Modified SEPIC Converter with High Static Gain for Renewable Energy Applications

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Abstract: In the modified SEPIC converter, two high static step-up DC-DC converters are implemented in this Paper. In the proposed type presents, reduced the switching voltage and increases the static gain of the converter for low input voltage and high output voltage application. The modified SEPIC configuration are magnetic and without magnetic coupling. Magnetic coupling can increase the static gain and switching voltage at lower level. In the module input voltage is 15 Volts. The efficiency at nominal power obtained with the prototype without magnetic coupling was equal to 91.9% and output voltage is 150. The prototype with magnetic coupling operating with an output voltage equal to 300 V, presents efficiency at nominal power equal to 92.2%. The performance of the proposed method and achievement of desired compensation are confirmed by the results of the simulation using MATLAB/ Simulink.

Keywords: SEPIC converter, Static Gain, Magnetic coupling.

1. INTRODUCTION

Nowadays, Renewable power generation is the most importance in power sector. The important researches are going on the high static gain DC–DC converters for several applications supplied by low dc output voltage power sources. Some examples are renewable energy sources as low power wind turbine, photovoltaic (PV) modules and other applications as fuel cells, embedded systems, portable electronic equipment's, uninterruptable power supply, and battery powered equipment .Some of the requirement are necessary in this application such as reduced losses, high power density, low weight, and volume. An application where the proposed converters can be applied is the photovoltaic energy generation in grid-connected systems using the ac module or micro inverter structure. The usually in high-power grid-connected photovoltaic generation PV modules are connected in series in order to obtain the DC voltage level necessary for the inverter operation and energy can be transferred to the grid with low-current harmonic distortion. However, a common problem in this structure is the power losses due to the centralized maximum power point tracking (MPPT), mismatch losses among the PV modules, and generation reduction due to a partial shading of the series-connected PV modules. These problems are rectified by the Multi string structure where reduced strings are connected with DC–DC converters with the MPPT algorithm and the output of these DC–DC converters are connected to the inverter input. In the home or domestic based application, most research is focused on the module-integrated converters where energy generated by the PV module is transferred to the grid through the high gain converter they can integrated with the PV module system. Some of the main advantages of this PV generation structure are the modularity, allowing an easy increase of the installed power, the individual MPPT and reduction of the partial shading and panel mismatching effects, thus improving the energy-harvesting capability. However, Efficiency improvement, cost reduction, and the reliable operation throughout the module lifetime are some design challenges in ac module system.

In the base topology presented in the paper is modification of the SEPICDC-DC converter and the main operation characteristics obtained with this modification complete with the requirements in high static gain applications. The basic design of without magnetic coupling, Static gain is twice and switching voltage is close to half of the value presented in the classical boost converter in the operation with high values of

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the duty cycle. In the proposed type magnetic coupling is obtained including the secondary winding in an inductor of the converter, like as fly back transformer, increasing the static gain.

In the magnetic coupling, part of power can flow through the coupling inductor of the converter to the output and another part of power is transferred directly by the non isolated converter, reducing the weight, volume, and losses of the transformer. The leakage inductance must be dissipated in snubber or clamping circuits.

The proposed Modified SEPIC DC–DC converter can be theoretical and experimental analysis for the low dc input and high output voltage application. The topology using the magnetic coupling with the inclusion of an inductor auxiliary winding operating as a fly back transformer is also presented in order to increase the static gain maintaining low switch voltage.

2. SEPIC CONVERTER

The single ended primary inductance converter (SEPIC) is a DC-DC converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. The advantage is output voltage not inverted and it is similarly to the buck boost converter. The SEPIC can be controlled by the duty cycle of the switch. They consists of two inductor are coupled together and electrically displaced them. The SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch S1, which is typically a transistor such as a MOSFET, MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistors (BJTs), and do not require biasing resistors as MOSFET switching is controlled by differences in voltage rather than a current, as with BJTs.
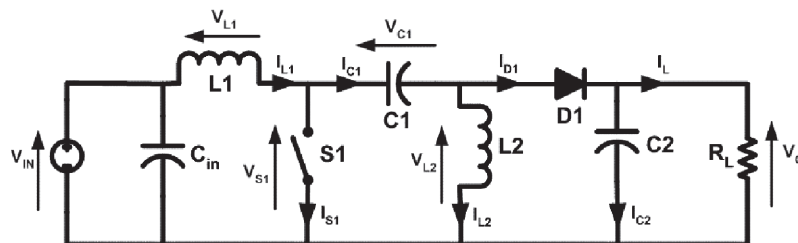

