Performance Analysis of Dual Stage Grid-Tied Three-Phase PV System

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Abstract**—** A simplified inverter topology using switching pulse Feed Forward Control Loop (FFCL) for grid integration of photovoltaic (PV) system is proposed. For grid-tied operation of PV-system two topologies are mentioned in literature, namely single-stage (SS) and dual-stage (DS). SS employs only one converter which regulates the DC voltage of PV and also integrates PV with grid. While in DS two converters are used to perform the above mentioned task individually. In this work for a three phase DS-PV system is designed for smooth operation with grid connectivity. Efficiency comparison between conventional Voltage Source Converter (VSC) and proposed inverter topology for PV system configurations is discussed. The system is designed in MATLAB simulink to study its performance for various loading conditions**.**

Keywords: Feed Forward Control Loop (FFCL), Renewable Energy Sources (RES), Voltage Source Converter (VSC), Grid Integration, Total Harmonic Distortion (THD)

I. INTRODUCTION

The production of electrical energy from Renewable Energy Sources (RES) has grown a lot in recent decades, mainly due to increased demand for electricity, as well as the global intensive efforts to overcome the harmful environmental impacts caused by pollutant energy sources, such as oil, coal, natural gas, and others. Distributed generation (DG) systems based on RES have contributed to find new modern solutions for planning conventional power systems [1]. Inserted in this scenario, solar energy has emerged as a promising RES due to its abundance across the earth's surface. In particular, by means of photovoltaic (PV) cells, PV panels have been properly designed to produce energy by converting sunlight into electricity. For grid-tied operation of PV-system two topologies are mentioned in literature, namely single-stage (SS) and dual-stage (DS). SS employs only one converter which regulates the DC voltage of PV and also integrates PV with grid. While in DS PV systems, an additional dc/dc converter is placed between the PV array and the inverter separately for DC bus conditioning. [10, 12]. For grid-connected operation of PV systems, while designing a converter control the main concern is to achieve high efficiency with power output for various modes of operation.

The converter control must include; maximum power point, control power injection, high efficiency, and reduced harmonic distortion in voltage and current waveform at point of connection **of** inverter. In the proposed work FFCL type topology has been discussed as shown in fig-1.

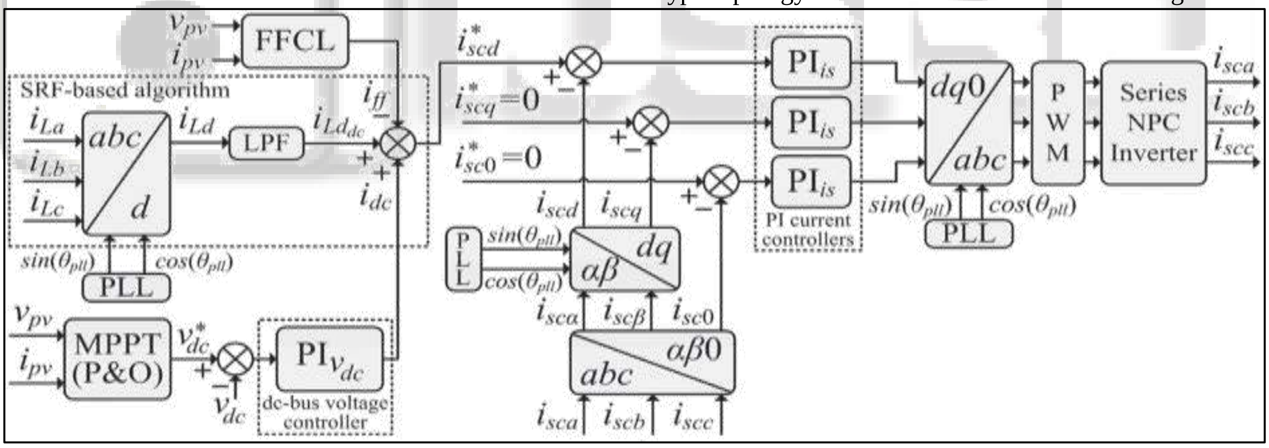

Fig. 1: Feed Forward Control Loop

The FFCL contributes to speed up computation of the input current references during the occurrence of fast variations in solar radiation. As a consequence, possible disturbances in the dc-bus, such as voltage oscillations and voltage overshoot/undershoot are reduced.

II. DUAL STAGE GRID TIED PV SYSTEM

Single-stage is the most commonly used topology having simple designing features. The state of the art of designing SS system is that the DC output of the solar panel is directly connected to the DC/AC converter for grid integration. The simplified block-diagram of this system is presented in fig. 2. The one sole converter incorporate MPPT algorithm, DC-bus regulator and inverter functionality.

