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RESEARCH ARTICLE

PHOTOVOLTAIC BASED HIGH-EFFICIENCY SINGLE-INPUT MULTIPLE-OUTPUT DC-DC CONVERTER

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ABSTRACT: The aim of this paper is to develop a photo voltaic power generation based high-efficiency multiple-output dc–dc converter. The proposed converter can boost the voltage of a low-voltage input power source to a controllable high-voltage dc bus and middle-voltage output terminals. In this paper, a coupled-inductor based dc–dc converter scheme utilizes only one power switch with the properties of voltage clamping and soft switching, and the corresponding device specifications are adequately designed. As a result, the objectives of high-efficiency power conversion, high step up ratio, and various output voltages with different levels can be obtained.

I. INTRODUCTION

The development of new energy sources is continuously enhanced because of the critical situation of the chemical industrial fuels such as oil, gas and others. Thus, the renewable energy sources have become a more important contributor to the total energy consumed in the world. In fact, the demand for solar energy has increased by 20% to 25% over the past 20 years [1]. The market for PV systems is growing worldwide. In fact, nowadays, solar PV provides around 4800 GW. Between 2004 and 2009, grid connected PV capacity reached 21 GW and was increasing at an annual average rate of 60% [2]. In order to get benefit from the application of PV systems, research activities are being conducted in an attempt to gain further improvement in their cost, efficiency and reliability.

Typically, a PV cell generates a voltage around 0.5 to 0.8 volts depending on the semiconductor and the built-up technology. This voltage is low enough as it cannot be of use. Therefore, to get benefit from this technology, tens of PV cells (involving 36 to 72 cells) are connected in series to form a PV module. These modules can be interconnected in series and/or parallel to form a PV panel. In case these modules are connected in series, their voltages are added with the same current. Nevertheless, when they are connected in parallel, their currents are added while the voltage is the same.

The newly designed multi output converter with a coupled inductor. The proposed converter uses one power switch to achieve the objectives of high-efficiency power conversion, high step-up ratio, and different output voltage levels. In the proposed multi output converter, the techniques of soft switching and voltage clamping are adopted to reduce the switching and conduction losses via the utilization of a low-voltage-rated power switch with a small $R_{DS(on)}$. Because the slew rate of the current change in the coupled inductor can be restricted by the leakage inductor, the current transition time enables the power switch to turn ON with the ZCS property easily, and the effect of the leakage inductor can alleviate the losses caused by the reverse-recovery current.

The voltages of middle-voltage output terminals can be appropriately adjusted by the design of auxiliary inductors; the output voltage of the high-voltage dc bus can be stably controlled by a simple proportional-integral (PI) control.

II. CONVERTER DESIGN AND ANALYSES

The system configuration of the proposed high-efficiency SIMO converter topology to generate two different voltage levels from a single-input power source is depicted in Fig. 1. This SIMO converter contains five parts including a low-voltage-side circuit (LVSC), a clamped circuit, a middle-voltage circuit, an auxiliary circuit, and a high-voltage-side circuit (HVSC). The major symbol representations are summarized as follows. V_{FC} (i_{FC}) and V_{O1} (i_{O1}) denote the voltages (currents) of the input power source and the output load at the LVSC and the auxiliary circuit, respectively; V_{O2} and i_{O2} are the output voltage and current in the HVSC. C_{FC}, C_{O1} , and C_{O2} are the filter capacitors at the LVSC, the auxiliary circuit, and the HVSC, respectively; C_1 and C_2 are the clamped and middle-voltage capacitors in the clamped and middle-voltage circuits, respectively. L_P and L_S represent individual inductors in the primary and secondary sides of the coupled inductor T_r, respectively, where the primary side is connected to the input power source; L_{aux} is the auxiliary circuit inductor.

The main switch is expressed as *S*1 in the LVSC; the equivalent load in the auxiliary circuit is represented as *RO* 1, and the output load is represented as *RO* 2 in the HVSC.

