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Simulation and Modelling of Single-Stage Single-Phase Grid Connected DC-AC Boost Converter with Active Power Injection and Reactive Power Compensation

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Abstract: This paper presents a new single-stage, single-phase SPV based, grid connected dc-ac boost converter with an active power injection and reactive power compensation scheme. The single stage topology consists of a full-bridge dc-ac inverter, but uses a single circuit for boost operation and dc-ac inversion. The sinusoidal output voltage is obtained by utilizing a variable duty cycle. A current based perturb and observe control algorithm is used for tracking the maximum power point of the solar panel. The active power is injected from the SPV panel and the reactive power is compensated by extracting the load current.

Keywords: Solar Photo Voltaic (SPV), Maximum Power Point Tracking (MPPT), Maximum Power Point (MPP), Perturb and Observe (P&O), Sample and Hold (S&H), Low Pass Filter (LPF)

I. INTRODUCTION

The depletion of fossil fuel energy has become a global concern, and the deficit between the demand and supply of energy, the difficulty and cost involvement in the planning and installation of centralized power plants, along with the environmental consequences of the non-conventional resources, have led to the search for alternate renewable energy sources which are abundant in nature, freely available and also, distributed throughout the earth. The most common among the existing renewable energy systems is the SPV system. The SPV systems are built using low-voltage photovoltaic cells, usually interconnected to form a solar array. So, it becomes necessary that the SPV dc output voltage be boosted with high conversion ratio before being inverted to ac. For this, usually a dc-dc boost converter is used between the source and the dc-ac inverter. But, such a multi-stage system can result in a higher volume, weight, cost and reduction in the efficiency and compactness of the system. In order to overcome the above said drawbacks, it becomes necessary to integrate the different stages of a multi-stage system into a single-stage unit. A single-stage system has the advantages of compactness, modularity, lower cost and higher efficiency. In this paper, a single-stage topology for interfacing SPV based non-conventional energy source with the grid is discussed. For extracting power from the solar energy, an MPPT controller utilizing a current based P&O algorithm for tracking the maximum power point and also for the generation of active current command is used. For the generation of reactive current command, a control scheme utilizing the actual grid current is used. For extracting the fundamental active component and the fundamental reactive component of the load current, the concept of unit vector is used. A control scheme for the duty ratio generation with variable pulse width modulation scheme for the dc-ac boost converter topology is also used.

II. MAXIMUM POWER POINT TRACKING USING CURRENT CONTROLLED P&O METHOD

For a given value of solar insolation and temperature, there exists a unique operating point corresponding to the MPP of the SPV array. Therefore, to extract maximum power from the array, it becomes necessary to operate it at the corresponding MPP, as the insolation and temperature varies. For this, MPPT method is used. In the proposed work, the P&O method using a current control algorithm is used. Here, MPPT operates by periodically measuring the voltage and current of the solar panel, so as to get the output power and then perturbing the array current, and comparing the current power with that of the previous perturbation cycle. If the power is increasing, the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction will be reversed. This process is repeated until the MPP is reached. The algorithm uses a fixed step to increase or decrease current. Here, a fixed step of 0.5 is used. Fig.1 shows the flowchart of P&O method.

