Arduino Controller Based 3-Switch Isolated DC-DC Boost Converter for PV and Battery Application

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Abstract. This paper discusses a Arduino controlled 3-switch Isolated DC-DC Boost converter for PV and battery application. The presented converter has vital benefits such as a switch reduction, snubber circuit elimination with an additional diode, a capacitor; obtain the same primary and secondary voltage waveforms of the transformer with duty cycle variation. The MATLAB Simulink model of the presented converter for 95W PV system has been developed for 20V dc input. The hypothetical forecasts and the performance of the PV based presented converter has been effectively confirmed with the aid of simulation results. The experimental setup of the presented converter for 100W PV module has been successfully implemented using Arduino Uno microcontroller to confirm the simulation outcomes.

Keywords: 3-switch, Photovoltaic (PV), Current-fed full-bridge (CFFB) converter, Voltage double rectifier (VDR);

1. Introduction

Owing to the huge demand, continuous usage of fossil fuels and its enormous harmful impact on the environment, non-conventional energy sources have become the much sought after source of fuel in recent years [7]. Amidst the various forms of non-conventional energy sources, solar energy is one of the firmest upward and capable because of non-pollution. Solar energy is transformed into electrical energy by Photovoltaic (PV) modules. PV modules are found attractive due to clean, lasting long and entail minimum maintenance.

In literature, various types of high step-up dc-dc converters have been introduced to obtain high dc output voltage from convert low voltages. The authors [1] presented the Current-Fed Full-Bridge (CFFB) is appropriate for high step-up voltage gain uses since they have the boost function of input voltage. However, in Voltage-Fed Full-Bridge (VFFB) dc–dc converters since the buck function the
major voltage gain is provided by a high frequency transformer with a large turn ratio. To increase the voltage enhance capability, a boost converter is devoted to the secondary side of the VFFB dc–dc converter. The authors discussed [6] the current-fed full-bridge (CFFB) dc–dc converters as the ripple current and the HF transformer turn’s ratio in CFFB converters are lower than those in VFFB dc–dc converters.

The transformer leakage inductor and the primary switching capacitor cause voltage spikes due to the presence of resonance between them. A passive snubber is used to fascinate the turn-off voltage spike of the switch in CFFB converters. Hence active clamping circuits with growing size and cost have been proposed for the energy recovery of the snubber circuit [6]. A range of topologies have been suggested to elude the use of the active clamping circuits [3].

They are soft-switching naturally clamped CFFB converters without snubber, interleaved CFFB converter to lessen the input current ripple, a dual-input CFFB converter based on a disseminated multi transformer construction and so on. On the other hand, the various types of CFFB converters have been introduced and it consists of more number of transformers and switches, which will escalate the loss and cost of the entire system. This paper describes a 3-switch isolated boost dc–dc converter for PV and battery application which consists of three switches with an additional diode and one more capacitor. The schematic of the 3-switch isolated dc–dc boost converter for photovoltaic application is illustrated in figure.1.

![Schematic of the intended system](image)

This paper comprises the following sections. First, the MPPT controller and P & O algorithm are discussed in section I. The 3-switch isolated dc-dc boost converter power circuit configuration is explained in section II. Then, the 3-switch Isolated Boost DC-DC converter power circuit with its operating modes is presented in detail in section III. Section IV briefly discussed the results of the simulation model of the presented power converter circuit for PV module. The experimental setup and the results are validated in section VI. The last section has the conclusion and the future scope is discussed.

### 2. Mppt Controller

The most vital rule of MPPT (Maximum Power Point Tracking) is to extort the ultimate existing power from the PV module by making them work at the maximum power point. The MPPT checks the PV panel output and match up to it to the battery potential and afterward sticks with the optimum power that PV panel can generate in order to charge the battery and converts it to the most excellent voltage to get utmost current into the battery. It can moreover deliver power to the dc load, which is connected to the battery directly.

#### A. Perturbation & Observe (P&O) MPPT Algorithm

In the given algorithm, the perturbations cause the PV panel power to adjust. Due to the perturbation, if the power increases then the perturbation is continued in that direction. At the next moment the power decreases after the crest power is reached and subsequently the perturbation reverses. This algorithm swings more or less the crest point when the firm state is reached. With the
help of flow chart [12] this algorithm can be straightforwardly implicit and the same is shown in figure 2.

![Flow chart of P&O Algorithm](image)

**Fig.2 Flow chart of P&O Algorithm**

The algorithm is move forward in such a manner that it puts a reference voltage of the PV module matching to the crest voltage of the PV module [12]. But still this algorithm is very popular because of its simplicity.

3. **Power Circuit Description**

The 3-switch isolated dc-dc boost converter consists of three semiconductor switches ($S_1$, $S_2$ and $S_3$), three capacitors ($C_1$, $C_2$ and $C_3$), three diodes ($D_1$, $D_2$ and $D_3$), a boost inductor ($L_i$), a transformer (TR) and the load (R). The presented power converter circuit [3] is illustrated in figure 3.

