

High Static Gain for Solar Application using Modified SEPIC Converter

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ABSTRACT: In the modified SEPIC converter, two high static step-up DC-DC converter are presented 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 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 150V. The prototype with magnetic coupling operating with an output voltage equal to 300 V, presents efficiency at nominal power equal to 92.2%.

KEYWORDS : DC—DC SEPIC conversion, MPPT, photovoltaic power systems, voltage multiplier, voltage regulation

I. 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 requirements 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 Multistring 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 be 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 is some design challenges in ac module system.

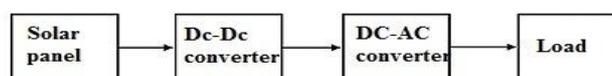


Fig.1. Two-stage AC module structure.

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An alternative for the ac module implementation is a two-stage topology as presented in Fig. 1. The operation with high efficiency is a problem for the dc–dc converter due to the low input voltage, high input current, high output voltage, and static gain. In normally Commercial monocrystalline and multicrystalline PV module presents normally maximum output powers (PMPP) lower than 350W with maximum power point voltage (VMPP) range from 15 to 40V. Here we consider $PMPP = 100\text{ W}$ with $VMPP = 15\text{ V}$, $PMPP = 200\text{ W}$ with $VMPP = 30\text{ V}$ and $PMPP = 300\text{ W}$ with $VMPP = 40\text{ V}$. In this study, the specification of $PMPP = 100\text{ W}$ with $VMPP = 15\text{ V}$ was considered, but increasing the PV module power, the voltage also increases at the maximum power point. Under this condition, dc–dc converter input current and the converter conduction losses are maintained almost at the same level. High step-up ratio can be 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.

Power converters that eliminate the power transformer can improve the efficiency and power density of the power conversion system. 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. The boost converter is the classical non-isolated step-up dc-dc converter has limited step-up static gain ($q=V_o/V_i$). It has normally operated duty cycle close to $D=0.8$ resulting in an output voltage around five times the input voltage. The static gain equal to $q=5$ is a limited value static gain consider in this paper. A dc–dc converter operating with a static gain range until $q = 5$ is considered a standard static gain, a static gain range higher than $q= 10$ is considered a high static gain solution and an operation with static gain higher than $q = 20$ is considered a very high static gain solution.

Main concept of this applications are a static gain equal or higher than ten times, low switch voltage, low input current ripple, reduce the weight and the volume and high efficiency. Main techniques are implemented for high static gain and good efficiency. In main technique are based on the boost topology with additional technique. Some of the techniques are switch capacitor and voltage multiplier cell, switch inductor/capacitor, magnetic coupling and also combination of these. In the base topology presented in the paper is modification of the SEPIC dc-dc converter and the main operation characteristics obtained with this modification comply 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 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.

Many techniques were developed in order to increase the static gain of the non-isolated structures for the implementation of high efficiency and high power density solutions. A review of the main techniques proposed is presented in [1]. The most part of the proposed solutions of non-isolated high static gain dc–dc converter are based on the boost topology with an additional technique associated. The chopper can be analyzed in the paper [2]–[3]. Performance of the converter and chopper can be studied from [4]–[10]. The main techniques used are the switch capacitors and voltage multiplier cells [11]–[12], switched inductors [13], [14], inductor magnetic coupling [14]–[20] and also combinations of these techniques as the integration of the voltage multiplier cell with the inductor magnetic coupling [21]–[24]. 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 and studied in this paper in order to increase the static gain maintaining low switch voltage.

II. PRINCIPAL OF MODIFIED SEPIC CONVERTER WITH MAGNETIC COUPLING

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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 [1]. 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 dutycycle and the switch voltage is to include a secondary winding in the L_2 inductor. The L_2 inductor operation is similar to abuck–boost inductor and a secondary winding can increasesthe output voltage by the inductor windings turns ratio (n), operating as a fly back transformer. Fig. 2 shows this alternativecircuit.

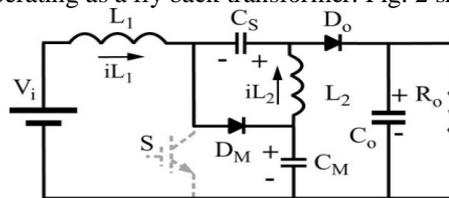


Fig. 2.Modified sepic converter.

However, this converter structure presents the problem of overvoltage at the output diode D_o due to the existence of the coupling winding L_2 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 D_o . This overvoltage is not easily controlled with classicalsnubbers or dissipative clamping. A simple solution for this problem is the inclusion of a voltage multiplier at the secondary side as presented in Fig. 3.