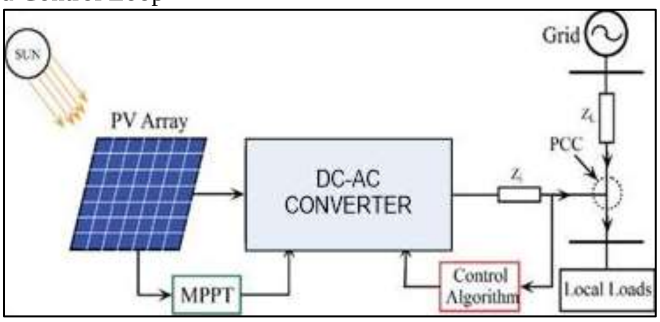

Fig. 2: general architecture of SS grid tied PV system

The complete power circuit scheme of the proposed Dual stage grid tied three phase PV system is presented in Fig. 3. To obtain desired DC voltage the generated output of the PV panel is boosted using DC-DC boost converter. The

Dc output is then connected to the DC to AC converter. The output of inverter voltage-current is much distorted due to the high frequency switching involved in inverter topology. These harmonics are removed by passive filtering elements.

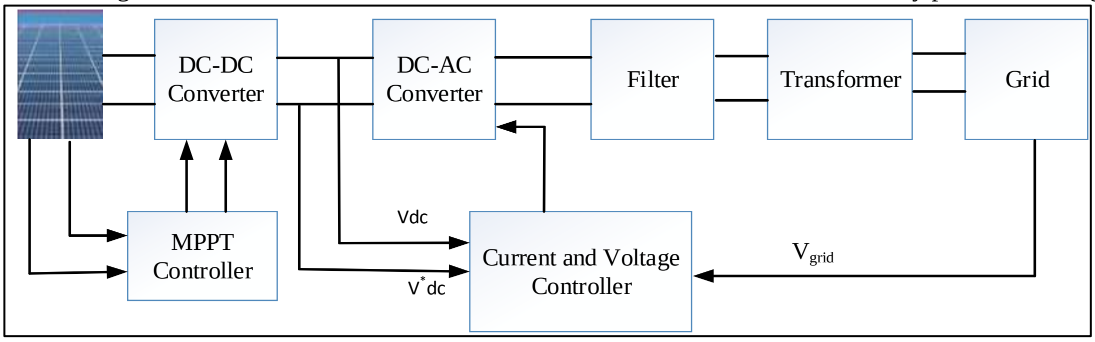

Fig. 3: shows the proposed system for dual stage grid tied PV system

The distributed generation source, without storage, is composed of a PV array, which is formed by a single string with thirty six series-connected PV panels, making possible the direct connection between the PV array and the dc-bus of the inverters via DC converter.

The DS-PV system is designed to operate with dc-bus voltage reference *Vdc* determined by the oost converter. Thus, under standard test conditions (STC), the PV system operates at a constant dc-bus voltage amplitude of around 400V.

III. Proposed Work

Although PV systems are emerging as power solution to meet the increased demand of electricity, but the reliability and robustness of the PV panel is always questionable.

We are designing a dual stage PV converter to stabilize the output of solar system at various modes of operation. A dual converter topology is adopted to operate the PV system, where Dc converter controls Dc voltage at DC-bus, while the AC converter is controlled to operate as a sinusoidal current source to synchronize the DS-PV with grid.

The control of inverter is designed via FFCL for fast convergence of reference value variations. Furthermore, regulated, balanced, and harmonic-free output voltages are provided to the load. The simulation model of the proposed system is shown in Fig-3. The control of inverter is designed using discrete controller. For grid synchronization, grid voltages are fed to the controller as a reference signal. Before feeding signals are synthesized to obtain positive sequence components using two axis theory of direct axis and quadrature axis as shown in figure 4.

