Application of GaN power devices on standalone solar PV

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***Abstract*— Nowadays, less converters are preferred for higher efficiency, low size and cost. Such a converter has its own problems. The output voltage of PV arrays is relatively low, requiring a high step-up converter to obtain the DC input voltage for the converter. In this paper, a step-up DC-DC converter is analysed, designed, simulated with MATLAB Simulink and practically implemented. Besides, the performance and effectiveness of some standard and improved boost converter circuits are discussed and compared in terms of voltage gain, power loss and switch voltage stress requirement A major aim of the project is to investigate the effectiveness of this converter regarding application in Solar systems. In short, DC-DC boost converter is designed to overcome the issues faced by the conventional converters such as low conduction and switching losses. a simulation study comparing the relative efficiency performance of the low-cost selected converters with Sic and GaN power switches. The two devices will be compared in terms of efficiency and performance. From this paper all results clarify that GaN devices has better efficiency and performance compared to Si devices. the results were achieved by simulation and experimentally.**

Keywords*— *DC-DC converters, solar, MATLAB Simulink, GaN power switches, Si devices

I. Introduction

Solar Energy is one of the significant renewable energy sources. Photovoltaic (PV) generation is gaining popularity among other renewable energy sources due to the various advantages it offers such as no fuel expenditure and nonpolluting aspects, and low noise by production, and the lower requirement of maintenance. The Photovoltaic array can be unstable due to fluctuations experienced by the peak power point as a result in variations of temperature and irradiation levels. A flexible peak point becomes a vital necessity; therefore, a peak point tracking will be useful in maintaining maximum efficiency. The solar photovoltaic systems are applicable in water pumping, and lighting solution. For this PV module must apply with power converted such as a DC-DC converter. to convert the low DC-voltage from solar PV module to the required voltage rating needed [1].

DC-DC converter can be divided into, Isolated and Non-Isolated DC-DC Converter. The difference between these two types of DC-DC converters id that "Isolated DC-DC" have the article of electrical isolation obtained by build in transformer that helps to filter noise and convert voltage with high ratio efficiently. The most typical example of application for DC/DC converters is in DC power supplies, motor drives and electric vehicles. DC-DC converters have different types such as "Buck, Boost, Buck-Boost, CuK, Zeta and SEPIC converters". Furthermore, DC-DC transfers direct current voltage from a DC voltage source to a load. firstly, the energy passes through are electronic switches, then passes through, storing devices Finally, it flows from storage devices onto the load. The switches involved are semiconductors specifically transistors and diodes. Inductors, Capacitors and switches were used as the storage devices. Depending on the duty ratios imposed by the switches, the available input voltage is linked to the output voltage. Pulse width modulation method is used in switching frequency of the gate signal above 20 KHz. DC-DC conversions stands as importance in various applications involving the flow of energy from low power to high power applications [2].

Moreover, Nowadays the increase of the efficiency in power semiconductor devices is crucial requirement for a better performing system. A material highly relevant to this use is Si, silicone, despite the limitations resulting from the physical properties of Silicone. Because of Si based devices are closer to their limits in terms of benefits, the study and effort, the growing interest in new semiconductor devices have led to a considerable advance of electronic power devices, using GaN components as secure applicants for renewable energy systems allowing the increase of the electrical efficiency and high power density due to the properties of the processing material, such as high current speed, higher bandgap and high dynamic response. On another sentence, the higher mobility and speed of its electron saturation, allows its operation at higher switching frequency [3].

Conventionally, silicon has been the heart majority of semiconductor device used for power transistors in high frequency DC–DC converters. It acts as issue resulting in multiple trouble in solar applications. The silicon Sic MOSFET has high gate capacitance and low switching frequency that results in high conduction, switching and reverse recovery losses in solar application systems that outcomes in poor efficiency. Linked to an equivalent Si MOSFET, GaN devices defined as one of widest- semi-conductors that have superior performance with low output charge and gate drive losses when compared to silicon in power applications. GaN FET power stage, has been optimized for applications requiring high efficiency and small form factor.

Its advanced package greatly simplifies manufacturability and board design while reducing costs. This project incorporates GaN to replace the Si devices to design a DC-DC Converter for Solar applications. The results will be validated via simulation and experimental prototype.

