Proceeding Paper

Efficiency Analysis of GaN Based LLC Resonant Converter for PV Applications †

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Abstract: Due to the increase in renewable energy resources the need for highly efficient power electronics converters at flexible operating conditions has increased. The newly introduced wide bandgap switches, such as Gallium Nitride (GaN) are more suitable mechanically, thermally, and in terms of fast switching, etc. In this paper, a 3kW LLC resonant converter was designed for PV applications using GaN as switching devices. The converter was designed to achieve zero voltage switching at a wide input voltage range. The proposed system was simulated on PSIM software under different loading conditions. A performance comparison was made between GaN and Si switches. Analysis shows that the GaN converter has better performance compared to Si at higher voltages. The designed converter achieved 98.55% maximum efficiency.

Keywords: gallium nitride (GaN); LLC resonant converter; efficiency; zero voltage switching (ZVS)

1. Introduction

DC/DC converters play an increasingly important role in renewable energy systems, particularly solar systems. These converters are required to tackle the problem of changing PV voltage due to its non-linear behavior and weather conditions. The fundamental goal of these converters is to maintain a consistent output voltage regardless of the input voltage provided by the PV [1].

Resonant converters have become the standard topology for DC–DC conversion among the various power electronic converters due to better and optimized performance compared to other converts [2]. Low losses, high efficiency, high power density, minimum electromagnetic interference (EMI), and rapid transient response are all advantages of soft switching. The resonant converter has the ability to operate at a high switching frequency which leads to the reduction of passive component size, such as a transformer, inductor, etc. [3].

For reduction in switching loss during high frequency operation of LLC resonant converters, both zero voltage switching ZVS feature and wide bandgap switch component will be activated. Novel Magnetics and developments in LLC resonant converters with GaN are responsible for the higher efficiency, higher power density, and additional switching frequency. Full ZVS should be surefire to avoid device failure, thermal stress, and shoot-through because of their switching frequencies which are higher than 500 kHz [4].

GaN-based transistors have some useful properties, such as a wide bandgap, and being hard and mechanically stable for favorable development in industries [5]. Their electric breakdown capability is ten times higher than Si. High Electron Mobility Transistors (GaN HEMT) are significant due to their faster switching speed, higher breakdown strength, lower on-resistance, and higher thermal conductivity. It has a shorter dead time and 96%

high efficiency due to smaller chip size, and an optimized internal structure, while in on-state conditions it has lower drain-source resistance [6]. There are some more advantages of GaN-based transistors which are responsible for their use in LLC converters, such as fewer losses during the charging and discharging process, less capacitance, and lower price. They also require less power for driving the circuit [7].

In this paper, a high frequency resonant converter is designed for a 3 kW PV system. GaN switches are used as a switching device in the proposed converter. Simulation software PSIM is used for designing and analysis of the proposed model. Zero Voltage Switching is achieved at a wide input range. The efficiency of the proposed model is compared with the efficiency of a model with Silicon Si switches. Switching and conduction losses are calculated at a wide input voltage range.

2. LLC Resonant Converter

In this paper, a 3 kW full bridge LLC resonant converter is designed using GaN as a switching device as shown in Figure 1. The designed converter consists of a resonant capacitor, magnetization inductance, resonant inductor, and a high frequency transformer. Four GaN (GS66508T) MOSFETS are used as switching devices in the proposed converter. Frequency modulation is used as a control in this proposed topology. Specification of the designed converter and GaN MOSFETs is shown in Tables 1 and 2 respectively.
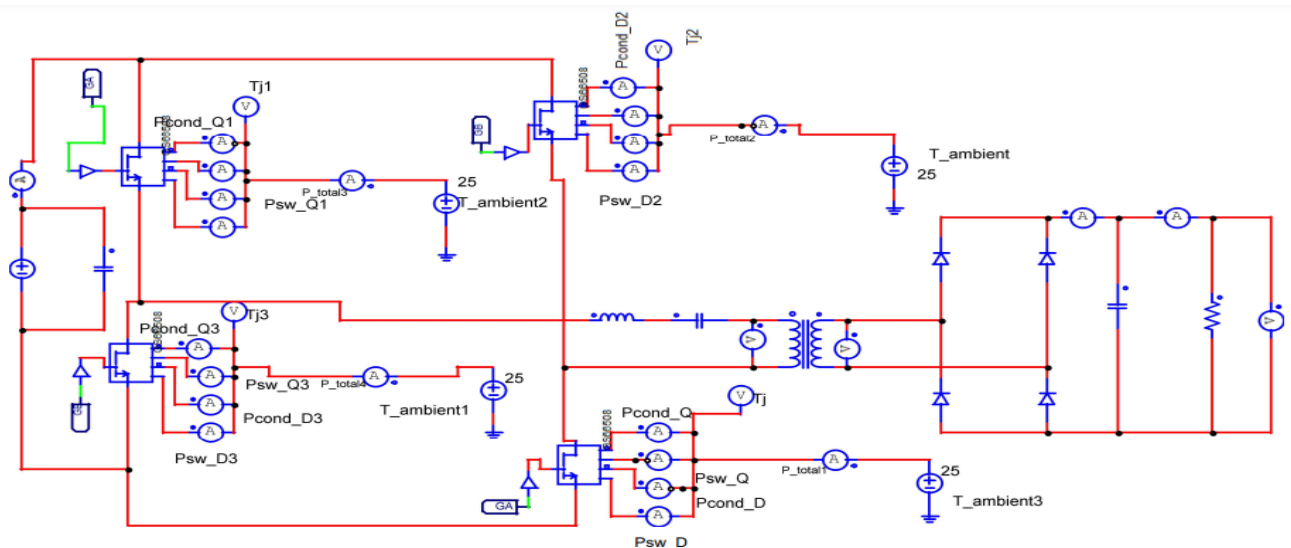