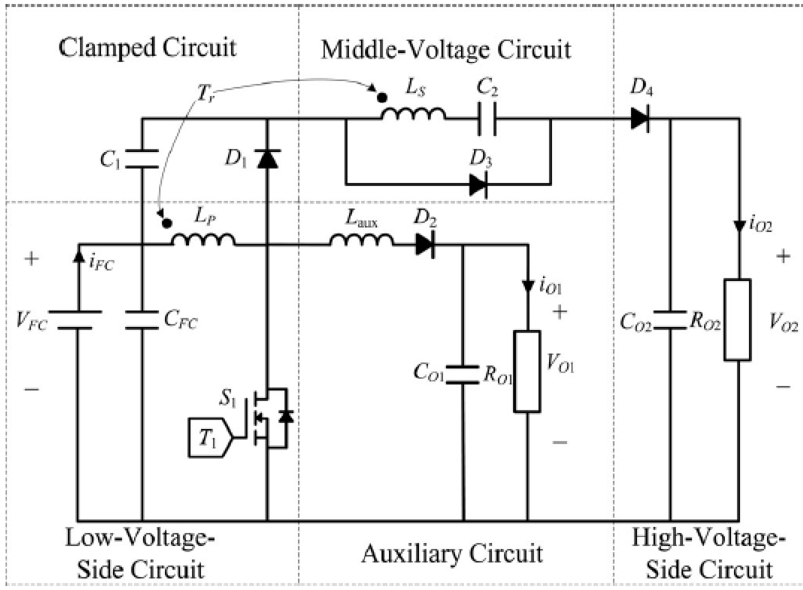

Fig 1.circuit configuration of multi output converter

The corresponding equivalent circuit given in Fig. 2 is used to define the voltage polarities and current directions. The coupled inductor in Fig. 1 can be modeled as an ideal transformer including the magnetizing inductor *Lmp*and the leakage inductor *Lkp*in Fig. 2. The turns ratio *N* and coupling coefficient *k* of this ideal transformer are defined as

$N = N2/N1$ ………..(1)

$k = L\text{mp}/(L\text{kp} + L\text{mp}) = L\text{mp}/LP$ ………(2)

where*N*1 and *N*2 are the winding turns in the primary and secondary sides of the coupled inductor *Tr*. Because the voltage gain is less sensitive to the coupling coefficient and the clamped capacitor *C*1 is appropriately selected to completely absorb the leakage inductor energy, the coupling coefficient could be simply set at one ($k = 1$) to obtain $Lmp= LP$ via (2).

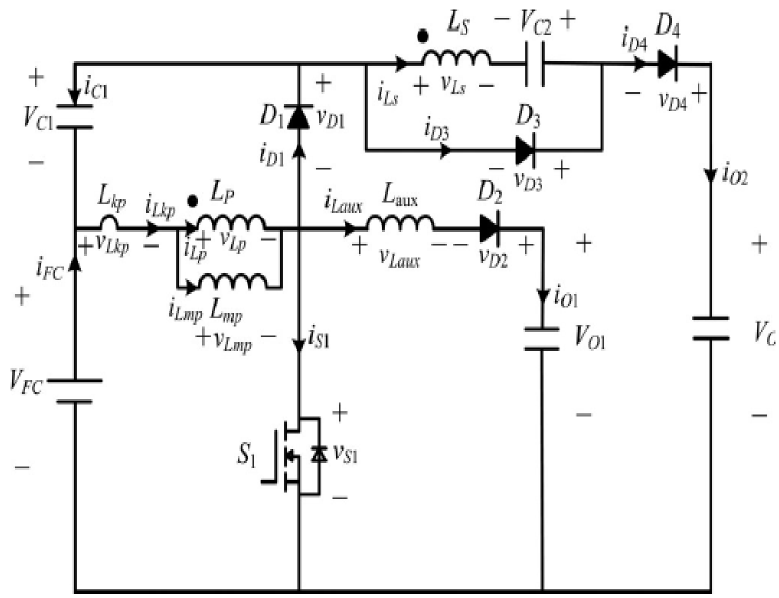

Fig 2.eqivalant circuit

In this paper, the following assumptions are made to simplify the converter analyses: 1) The main switch including its body diode is assumed to be an ideal switching element; and 2) The conduction voltage drops of the switch and diodes are neglected.