Figure 1: Circuit diagram for SEPIC converter

All dc-dc converters operate by rapidly turning on and off a MOSFET, generally with a high frequency pulse. What the converter does as a result of this is what makes the SEPIC converter superior. For the SEPIC, when the pulse is high the MOSFET is on, inductor 1 is charged by the input voltage and inductor 2 is charged by capacitor 1. The diode is off and the output is maintained by capacitor 2. When the pulse is low/the MOSFET is off, the inductors output through the diode to the load and the capacitors are charged. The greater the percentage of time (duty cycle) the pulse is low, the greater the output will be. This is because the longer the inductors charge, the greater their voltage will be. However, if the pulse lasts too long, the capacitors will not be able to charge and the converter will fail to shut down.

3. BLOCK DIAGRAM AND DESCRIPTION

The Modified SEPIC is essentially a boost converter followed by a buck-boost converter, therefore it is similar to a traditional buck-boost converter, but has advantages of having non-inverted output the output performance. It can be used for the high static gain application using renewable energy sources.

The MPPT (maximum power point tracking) technique can be used to tap the high power output from the panel. The issue of MPPT has been addressed in different ways in the literature but, especially for low-cost implementations, the perturb and observe (P&O) maximum power point tracking algorithm is the
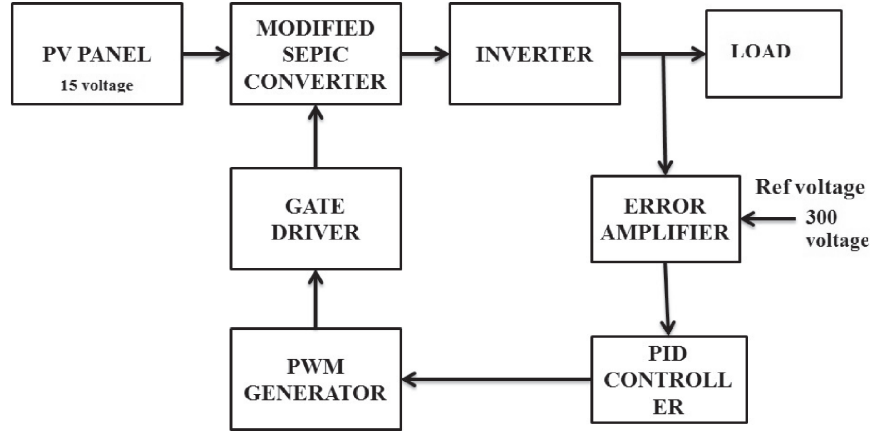
Figure 2: Block Diagram

most commonly used method due to its ease of implementation. The duty cycle are varied by the MPPT (P&O) algorithm respectively to the error generated by the PID controller. Normally the duty cycle ratio is 0.8 for the switch.

The PID controller can be used to find the error and maintain the output voltage at the constant level. In the modified SEPIC converter three capacitors are used where two are inverted, two diodes and transformer is used for high gain and reduce the voltage stress.

When a high step-up ratio is necessary for the implementation of the first power stage, the usual solution is the use of isolated DC–DC converters. The transformer turns ratio allows us to increase the converter static gain. However, the isolated solution presents some problems as the efficiency reduction due to the power transformer losses and intrinsic parameters as the leakage inductance. The power transformer also presents an important contribution in the converter weight and volume. The power converters used with renewable energy sources must present a high efficiency due to the high cost of the energy source, as photovoltaic module or fuel cells. Also in embedded systems and portable equipment, the converter power density is an important design parameter. Therefore, the solutions that allow the elimination of the power transformer can improve the efficiency and power density of the power conversion system.