The main aim of this project is to simulate and validate performance of GaN device power converter to achieve high efficiency in a standalone solar PV system.

[4] adds a new technique to increase the efficiency of the DC-DC converter using the RCN (Resistance Compression Network) to deliver zero voltage and current switching at the same time across a wide range of input, output voltage and power levels. Over a wide range of voltage operating conditions, the system maintains the required current wave condition. In [5], High gain boost converter designed to achieve high output voltage and solve the related disadvantages of conventional converters such as high duty ratio and low switch off intervals. The proposed converter comprises of two interleaved components linked to the input part and the voltage multiplier assigned to the voltage output to obtain a high gain ratio. the voltage multiplier Consists of four diodes and four capacitors, these four stages lead to high gain voltage (ten times the input voltage) with 50% duty cycle.

[6] designed a non-isolated high step up DC-DC converter for PV application to compare the performance of boost, SEPIC and the improved SEPIC converters. in short. The paper presents a high step up non isolated DC-DC converter using two loading capacitors with equal rating for voltage stress sharing and unwanted current, the proposed converter is a combination of both Boost and SEPIC converter, consisting of one switch, two inductors, three capacitors and two diodes. [In [7], A unique non-isolated DC/ DC converter is recommended with a high voltage transfer gain and low "voltage stress" for semiconductors. The planned converter is intended to integrate a quadratic boost converter. The capacity of duty cycles high voltage increases and low voltage switch stress classifies the use of low voltage and MOSFET to reduce costs, conductivity and Schottky rectifiers was used to remove the unwanted reverse-recovery current leads to reduce the switch and conduction losses.

[8] designed a "DC/DC boost converter" for high voltage. The proposed converter is made up of a single switch, paired inductor. In addition to four diodes and four capacitors, the clamp system has been used to recycle the connected conductor to prevent the present leakage that will decrease the converter's switch loss and voltage stress. [9] designed a new step up DC-DC converter with high ratio capability. The use of the DC-DC converter is resulting using amalgamation of boost and buck-boost converters to decrease the input and output ripples for well efficiency. the two converters are undistinguishable and conflicting in phase. The switching maneuvers have been executed by using MOSFET. [10] proposed a solution for the issue of partial shading of photovoltaic module. The solution involves the introduction of a boost converter, which could be further advanced by swapping the boost converter with switch inductor branch. Maximum power extraction is ensured by implementing a power point tracking mechanism.

II. System Implementation

A) *Overall Block Diagram*

The design will use a solar PV panel as an input for the boost converter, and the rechargeable battery will be installed on the device in the case that the solar panel does not provide sufficient power, then the battery must feed the load and, if the battery is low, the solar panel will charge the battery. The whole simulation should be carried out in durability of MATLAB / Simulink software. Only current and voltage sensors here added the input and load side to measure the voltage and current, the data will be displayed in LCD screen.

As mentioned before the proposed system is divided into three sections the have to be constructed then implemented in hardware. Firstly, the solar panel to be used in our planned system is an 18V, 50W panel. The solar panel has a 50 W of max power.it will achieve a 18V and 3A at maximum power. Secondly The boost converter is a step-up power converter that takes in a low voltage supply and generates even higher voltage. The proposed boost converter has five components, a power semiconductor regulator, a diode, an inductor, capacitor and PWM device. The boost converter circuit used to boost the voltage that the solar panel obtains. This boosted voltage is used to charge the battery, since charging the battery requires greater potential than charging its own potential. This requires the help of the booster converter, since the output of the solar panel is 18V or less. Components details and their specifications used to construct the proposed system shown in Table I:

TABLE I. COMPONENTS FOR CONSTRUCTION DETAILS

Component	Model	Specifications
Solar panel	SM-50WP	Vmax= 18 Volts / Pmax = 50 Watt / Imax = 3 A
Toroidal Inductor	TLC	TLC/ 330uH / 4 A
Arduino Uno	ATMEGA328P	
MOSFET	IRF540N	Si-FET /17A, 600V, 0.040 Ohm, N-Channel, Power MOSFET
	TPH3206PS	GaN-FET / 17A, 600V, 0.040 Ohm, N-Channel, Power MOSFET
Gate Driver	TC4427CPA	25V/2.5A
Diode	IN540NC	-
Radial Capacitor	-	22 uF/ 50 V
Rechargeable Battery	GP1245/ 12V /4.5Ah	cycle use :14.5 -14.9 V Standby use :13.6-13.8 V Initial current : Less than 3.5 A
	GP645/6V/4.5Ah	cycle use :7.25 -7.45 V Standby use :13.6-13.8 V Initial current : less than 1.35 A
DC Voltage Sensor	AVS712	Voltage input range : DC 0-25 V
DC Current Sensor	ACS712	Input currnt up to 5A

The proposed system constructed as shown in figure 4.3, Arduino Uno used to generate the PWM, in addition to the gate drive TC4427 was used to drive the MOSFET was placed because the Arduino generates only 5V therefore the driver was used to drive the required voltage for the MOSFET for full functioning. The voltage and current sensors were place after solar panel and add load to measure the input and output data of the entire system. in addition to, an additional diode added before the battery to allow the current to pass to battery without reverse biased that can affect the converter. Finally, the overall system circuit was implemente. For boost converter an N-channel enhancement mode control MOSFET used as a high-speed switching system. In n-MOSFET, the voltage of the gate is high enough, and the current flows from drain to source. Si MOSFET will be replaced with GaN MOSFET in the proposed system to evaluate the performance for each device.

B) Working Principle

The Solar PV cell is an electrical device that creates electrical power when exposed to sunlight, and is attached to the converter boost. The current is treated as a regulated constant current source in the proposed model, and the voltage variations are dependent on the degree of irradiation. the boost converter consists from inductor on the input side to filter separate signals of different frequencies and the output has a strictly capacitor to store energy and give it again to the circuit. Diode is attached to the circuit to allow current to flow in one direction.

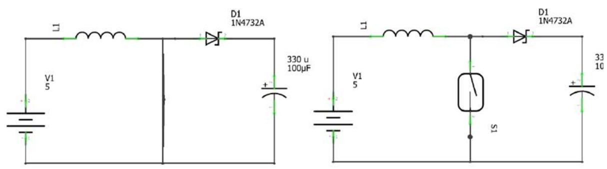

Fig. 1. Circuit operation in ON and OFF state

Firstly, The MOSFET used as switch, when MOSFET turn ON, the source of signal turns up high, turning MOSFET on. All the current is redirected by the inductor through the MOSFET. The capacitor stays charged during this period as it cannot discharge through the forward based diode. Naturally, the power source is not necessarily faster, as the inductor lets the current ramp up relatively slowly. The magnetic fields are also produced around the inductor of the circuit. while as the MOSFET turns off, the inductor current drops. The very essence of the inductor is to keep the current flow steady, So, it responds to this by producing voltage using the energy stored in the magnetic field to sustain the current flow with the opposite polarity of the voltage initially supplied to it.

Secondly, once the switches are turned Off, diode D is skewed backwards and input voltage is spread across the inductor. Current rises to a peak value in the inductor. The voltage around inductor reverses when the control is switched off allowing the voltage at the diode to increase above the voltage supply. The diode then carries out the energy stored in inductor and energy direct from the smoothing capacitor supply and load. Output voltage is thus usually higher than input voltage, making this a step-up converter.

In summary, as shown in the above in figure 4.4 above, solar PV panel as an input for the boost converter, the solar panel will generate a variable input voltage from 12V to 18V liable on the weather condition. The Arduino will produce PWM to control the duty cycle of the boost converter. The MOSFET needs minimum of 10 peak to peak amplitude voltage for gate to fully open therefore as the Arduino supplies only 5 V the MOSFET driver IC TC4427CPA was used to drive the gate with 10 V. The duty cycle will be variable as the input. Then the boost converter will step up the input voltage. the load set as constant to charge the battery safely and avoid overcharge. The rechargeable battery fuels the load and, if the battery is low, the solar panel must charge the battery.

