A Constructed Solar DC-DC Static Boost Converter Review of Switching Losses

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Abstract— **The DC-DC converter is majorly used in several renewable energy applications. It is usually rel- evant in a hard-switching operating mode at the cost of increasing power losses and declining efficiency. Power losses are comprised of switching losses and conduc- tion losses, which affect the reliability and speed up the aging of the switch. Therefore, soft-switching tech- niques are inescapable to reduce electromagnetic inter- ference EMI, minimize losses, and enhance power con- version efficiency. Among the sundry techniques of soft-switching, passive snubbers are uncomplicated and vigorous, besides it has been spotlighted as a finer al- ternative compared to the active snubbers that involve extra switches and an additional control circuit. This paper investigates the power loss of a conventional solar DC-DC static converter designed and controlled through Maximum Power Point Tracking (MPPT). It evaluates the switch's temperature in the hard- switching operating mode. Besides, this paper presents a new research initiative that aims to allow a zero switching and stabilizing the temperature of the switch through a novel approach of design for RLD and RCD snubber cells. This new design allows the switch to achieve soft-switching, by abolishing the voltage stress, minimizing the power losses, and stabilizing the junc- tion temperature. This snubber has a simple structure with a few components and ease of control, which helps to upgrade the power conversion efficiency through controlling the high voltage and current stress in the switch. In this treatise, elements of the snubber are designed and adjusted for maximum reliability through the simulation in OrCAD environment. Furthermore, the effectiveness of the model is approved through ex- perimental results on a 1600 W conventional boost to validate the proposal.**

Keywords— **Continuous Conduction Mode (CCM), DC- DC converter, Passive snubber, Soft-switching reverse-recovery loss, Zero Current Switching (ZCS), Zero Voltage Switching (ZVS).**

I. INTRODUCTION

In recent years, renewable energy has presented a high development, assignable to the inexhaustible resources, and the lowest environmental effects. Furthermore, day to day, the development of renewable energy resources is based essentially on the power electronics applica-tions [1] and [2].

The DC-DC boost converter has been highlighted in numerous research so far for distinct purposes which allow good controllability, simple and inexpensive de- sign to implement [3] and [4]. The classical converter, as can be seen in Fig. 1, is usually used in a hard- switching operating mode occurring switching losses. Moreover, higher switching frequency increases switch- ing losses along with the electromagnetic interface. The conventional hard-switching converters are still an adequate choice for improving the power density, efficiency, reliability, and cost for regular commercial applications. However, the converters supplied with renewable energy sources, mainly photovoltaic panel sources, are recognized by their significant low yield. Therefore, this type of application needs the follow- ing design specifications: reduction of EMI, minimiza- tion of power losses, and stabilization of junction tem- perature. These lead to increased efficiency of such converters. To address these problems, soft-switching techniques are incited instead of hard-switching [5], [6] and [7].
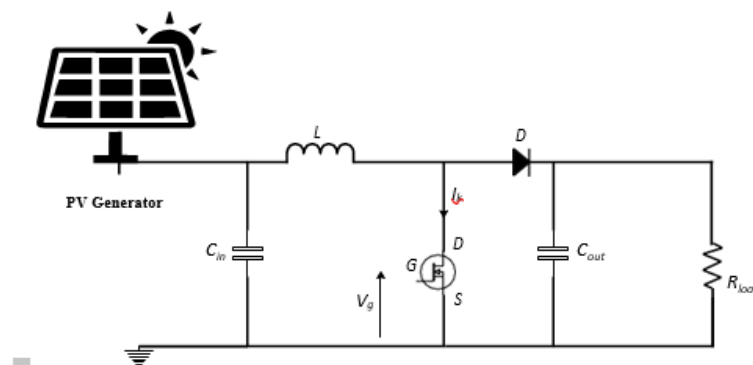

Fig. 1: DC-DC conventional boost converter.

Power losses in the boost converters are resulting from two major sources: conduction loss and dynamic loss. These power losses lead to overheating that im- pacts the reliability and contributes to accelerated ag- ing of interrupters. To eschew these power losses, sev- eral snubbers have been recommended to limit the rate of change in voltage dv or current di and overvoltage during the turn on/off. These various snubbers are classified into active and passive snubber.

