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Design of Single Phase Grid Connected Solar PV Inverter Using MATLAB

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Abstract- This project presents the design, simulation, and performance analysis of a single-phase grid-connected solar photovoltaic (PV) inverter using MATLAB /SIMULINK. The primary objective is to develop an efficient and reliable inverter system that ensures maximum power extraction from the solar PV array and seamless integration with the grid. The main elements of the PV control structure are: a maximum power point tracker (MPPT) algorithm using the incremental conductance method: a synchronization method using the phase-locked-loop (PLL), based on delay: the input power control using the DC voltage controller and power feed-forward and the grid current controller implemented in two different ways, using the classical proportional integral (PI) and the novel proportional resonant (PR) controllers. The control strategy was tested experimentally on 2kW PV inverter.

Index Terms-MPPT, PWM, PI Controller, Inverter, Current Controller, Lowpass filter

I. INTRODUCTION

World is moving towards the greener sources of energy to make the planet pollution free and environment friendly. Solar PV is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. More than 100 countries use solar PV. Installations may be ground-mounted (and sometimes integrated with farming and grazing) or built into the roof or walls of a building (either building-integrated photovoltaics or simply rooftop).

The purpose of the power electronics in PVPS is to convert the DC current from the PV panels into an AC current to the grid, with the highest possible efficiency, the lowest cost and keep a superior performance. With PV sources connected at the DC side of the inverter, it is utmost essential to fetch maximum power from the source to make the system efficient. Out of different algorithm to track maximum power point (MPP) like Incremental Conductance (IC). IC based method provides fast dynamics and control over fast changing insolation condition.

For current-controlled PV inverters in most of the cases a PI controller with grid voltage feed-forward (VFF) , but this solution exhibits two well known drawbacks: inability of the PI controller to track a sinusoidal reference without steady-state error and poor disturbance rejection capability. An alternative solution in order to alleviate the PI's drawbacks is presented , Another approach in where a new type of stationary-frame regulators called Proportional Resonant (PR) is introduced. In this approach the classical PI d.c.-compensator is transformed into an equivalent a.c.-compensator having the same frequency response characteristics in the bandwidth of concern.

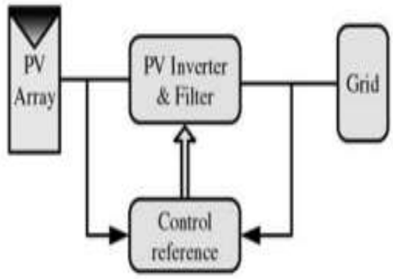

Fig 1: Power electronic system with the grid, source (PV array), power converter and control.

II. LITERATURE SURVEY

The introduction highlights the importance of analyzing the dynamic stability of photovoltaic (PV) grids, emphasizing the interaction between PV arrays and the grid. It presents a developed mathematical model that captures the complex behavior of these systems in grid-connected systems.

The current-controlled voltage source inverter (CCVSI) utilizes a combination of hysteresis and Proportional-Integral (PI) controllers to regulate the output voltage, ensuring stable and precise performance by continuously adjusting the control signals based on real-time feedback.

MATLAB/Simulink model for simulating a single-phase grid-connected photovoltaic (PV) system. The model probably

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includes components such as solar panels, inverters, and grid connection systems.

Novel control method for a three-phase voltage-source solar power conditioner, which is a type of power converter used in solar power systems. The control method uses a single-phase pulse-width modulation (PWM)technique.

The impact of distributed energy resources on the grid, with and without voltage and reactive power control, under various load types.