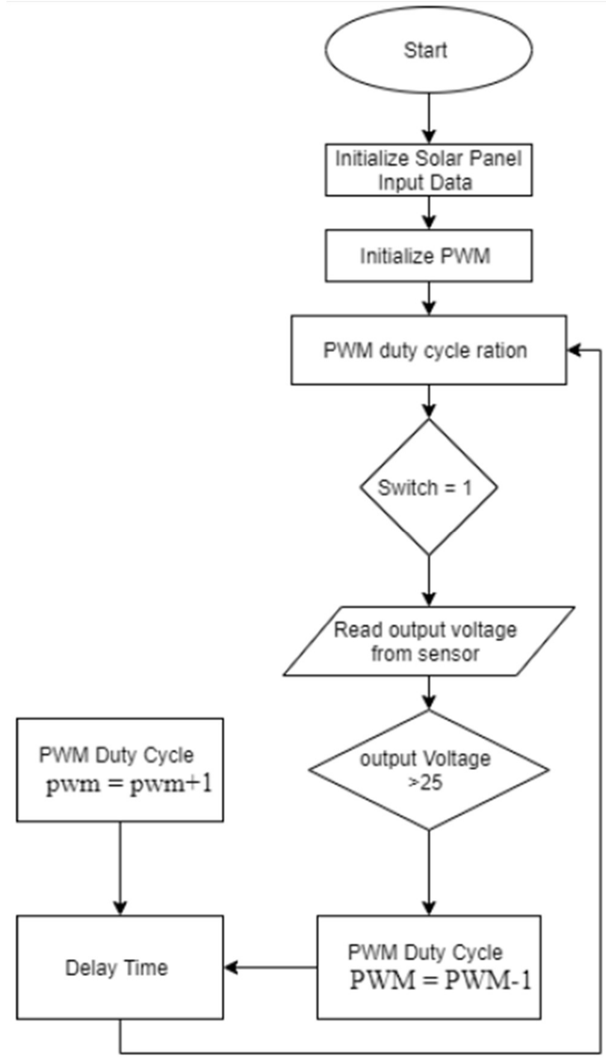

Fig. 2. Flow Chart for the entire system

III. HARDWARE AND SIMULATION RESULTS

The proposed boost converter for both GaN HEMTs and Si MOSFETs as switching devices is simulated and experimentally tested at different loads and different input voltages (12V &18V) with 25Khz Switching frequency. To validate the given simulation results, the simulation results the boost converter was tested experimentally and implemented as shown in Fig 1. The testing was done using DC power supply with (Vmin = 12 V, Vmax = 18 V) at 25Khz switching frequency. The Arduino uno supporting the proposed system with the PWM according to the input voltage. The maximum and minimum duty cycle calculated for the proposed system shown in the Table II and Fig 3.

TABLE II. CALCULATED DUTY CYCLE

Input voltage	duty cycle
12V	52%
13V	48%
14V	44%
15V	40%
16V	38%
17V	34%
18V	28%

Before results observed, some calculations were done for variable input voltage where the solar will generate a minimum voltage of 12 V and maximum input voltage of 18 volts. The simulation was set in Matlab/Simulink software to evaluate and compare the performance of the Si and GaN devices the simulation. The Output voltages, current and power results are measured and recorded for each experiment.