As treated in [8] and [9], the active snubbers are em- ployed to minimize the turn-on switching losses. The majority proposed in the literature uses an auxiliary switch that involved an intermediate interface control circuit. The synchronization problems among control signals of the switches during transients increase the complexity of the control strategy, circuit's size, and the cost. Over and above, the proposed active snubber provides soft-switching operation for the main switches and reduces the voltage stress of the main switches. However, the voltage stress of the main diode is twice the output voltage, and the auxiliary devices are oper- ated by hard-switching. Hence, the snubber elements cause extra switching power losses. In [13], Zero Volt- age Transition (ZVT) is achieved for high set-up in- terleaved switches, but there is a transformer in the auxiliary circuit. The leakage inductance causes addi- tional losses in this converter. However, passive snub- bers have low cost, easy control and application. There are some downsides needed to be controlled in passive snubber cells. In [5], Zero Voltage Switching (ZVS) is not able to accomplish perfect turned off, despite Zero Current Switching (ZCS) can realize a correct turn on.

II. THE HARD-SWITCHING PROPERTIES

SWITCHING ON PROPERTIES

A forward-biased MOSFET can be turned on by apply- ing a positive voltage between the gate and the source. However, to go from forward blocking mode to forward conduction mode, it takes some transition time td. It can be subdivided into three small intervals as delay time, rise time tr, and time on ton, as shown in Fig. 2.
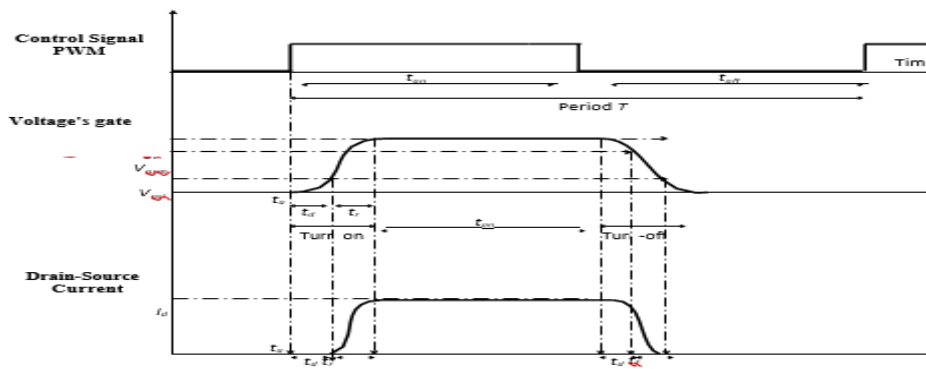

Fig. 2: MOSFET's switching characteristics.

After the application of the gate voltage, the MOS- FET will start conducting over a very tiny region td. Through delay time, the gate's input capacitance gets charged from 0 V to Vgsi, where Vgsi is the starting point where the current Id is in condition to start flow- ing, but it is not flowing. Rising the gate voltage from Vgsi to Vgsm, the current Id starts to drain and achieves the saturation at the value of Vgsm, where Vgsm is the necessary voltage to drive the MOSFET to turn-on condition. This period is defined as the rise time where the switch tries to reach the turn-on and it is the gen- esis of the switching turn-on loss Eon. Afterward, the switch gets fully turn-on for a period ton.

SWITCHING OFF PROPERTIES

The switching-off started at the tb, once the gate volt- age is eliminated. It can be divided into two intervals, as shown in Fig. 2, the delay time for the turning-off, However, the current stands constant until Vgsm. Afterward, while the fall time tf , the input capacitance endures discharging from Vgsm to Vgsi. Identically the drain current begins to reduce from Id to zero. So, every time that the drain cur- rent Id gets to zero or the gate voltage reaches lesser than the threshold Vgsi, and the turn-off operation gets done.