A. PID Controller

A proportional integral derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.
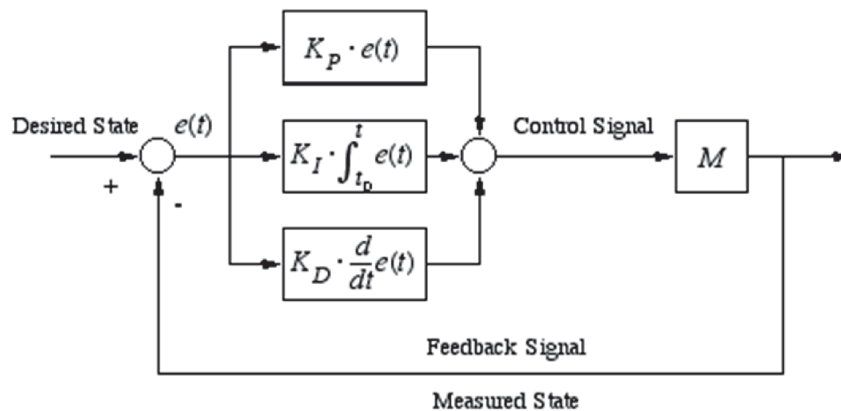
Figure 3: PID Controller Model

Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element. PID controller is a generic name for a controller containing a linear combination of the Combination of the Controllers like P, PI, or PD controller

It has been estimated that of all controllers in the world 95 % are PID controllers PID (proportional integral derivative) control is one of the earlier control strategies. Its early implementation was in pneumatic devices, followed by vacuum and solid state Analog electronics, before arriving at today's digital implementation of microprocessors. It has a simple control structure which was understood by plant operators and which they found relatively easy to tune. Since many control systems using PID control have proved Satisfactory, it still has a wide range of applications in industrial control. According to a Survey for process control systems conducted in 1989, more than 90 of the control loops were of the PID type.

PID control has been an active research topic for many years. Since many process plants controlled by PID controllers have similar dynamics it has been found possible to set satisfactory controller parameters from less plant information than a complete mathematical model. These techniques came about because of the desire to adjust controller parameters in situ with a minimum of effort, and also because of the possible difficulty and poor cost benefit of obtaining mathematical models. The most popular PID techniques were the step reaction curve experiment, and a closed-loop "cycling" experiment under proportional control around the nominal operating point.

B.   Maximum Power Point Tracking (MPPT)

The Maximum Power Point Tracking (MPPT) is a technique used in power electronic circuits to extract maximum energy from the Photovoltaic (PV) Systems. In the recent decades, photovoltaic power generation has become more important due its many benefits such as needs a few maintenance and environmental advantages and fuel free. However, there are two major barriers for the use of PV systems, low energy conversion efficiency and high initial cost. To improve the energy efficiency, it is important to work PV system always at its maximum power point.

Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

There are various algorithm technique are used in the MPPT, such as Perturb and observe, Incremental conductance, Current Sweep Method, Constant voltage and Hill climbing methods. Mostly P&O can be used for the MPPT because easy to implemented and cost factor is less.

C.   Perturb and Observe (P&O) Algorithm

The perturb-and-observe method, also known as perturbation method, is the most commonly used MPPT algorithm in commercial PV products. This is essentially a "trial and error" method. The PV controller increases the reference for the inverter output power by a small amount, and then detects the actual output

power. If the output power is indeed increased, it will increase again until the output power starts to decrease, at which the controller decreases the reference to avoid collapse of the PV output due to the highly non-linear PV characteristic.