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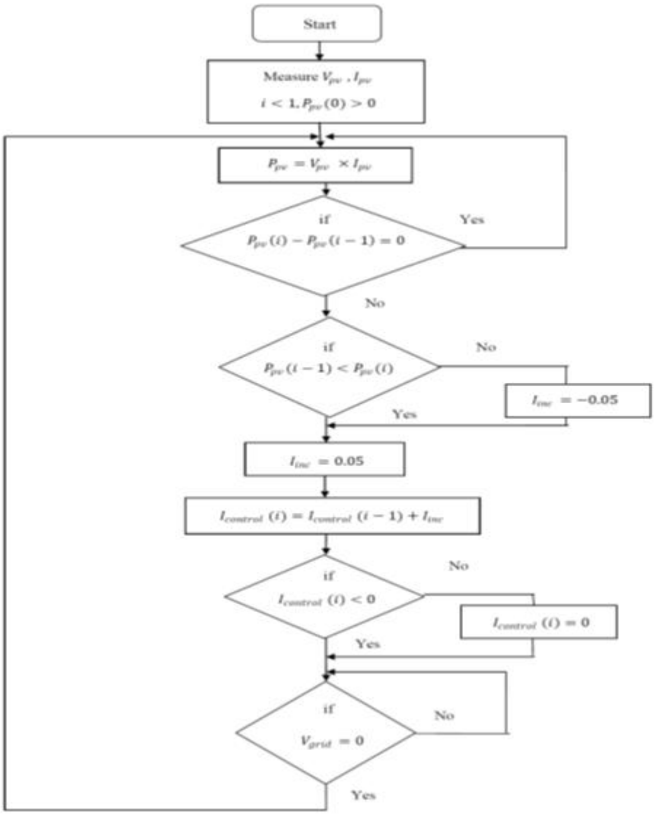

Fig.1. Flowchart of the P&O method

III. PROPOSED SINGLE-STAGE DC-AC BOOST CONVERTER

A new single-stage dc-ac converter is proposed, which not only acts as inverter, but also boosts the output voltage with respect to the input [4]. The proposed topology, as shown in Fig.2, is based on a full-bridge inverter, but uses a single circuit for dc-dc boost operation and dc-ac conversion. Two additional diodes and one input inductor implement the two boost converters that share the same inductor. Switching strategy is similar to a conventional inverter. In each half cycle, the boost operation is done by one of the two boost converter. For generating sinusoidal output voltage, a variable duty cycle is applied to the switches.

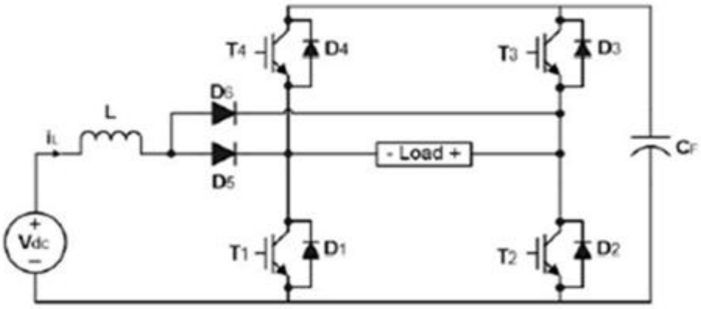

Fig2. Block diagram of proposed system

3.1 Modes of operation of the proposed converter

There are two states for the converter operation, and in each state, there are two stages for the boost operation. The ac output frequency is 50Hz and the switching frequency is taken as 10 kHz. The modes of operation are as discussed.

3.1.1 State I [$0<t<T/2$]

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In state I, T_1 and T_3 are switched with a fixed frequency and a variable duty cycle, while T_2 and T_4 are completely off. This state has two stages. First stage is when T_1 and T_3 are on, and the second, when T_1 and T_3 are off, as shown in Fig.3 and Fig.4.

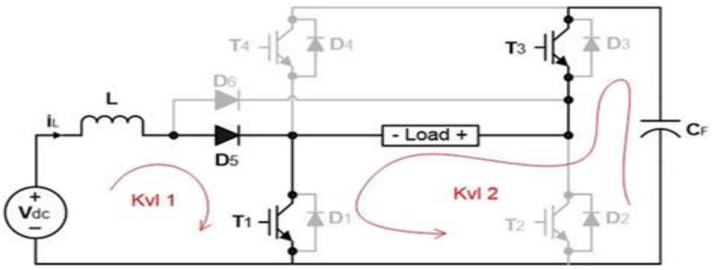

Fig3. Stage 1 of state I (T_1, T_3 → on T_2, T_4 → off)