Therefore, the switching losses arise ascribable to the stored charges. Besides, when the voltage's gate is decreased to a value lower than the threshold Vasi, the process of switching-off is realized. While switch-ing on/off, the MOSFET experiences a decrese of one parameter anf the corresponding increase of the other. This transition is not instan-taneous, hence during every turn on/off, there is afinite duration for whuch both voltage and current are non-zero. And so, there is power loss in the hard-switching device. The higher the switching frequency, the higher is the loss and the more heat is dissipated. To reduce the switching stress, the switching point of the voltage and the current must be reduced.

III. POWER LOSSES IN THE CONVENTIONAL BOOST CIRCUIT

The losses in the boost converter are separated into conduction and dynamic losses. While the conduction losses occur when the MOSFET is in full conduction, they are practically resulting from the resistance in the elements of the circuit, such as diode, capacitors, in- ductor, and MOSFET. Yet, the dynamic losses repre- sent a considerable part of losses. They occur in every transition period of the switching. These losses are di- rectly proportional to switching frequency and the less dependent on the load, which means the higher the frequency, the higher the losses.

The equivalent schema of the DC-DC converter is given in Fig. 3. With certain assumptions, presented as follow, the converter elements are independent in time, temperature, frequency, and they are linear [13].
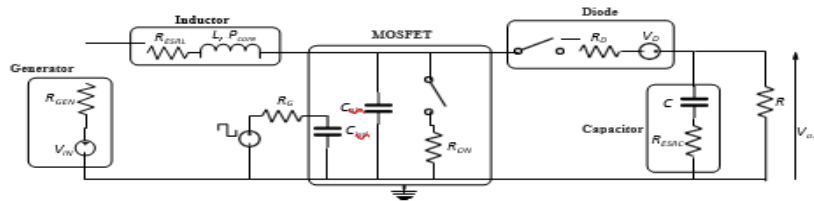

Fig. 3: Equivalent circuit of the DC-DC converter with para- sitic elements.

Depending on the switching frequency, duty factor and load, the converter can operate in two different modes, the Continuous Current Mode (CCM) or the Discontinuous Current Mode (DCM). This fact must be taken into account while calculating the current equation for the converter.

IV. THE PROPOSED SNUBBER CIRCUIT AND IT'S OPERATION

The MOSFET utilized in power converters operate usually in the hard-switching mode. The dynamic be- havior of power semiconductor devices attracts atten- tion, especially for the faster ones, for a number of reasons: optimum drive, power dissipation, EMI/RFI issues, and the junction's temperature [14]. The hard- switching refers to the stressful switching behavior of the power electronic devices during the turn-on and the turn-off processes. The device has to withstand high voltage and current simultaneously, which engenders a high switching loss and stress [6].

Several varieties of resonant snubbers structures are proposed by D. Tardiff [17] and W. McMurray [18]. They can be classified into unpolarized snubber circuits and polarized ones. The proposed passive snubber cir- cuit is employed to conserve the semiconductor and minimize the stress in the switch during the switching operations. It assures that the electrical rating of the device does not reach out to the limits of the semicon- ductor [16].
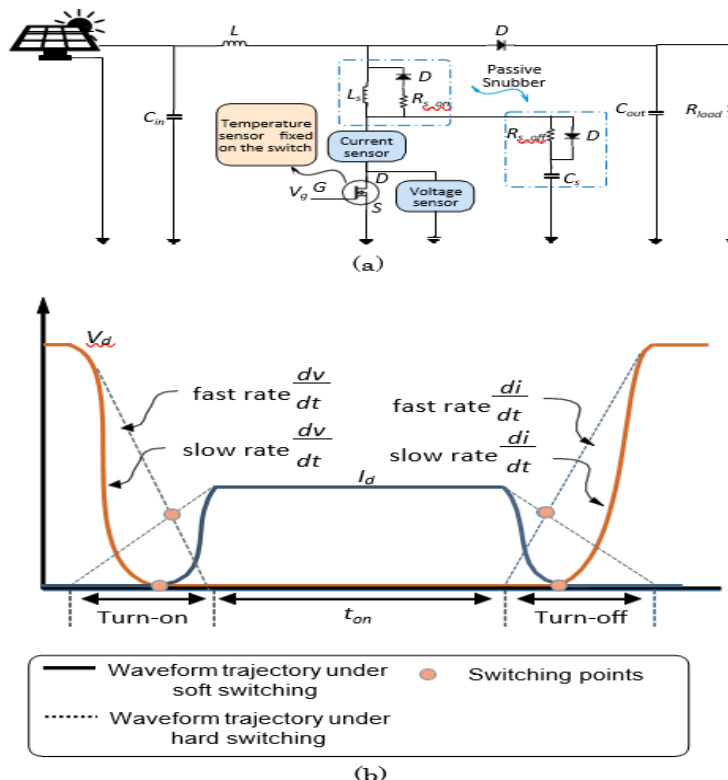