![3-Switch Isolated DC-DC boost converter power circuit](image)

**Fig. 3 3-Switch Isolated DC-DC boost converter power circuit**

The abridged converter topology is reasonably economical compared to other existing topologies, i.e., it uses a switch reduction, snubber circuit elimination with an additional diode, a capacitor than the conventional isolated boost dc-dc converter [3].

4. **Power Circuit Operation**

The operating modes of the 3-switch Isolated DC-DC Boost converter can be steadily implied by the following table. I
Table 1. Operating Modes

| Operating Modes | Switching Condition | Capacitance & Inductance | Diodes | Transformer Voltage | Secondary Voltage |
|-----------------|---------------------|--------------------------|--------|---------------------|-------------------|
| Mode-I          | S₁: ON S₂ & S₃: OFF | C₁: Charging L₁: Discharging | D₁ & D₂: Forward biased D₃: Reverse biased | Positive Voltage   |                   |
| Mode-II         | S₁: ON S₂ & S₃: OFF | L₁: Charging             | D₃: Reverse Biased                  | Positive Voltage   |                   |
| Mode-III        | S₂ & S₃: ON S₁: OFF | L₁: Charging             | D₁, D₂ & D₃: Reverse Biased         | Zero               |                   |
| Mode-IV         | S₁: ON S₂ & S₃: OFF | L₁: Discharging           | D₃: Free wheels                     | Zero               |                   |
| Mode-V          | S₁: ON S₂ & S₃: OFF | L₁: Discharging           | D₃: Free wheels D₁ & D₂: Reverse Biased | Zero               |                   |
| Mode-VI         | S₂ & S₃: ON S₁: OFF | L₁: Charging C₁: Discharging | D₃: Forward Biased D₁ & D₂: Reverse Biased | Negative Voltage   |                   |
| Mode-VII        | S₂ & S₃: OFF S₁: OFF | L₁: Discharging           | D₃: Forward Biased D₁ & D₂: Reverse Biased | Zero               |                   |
| Mode-VIII       | S₁: ON S₂ & S₃: OFF | L₁: Discharging           | D₃: Free wheels D₁ & D₂: Reverse Biased | Zer               |                   |
| Mode-IX         | S₁ & S₃: ON S₂: OFF | L₁: Charging             | D₁, D₂ & D₃: Reverse Biased         | Zero               |                   |

5. Discussions On Simulation Results

The MATLAB simulation model of the 3-switch isolated dc-dc boost converter and with PV module are shown in figure.4 and figure.5 respectively. This developed model consists of various modules like PV module, power MOSFET switches passive elements like resistors, inductors and capacitors. The parameter specifications of the PV array and the presented converter are illustrated in table II and table III respectively.

Table 2. Specifications of the PV array (Sun Earth Solar Power TBPb125x125-36-P 95w)

| S.No | Parameters                  | Specifications |
|------|-----------------------------|----------------|
| 1    | Short Circuit Current, I_sc | 5.52A          |
| 2    | MPPT Current, I_MPPT        | 5.28A          |
| 3    | Open Circuit Voltage, Voc   | 22.3V          |
| 4    | MPPT Voltage, V_MPPT        | 18V            |
| 5    | Maximum Power, W            | 95W            |
| 6    | No. of Cells/Module         | 36 cells       |

Table 3. Simulation Parameters Specification of 3-Switch DC-DC Boost Converter

| S.No | Parameters                  | Specifications |
|------|-----------------------------|----------------|
| 1    | Switching frequency, fₛ     | 10kHz          |
| 2    | Fundamental frequency, f     | 50Hz           |
| 3    | Capacitor C₁                | 220 μF         |
|      | Capacitors C₂ = C₃          | 160 μF         |
| 4    | Inductor, L₁                | 2 mH           |
| 5    | Resistor                    | 500 Ω          |
6. Primary Inductance 1.5mH
7. Leakage Inductance 15 μH
8. Transformer Turns Ratio 1:2.5
9. Input voltage 40V
10. Output voltage 428V

Fig.4 Simulation model circuit of 3-switch Isolated DC-DC Boost converter

Fig.5 Simulation model circuit of 3-switch DC-DC Boost converter for PV System

The developed PV simulation model I-V characteristic is illustrated in figure 6. The obtained parameter values are 23.3V and 5.52A which represents the open circuit voltage ($V_{oc}$) and short circuit current ($I_{sc}$) respectively.
The developed PV simulation model P-V characteristic is illustrated in figure 7. The obtained parameter values are 23.3V and 95W which represents the open circuit voltage ($V_{OC}$) and the maximum output power respectively. The input dc voltage to the 3-switch isolated dc-dc converter circuit is 40V is obtained from the PV module and the battery is shown in figure 8.
The PWM switching pulses for the MOSFET switches $S_1$, $S_2$ and $S_3$ of the 3-switch isolated dc-dc boost converter are illustrated in figure 9 and figure 10 respectively.