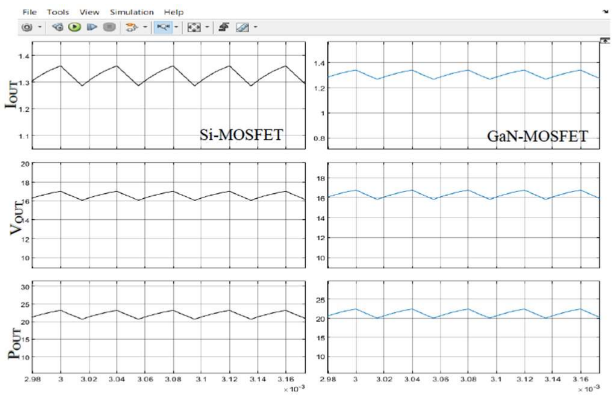

Fig. 3. Output data for Si and GaN MOSFETS at Vmin

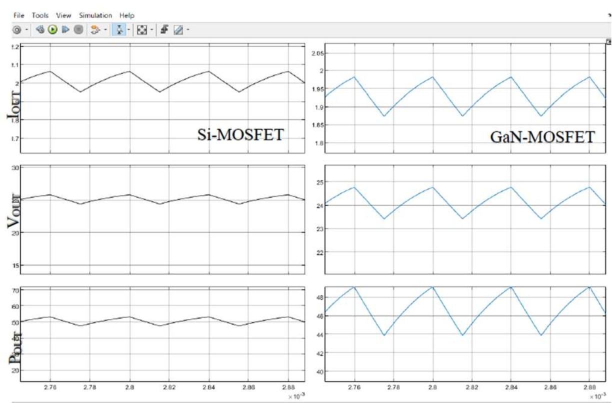

Fig. 4. Output data for Si and GaN MOSFETS at Vmax

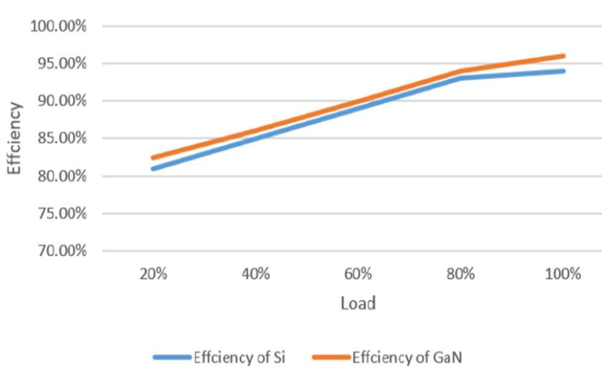

Fig. 5. Effciency for Si and GaN at Vmin

Fig. 6. Efficiency for Si and GaN at Vmax

The simulation Operating frequency was set as 25 kHz at variable input voltage (12V and 18 V) where the duty cycle maintained at (52% for Vmin) and (28% for Vmax). Fig 3. and Fig 4. compare the performance of both semi-conductors and its analyzed that:

at Vmin, the simulations results recorded for 100% load. The simulation obtained output currentas (1.36A for Si)and (1.34 A for GaN).while output voltage obtained at range of (17.01 V for Si) and range of (16.80V for GaN). in addition to the output power (23.16Wfor Si) and (22.27 for GaN) as shown in Fig 3.

At Vmax the simulations results recoeded the simulation obtained output current as (2.10 A for Si) and (2.05A for GaN). While output voltage obtainedis 25.80 V for Si and 25.76V for GaN . in addition to the output power observed 54.18for Si and 52.90 for GaN as shown in figure 4.9. It is clearly observed from the results obtained that the boost converter steps up the voltage for both semiconductors devices and it conclude that, GaN devices achieved high efficiency at variable loads compared to Si devices as clearly shown in Fig 4.

IV. EXPERIMENTAL RESULTS

The proposed boost converter for both GaN and Si MOSFETs as switching devices is simulated and experimentally tested at different loads and different input voltages (12V &18V) with 25Khz Switching frequency. To validate the given simulation results, the simulation results the boost converter was tested experimentally and implemented. The testing was done using DC power supply with (Vmin = 12 V, Vmax = 18 V) at 25Khz switching frequency. The Arduino uno supporting the proposed system with the PWM according to the input voltage. The Output voltages, current and power are measured and recorded for each experiment. In short, Experimental tests as ongoing to validate the performance of the proposed boost converter.

