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Recent advance and future progress of GaN power semiconductor devices used in PV module integrated converters

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Abstract: Power semiconductor devices are essential from the operation point of view, size, efficiency and cost, these components are used in a myriad of applications, providing features that make them an important part of the system in which they are operating. This document analyzes and compares the basic structure, properties, design aspects, as well as temperature performance, stability and switching losses, present in devices on silicon (Si), silicon carbide (SiC) and new generation devices fabricated in gallium nitride (GaN) applied in renewable energy systems. The main objective is determinate the viability of the new generation components, which present a superior performance in view of an increase in efficiency, conductivity, decreases in switching losses, lower resistances and parasitic capacitances as well as higher operating frequency range. Therefore demonstrating the GaN components are a strong and viable candidate to solve some of the problems present in renewable energy systems.

Keywords— Gallium nitride (GaN), silicon carbide (SiC), silicon (Si), converters, power devices, power electronics.

1. INTRODUCTION

Currently the increase of the efficiency in power semiconductor devices, is crucial for a better performance in a system or application. The material commonly used for the development of this type of devices is Si, however, the physical properties of these components have certain limitations, which mean avoiding to think of this material as a firm candidate for the future of power electronics. Because of Si based devices are closer to their limits in terms of benefits, the study and effort, both academic and scientific has focused on finding alternatives to increase the performance of these components, through the use of new construction materials [1].

The growing interest in new semiconductor devices has led to a substantial development of electronic power devices, using GaN components as firm candidates for renewable energy systems allowing the increase of the electrical efficiency and high power density [2-5] due to the properties of the processing material, such as high current speed, higher bandgap and high dynamic response. On the other hand, the higher mobility and speed of its electron saturation, allows its operation at higher switching frequency. Part of these characteristics are presented in [6] and shown in Table 1, on the other hand, Table 2, shows the impact of GaN devices applied in conventional power amplifiers (PA) [7-9].

TABLE 1. Material properties of semiconductors

Material	Dielectric Constant, ε	Tmax °C	Break down field, Eb $10^6\ V/cm$	Bangap, Eg, eV
Si	11.9	300	0.3	1.12
SiC	10	600	3.5	3.2
GaN	9.5	700	2	3.4

TABLE 2. Impact of GaN on PA concepts [6]

Concept	Silicon	GaN on SiC
Class E/F/J	Low f_T, moderate breakdown voltage	High f_T, high breakdown voltage
Doherty	Low off-state impedance, high output capacitance	High off-state impedance, low output capacitance

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LINC	Large non-linear output capacitance	Small non-linear output capacitance
EER/ET	Poor amplitude to phase modulation conversion, moderate bandwidth	Good amplitude to phase modulation conversion, large bandwidth

The main characteristics of the GaN devices lead to greater breakdown voltage and operating temperature [6], allowing to use higher drain voltage levels, obtaining lower energy losses.

Recent advances on GaN substrates, present better operating conditions than their predecessor technologies, attracting a renewed interest in the development of nitride devices [10,11], on the other hand, despite the fact that the cost of these components remains high and its availability relatively low, academic and scientific interest has increased over time, opening an area with great growth potential, accelerating progress in the development of various electronic and optoelectronic devices today.

This paper presents a review of the emerging emergence of new switching technologies based on GaN devices applied to power electronics and renewable energy systems. The main contribution of this paper, is to present the advantages and qualities of the GaN devices, according to a comparison an evaluation of these types of devices, in conventional and emerging technologies currently available.

This paper is organized as follows: Section II presents some antecedents and data from the composition of the nitride material, Section III presents the characteristics of the materials most commonly used nowadays, section IV shows the physical properties and main characteristics of the different devices analyzed, section V shows some applications in more recent photovoltaic systems reported in the literature, section VI presents some of the benefits gained due to the superior performance that the devices GaN present in front of other materials, finally in section VII concludes the current review mentioning the most outstanding points and characteristics.

2. BACKGROUND AND DESCRIPTION

The evolution of new construction materials for semiconductor power devices has progressed in recent years, leading to the use of devices made in nitride. The initial progress in GaN devices technology, started in the 1990s, focusing first on three important parameters [12]; the improvement of the quality of the material, the selection of the best materials of substrate and the development and innovation in the process of the elaboration and manufacture of new devices.

Some of first advances, were based on works of Metal-Organic Chemical Vapour Deposition (MOCVD) in the optoelectronic area, observing the feasibility of using electronic devices based on GaN [12-14], in this way part of these advances are they achieved first in sapphire due to their availability, to later opt for different materials in order to obtain superior properties of efficiency and performance [15-17].