The major advantages of proposed dc-dc converter as follows: 1) this topology adopts only one power switch to achieve the objective of high-efficiency SIMO power conversion; 2) the voltage gain can be substantially increased by using a coupled inductor; 3) the stray energy can be recycled by a clamped capacitor into the auxiliary battery module or high-voltage dc bus to ensure the property of voltage clamping; 4) an auxiliary inductor is designed for providing the charge power to the auxiliary battery module and assisting the switch turned ON under the condition of ZCS; 5) the switch voltage stress is not related to the input voltage so that it is more suitable for a dc power conversion mechanism with different input voltage levels; and 6) the copper loss in the magnetic core can be greatly reduced as a full copper film with lower turns

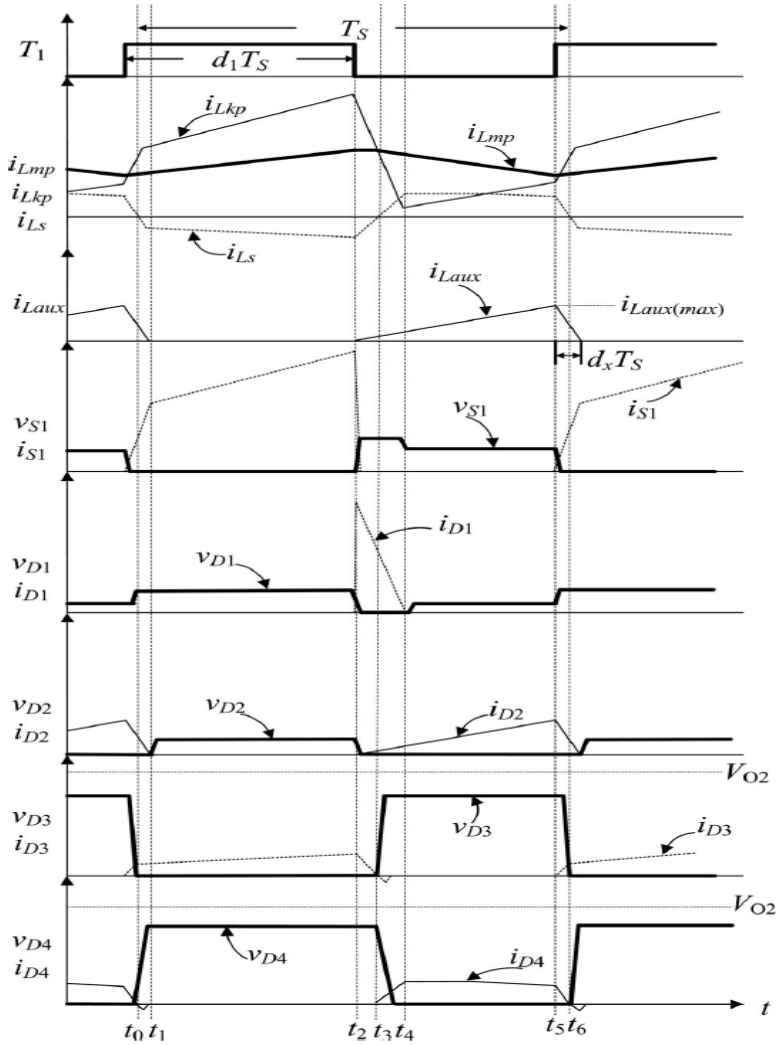

Fig 3.checterisitc wave form of proposed converter

III. Mathematical Model of PV cell

A general mathematical description of I-V output characteristics for a PV cell has been studied for over the pass four decades. Such an equivalent circuit-based model is mainly used for the MPPT technologies [3,4,5,6]. The equivalent circuit of the general model which consists of a photo current, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow, is shown in Fig.1. The voltage-current characteristic equation of a solar cell is given as

$$I = I_{ph} - I_S\left[\exp\left(\frac{q(V + IR_S)}{KT_C A}\right) - 1\right] - \frac{V + IR_S}{R_{Sh}}$$

