents of the three phases with small variation in the current at 0.3sec due to change in solar insolation. The load voltages and current always remains the same irrespective of any change in the PVA parameter or the grid system.

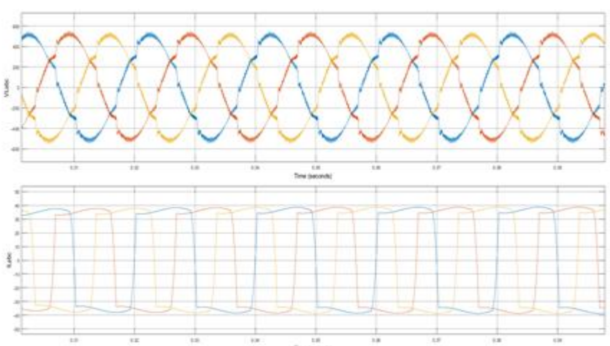

Figure 9 Load voltages and currents

The below are voltage and current of the PVA with change in solar irradiation at 0.3sec from 700W/mt2 to 1000W/mt2. As observed the voltage of the PVA changes from 525V to 710V when the solar irradiation reaches to optimum value. Therefore the power input to the grid also changes.

The internal modeling of the DSM-PI controller can be seen below. The Kp and Ki are the variable proportional and integral gains which change as per the error input given to the controller. The THDs of the source current without the PVA four legged VSI module, with connecting the module operated with PI controller and DSM-PI controller are compared using FFT analysis tool and are shown below. As seen in the analysis the THD of the source current is high at 37.87% when the grid is operated without the VSI module connected at PCC. And when the PVA four legged VSI module is connected to the grid the THD is dropping down to 6.61% when the controller is operating with PI controller. With the update of the DSM-PI controller the THD of the source current is further reduced to 3.91% which is maintained below 5%.

5. Conclusion

A successful simulation of the proposed 3P4W system is implemented with non-linear load connected to the source injecting harmonics. A dual-function single-stage PV-ECS integrated to the 3P4W distribution grid has been proposed here. Two modes of operation of PV-ECS are to supply and transfer active power to the grid and tied loads as well as to improve quality of power at PoI. An InC-based approach is utilised here for tracking MPP of solar PV array and a 3M-PLL-based control scheme is utilised for extracting fundamental components of load current. The performance of the system under several circumstances such as nonlinear loading, unbalanced loading and different levels of irradiance have been shown by simulated and test results. Test findings showed that the power quality at the PoI was enhanced by adjusting for neutral current and reactive power, correction of the power factor as well as balance of grid loads. The harmonics on the grid, which is within the IEEE-519 standard, are lowered to below 5 percent. The DSM-PI controller connection increases the THD value to 3.91%.

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