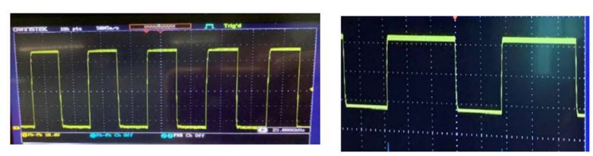

Fig. 7. Duty cycle at Vmin and Vmax

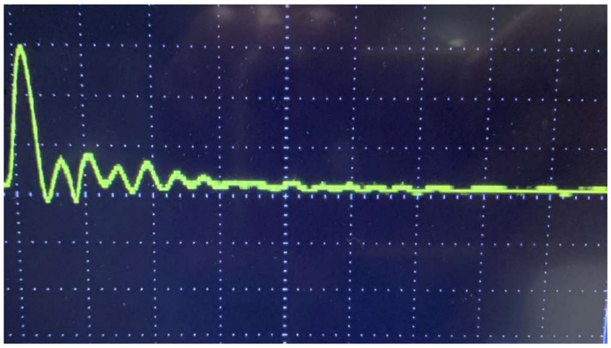

Fig. 8. Output voltage for Si at Vmax

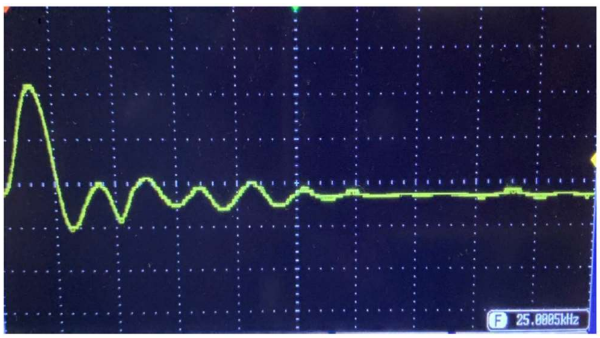

Fig. 9. Output voltage for GaN at Vmax

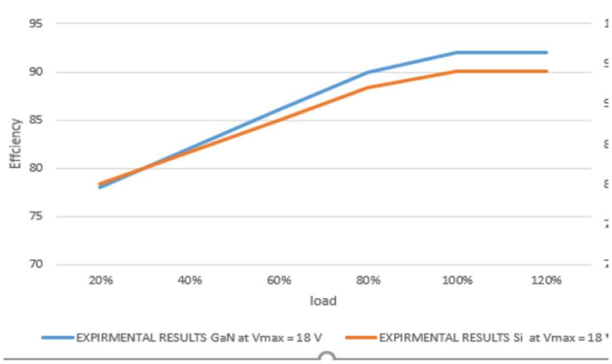

Fig. 10. Effciency for Si andGaN at Vmin

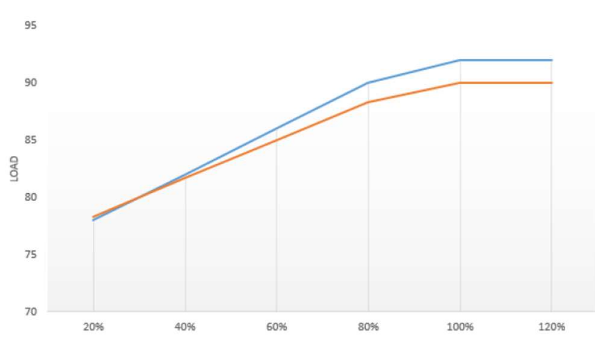

Fig. 11. Effciency for Si and GaN at Vmin

At Vmin, the results of the simulations were recorded at 100% load. its obtained output voltage as (1.36A for Si) and (1.34 A for GaN) while output voltage at range (17.01 V for Si) and (16.80V for GaN) was obtained. The output power (23.16 W for Si) and (22.27 for GaN) while,

at Vmax restored the output current obtained as (2.10 A for Si) and (2.05A for GaN). The resulting output voltage was 25.80 V for Si and 25.76 V for GaN. In comparison to the output power measured 4.9, 54.18 for Si and 52.90 for GaN.

The voltage is inversely proportional to current, meaning the higher the output voltage the lower the current and power. All results shown in this section, efficiency decreases as the output voltage increases. In short, From the results obtained, it is clearly observed that the boost converter increases the voltage for both semiconductor devices and concludes that, GaN devices achieved high efficiency at variable loads compared with Si devices.

V. CONCLUSION

Implementing the power converter in a solar PV system without MPPT was expected to have a minor impact on system I/O ratings and had to be understood before working on GaN devices to check by how much these devices improved converter efficiency. While the entire research focused on implementation and experimentation of the device, looking at an industrial scale, the manufacturing costs of the GaN device are high thus implementing the system will be costly. Furthermore, effect of temperature variations on thermal properties were not considered. On a general scale, Si devices are much cheaper and thus favored in case a replacement is needed. integrating IoT with the system can make load monitoring and system health checks a valuable asset for consumers looking for a more advanced system to help keeping tabs on power utilization. With emerging methods to acquire and to process data by the electrical industry, this is a useful suggestion.

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