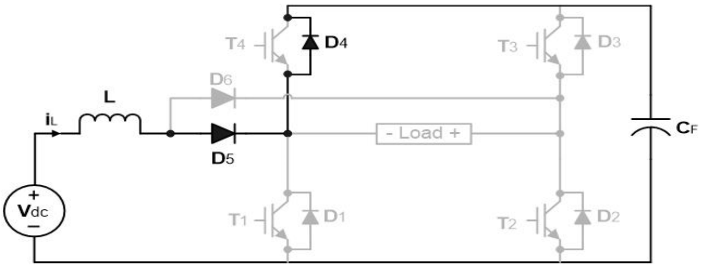

Fig4. Stage 2 of state I (T_1, T_3 → off T_2, T_4 → off)

In stage 1 of state I, inductor current increases. At the same time, the capacitor which has stored energy from the source and the inductor, discharges through the load. As inductor current and the duty cycle is variable, capacitor voltage is also variable. As the load voltage is same as the capacitor voltage, the positive half cycle of the load voltage is thus obtained. In stage 2, the inductor discharges, and capacitor gets charged by the source voltage and the inductor current.

3.1.2 State II [$T/2<t<T$]

In state II, T_2 and T_4 are switched with a fixed frequency and a variable duty cycle, while T_1 and T_3 are completely off. In stage 1, T_2 and T_4 are on, and in the stage 2, T_2 and T_4 are off, as shown in Fig.5 and Fig.6. As the duty cycle for both states is similar, capacitor voltage in both states are same. But, the output voltage in state 2 is negative, as T_2, T_4 changes the circuit path. Thus, a higher amplitude ac voltage is obtained.

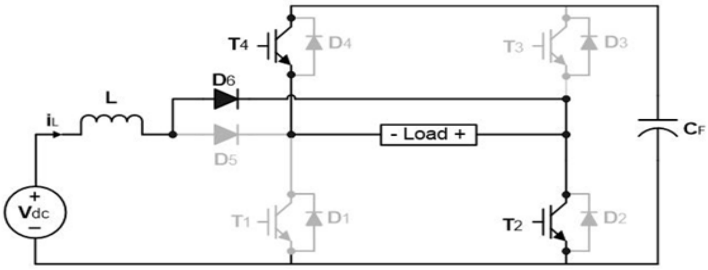

Fig5. Stage 1 of state II (T_2, T_4 → on T_1, T_3 → off)

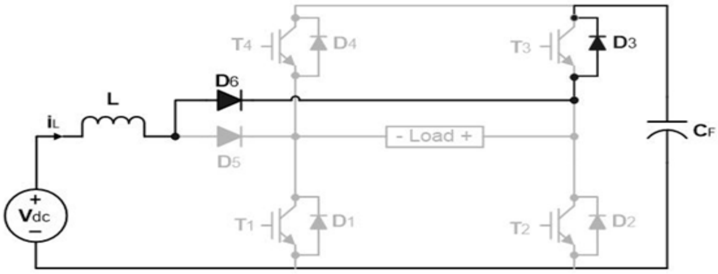

Fig6. Stage 2 of state II (T_2, T_4 → off T_1, T_3 → off)

IV. CONTROL SCHEME FOR THE GRID CONNECTED DC-AC BOOST CONVERTER

The control block diagram for the proposed single-stage grid connected boost converter is as shown in Fig.10. For extracting the active power component and the reactive power component separately, the concept of unit vector is used.