Part of the advantages in the performance of GaN devices are highly notable due to their ability to “create” heterostructures in the same system, in addition of supporting high breakdown fields [18-20], due to their composition. Figure 1 shows the schematic cross section of their material, where the device is manufactured with ohmic contacts that are formed directly in the upper of the A1GaN structure.

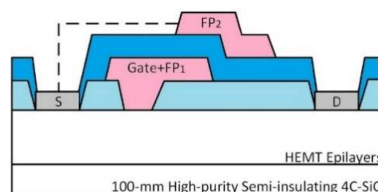

Fig. 1 Schematic cross section of the AlGaN/AlN/GaN structure

The isolation of the device is obtained using layers of nitrogen, to have a planar structure [21,22], on the other hand, the electrodes are formed from a dielectric, and finally the high electric fields take form at the side edge of the semiconductor junction of metal, which once optimized, includes a lateral extension to have a

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conformation with the gate metallization, which is used to compensate and reduce the resistance, the device´s gate length is nominally of 0.4 μm and the separation to drain is approximately 3 μm.

As part of optimization for this type of devices, a second board is included in the original design, to provide additional electric potential, which will form a high drain voltage to drain the feedback capacitance of the device [23-25].

The Gallium Nitride transistors (GaN) HEMT (High Electron Mobility transistor) has followed a remarkable evolution in its composition and fabrication, these devices appeared for the first time in 2004 as radio frequency transistors (RF), manufactured in Japan by Eudyna Corporation [26], which manufacture basically consisted of using GaN on SiC substrates. Its structure was based on the demonstration of unusually high electron mobility, described for the first time in 1975 by T. Mimura and in 1994 by M. A. Khan, describing this phenomenon as a two-dimensional electron gas (2DEG) near the interface between a heterostructure A1GaN and GaN.

With the emergence of this phenomenon, the possibility of adapting it on gallium nitride was studied [26], cultivating on SiC and producing a reference power gain in the range of several gigahertz. Later in 2005, Nitroex corporation introduced the first HEMT RF transistor manufactured on GaN cultivated on Si, using patented technology SIGANTIC®, finally in 2009, the first MOSFET´s model developed on GaN was introduced by the Efficient Power Conversion Corporation.

Currently the basic requirements for any power semiconductor [27,28], are directly linked to efficiency, reliability, control, profitability and cost, the latter being the main current problem of new generation devices. In the following sections, a brief comparison between Si, Sic and GaN devices is analyzed and mentioned in order to determinate the ideal candidate applied as switching device in power electronics. The comparison parameters considerate are driving efficiency, breakdown voltage, switching efficiency, size and cost.

3. PHYSICAL PROPERTIES AND PERFORMANCE OF Si, SiC y GaN

In an electronic power system there are key parameters that are important to know in order to elaborate an optimal design, some of these parameters or electrical magnitudes are given directly by the voltage, frequency, current or operating temperature, where according to these magnitudes, characteristics or utility of the system a certain application can be defined.

Part of the parameters necessary to carry out the experimental development of an electronic power system, is related to the appropriate choice of semiconductor devices. The choice of these devices depends on the application and operational characteristics that may have, in this sense Table 3 shown physical properties of Si, 4H-SiC and GaN devices that have been reported in the literature [29-31].

TABLE 3. Physical Properties of Silicon (Si), Silicon Carbide (4H-SiC) and Gallium Nitride GaN

Electrical Property	Uni.	Si	4H-SiC	GaN
Band Gap Energy	eV	1.1	3.26	3.4
Thermal Conduction	W/cm. K	1.5	3.7	1.3
Electron Mobility	cm^2/ V.s	1300	900	900-2000
Saturation Drift Velocity	cm/s	$1 X10^7$	$2 X10^7$	$2.5 X10^7$

Table 3 shows that the semiconductors made with SiC and GaN present a higher wide-bandgap than semiconductors made in Si, this fact results in more efficient and resistant components to applications of higher temperature ranges, due to the fact that SiC and GaN as the temperature increases the thermal energy of the electrons in their balance band increases, avoiding uncontrolled energy conductions that occur at a temperature of around 150 ° C [32], increasing their efficiency and quality of operation.

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Another important feature in devices made on GaN, is the fact that they are thinner power devices than their counterparts based on Si and SiC. In addition to present lower resistance (R_{ON}). Some comparisons between different materials are reported in [33] regarding this point, of which the comparison among the 3 materials mentioned above is presented in Fig. 2.