Fig. 5: Solar DC-DC converter with the proposed snubber cir- cuit, (a) soft-switching boost converter with RLD and RCD snubber cell, (b) the current and the voltage wave- form of the switch in the transition time.

As Fig. 5(a) shows, the RLD or the turn-on circuit includes a diode and resistor with a parallel inductor in series to the switch device. Whereas, RCD or turn-off circuit includes a parallel resistor and diode in series connected to the fast-changing of and causing the with a capacitor. The capacitor C and the inductor electromagnetic noise generated in the switching mo- ment, as the frequency rises, the noise frequency gets higher [15].L delay the time at which the switch reaches the final value of voltage and current. In return, the values of the capacitor and the inductor are usually optimized in

V. A SIMULATION RESULTS

In order to validate the impact of passive snubber on the circuit, a simulation model is proposed in the envi- ronment of Pspice OrCAD, using the same switches ref- erence chosen for the implementation of the Boost con- verter: the STW45NM50 MOSFET and the BYT30P diode from the STMicroelectronics, as shown in Fig. 6.
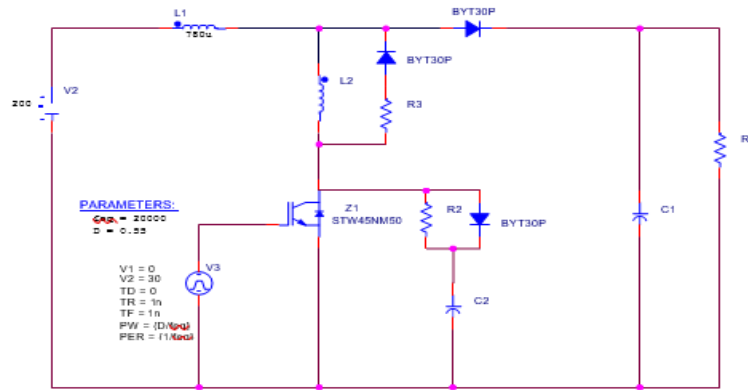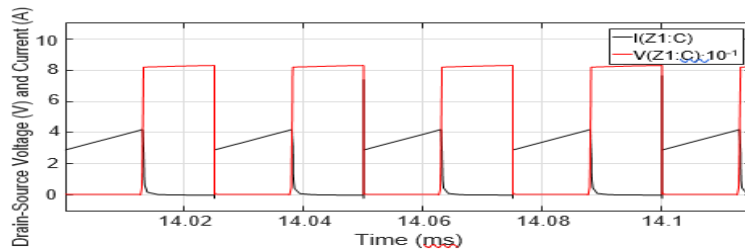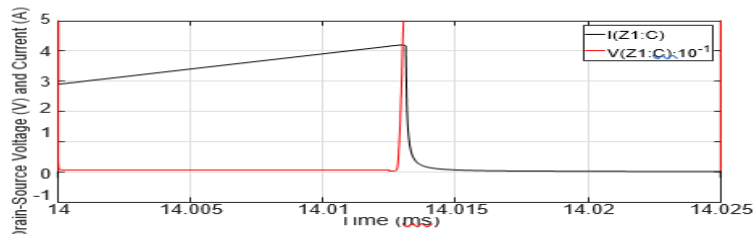