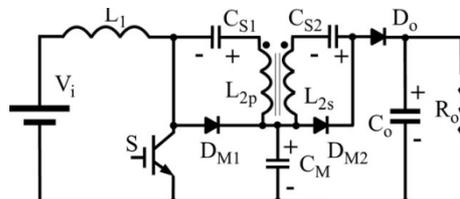


Fig 3: Modified Sepic converter with Voltage doubler circuit.

This voltage multiplier increases the converter static gain, the voltage across the output 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 solutions based on the classical boost converter with magnetic coupling or the integration of the magnetic coupling and the voltage multiplier cell can present very high voltage gain and an excellent performance as presented in [17]–[25].However, as 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 rippleincrement is a non-desirable operation characteristic for someapplications as the fuel cell power source. As the magneticcoupling is not accomplished with the input inductor in theproposed topology, the input current ripple is low and is notchanged by the magnetic coupling.There are also some proposed solutions based on the integrationof the SEPIC converter with boost and flyback dc–dcconverters. An isolated active clamp SEPIC-flybackconverters presented in [25] in order to obtain high efficiency. However, the proposed topology presents pulsating input current, and theactive clamp technique increases the converter complexity withan additional controlled switch and command circuit.. Some operation characteristics of this converter are similar to the circuitwith magnetic couplingproposed in this paper. The main differences of the proposedconverter with respect to the previous topology are the ZCS switchturn-on obtained with a resonant operation stage, reducing thecommutation losses even in the operation with light load and ahiger static gain considering the same transformer turns ratio,reducing the converter duty cycle and the switch voltage.The CCM operation of the modified SEPIC converter withmagnetic coupling and output diode clamping presents five operationstages. All capacitors are considered as a voltage source,and the semiconductors are considered ideals for the theoreticalanalysis.

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III. PRINCIPAL OF OPERATION

In modified sepic converter with magnetic coupling can be operated in five stage of operation. The operation can be explained below the circuit of the Modified can be shown.

1. First Stage [t₀-t₁] (Fig. 4): The power switch S is turned on and the input inductor L₁ stores energy. The capacitor C_{S2} is charged by the secondary winding L_{2S} and diode D_{M2}. The leakage inductance limits the current and the energy transference occurs in a resonant way. The output diode is blocked, and the maximum diode voltage is equal to (V_o-V_{CM}). At the instant t₁, the energy transference to the capacitor C_{S2} is finished and the diode D_{M2} is blocked

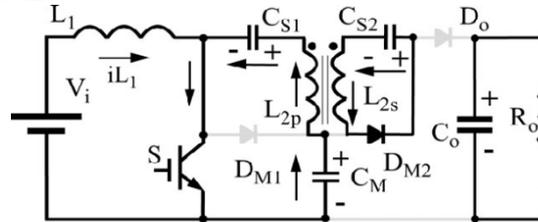


Fig. 4 First operation

2. Second Stage [t₁-t₂] (Fig. 5): From the instant t₁, when the diode D_{M2} is blocked, to the instant t₂ when the power switch is turned OFF, the inductors L₁ and L₂ store energy and the currents linearly increase.

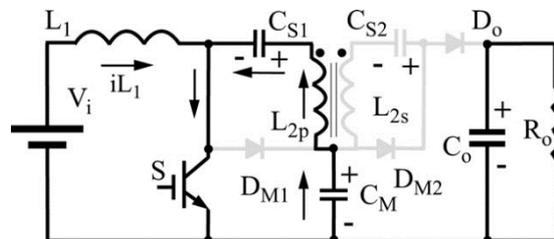


Fig. 5 Second operation

3. Third Stage [t₂-t₃] (Fig. 6): At the instant t₂ the power switch S is turned OFF. The energy stored in the L₁ inductor is transferred to the C_M capacitor. Also, there is the energy transference to the output through the capacitors C_{S1}, C_{S2} inductor L₂ and output diode D_o.

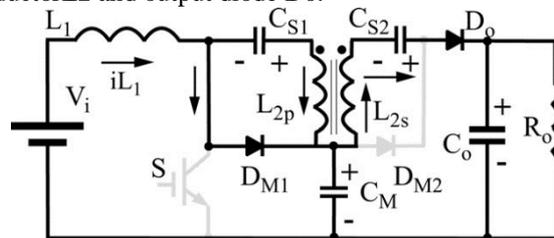


Fig. 6 Third operation

4. Fourth Stage [t₃-t₄] (Fig. 7): At the instant t₃, the energy transference to the capacitor C_M is finished and the diode D_{M1} is blocked. The energy transference to the output is maintained until the instant t₄, when the power switch is turned ON.