The P&O algorithm is also called "hill-climbing", but both names refer to the same algorithm depending on how it is implemented. Hill-climbing involves a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and the power converter. In the case of the Hill-climbing, perturbing the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both names refer to the same technique.
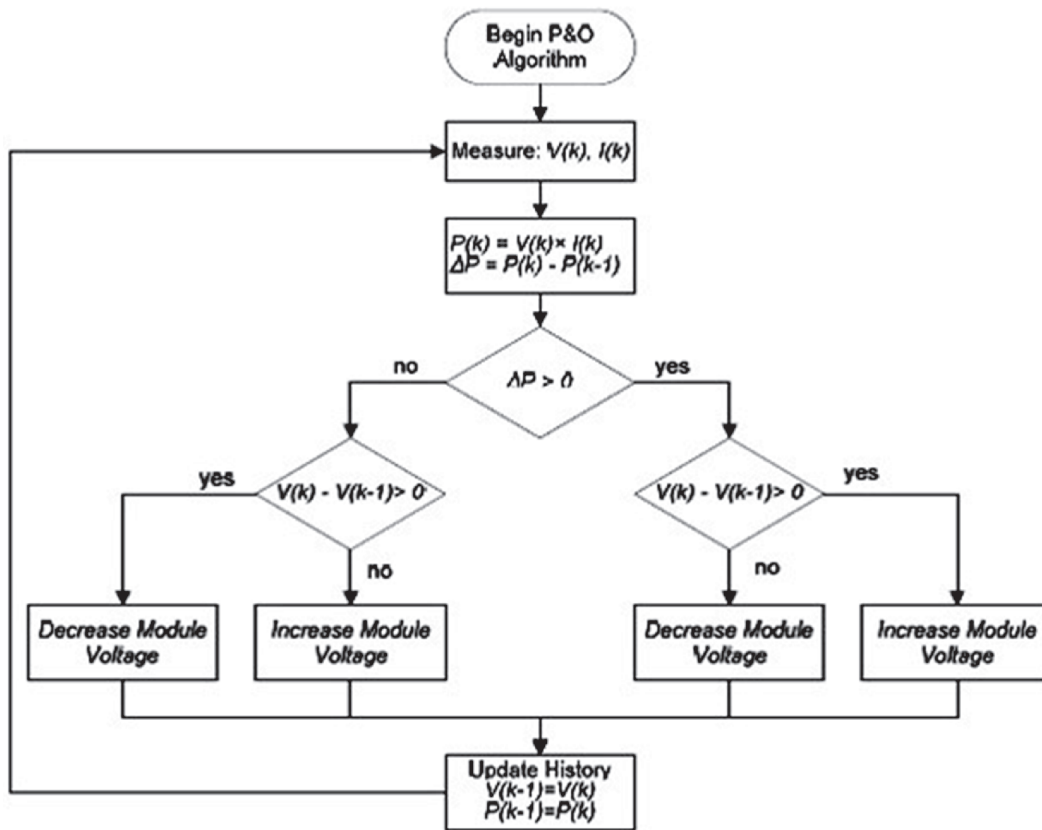

Figure 4: Flow chart of the P&O algorithm

It can generate the Duty cycle for the MOSFET, value of the duty cycle depend upon the parameter of the irradiation, temperature, input and output voltages. The duty cycle can be varied respect to the output voltage variation. By varying the duty cycle, we obtain the respective output voltage.

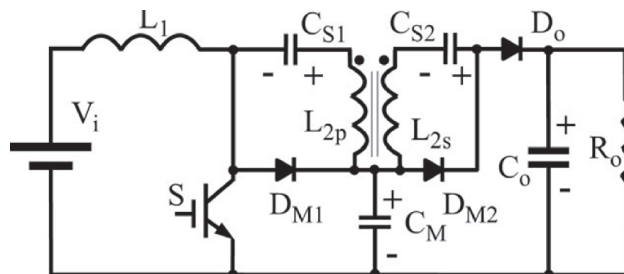## 4. MODIFIED SEPIC CONVERTER WITH MAGNETIC COUPLING

Figure 5: Modified SEPIC converter without magnetic coupling

The modified SEPIC converter without magnetic coupling can operate with the double of the static gain of the classical boost converter for a high duty-cycle operation. However, a very high static gain is necessary in some applications. A practical limitation for the modified SEPIC converter in order to maintain the converter performance is a duty cycle close to $D = 0.85$, resulting in a maximum static gain equal to $q = 12.3$. A simple solution to elevate the static gain without increases the duty cycle and the switch voltage is to include a secondary winding in the $L2$ inductor. The $L2$ inductor operation is similar to a buck–boost inductor and a secondary winding can increases the output voltage by the inductor windings turns ratio (n), operating as a fly back transformer.

In this converter structure presents the problem of overvoltage at the output diode Do due to the existence of the coupling winding $L2$ leakage inductance. The energy stored in the leakage inductance, due to the reverse recovery current of the output diode, results in voltage ring and high reverse voltage at the diode Do. This overvoltage is not easily controlled with classical snubbers or dissipative clamping. A simple solution for this problem is the inclusion of a voltage multiplier at the secondary side. This voltage multiplier increases the converter static gain, the voltage across the output. First operation stage diode is reduced to a value lower than the output voltage and the energy stored in the leakage inductance is transferred to the output. Therefore, the secondary voltage multiplier composed by the diode $DM2$ and capacitor $CS2$ is also a non-dissipative clamping circuit for the output diode.

