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Utility Grid Connected PV Array through In-Line MPPT Strategy Based Boost Converter

lingaswamy Adepu
M.Tech-Energy Systems,
Department of EEE,
JBIET-Hyderabad, Telangana, India.

G Raja Sekhar
Assistant Professor,
Department of EEE,
JBIET-Hyderabad, Telangana, India.

Abstract:

This paper presents the design, simulation and implementation of a simple power electronic interface for grid connected PV array using boost converter and line commutated inverter. The controller extracts maximum power from the solar array and feeds it to the three-phase utility grid. The control system of VSC designed with voltage and current controllers as well as for the PLL synchronization unit. Boost converter uses a MPPT system which automatically varies the duty cycle in order to generate the required voltage to extract maximum power. The simulation result clearly shows the synchronization of inverter fed PV array and grid for any arbitrary load condition.

I. INTRODUCTION:

The development in renewable energy sources replaces the other traditional energy sources. Among the renewable energy sources, solar energy plays a major role due to its pollution free nature. For economical reasons the solar energy is not directly interfaced with the utility grid. Hence a power electronic interface is developed to interface the solar systems to the utility grid [1, 2]. This power electronic interface consists mainly an inverter and its output is given to a step-up transformer primary. The secondary of the transformer is connected to the grid [3, 4]. The use of transformer introduces losses in the system and also needs more space and leads to noisy operation. Hence a boost converter is introduced between solar system and inverter which eliminates the use of transformer thereby reducing the losses. Further, recent researches have focused on how to get maximum power from solar energy [5] - [8]. All the schemes invariably employ forced commutation for an inverter.

In the present paper, a closed loop controller employing line commutated SCR inverter for extracting maximum power from solar energy has been proposed. The inherent advantage of self latching property of SCRs has been exploited in the proposed scheme.

II. SYSTEM DESCRIPTION:

The work illustrates use of Sim Power Systems for modeling a PV array connected to a utility grid. PV array Grid model is a detailed model of a 100-kW array connected to a 25-kV grid via a DC-DC boost converter and a three-phase three-level Voltage Source Converter (VSC). Maximum Power Point Tracking (MPPT) is implemented in the boost converter by means of a Simulink model using the “Incremental Conductance + Integral Regulator” technique.

The detailed model contains:

- PV array delivering a maximum of 100 kW at 1000 W/m2 sun irradiance.
- 5-kHz boost converter increasing voltage from PV natural voltage (272 V DC at maximum power) to 500 V DC. Switching duty cycle is optimized by the MPPT controller that uses the “Incremental Conductance + Integral Regulator” technique.
- 1980-Hz (33*60) 3-level 3-phase VSC. The VSC converts the 500 V DC to 260 V AC and keeps unity power factor.
- 10-kvar capacitor bank filtering harmonics produced by VSC.
- 100-kVA 260V/25kV three-phase coupling transformer.
- Utility grid model (25-kV distribution feeder + 120 kV equivalent transmission systems).

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For this detailed model, the electrical circuit is discredited at 1 µs sample time, whereas sample time used for the control systems is 100 µs.

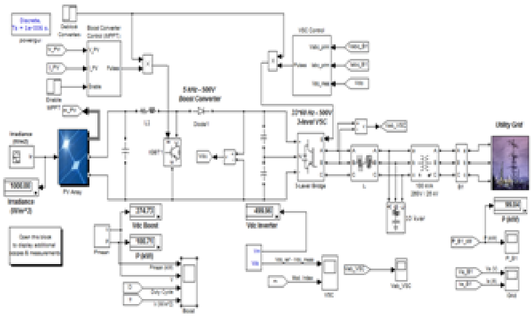


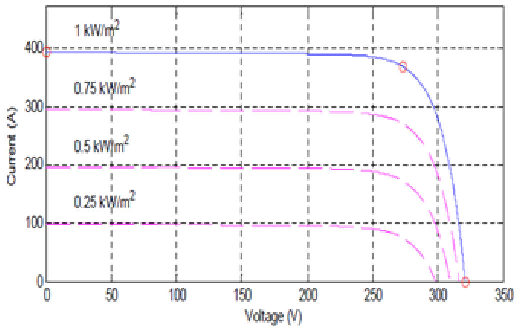
Fig 1: Proposed Grid connected PV array

III. PV ARRAY

The 100-kW PV array of the detailed model uses 330 Sun Power modules (SPR-305). The array consists of 66 strings of 5 series-connected modules connected in parallel (66*5*305.2 W= 100.7 kW). Open the PV-array block menu and look at model parameters.
Manufacturer specifications for one module are:

- Number of series-connected cells : 96
- Open-circuit voltage: Voc= 64.2 V
- Short-circuit current: Isc = 5.96 A
- Voltage and current at maximum power : Vmp =54.7 V, Imp= 5.58 A

The PV array block menu allows you to plot the I-V and P-V characteristics for one module and for the whole array. The characteristics of the SunPower-SPR305 array are reproduced below.



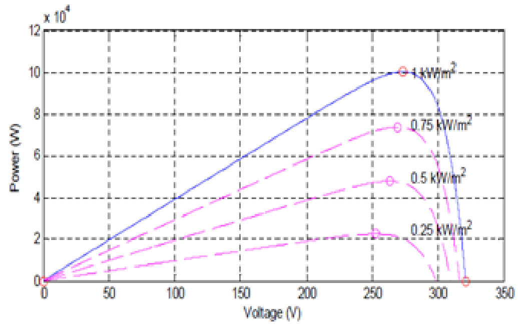


Fig 2: I-V and P-V characteristics of PV array

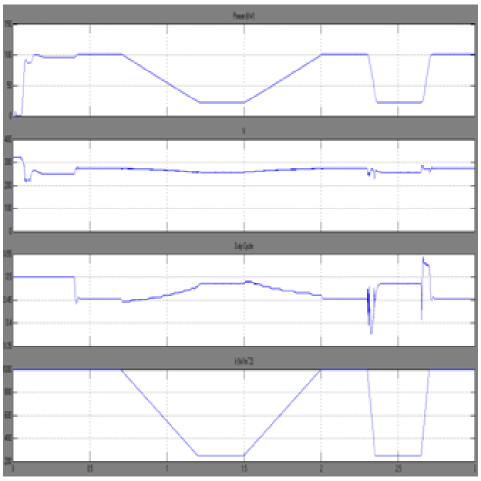


Fig 3: PV array measurements: PV power, PV voltage, Duty cycle, Irradiance

IV. BOOST CONVERTER

In the detailed model, the boost converter (orange blocks) boosts DC voltage from 273.5 V to 500V. This converter uses a MPPT system which automatically varies the duty cycle in order to generate the required voltage to extract maximum power.

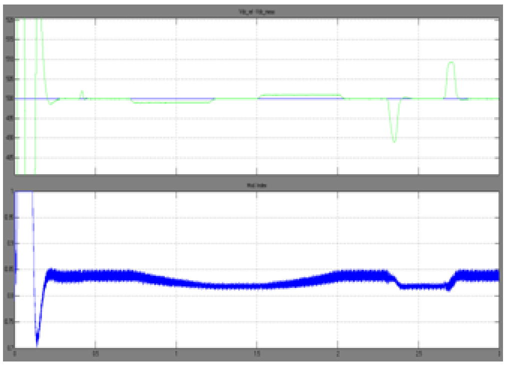


Fig 4: Boost converter: comparison between Vdc reference and Vdc measured, Modulation index

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V. VSC CONVERTER

The three-level VSC (blue blocks) regulates DC bus voltage at 500 V and keeps unity power factor. The control system uses two control loops: an external control loop which regulates DC link voltage to +/- 250 V and an internal control loop which regulates Id and Iq grid currents (active and reactive current components). Id current reference is the output of the DC voltage external controller. Iq current reference is set to zero in order to maintain unity power factor. Vd and Vq voltage outputs of the current controller are converted to three modulating signals Uref_abc used by the PWM three-level pulse generator. The control system uses a sample time of 100 μs for voltage and current controllers as well as for the PLL synchronization unit. In the detailed model, pulse generators of Boost and VSC converters use a fast sample time of 1 μs in order to get an appropriate resolution of PWM waveforms.