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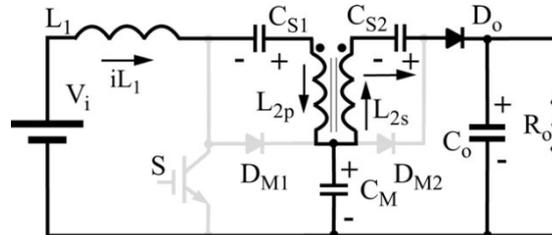


Fig.7 Fourth operation

5. Fifth Stage [t₄–t₅] (Fig. 8): When the power switch is turned ON at the instant t₄ , the current at the output diode D_o linearly decreases and the di/dtis limited by the transformer leakage inductance, reducing the diode reverse recovery current problems. When the output diode is blocked, the converter returns to the first operation stage.

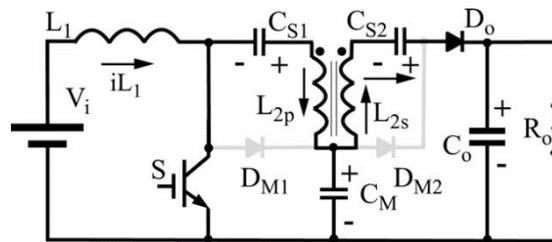


Fig.8 Fifth operation

The main theoretical waveforms of the modified SEPIC converter with magnetic coupling and with the voltage multiplier at the secondary side are presented in Fig. 8. The voltage across all the semiconductor devices is always lower than the output voltage. To reduce the switching losses by turn on the switching during the zero current of the power switches. Due to the leakage inductance presence of the coupling inductor, the current variation ratio (di/dt) presented by all diodes is limited and also reducing the negative effects of the diode reverse recovery current. The static gain of the modified SEPIC converter with magnetic coupling and voltage multiplier is calculated by (1).

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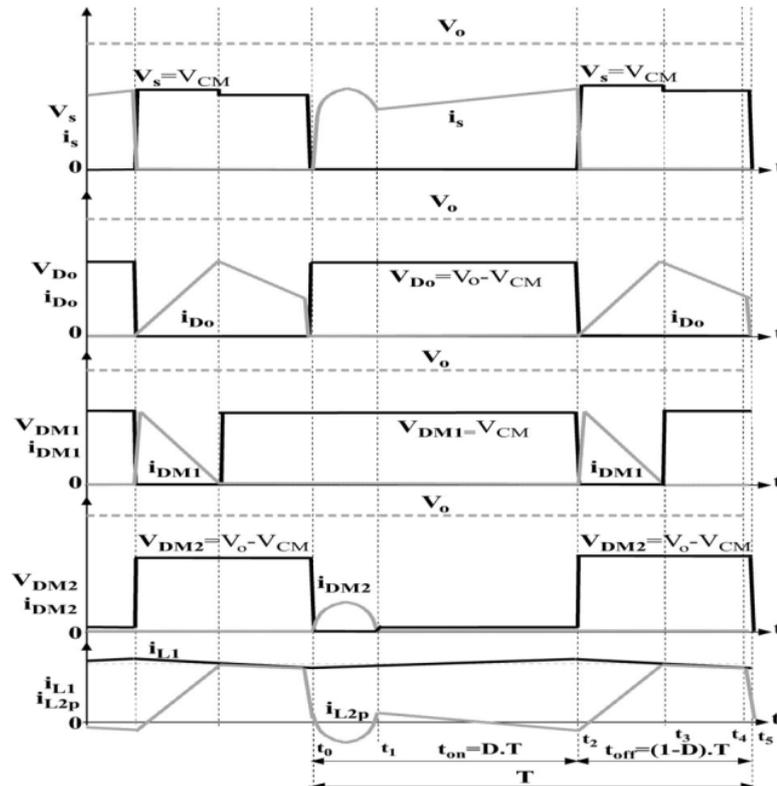