Where

I_{ph} is a light-generated current or photocurrent,

I_s is the cell saturation of dark current,

q(= 1.6 ×10−19 C) is an electron charge,

k(= 1.38 ×10−23J/K) is a Boltzmann's constant,

T_c is the cell's working temperature,

A is an ideal factor,

R_{sh} is a Sunt resistance, and

R_s is a series resistance of solar cell

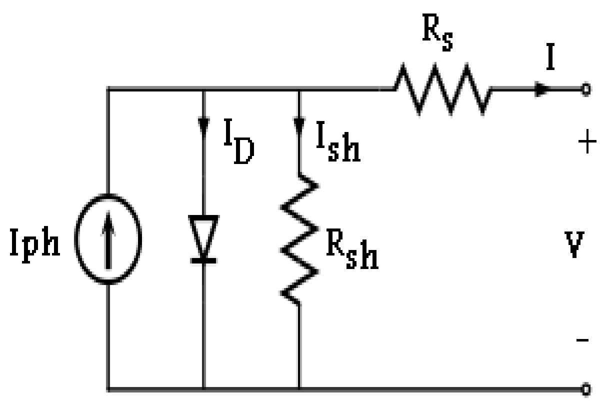

Fig. 4.PV cell equivalent circuit

The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

$$I_{ph} = [I_{SC} + K_I(T_C - T_{Ref})]H$$

where

I_{sc} is the cell's short-circuit current at a 25°C and 1kW/m2,

K_I is the cell's short-circuit current temperature coefficient,

T_{ref} is the cell's reference temperature, and

H is the solar insolation in kW/m2

IV. SIMULATION RESULTS

The proposed PV –based single input multi output converter system with single stage power conversion is simulated with MATLAB/SIMULINK (7.8 R 2009Aversion) environment