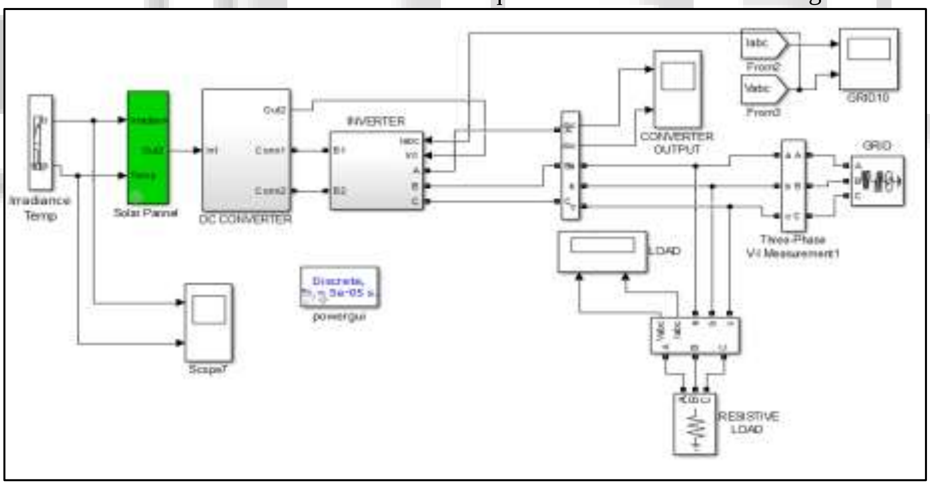

Fig. 3: shows the MATLAB model for dual stage grid tied PV system

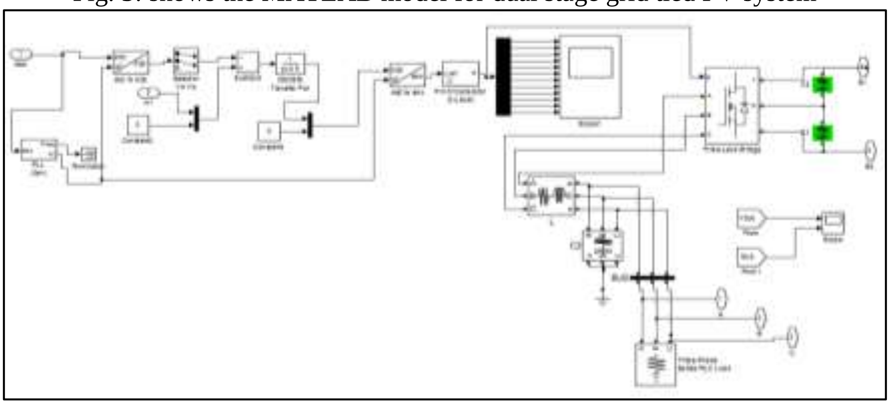

Fig. 4: shows the MATLAB model for inverter control

In the paper D-S 3P4W grid-connected PV system with combined operation to improve power quality is presented. The performance analysis of the designed system is carried out under various loading;

- Dual stage PV system grid tied with resistive load of 40 ohms (OPM-1).
- Dual stage PV system grid tied with dynamic three phase variable loading. (OPM-2)

IV. SIMULATION RESULTS

A PV array is modeled in matlab simulink at 250 to 1000 w/m2 with solar irradiance with 15 series and 20 parallel module. The ideality factor of PV-cell is chosen as 1.3, and open-circuit voltage is 54.2 with current at short circuit is 5.9A.

The system is synchronized with the grid using PI controller and Phase Lock Loop. Three phase voltage source is considered as a AC bus, replica of grid with 5KW power. To design a two back to back DC/AC converter is connected through a dc link capacitor with 1micro farad capacitance. The AC converter one side is connected to the regulated DC output of the PV system and other side to the grid. The system parameters for the model is presented in table 1.

Parameter	Symbol	Value
Nominal utility voltages	V (RMS)	127.27
Nominal Frequency	ω	50Hz
Inverter inductance	L	45mH
Filter Capacitance	C	60e-6 F
Filter Inductance	L_f	10.45 mH
Nominal Load 1	P_{Load1}	40 ohms
Load 3	Three phase dynamic load	P_L=50e6 Q_L=25e6

Table 1: Parameter selection

The result of the proposed topology of dual stage grid tied inverter is compared with the single stage grid tied inverter for all the three phases of voltage and current at grid side and converter side. The output waveforms of dual stage grid tied PV system with linear loading both at grid side and load side are shown in Fig 5 and 6 respectively. The output waveforms of dual stage grid tied PV system with dynamic reactive and active power loading both at grid side and load side are shown in Fig 7 and 8 respectively.

Table-2 shows the comparative analysis of the THD for the Single stage and dual stage system. The harmonic content in dual stage system is 0.46% in case of current where as it is 2-3 % in case of single stage system. For three phase voltages THD is 0.59% in case of DS and around 2% in case of SS system.