Fig.9 Output graph of the all semiconducting devices

The static gain can be increased by the windings turns ratio (n) without increasing the switch voltage

$$V_o/V_i = 1/(1-D) \cdot (1+n) \quad (1)$$

Turns ratio of the inductor winding (n) by

$$n = NL_{2s}/NL_{2p} \quad (2)$$

Considering a duty cycle equal to 0.8, a static gain equal to $toq = 10$ is obtained for $n = 1$, $q = 15$ for $n = 2$ and $q = 20$ for $n = 3$ and the switch voltage is equal to five times the input voltage for all cases. Static gain can be increased by increasing the ratio of the transformer winding turns. The third operation stage, determine the maximum switch voltage. Therefore, the maximum switch voltage is equal to the capacitor CM voltage calculated by (2). During the fourth operation stage, the switch voltage presents a small reduction calculated by (2), as presented in Fig. 9 at the interval ($t_3 - t_4$). The voltage across the leakage inductance must be reduced from the voltage calculated by (2) during the fourth operation stage, and this voltage reduction is proportional to the relation between the leakage inductance of the coupling inductor $L_{2p} - L_{2s}$ and the input inductance L_1

IV. EXPERIMENTAL RESULT

The experimental results were obtained using MATLAB Simulink 2013a presented in Fig. 10 and the simulation result for Switch and Capacitor voltage can be shown in Fig. 11 for DC&AC output can be shown in Fig. 12.

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Table

Parameter	Modified SEPIC without magnetic coupling	Modified SEPIC with magnetic coupling
Input voltage	15V	15V
Output voltage	150V	300V
Output power	100W	100W
Switching frequency	24Khz	24kHZ
Duty-cycle	0.82	0.82
Switch voltage	83V	83V
Static gain	10	20

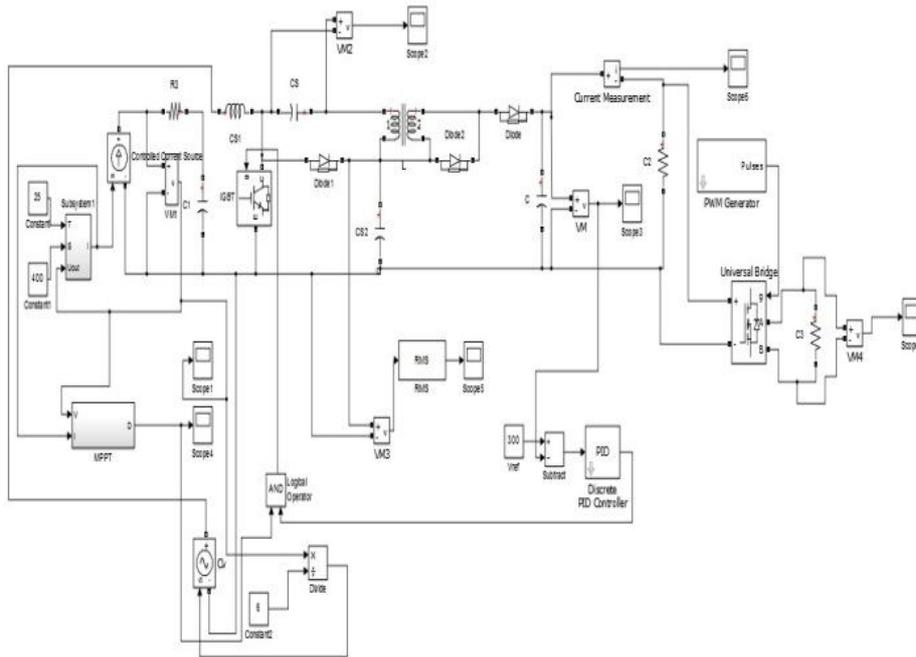


Fig.10 By using the Matlab Simulink 2013 developed the proposed Modified SEPIC converter