The magnetic coupling is accomplished with the input inductor in the boost-based solutions, the input current ripple is significantly increased and depends on the inductor winding turns ratio. Increasing the inductor turns ratio and the static gain, the input current ripple rises. The input current ripple increment is a non-desirable operation characteristic for some applications as the fuel cell power source. As the magnetic coupling is not accomplished with the input inductor in the proposed topology, the input current ripple is low and is not changed by the magnetic coupling. There are also some proposed solutions based on the integration of the SEPIC converter with boost and fly back DC–DC converters.

However, the proposed topology presents pulsating input current, and the active clamp technique increases the converter complexity with an additional controlled switch and command circuit. The integration of the boost converter with a SEPIC converter is also proposed in some applications for high static gain. Some operation characteristics of this converter are similar to the circuit with magnetic coupling proposed. The main differences of the proposed converter with respect the previous topology are the ZCS switch turn-on obtained with a resonant operation stage, reducing the commutation losses even in the operation with light load and a higher static gain considering the same transformer turns ratio, reducing the converter duty cycle and the switch voltage.

The integration of the boost converter with a SEPIC converter is also proposed. Some operation characteristics of this converter are similar to the circuit with magnetic coupling proposed in this paper. The main differences of the proposed converter with respect the previous topology are the ZCS switch turn-on obtained with a resonant operation stage, reducing the commutation losses even in the operation with light load and a higher static gain considering the same transformer turns ratio, reducing the converter duty cycle and the switch voltage.

5. SIMULATION RESULTS

The proposed method is validated by simulation results of MATLAB.
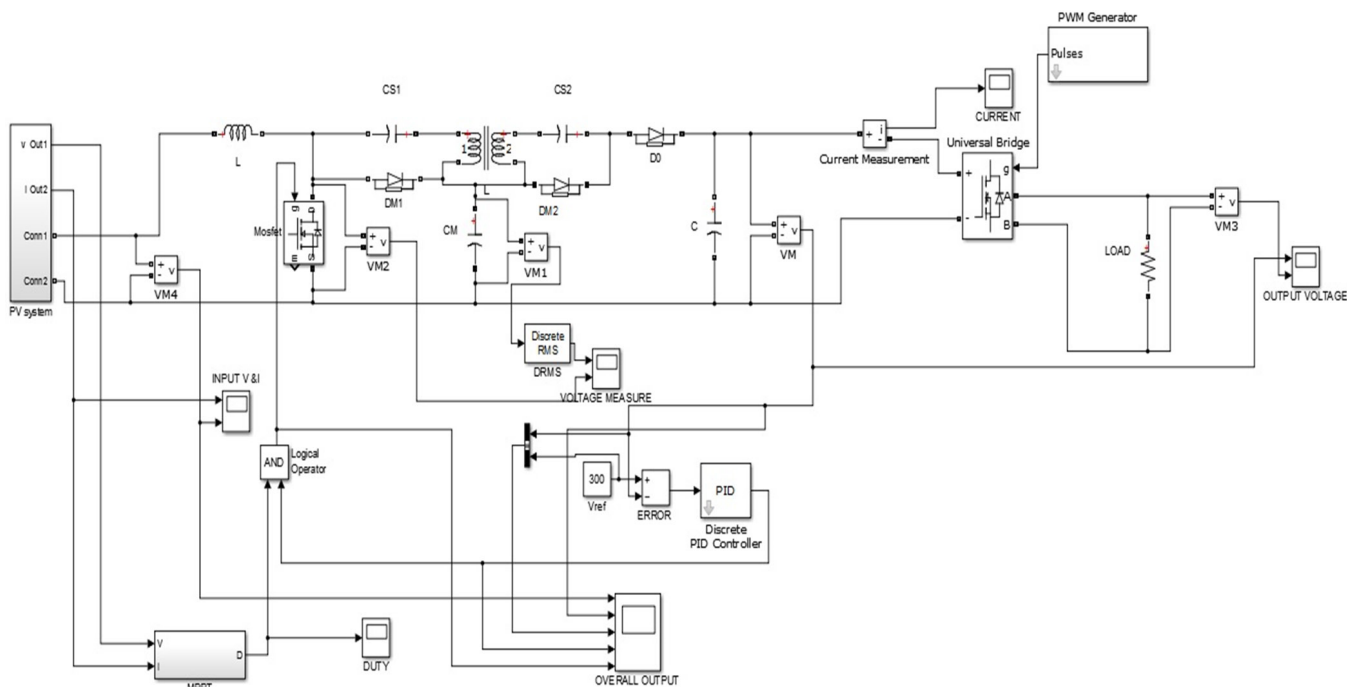
A.   Simulation Diagram with DVR