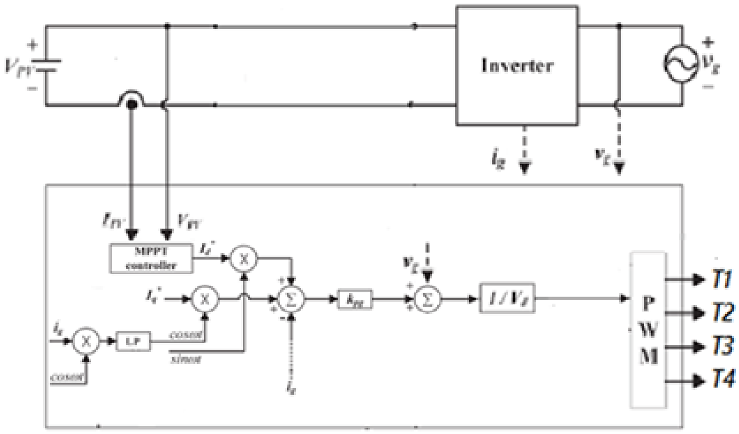

Fig10. Control block diagram for the proposed system

4.1 Unit vector for single-phase grid

Unit vector is two unity magnitude fundamental sinusoidal quantities, which are displaced by 90° from each other [6]. One of the sinusoidal quantities is in phase with the grid voltage and the other is 90° displaced with respect to the grid voltage. Also, the unit vector components are always 90° displaced, as shown in Fig.11. The unit vector can be used for extracting the active and the reactive power components separately. The in phase component is used in extracting the active component, while the 90° displaced component is used in extracting the reactive component.

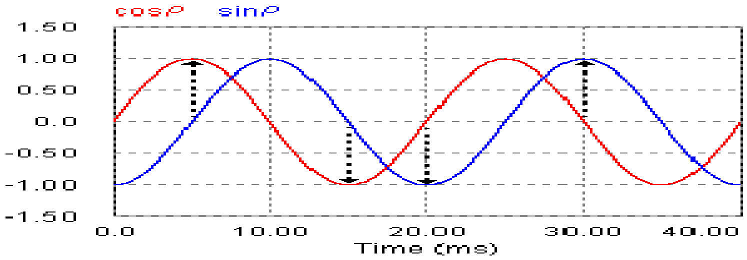

Fig11. Unit vector components

IV. SIMULATION OF THE PROPOSED SYSTEM

The simulation of the proposed single-stage grid connected converter is done using PSIM software, as shown in Fig.12. Fig.13 shows the simulation of MPPT and active current command generation. Instantaneous power is first calculated, and is compared with the previous value. The output is then given to a multiplex, where the increment or decrement to be done is decided. Feedback current command is first added to a constant. The resultant is then added to the multiplex output, and is then fed to a circular buffer consisting of two S&H. The current command is held before being fed back, at the rising edge of trigger point, at the first S&H, and is then sent at the falling edge at the second S&H. Fig.14 shows the simulation diagram for the generation of active and reactive components of the load current and of the reference current. The active current command from MPPT is multiplied with the in phase template of the unit vector, to obtain the active component of the load current. For the reactive component, the grid current is multiplied with the 90° lagging template of the unit vector. The resultant is a dc quantity, which is then extracted using a LPF of corner frequency, 1Hz. It is then multiplied with the same 90° lagging unit vector template, to give the reactive component of the load current. The sum of the active and the reactive components gives the reference current. Fig.15 shows the simulation diagram for obtaining variable duty cycle. The difference between the reference current and the inverter current is given to the proportional current controller. To get the modulating signal, and to scale it to the carrier, the grid voltage is added to the controller output, and the resultant is divided with the dc bus voltage. The 10 kHz carrier signal is then compared with modulating signal using comparators, to get a variable duty cycle, which is then given to the switches.