III. SYSTEM DESCRIPTION

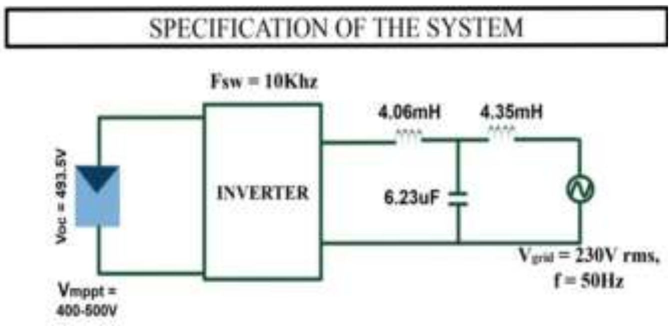

Fig 2: Specification of the system

Usually the power converter interface from the DC source to the load and/or to the grid consists of a two stage converter: the DC-DC. converter and the DC-AC converter. An alternative solution could be the use of a single-stage converter where the DC-DC converter is avoided and in order to ensure the necessary DC voltage level the PV array can be a string of PV panels or a multitude of parallel strings of PV panels. In the classical solution with twostage converter, the DC-DC converter requires several additional devices producing a large amount of conduction losses, sluggish transient response and high cost while the advantages of the single stage converters are: good efficiency, a lower price and easier implementation. The disadvantages of the single-stage converter are the fact that the PV panels are in series and if shading occurs on one or several PV panels then the efficiency of the whole system is reduced.

The PV inverter system consists of a solar panel string and a DC link capacitor Cdc on the DC side with an output AC filter (LCL), insulation transformer and grid connection on the AC side. The number of panels in the string has to ensure a DC voltage higher than the AC peak voltage at all time. The energy conversion from DC to AC side is made by a single-phase voltage source inverter. The used solar panel string consists of sixteen uniserial PV panels (120 W for each panel).

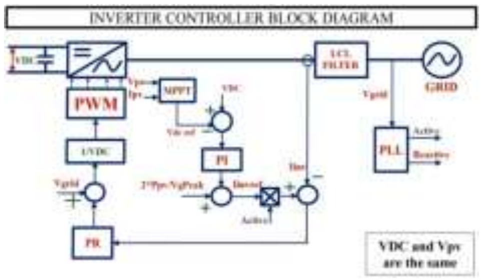

Fig 3: Block Diagram

Control Strategy
For the grid-connected PV inverters in the power range of 1-5 kW, the most common control structure for the DC-AC grid converter is a current-controlled H-bridge PWM inverter having a low-pass output filter. Typically L filters are used but the new trend is to use LCL filters that have a higher order (3rd) which leads to more compact design. The drawback is its resonance frequency which can produce stability problems and special control design is required. The main elements of the control structure are the synchronization algorithm based on PLL, the MPPT, the input power control, the grid current controller including PWM.

PLL Structure
The PLL is used to provide a unity power factor operation which involves synchronization of the inverter output current with the grid voltage and to give a clean sinusoidal current reference. The PI controller parameters of the PLL structure are calculated in such a way that the settling time and the damping factor of this PLL structure can be set directly. The PLL structure is also used for grid voltage monitoring in order to get the amplitude and the frequency values of the grid voltage. The general form of the PLL structure including grid voltage monitoring Isolation Inverter systems often operate with high-voltage power circuits. Gate drivers provide electrical isolation between the low-voltage control circuits and high-voltage power circuits, typically through opto-isolators or transformer-based designs.

MPPT Algorithm
The task of the MPPT in a PV energy conversion system is to tune continuously the system so that it draws maximum power from the solar array regardless of weather or load conditions. Since the solar array has a non-ideal voltage-current characteristics and the conditions such as irradiance, ambient temperature, and wind that affect the output of the solar array are unpredictable, the tracker should deal with a nonlinear and time-varying system. The conventional MPPT algorithms are using $dP/dV = 0$ to obtain the maximum power point output. Several algorithms can be used in order to implement the MPPT as follows: perturb & observe, incremental conductance, parasitic capacitance and constant voltage, but only the first two are the most frequently used. The incremental conductance algorithm has been chosen as a

MPPT strategy in this paper. This algorithm has advantages compared to perturb & observe as it can determine when the MPPT has reached the MPP, where perturb and observe oscillates around the MPP. Also, incremental conductance can track rapidly the increase and decrease of irradiance conditions with higher accuracy than perturb & observe. One disadvantage of this algorithm is the increased complexity when compared to perturb & observe. This increases the computational time and slows down the sampling frequency of the array voltage and current.