Fig. 6: Pspice model of soft-switching DC-DC boost converter.
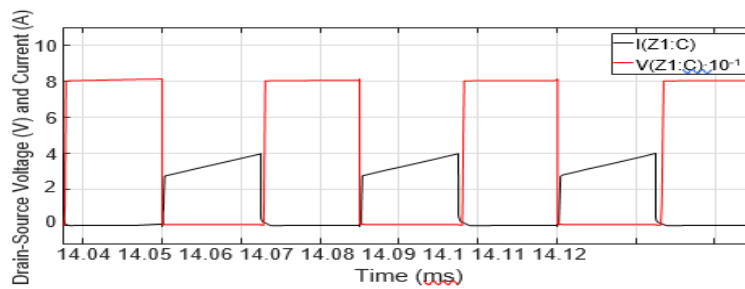

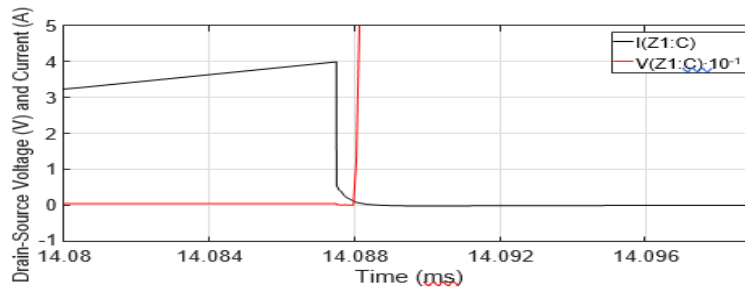(a) Voltage and current waveform.

(b) The turn-off moment.

Fig. 7: The waveform in the active switch for the hard- switching, (a) voltage and current in the switch for the conventional circuit, (b) zoom in on the turn-off moment for the switch.

(a) Current and voltage waveform.


(b) The turn-off moment.

Fig. 8: The waveforms for the active switch in the soft-switching operating mode, (a) voltage and current in the switch for the proposed circuit, (b) zoom in on the turning-off moment in the switch.

Figure 7 presents the switch waveforms of a conven- tional boost converter operated in the hard-switching condition. In this case, the turn-off processes of the device attained high voltage and current values. And, that is linked to the fast changes of the voltage dv . The proposed circuit achieved a soft-switching with a zero voltage switch at turn-off. Due to the control of Rs, Cs improved the performance significantly by reducing the changing rate dv , which raised the switch's voltage.

On this ground, the switching loss of the proposed advanced circuit gets reduced to a lower loss compared to the one in the conventional boost converter with hard-switching operating mode, owing to the deduction of the differential voltage and differential current. As Fig. 9 shows, the lessen losses reach 65.55 % in the switch.
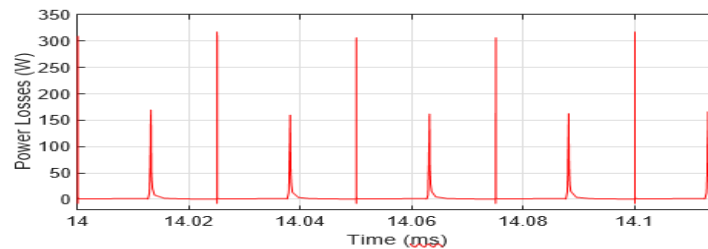
(a) Hard-switching power losses.
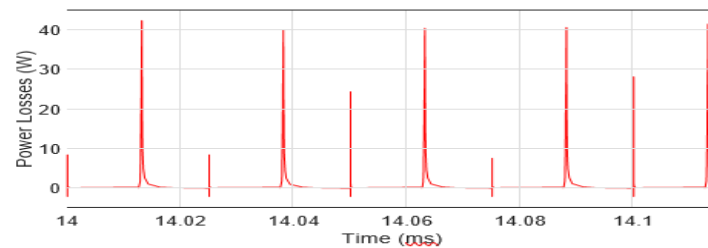
(b) Soft-switching power losses.

Fig. 9: Power losses in the switch: (a) hard-switching operating mode, (b) soft-switching operating mode.