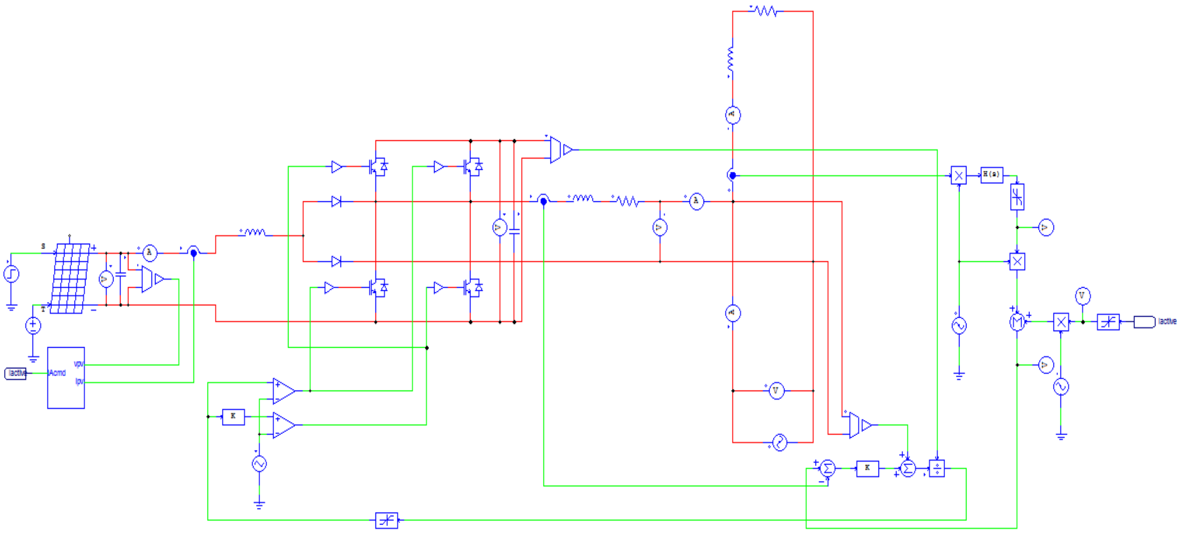

Fig12. Simulation diagram of the proposed system

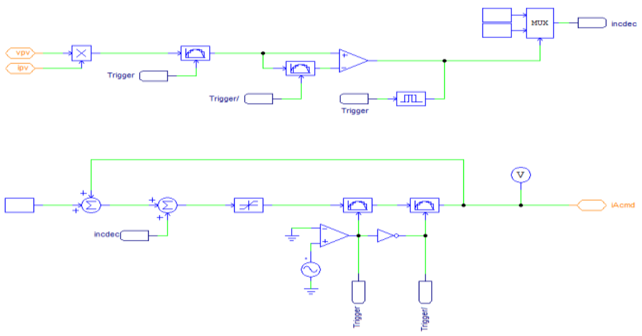

Fig13. Simulation diagram of MPPT and generation of active current command

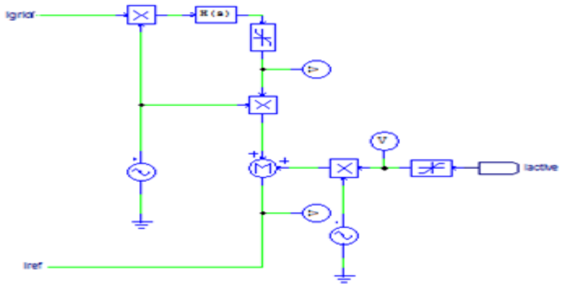

Fig14. Simulation diagram for reference current generation using active and reactive current command

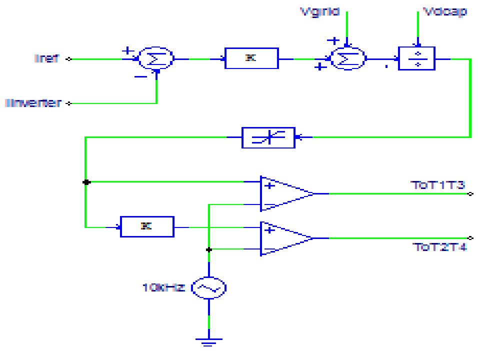

Fig15. Simulation diagram for variable duty cycle generation for the switches

V. SIMULATION RESULTS

Fig.16 shows the variation of irradiation with time. The initial irradiation is taken as 800W/m^2 and rises to 1000W/m^2. Fig.17 shows the corresponding variation of SPV current. Fig.18 shows the current command generation using MPPT. The current command starts from zero, and reaches a value of 2.5A, for the irradiation of 800W/m^2. As the irradiation increases, current command also increases, and reaches a value of 3.25A, for the irradiation of 1000W/m^2. Fig.19 shows the voltage waveform of the boost converter capacitor, which is variable. Fig.20 and Fig.21 show the duty cycle, for the upper and lower level switches respectively, which, in both the periods, is variable. Fig.22 shows the waveform of the active current component. It is constant for a given value of irradiance, and increases with an increase in the irradiance. Fig.23 shows the waveform of the reactive current component, which is always constant. Fig.24 shows the combined waveform of the grid current and the active current component, which shows a proportional decrease in the grid current, with an increase in the active current. Fig.25 shows the waveform of the net load current, which is always a constant. Fig.26 shows the waveform of the proposed converter voltage, which is same as the grid voltage.