Figure 1. Simulation model of LLC resonant converter having GaN as switching device.

Table 1. Specification of proposed Converter.

Parameter	Value	Unit
Input Voltage Range [V]	200–400	V
Switching frequency f_{sw} [Hz]	98	kHz
Output Voltage [V]	400	V
Total Power [kW]	3	kW
Magnetization Inductance L_m [H]	51.6	μH
Resonant Inductor L_r [H]	10.6	μH
Resonant Capacitor C_r [F]	200	nF

Table 2. Specification of GaN (GS66508T) MOSFET.

Parameter	Value
V_{ds}	650 V
$R_{DS_{(on)}}$	50 mΩ
$I_{Ds_{(ON)}}$	30 A
Turn on Delay T_{Don}	4.1 nsec
Turn off time T_{Doff}	8 nsec
Reverse recovery charge	0
Operating junction temperature	-55 to 150
Total gate charge	5.8 nC
Gate to drain charge	1.8 nC

3. Mathematical Modelling

The equations for calculating resonant inductance, magnetization inductance, resonant capacitors, and equivalent AC resistance for LLC resonant converter are as follows:

$$C_r = \frac{1}{2\pi f_{sw} Q R_{ac}} \tag{1}$$

$$L_r = \frac{1}{(2\pi f_{sw})^2 C_r} \tag{2}$$

$$L_m = L_n L_r \tag{3}$$

$$R_{ac} = \frac{8 * n^2}{\pi^2} R_L \tag{4}$$

Switching and conduction losses are calculated as follows [8,9].