VI. HARDWARE IMPLEMENTATION RESULTS

The performance characteristics of both the conven- tional and the proposed boost converters are verified by the prototype of 1.6 kW and 20 kHz switching op- eration using the same components and the same con-ditions as the model studied in the simulation environment. The prototype is itself summarized in the appendix, with the aforementioned design considerations. The converter operated with a source simulating photovoltaic panel (PV) as a source.The signal gate is given to the devices through an intermediate interference circuit that provides isolation from the hardware power circuit and the control

circuit, as shown in Fig. 10. This circuit integrates a 6N137 optocoupler for insulation, and an IR2112 driver, which amplifies output signals delivered by the control card.

Fig. 10: Hardware set-up of the boost converter with the galvanic-isolation circuit.

In the proposed implementation, we tested our pro- totype using a low power supply. As illustrated in Fig. 11, the voltage in the conventional circuit presents a high voltage spike between the drain and the source during device turn-off. It exceeds the rating of the switch device.
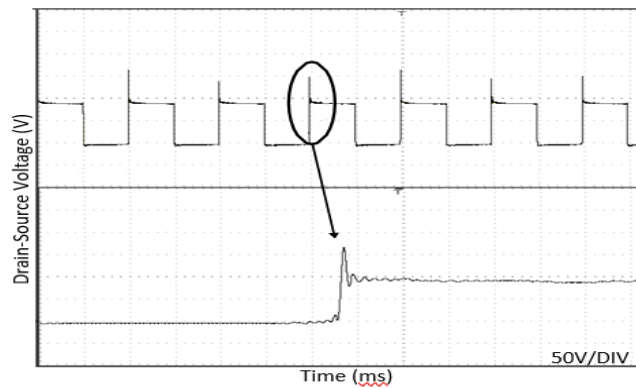

Fig. 11: Voltage waveform of the conventional boost's switch in hard-switching.
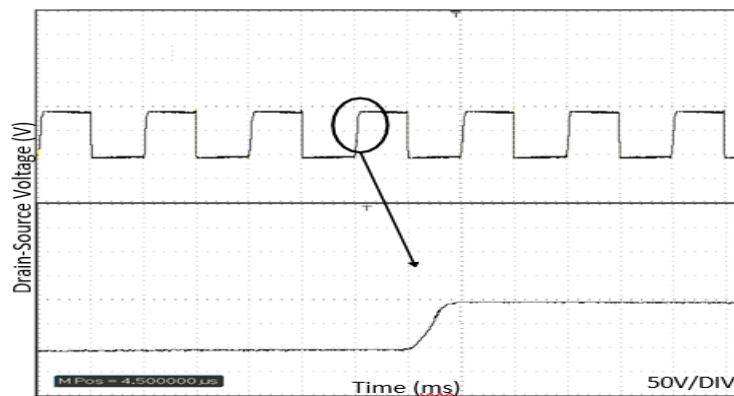

Fig. 12: Voltage waveform V_k of the proposed boost's switch in soft-switching.

(a) Hard-switching operating mode.
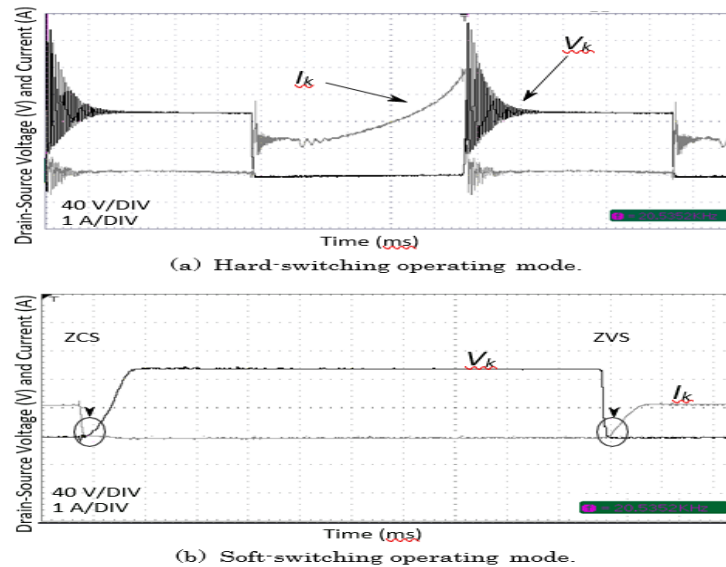

(b) Soft-switching operating mode.