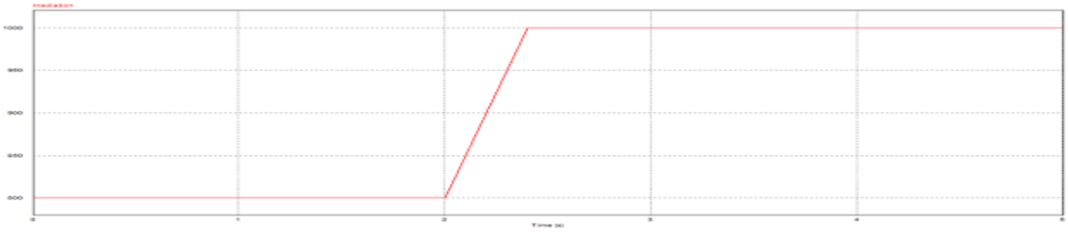

Fig16. Simulation diagram of variation of irradiation level with time

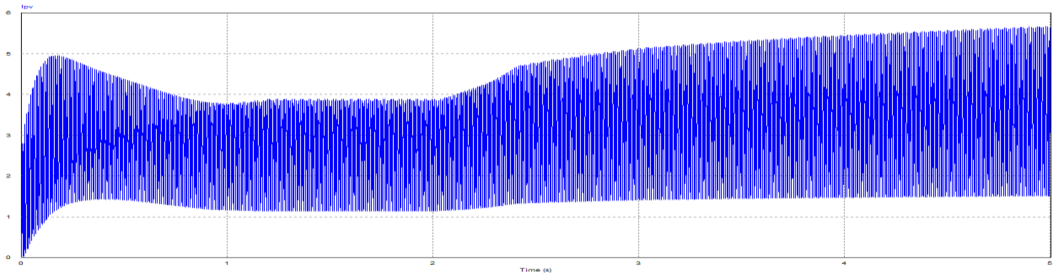

Fig17. Simulation diagram showing variation of PV current with time

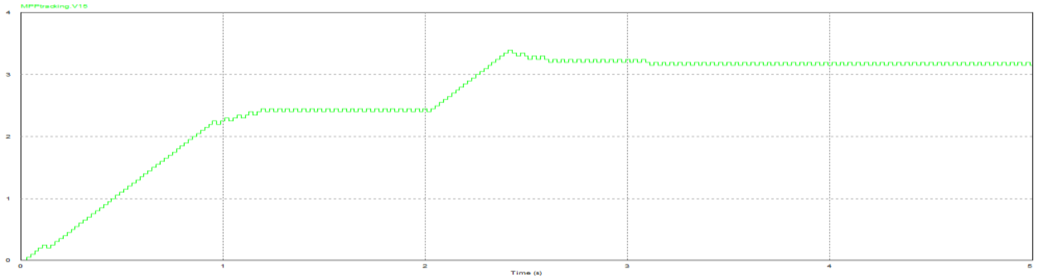

Fig18. Simulation diagram showing current command generation using P&O method

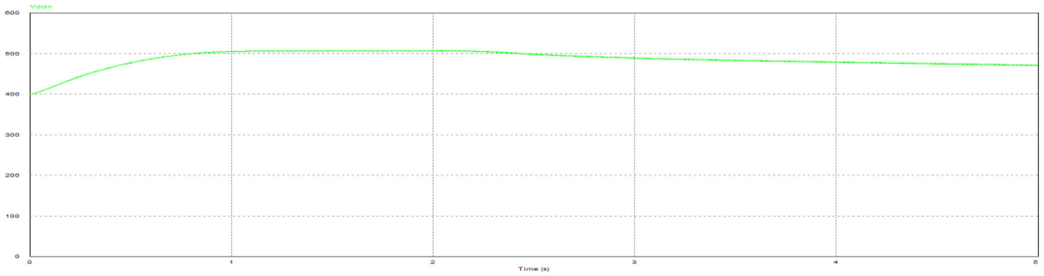

Fig19. Simulation diagram showing the variation of capacitor voltage

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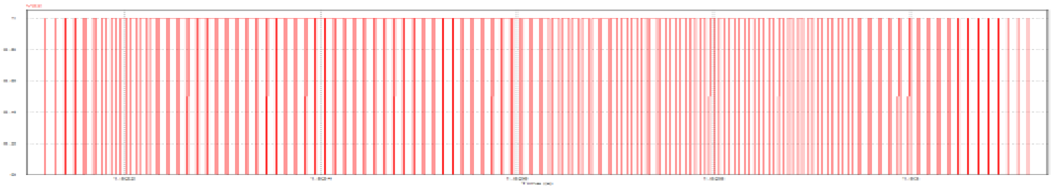

Fig20. Simulation diagram showing the variation of duty cycle in one period, for T_1 and T_3

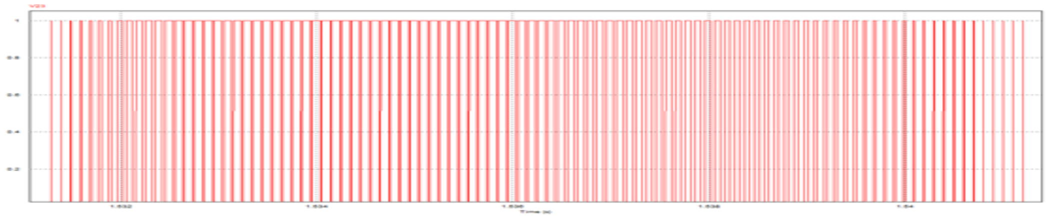

Fig21. Simulation diagram showing the variation of duty cycle in one period, for T_2 and T_4