$$Pcond = Irms^2 * Rd * Duty\ cycle \tag{5}$$

$$Psw = \left(\frac{Vin}{2}\right) * Ipeak * toff * fsw \tag{6}$$

$$Ptotal = 4 * (Pcond + Psw) \tag{7}$$

4. Results and Discussion

A GaN-based high frequency resonant converter is designed in PSIM. Figure 2 shows the 3kW output power of the designed converter. Figure 3a,b show the output voltage and current at the load side. Zero voltage switching is achieved, which is shown in Figure 4, where current and voltage across MOSFET are shown. In Figure 4 a red line shows the current entering the MOSFET and the amplitude of the current is a multiple of 20 and the black line shows the voltage across the GaN MOSFET. Figure 5a shows an analysis of efficiency for change in input voltage. From the results, it is shown that the efficiency of GaN is higher than Si at a wide input voltage range. The performance of GaN MOSFET is much more stable than Si MOSFET at high voltage. From the graph, it is shown that the efficiency of a converter with GaN MOSFET was 98% while the converter with Si MOSFET was 93%. Figure 5b shows efficiency analysis for the change in power for the GaN MOSFET and the Si MOSFET. The converter with GaN MOSFET is more efficient than a converter with Si MOSFET at a wide power range.
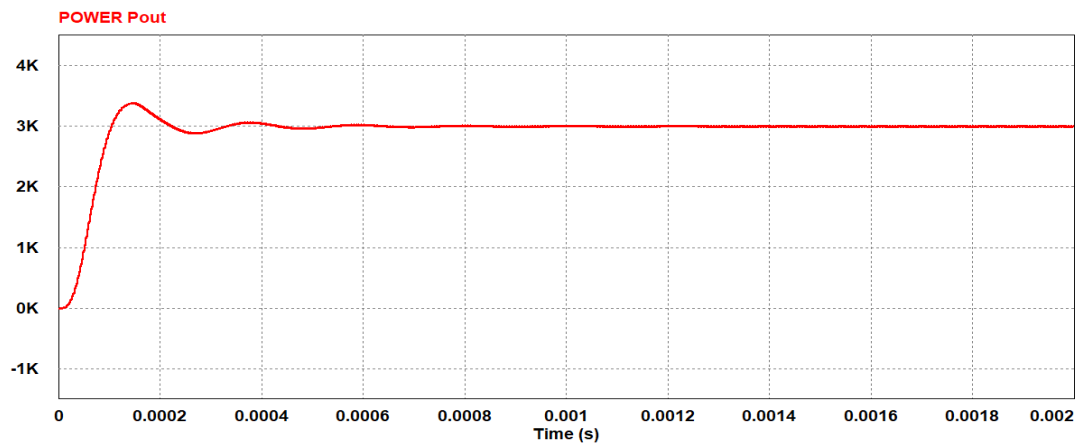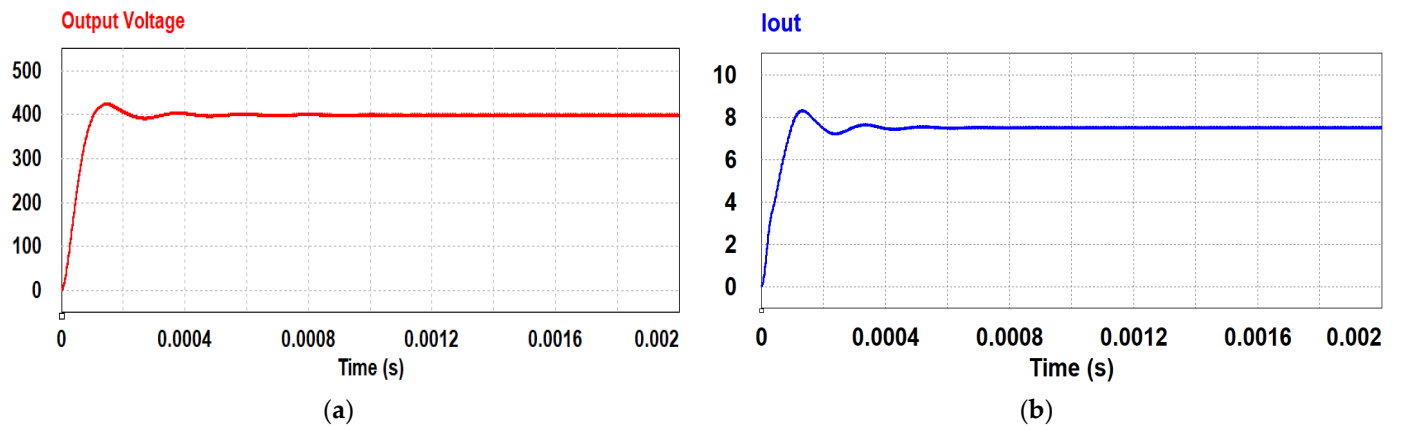
Figure 2. Output power of the designed converter.