The flowcharts of the perturb & observe and of the incremental conductance algorithm, where Vk and Ik are the momentary voltage and current of the PV array and Vk-1, Ik-1 are the previous sampled voltage and current, respectively. The dP/dV term can be replaced by I + (ΔI/ΔV) · V. The output of the MPPT is the DC voltage reference (V* pv).

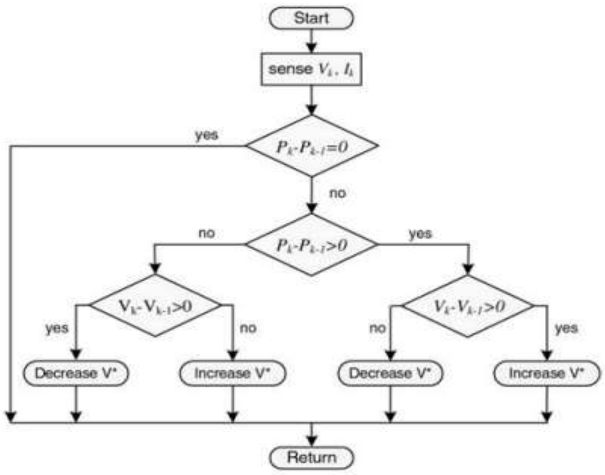

Fig 4: Perturb & Observe

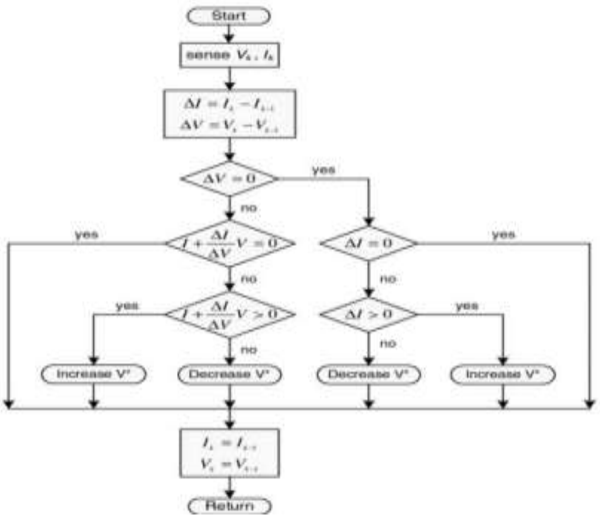

Fig 5: Incremental Conductance Algorithm

Input Power Control

The control strategies of input power in the case of a power configuration of PV system without DC-DC converter are presented in the following section. A new control strategy of input power is proposed. The new element introduced is the power feedforward. The computed value of the current amplitude reference using the PV Power and the RMS value of the AC voltage (Vac RMS) is added to the output value of the DC voltage controller (Ir) resulting in the AC current amplitude reference (Iref). Using the input power feed-forward the dynamic of the PV system is improved being known the fact that the MPPT is rather slow. The DC voltage controller ensures a quick response of the PV system at a sudden change of the input power.

Grid Current Controller

Classical PI control with grid voltage feed-forward (Vff) as depicted in Fig. 7a, is commonly used for current-controlled PV inverters. The PI current controller GPI(s) is defined as:

$$Gpi(s)= Kp +Ki/s \quad \text{-------------(1)}$$

In order to get a good dynamic response, a grid voltage feed-forward is used, as depicted in Fig. 7a. This leads in turn to stability problems related to the delay introduced in the system by the voltage feedback filter. In order to alleviate this problem an advanced filtering method for the grid voltage feed-forward should be considered. The Root-locus and Bode diagram analysis of the PI controller is presented .As it has been mentioned in the introduction of this paper, an alternative solution for the poor performances of the PI controller is the PR controller.