Figure 6: Simulation Diagram
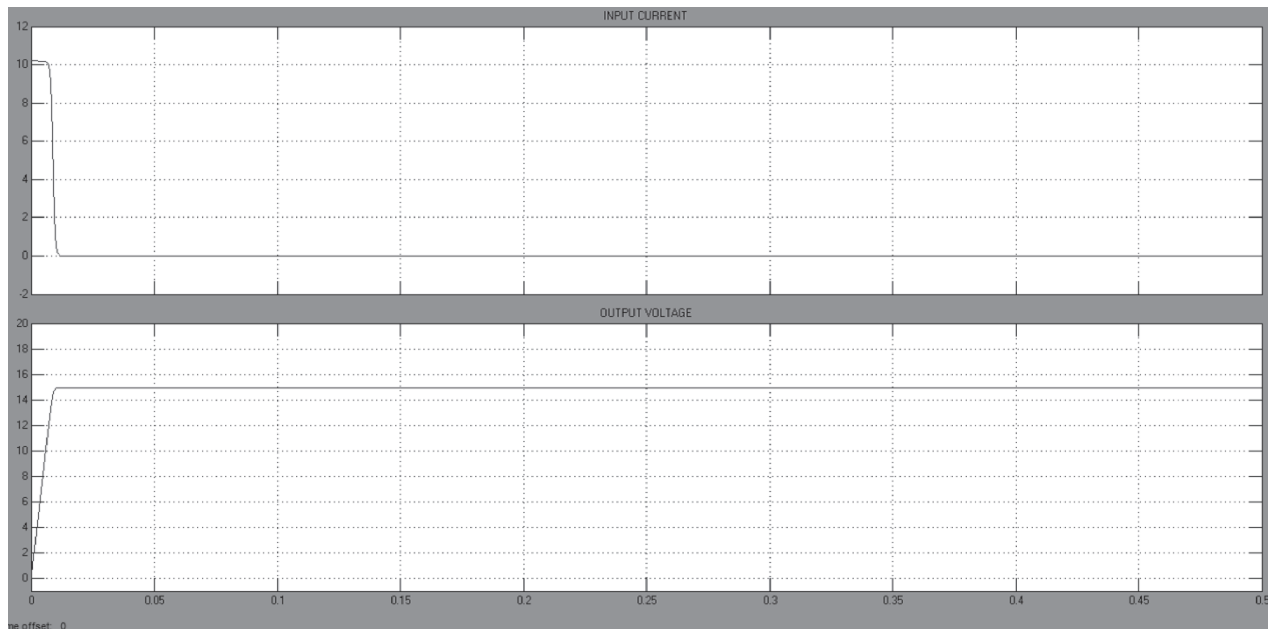
B.   Waveform of Input Voltage and Current

Figure 7: Waveform of Input Voltage and Current

The above waveform shows the input voltage and current of PV module. Initially voltage is low and having large value of current, voltage increases with decrease in current.

C.   Waveform of Output Voltage

The above figure shows the output waveforms of DC-DC converter and the inverter. Inverter voltage increases by 10% with increase in DC-DC converter voltage.
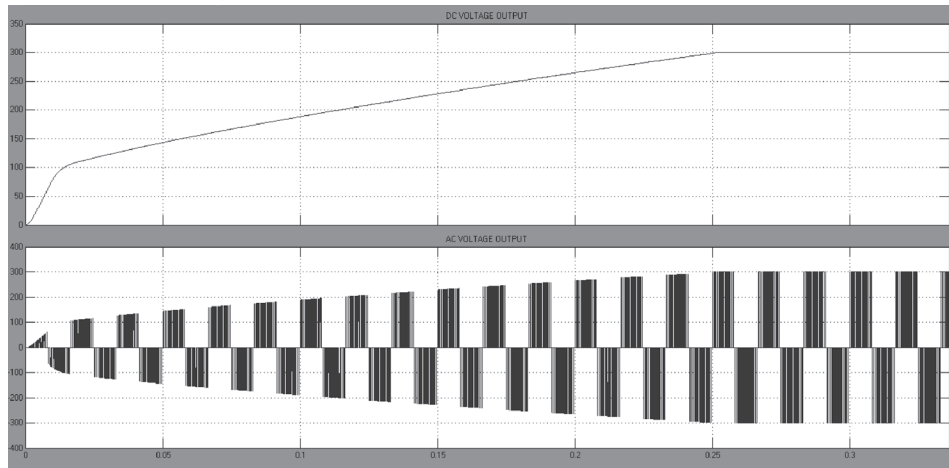
Figure 8: Waveform of Output Voltage