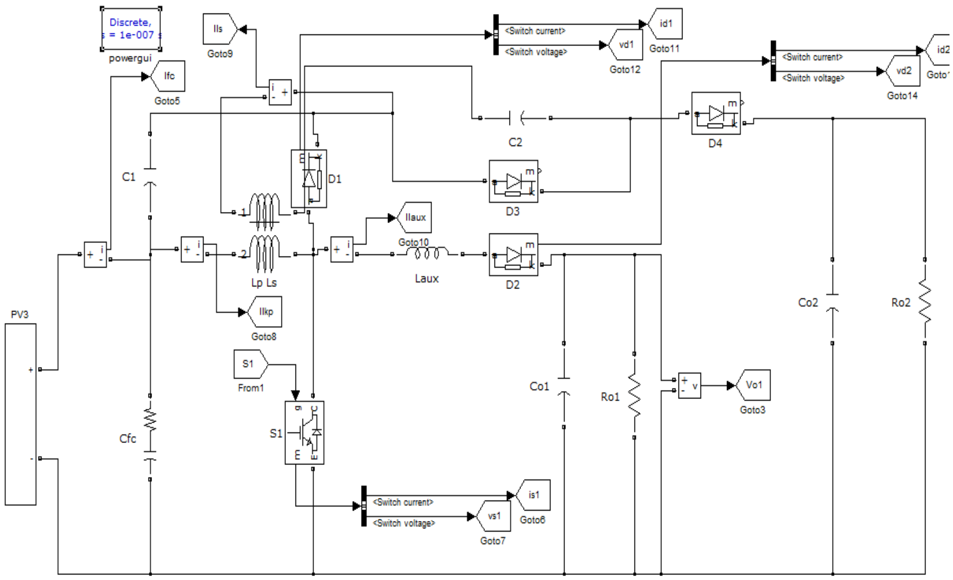

Fig 5.Complete Simulink model for proposed converter

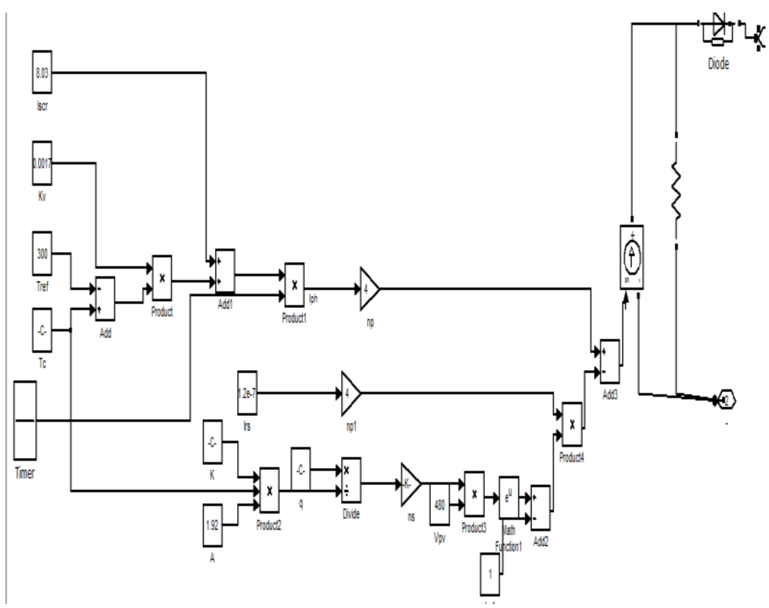

Fig 6 .Simulink model for pv-power generation

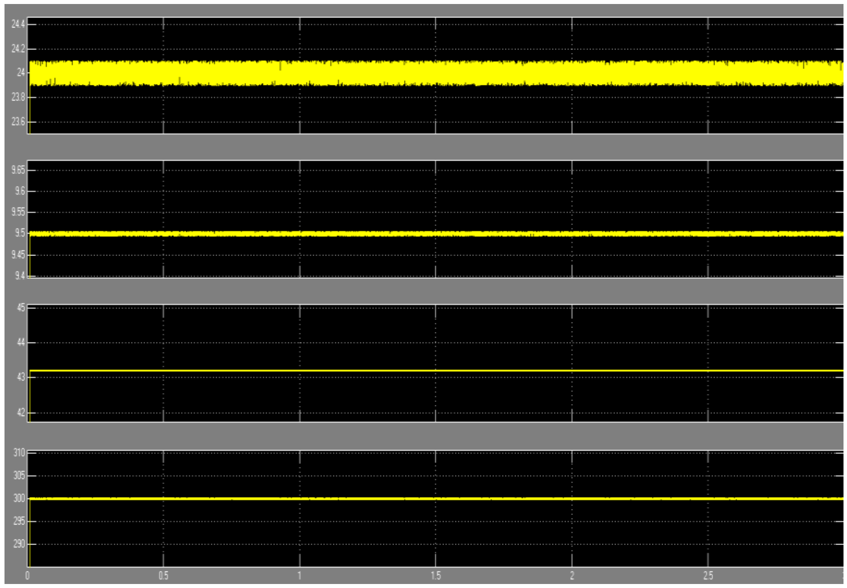

Fig 7.voltage and current responses of proposed converter with 200-W output power

Fig 7 shows the input voltage, input current, output voltage at terminal1 and output voltage at terminal2.input voltage is from solar panel which is 24 volts and input current is 9.5amperes.outut voltage at terminal1 is 44 volts and output voltage at terminal2 is 300volts.Fig 8 shows the switching voltage and switching current of proposed converter with 200-W output power. These wave forms show effectiveness of switching pulses with less distortion. The switching frequency is 100 kHz. Fig 9 shows the leakage current, secondary current, auxiliary current responses of proposed converter with 200-W output power.

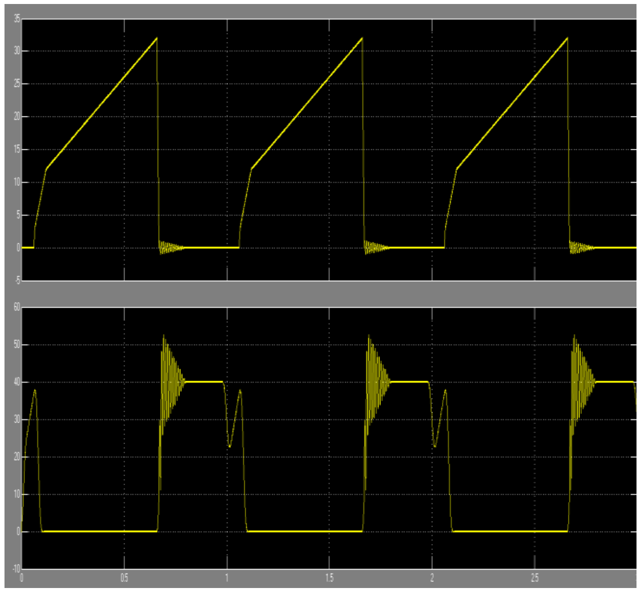

Fig 8.switch voltage and switch current responses of proposed converter with 200-W output power