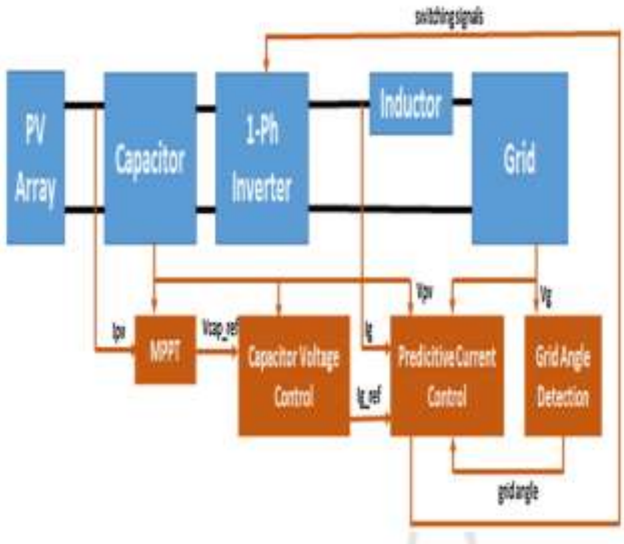

Fig 6: Flow of the system control

PR Controller

Proportional resonant controllers (abbreviated PR controllers) are a particular type of transfer function that are often implemented for the closed-loop control of systems with a sinusoidal behavior. As their name indicates, they possess both a proportional and a resonant term, which can be tuned independently. When needed, additional resonant terms can also be added to attenuate specific harmonics.

A shortcoming with the PI controller generally is that it is not able to follow a sinusoidal reference without steady state error due to the dynamics of the integral term. The inability to track a sinusoidal reference causes the need to use the grid voltage as a feed-forward term to obtain a good dynamic response by helping the controller to try to reach steady state faster. A current controller which is more suited to operate with sinusoidal references and does not suffer from the above mentioned drawback is the PR controller. The PR controller provides gain at a certain frequency (resonant frequency) and almost no gain exists at the other frequencies..

IV. IMPLEMENTATION

Simulink Blocks used in the Project Simulation:
1. Parks Transformation:

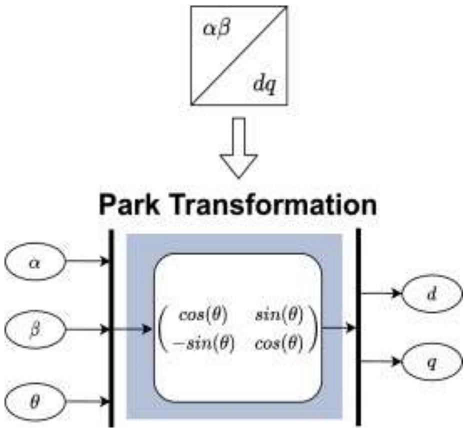

Fig 7: Parks Transformation

Purpose: Parks transformation block improves park design and functionality.

Description: The Park Transform block computes the Park transformation of two-phase orthogonal components (α, β) or multiplexed αβ0 components in a stationary αβ reference frame. The block accepts the following inputs. Either α-β axes components or multiplexed components αβ0 in the stationary reference frame. Use the Number of inputs parameter to use either two or three inputs. Sine and cosine values of the corresponding angles of transformation.

2. Bus Selector

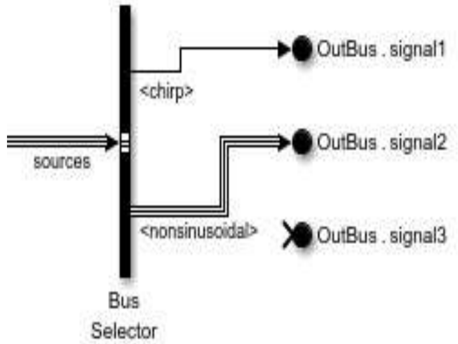

Fig 8: Bus Selector

Purpose: Bus Selector extracts and isolates signals from buses.

Description: The Bus Selector block extracts the elements you select by name from the input bus hierarchy. The block can output the selected elements separately or in a new virtual bus. When the block outputs the selected elements separately, each selected element corresponds to an output port. When the block outputs a new virtual bus, the block has one output port for the virtual bus that contains each selected element.