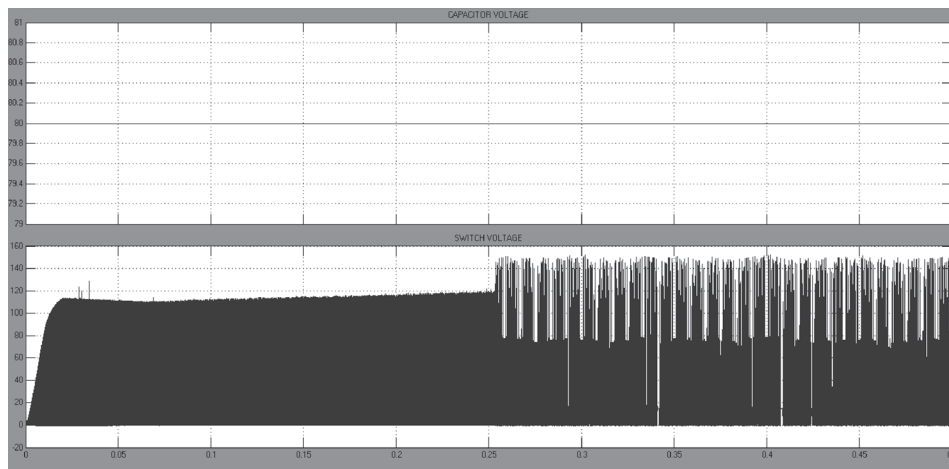## D.   Waveform of Capacitor and Switch Voltage

Figure 9: Waveform of Output Voltage

The above waveform shows the voltage across switch and capacitor connected in the SEPIC converter. It's clear that the capacitor voltage is equal to switch voltage given in RMS value.

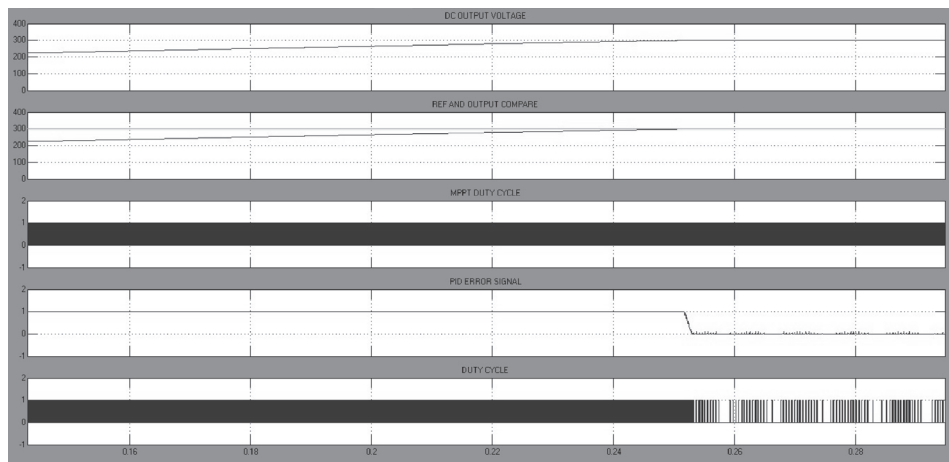## E.   Waveform of Input Voltage, Duty Cycle and Output Voltage

Figure 10: Waveform of Input Voltage, Duty cycle and Output Voltage

6. CONCLUSION

The efficiency of the proposed converter with magnetic coupling is equal to 92.2% operating with input voltage equal to15V, output voltage equal 300V, and output power equal 100W. The commutation losses of the proposed converter with magnetic coupling are reduced due to the presence of the transformer leakage inductance and the secondary voltage multiplier that operates as a non dissipative clamping circuit to the output diode voltage.

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