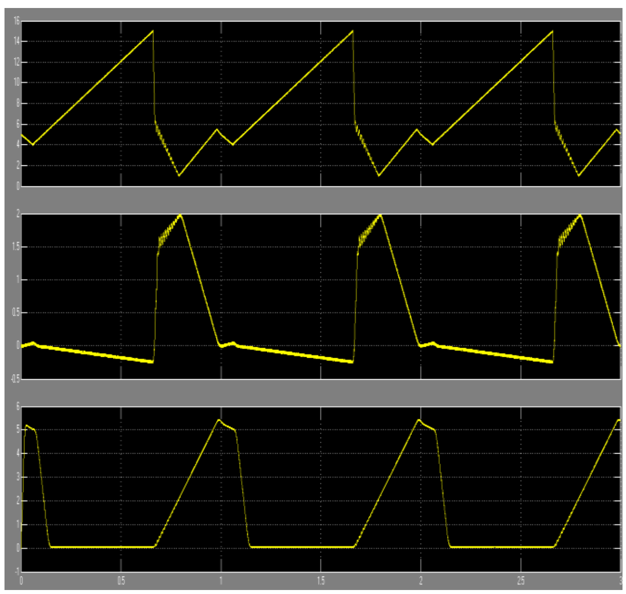

Fig 9: leakage, secondary, auxiliary current responses of proposed converter with 200-W output power

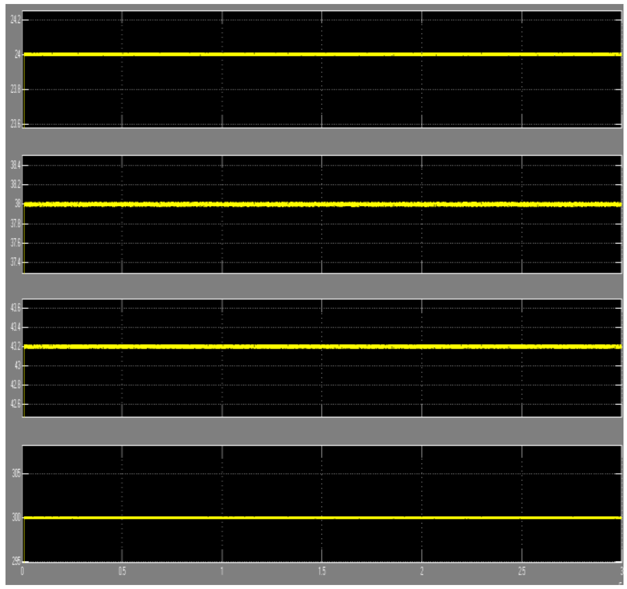

Fig 10.voltage and current responses of proposed converter with 800-W output power

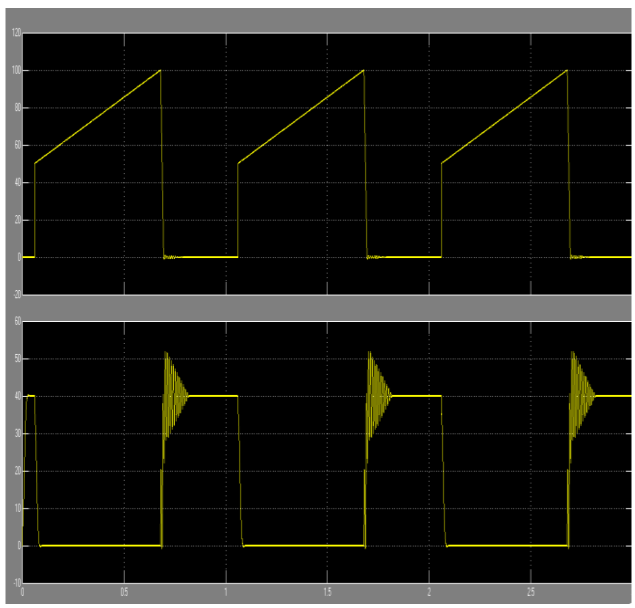

Fig 11.switch voltage and switch current responses of proposed converter with 800-W output power