3. Scope

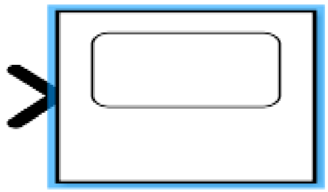

Fig 9 Scope

Purpose: Display signals during simulation.

Description: While the simulation is running, the Scope block displays the output of the block driving it. Opening a scope block produces a scope window. The title of this window matches the name of the block. The Scope block in Simulink provides a graphical display of signals during simulation. It allows users to visualize time-domain data, track signal behaviour, and analyze system performance in real-time, making it essential for debugging and system evaluation.

V. SIMULATION MODEL & RESULTS

I have designed and simulated the circuit in MATLAB, a powerful simulation tool widely regarded as one of the best platforms for power electronics applications. MATLAB is used in wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas, MATLAB provides a number of features for documenting and sharing your work. You can integrate your MATLAB code with other languages and applications, and distribute your MATLAB algorithms and applications.

Simulink is integrated with MATLAB, providing immediate access to an extensive range of tools that let you develop algorithms, analyze and visualize simulations, create batch processing scripts, customize the modeling environment, and define signal, parameter, and test data.

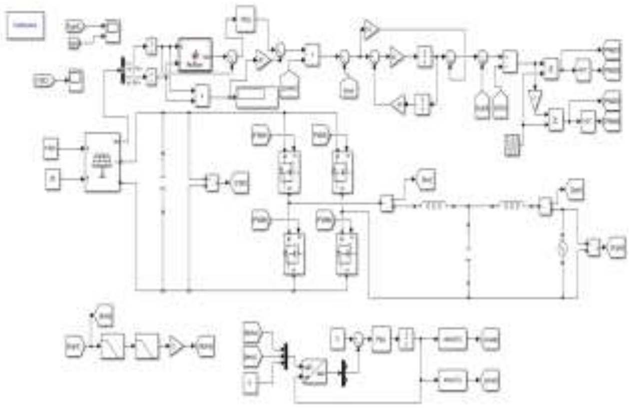

Fig 10: Simulation Setup

The system inputs are Solar Irradiance and Temperature to the PV Array. Solar irradiance is Given as 1000W/m2 and 25 degree Celsius Temperature. From PV array we get the DC Voltage and it is converted to 230V AC by a single phase Grid Connected Solar PV Inverter circuit. DC components are filtered out by LC filter and the ripple free signal is fed to the load. The filter output is maintained by developing a closed loop system with a current controller. The controller compares the actual load current and the reference current and the error signal is modulated with the help of proposed PR controller. From the PR controller output unipolar PWM pulses are generated to trigger the power semiconductor switches of the inverter.

Design of LCL filter
Inductor
The voltage across the inductor is given by and the potential difference between the inductor is defined. Inductor ripple current is calculated by using and the maximum ripple current is derived by differentiating with respect to time and equate it to zero.

Capacitor C
The cut-off frequency is calculated and it is 10% of switching frequency.

Design of PR Controller: The general block diagram of PR controller. The ideal and non-ideal PR controller in s domain is represented respectively . The ideal PR controller suffers from stability problem and sudden phase shift and these are eliminated by non-ideal PR controller.

Fig 11: Simulation results for grid voltage and grid current

VI. CONCLUSION

The design and simulation of a single-phase grid-connected solar photovoltaic (PV) inverter using MATLAB/SIMULINK have demonstrated significant advancements in efficient solar energy conversion and integration. The maximum power point tracking (MPPT) algorithm based on the incremental conductance method, ensuring optimal energy extraction from the solar PV array under varying environmental conditions. The synchronization with the grid was achieved using a phase-locked loop (PLL). Proportional-integral (PI) and Proportional-resonant (PR) controllers for grid current regulation provided of their effectiveness in maintaining power quality and minimizing harmonic distortion..

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