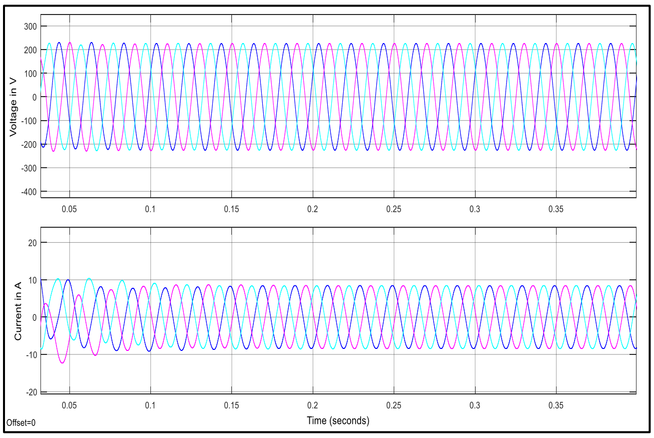

Fig. 5: Grid Side Voltage-current Waveform of Grid-tied PV System with Linear load

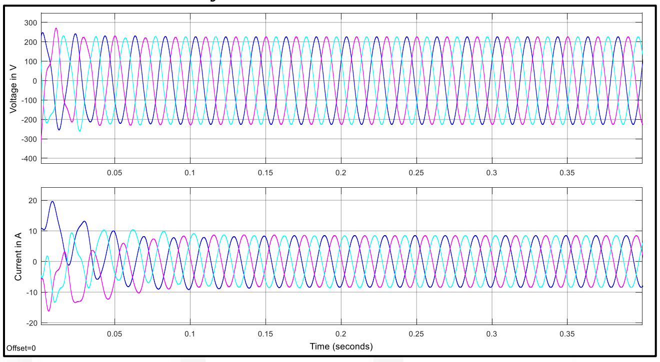

Fig. 6: Load Side Voltage-current Waveform of Grid-tied PV System with Linear load

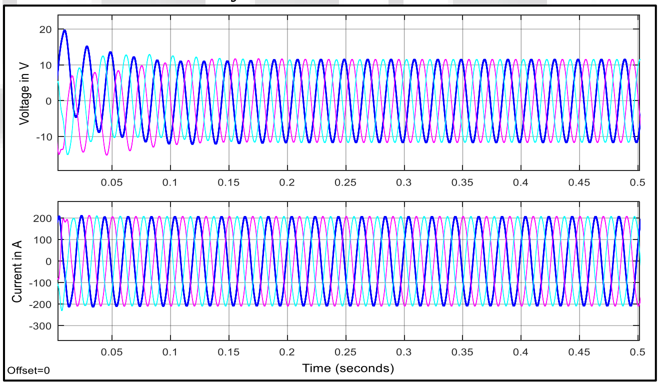

Fig. 7: Grid Side Voltage-current Waveform of Grid-tied PV System with Dynamic load

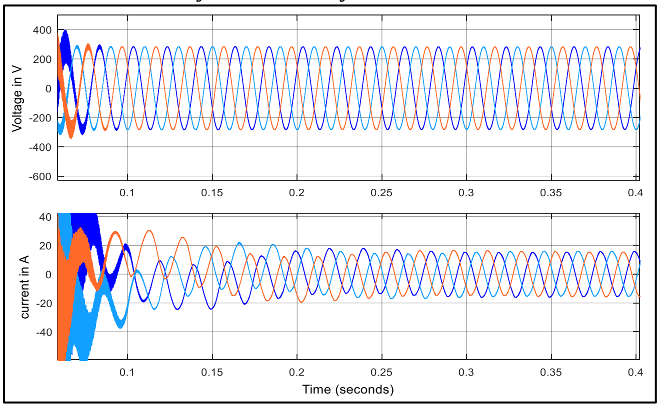

Fig. 8: Load Side Voltage-current Waveform of Grid-tied PV System with Dynamic load

CURRENT						
	SSPV			DSPV		
THD%	Ia	Ib	Ic	Ia	Ib	Ic
Linear load	2.8	2.7	2.6	0.46	0.46	0.46
Dynamic load	3.2	3.1	3.1	0.46	0.46	0.46
THD%	VOLTAGE					
Linear load	1.7	1.9	1.8	0.59	0.59	0.59
Dynamic load	2.3	1.9	1.4	0.59	0.59	0.59

Table 2: Comparison of THD for single and dual stage system

V. CONCLUSION

Static and dynamic performances of the system were evaluated under various modes of operation of grid voltage conditions, including sags, unbalances, and harmonics.

Apart from series compensation, suppression of load harmonic currents, carried out, such that an effective Unified power conditioning was achieved.

Comparative analysis of the obtained results with base paper is presented and the results of the proposed topology are better as the THD at maximum cases are nearly 0.5 % in the proposed topology as compared to near about 2-3% in base paper.

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