**Fig.9.** Switching pulses for switches $S_1$ and $S_2$

**Fig.10.** Switching pulse for switch $S_3$

The drains to source voltages of the three switches (MOSFETs) are illustrated from figure 11 to figure 13.
The presented 3-switch dc dc boost converter follows the vibrant change in the duty cycle and has a improved transient behaviour during the step variation in the load through voltage regulation.
Fig.14. Output voltage

The observed output voltage of the 3-switch isolated dc-dc boost converter with PV module and battery is 428V and it is shown in figure 14. Hence the simulation model of the PV based converter has boosted a changing low input dc voltage in to a fixed high output dc voltage. The obtained results from the 3-switch isolated dc-dc boost converter with PV module simulation are validated with the theoretical outcomes.

6. Experimental Validation

A. Experimental Setup

An experimental setup of 3-switch DC-DC Boost converter with PV module and battery has been developed to prove the hypothetical and simulation results. The specifications of the intended experimental setup are given in the table IV.

| S.No. | Component                        | Specification                                      |
|------|----------------------------------|---------------------------------------------------|
| 1    | PV Module (Model No: RSP-100W)   | All technical data at STC:                          |
|      | Poly Silicon Solar Panel        | • Peak Power: 100W                                 |
|      |                                  | • Maximum Voltage (V_{mp}): 16.9V                  |
|      |                                  | • Maximum Current (Imp): 5.91A                     |
|      |                                  | • Open Circuit Voltage (V_{OC}): 21.2V             |
|      |                                  | • Short Circuit Voltage (I_{SC}): 6.33A            |
|      |                                  | • Insolation: 1000W/m^2                            |
|      |                                  | • Dimension: 1010*670*30 mm                        |
| 2    | Battery                          | Lead-Acid sealed type (CS 7-12)                    |
|      |                                  | • 12V & 7Ah                                        |
|      |                                  | • Cycle use (14.1V-14.4V)                          |
| 3    | MOSFETs                          | IRF840 – 3 numbers                                 |
|      |                                  | • I_D = 8A, V_{DS}(BV) = 500V,                     |
|      |                                  | • R_{DS} =0.85Ω                                    |
| 4    | Arduino Uno Board (ATmega328P)   | Operating Voltage range : 5V                       |
|      |                                  | • Digital Input/output Pins:14                     |
|      |                                  | • Available analog Input Pins: 6                   |
| 5    | MPPT Controller                 | PWM/6-DDD-12V/6A                                   |
| 6    | Diode                           | 1N4007                                            |
| 7    | Capacitors                      | C_1 = 220µF/450V,                                 |
|      |                                  | C_2 = C_3 = 150µF/450V                             |
| 8    | Inductor                        | RFB0807-121L, 120 µH, 1.14A                        |
| 9    | Transformer                     | 12V to 40V                                        |
| 10   | Load                            | 40W Lamp load                                     |

A 3-switch isolated DC-DC Boost converter power circuit is fabricated using IRF840 power MOSFETs and the switching pulses are obtained from the ATmega328P based Arduino Uno microcontroller board. It have totally 14 digital input/output pins and 6 analog input pins. The different components and the experimental setup of the 3-switch isolated DC-DC Boost converter
power circuit for a Photovoltaic (PV) module using Arduino Uno microcontroller are illustrated in figure 15 and figure 16 respectively.

**Fig.15** Power circuit and Transformer

The fabricated 3-switch isolated DC-DC Boost converter power circuit with a lamp load and the entire experimental setup of the intended system are illustrated in figure 17 and figure 18 respectively.

**Fig.16** Arduino and MPPT Controllers

**Fig.17** Fabricated 3-switch Isolated DC-DC Boost converter Power circuit with a Lamp load
Fig. 18 Complete experimental Setup of the 3-switch Isolated DC-DC Boost converter Power circuit with 100W PV panel and a load

B. Experimental Setup Results
The output parameters of the 3-switch Isolated DC-DC Boost Converter power circuit for a Photovoltaic (PV) module with battery are measured by using the Digital Multimeter and the observed results are cited in the Table V.

| S.No | Parameters                  | Observed Values |
|------|-----------------------------|-----------------|
| 1    | Input Voltage (V<sub>i</sub>) | 20V             |
| 2    | Boosted Output Voltage (V<sub>o</sub>) | 194.8 V |
| 3    | Inductor current (I<sub>L</sub>)  | 1.12A           |

It is observed that for a given low input voltage of 20V, it is boosted to a high dc output voltage of 194.8V using the 3-switch Isolated DC-DC Boost Converter power circuit with a inductor current of 1.12A. Thus, the hardware implementation of the presented converter for a PV module with a battery and its experimental results has been effectively validated with the theoretical and simulation results.

7. Conclusion
The simulation and the hardware implementation of a 3-switch isolated DC-DC Boost converter for PV and battery application have been successfully implemented and their results are examined in this paper. The functionality verification of the 3-switch isolated DC-DC Boost converter using Arduino Uno microcontroller has been made and the output values measured from the experimental setup provides as good results as anticipated. In the future, the presented converter is a good alternative for renewable energy systems and electrical drives applications. Also its efficiency could be further improved by employing a current digital controller for fast dynamic response and superior control.

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