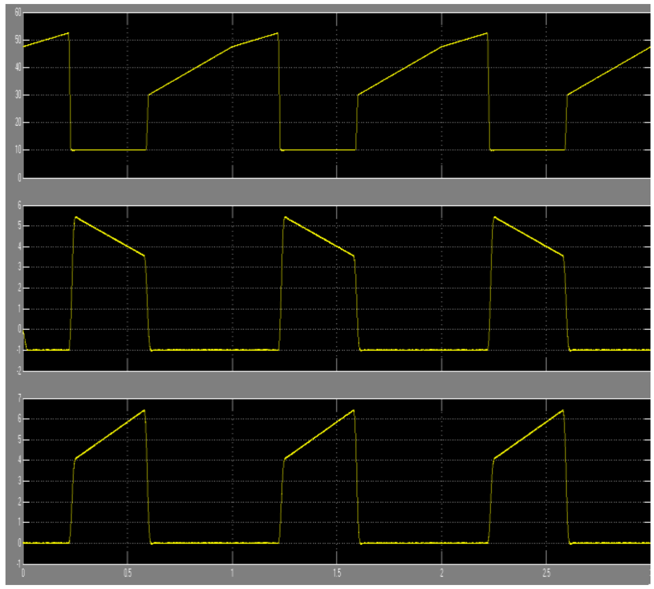

Fig 12.leakage, secondary, auxiliary current responses of proposed converter with 800-W output power

Fig 10 shows the input voltage, input current, output voltage at terminal1 and output voltage at terminal2.input voltage is from solar panel which is 24 volts and input current is 38 amperes. output voltage at terminal1 is 44 volts and output voltage at terminal2 is 300volts. Fig 11 shows the switching voltage and switching current of proposed converter with 800-W output power. These wave forms show effectiveness of switching pulses with less distortion. The switching frequency is 100 kHz.Fig 12 shows the leakage current, secondary current, auxiliary current responses of proposed converter with 800-W output power.

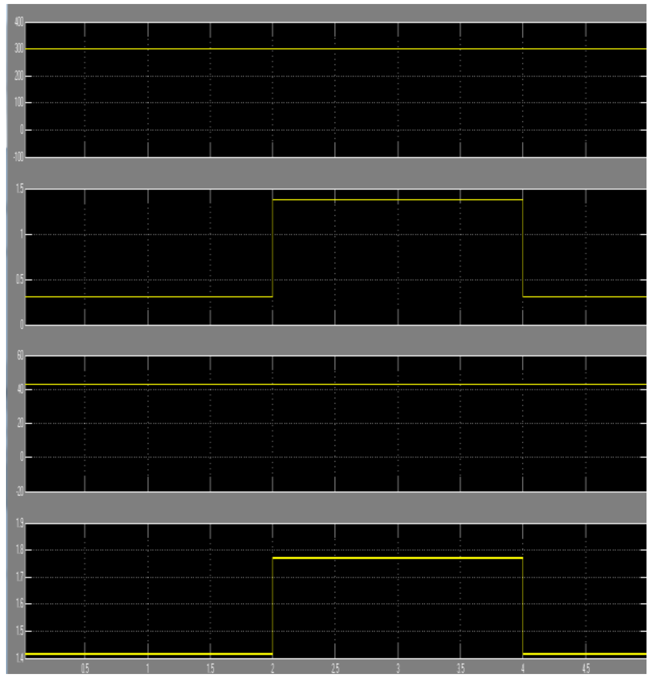

Fig 13.proposed converter response during output power change from 125w to 550w

Figure 13 shows the output voltage at terminal 2 is 300 volts, output current at load terminal2 is varies from 0.32amperes to 1.4 amperes during load power change. output voltage at terminal 1 is 40 volts and output current at load terminal1 is varies from 1.4 amperes to 1.8 amperes during load power change.

V. CONCLUSION

This study has successfully developed a photovoltaic power generation based high-efficiencymulti output dc–dc converter, and this coupled-inductor-based converterwas applied well to a single-input power source plustwo output terminals composed of an auxiliary battery moduleand a high-voltage dc bus. This high-efficiency dc-dc converter topology provides designerswith an alternative choice for boosting a low-voltagepower source to multiple outputs with different voltage levelsefficiently.

Appendex

Design arametres

Capacitor $C1$ = 85 μF/100 V;

$C2$ = 10 μF/250 V;

$CO1$ = 100 μF/35 V;

$CO2$ = 20 μF/250 V;

Input power source = 24V

Auxiliary output voltage $VO1$ = 42 – 44V

Desired output voltage Vcmd = 300V

Switching frequency fS= 100 kHz;

Coupled inductor LP = 3 μH; LS = 75 μH;

Auxiliary inductor Laux = 2 μH;

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