Fig. 13: Comparison of voltage and current waveform for the boost's MOSFET for the (a) conventional converter and (b) proposed model.

The proposed circuit with a passive snubber has shown a better waveform of the voltage by eliminating the high spike voltage and reducing the fast-changing rates, as visualized in Fig. 12. The voltage and the current in Fig. 13(a) and Fig. 13(b), in both conven- tional and the proposed converter, verify the theoret-ical waveform. Due to the resonant circuit, RLD and RCD provide a retard for the current and voltage in- creases by raising the changing rate current and voltage respectively. The MOSFET in the proposed circuit had zero switching point at the turn-off and turn-on. Conse- quently, it exhibits zero power losses during turn-on and turn-off.

The junction temperature is one of the most impor- tant parameters that influence the performance and the behavior of the MOSFET. Thus, to provide a realistic visualization of the temperature dynamic behavior for the conventional boost and proposed circuit, an LM35 temperature sensor was implemented into the switch device.
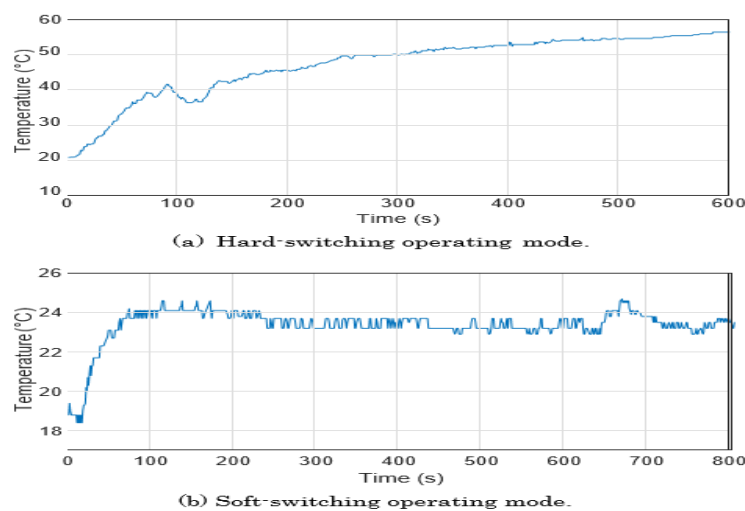

(a) Hard-switching operating mode.

(b) Soft-switching operating mode.

Fig. 14: The MOSFET junction temperatures measured for the conventional boost and the proposed boost, (a) hard- switching operating mode, (b) soft-switching operating mode.

From Fig. 14(a), it can be observed that hard- switching mode operating increases the temperature in the MOSFET up to 58 ◦C due to the presence of the spikes, ripples as was seen in Fig. 13(a), and the high-power losses, which impact the performance of the switch and contribute to accelerated aging of the device. Comparing to that, the proposed circuit has shown a better dynamic behavior of the temperature by reducing it into 44.44 %, as given in Fig. 14(b), owing to the fewer power losses and the good wave- forms of the voltage and current above the switch.

VII. CONCLUSIONS

This paper points out the comparison between hard- switching and soft-switching for a solar DC-DC boost converter. The soft-switching is based on a passive snubber RLD and RCD circuits. The operation princi- pals and the design consideration of the proposed cir- cuit have been described on the basis of the theoretical and experimental points of view. It was observed that the soft-switching enhances the circuit's waveform, by reducing the stress on the switch and hence lessening the power losses in the converter into 65.55 %. More- over, the junction temperature is reduced by 44.45 %. It keeps it stable at a nominal temperature area of the MOSFET. On that ground, analytically and experi- mentally, it was found that the conventional boost con- verter circuit achieves better efficiency when the pas- sive snubber circuit is implemented compared to the hard-switching operating mode.

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APPENDIX A

Tab. 1: Boost Converter Parameters.

Parameter	Specification
Input voltage	200 V
Output voltage	400 V
Output power	1.6 kW
Maximum output current	4 A
Switching frequency	20 kHz
Filter inductor	700 µH
Output filter capacitor	100 µF
Diode	BYT30P
Active switch	MOSFET STW45NM50