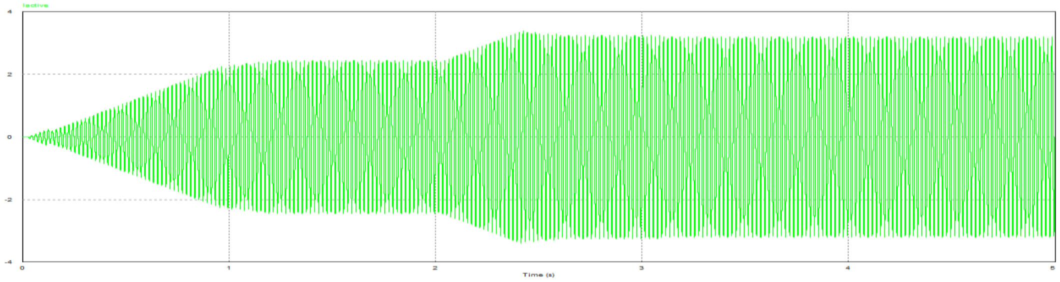

Fig22. Simulation diagram showing the variation of active current

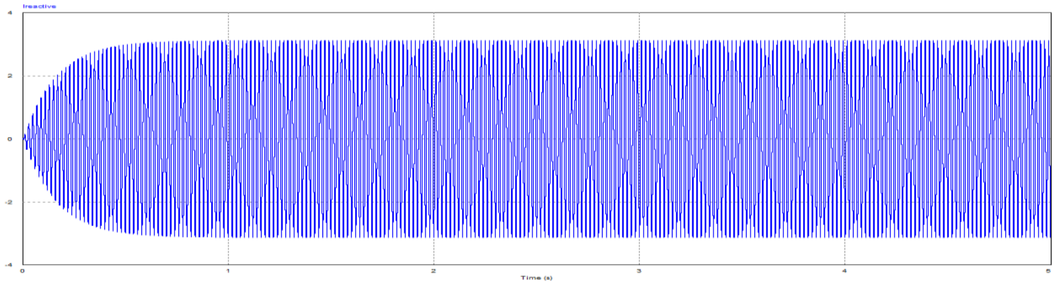

Fig23. Simulation diagram showing the variation of reactive current

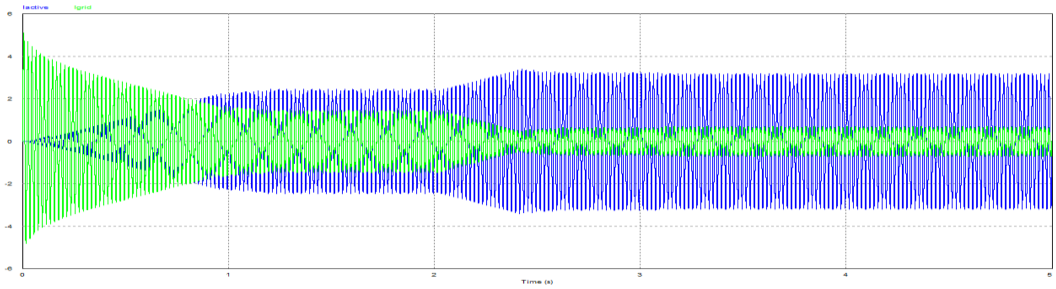

Fig24. Simulation diagram showing the variation of active current component and grid current

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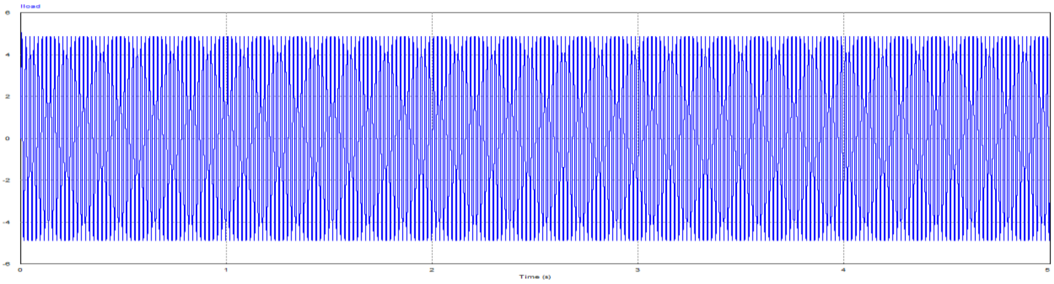

Fig25. Simulation diagram showing the variation of load current

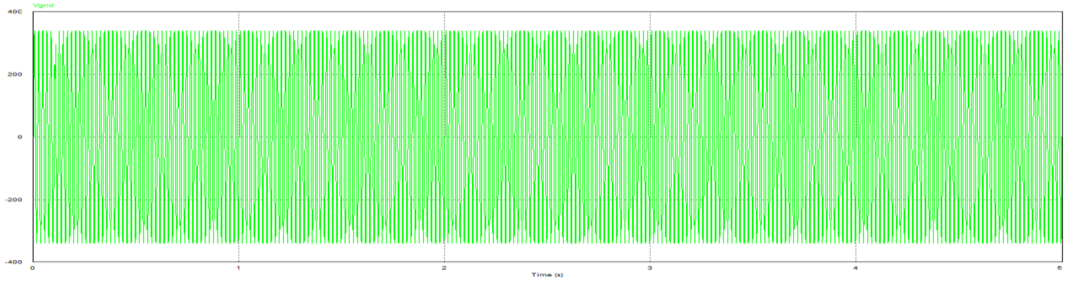

Fig26. Simulation diagram showing the variation of converter voltage/grid voltage

VI. CONCLUSION

A new single-phase single-stage dc-ac boost converter, with lesser number of switches is modelled. An MPPT algorithm for the SPV system is developed using a current controlled P&O method. A control scheme for active power injection, and reactive power compensation, for grid interfacing of the proposed single-stage boost converter is developed using the concept of unit vector. The PSIM simulation results show that, for the single stage dc-ac converter, from a low voltage dc input, an ac voltage with higher amplitude and desired frequency is achieved. The performance of the system is verified for varying irradiance levels. The results also validate that, the fundamental active component of the load current can be obtained from the in-phase component of the unit vector, and the fundamental reactive component from the 90° displaced component of the unit vector. It is also seen from the simulation results, that the grid interfaced single-stage system is capable of injecting active power into the grid and is also able to compensate for the load reactive power. Thus, the performance of the power controller is found satisfactory.

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