Figure 3. (**a**) Output Voltage of converter (**b**) Output Current of converter.
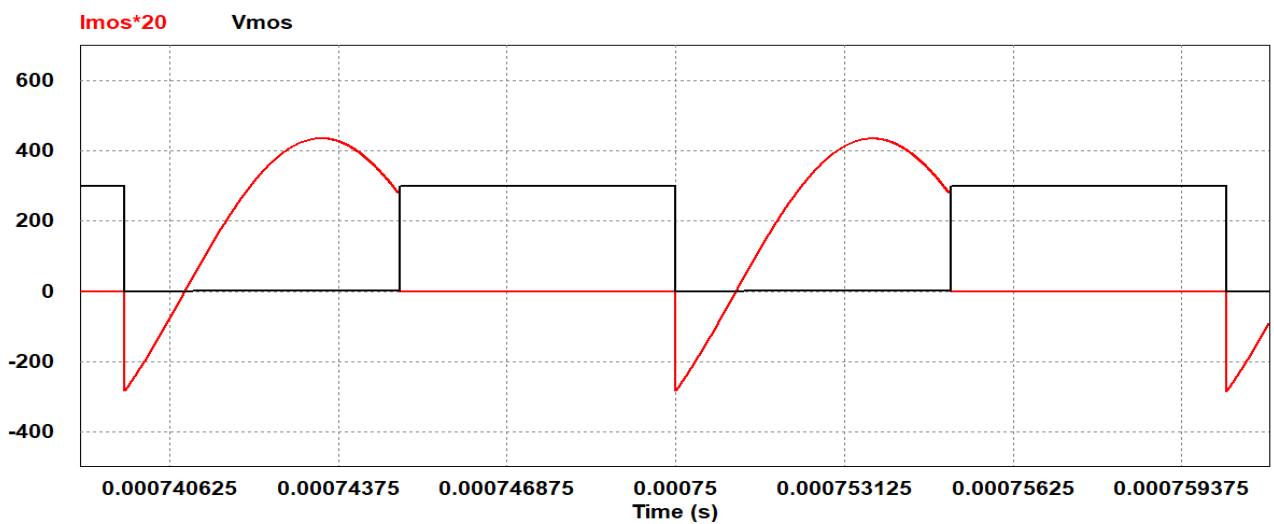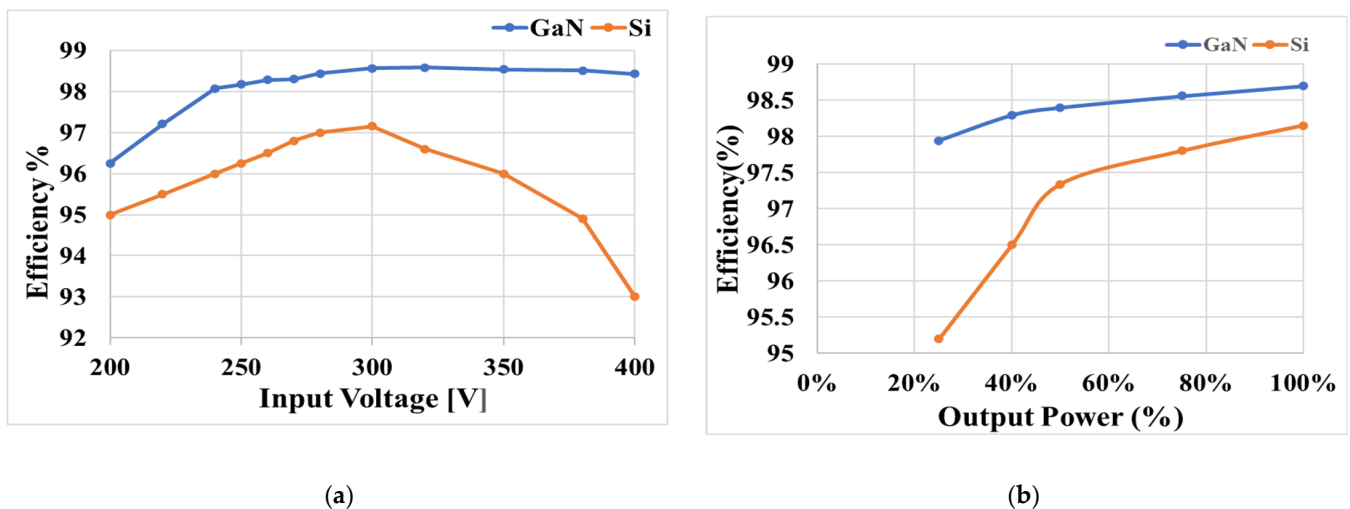
Figure 4. ZVS is achieved where the red line shows current across MOSFET while the black line shows the voltage across MOSFET.

(**a**)   (**b**)

Figure 5. (**a**) Analysis of Efficiency for change in input Voltages. (**b**) Analysis of Efficiency for change of Load.

5. Conclusions

In this paper, an optimal design of a high frequency LLC resonant converter for a 3kW Pv system was designed using GaN as a switching device The efficiency performance was analyzed at different operating loads, i.e., 25%, 50%, 75%, and 100% with a wide input voltage range from 200 to 400V. The performance was compared with Si switches. Results show that GaN has less conduction and switching losses than Si switches. At higher voltages, i.e., above 300V, the efficiency of Si switches dropped from 97% to 93% rapidly, while the efficiency of GaN switches deviated little from 98 to 97%. The efficiency of GaN MOSFET is around 98% for a wide output power range w.r.t Si MOSFET. GaN can operate at a higher voltage and higher frequency more efficiently, reducing the overall losses of the converter.

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