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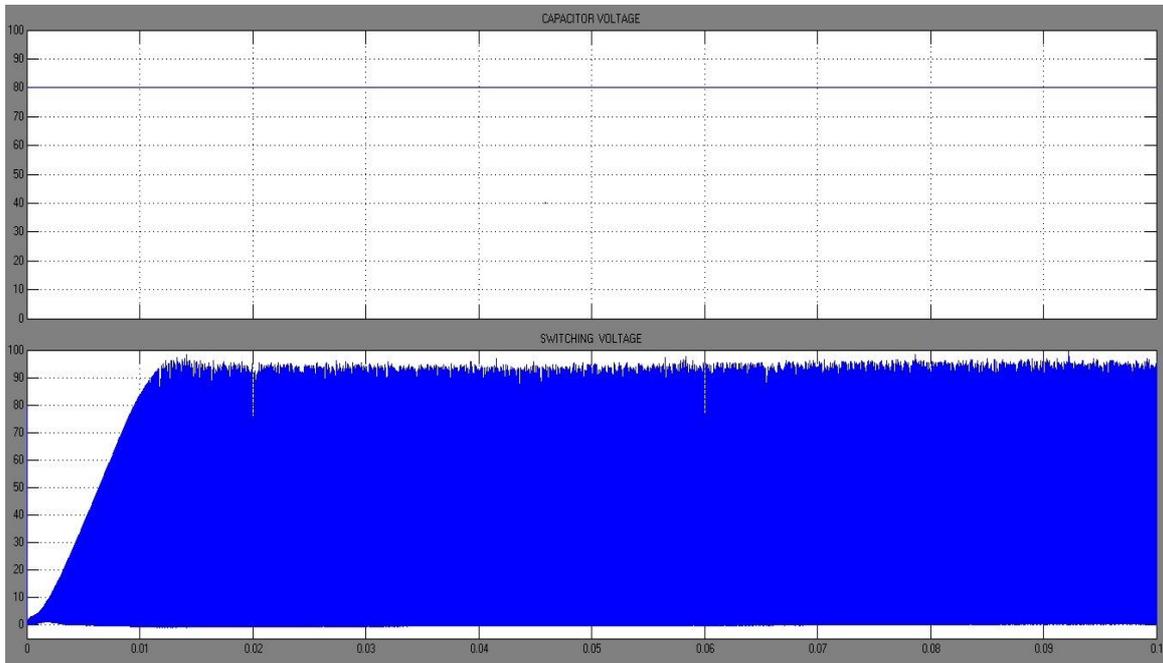


Fig.11 By using the Matlab Simulink 2013 the simulation result for Switching and Capacitor voltage can be shown.

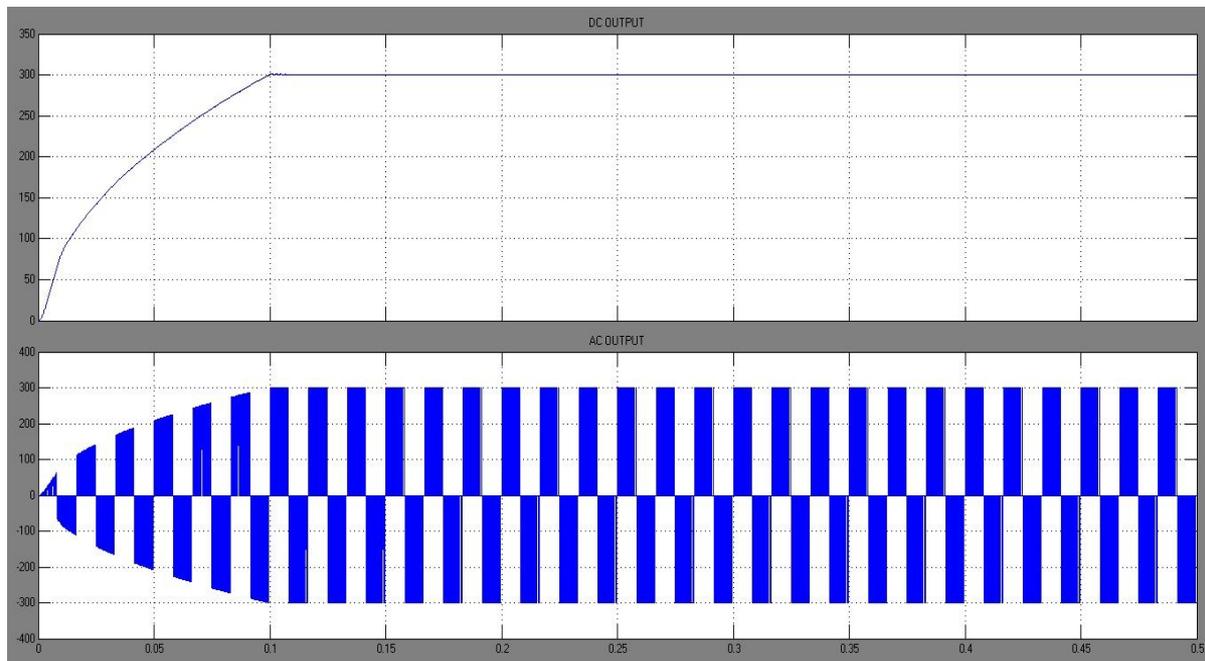


Fig.12 By using the Matlab Simulink 2013 the simulation result for output can be shown.

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V. CONCLUSION

The efficiency of the proposed converter with magnetic coupling is equal to 92.2% operating with input voltage equal to 15V, 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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