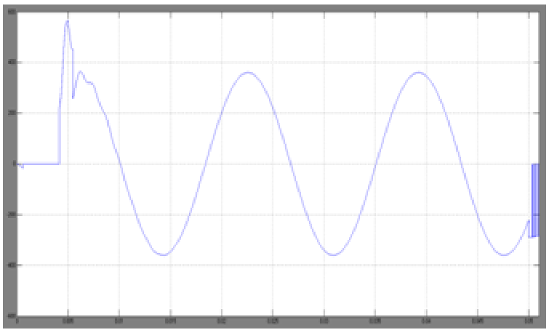

Fig 5: VSC voltage

VI. RESULTS DISCUSSION

- From t=0 sec to t= 0.05 sec, pulses to Boost and VSC converters are blocked. PV voltage corresponds to open-circuit voltage (Nser*Voc=5*64.2=321 V, see V trace on Scope Boost). The three-level bridge operates as a diode rectifier and DC link capacitors are charged above 500 V (see Vdc_meas trace on Scope VSC).
- At t=0.05 sec, Boost and VSC converters are de-blocked. DC link voltage is regulated at Vdc=500V. Duty cycle of boost converter is fixed (D= 0.5 as shown on Scope Boost) and sun irradiance is set to 1000 W/m2. Steady state is reached at t=0.25 sec. Resulting PV voltage is therefore V_PV = (1-D)*Vdc= (1-0.5)*500=250 V (see V trace on Scope Boost). The PV array output power is 96 kW (see Pmean trace on Scope Boost) whereas maximum power with a 1000 W/m2 irradiance is 100.7 kW. Observe on Scope Grid that phase A voltage and current at 25 kV bus are in phase (unity power factor).
- At t=0.4 sec MPPT is enabled. The MPPT regulator starts regulating PV voltage by varying duty cycle in order to extract maximum power. Maximum power (100.7 kW) is obtained when duty cycle is D=0.453. At t=0.6 sec, PV mean voltage =274 V as expected from PV module specifications (Nser*Vmp=5*54.7= 273.5 V).
- From t=0.7 sec to t=1.2 sec, sun irradiance is ramped down from 1000 W/m2 to 250 W/m2. MPPT continues tracking maximum power. At t=1.2 sec when irradiance has decreased to 250 W/m2, duty cycle is D=0.485. Corresponding PV voltage and power are Vmean= 255 V and Pmean=22.6 kW. Note that the MMPT continues tracking maximum power during this fast irradiance change.
- From t=1.5 sec to 3 sec various irradiance changes are applied in order to illustrate the good performance of the MPPT controller.

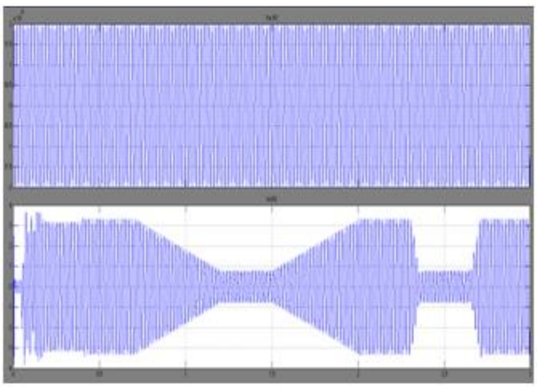

Fig 6: Utility Grid voltage and current

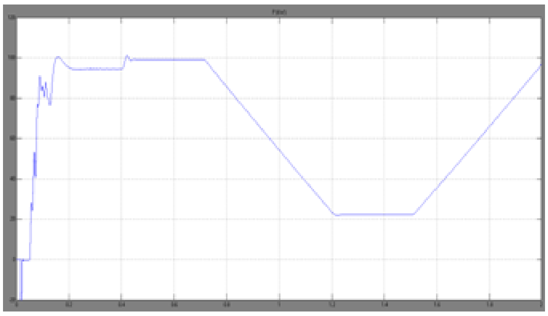

Fig 7: Utility Grid power

VII. CONCLUSION

Simulation studies have been carried out to get the various parameters of the system such as active power and reactive powers, DC link voltage, current and the firing angle corresponding to the maximum power for given solar radiation. As the inverter is being operated as line commutated, the synchronization of output frequency with grid frequency does not arise. The inductive filter connected at input terminals of utility grid will cancels ripple currents injecting into utility grid. The simulation results are clearly describes proposed system has better performance under given conditions.

Future Scope

Further implementation of study by converting isolated system into hybrid system like interconnecting of wind systems, fuel cells. And also multi-input bidirectional dc/dc converter for interconnecting multiple energy sources and storage systems like batteries and super capacitors.

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