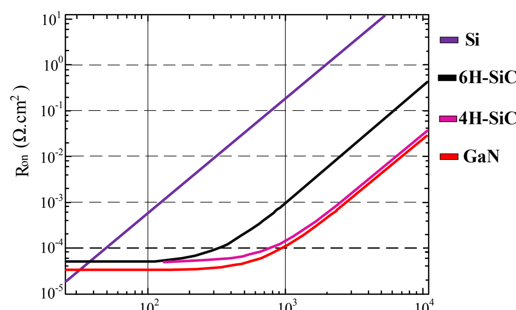

Fig. 2 On-State Resistance vs Breakdown Voltage

The capacity that every semiconductor device presents to achieve high switching frequency is directly proportional to its saturation drift velocity, the speed presents in GaN devices is more than twice the speed in components made of Si ($1\ X10^7$), achieving commutations at much higher frequencies, which improves aspects related to efficiency for certain applications, decreasing some of the most common problems presented by robust elements such as inductors or transformers, due to the higher frequency of operation, it is possible to decrease the construction size of the same, giving smaller elements and therefore with lower power losses due to the core [34-36].

Another important part in this type of devices is related to the displacement speed, allowing an almost nonexistent reverse recovery present in devices made of silicon [37,38].

On the other hand, a negative part that the GaN devices presents in comparison with Si and SiC devices, is a lower thermal conductivity [39-41], which means that heat generation of SiC devices can be easily dissipated than in one made development of GaN. An analysis more thorough and detailed of the physical properties of these three materials, is shown in Fig. 3.

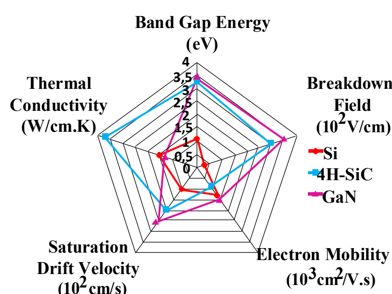

Fig. 3 Comparison between Si, 4H-SiC and GaN

From the analysis presented in Fig. 3, it can be concluded that the power devices of GaN are a good choice for applications in high switching frequency and high voltage levels, however the devices manufactured of SiC have qualities very similar to those of GaN, currently positioning them as a strong candidate for a lot applications, due to its lower cost and easy access. On the other hand, the recent emergence of devices developed in GaN provides for a wide margin of improvement, which could be positioned as the most complete device for a host of applications, even over the devices developed of SiC [42].

The next section shown the main questions that are presented in new generation devices, as well as a series of comparisons and inflection points, which position the semiconductor devices of GaN as a good choice of present and better alternative to the future, in comparison with devices made of silicon.

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4. QUESTIONS AND ADVANTAGES

GaN power semiconductor devices have been designed for an efficient and reliable energy conversion [43-45], unfortunately, nowadays it is a technology that does not have much more significant attention from the academic and scientific areas. Due to certain factors that keep them somewhat in the shadow of the devices elaborated of Si [46], but especially from devices elaborated on SiC [47], part of these problems is related, with four fundamental points, same that are presented in [48] and are briefly mentioned below.

4.1 Product accessibility

The first point is related to the risk of supply or difficult access to devices, this point is not entirely true, because the list of companies that sell GaN devices is growing almost every month, companies as; Efficient Power Conversion Corp., GaN Systems, Dialog Semiconductor, Navitas Semiconductor, Panasonic, Transphorm, Texas Instruments, ON Semiconductor, Sanken among others, they represent the possibility of acquiring a detailed series of devices made on GaN, in this way, it is difficult to believe that with the support of such companies there is a real risk of supply.

4.2 Cost

The aspect related to cost is an interesting point to analyze [49-51], because the devices of GaN lead to greater investment than its counterpart in Si, due to the fact that they are relatively recent technologies, at this point you will have much to see if the investment is necessary depending on the application, on the other hand from a broader point of view, the higher cost not only leads to the purchase of a new device generation, but also all the features that it presents, which as shown in section VI of this document, are better than in other cheaper devices, so depending on the perspective that is given, results in a justifiable investment. A clear example is shown in Table 4, where a comparison of costs between GaN and Si MOSFETs, under the same voltage levels, and ignition resistance is shown, so the cost reduction by the components of GaN mark a decreasing trend over the years.

TABLE 4. Comparison of GaN transistor costs and silicon MOSFETs with the same voltage and ON-Resistance [48]

	2010	2015
Starting material	Same	Same
Epi Growth	Higher	Same
Wafer Fab	Same	Lower
Test	Same	Same
Assembly	Lower	Lower
Overall	Higher	Lower

4.3 Reliability

The criterion focused on the reliability of some devices is fundamental because in any power electronic system, this parameter is vital for any application [52,53], in this sense there has been a huge amount of evidence related to the appearance of reliability, on devices of GaN by EPC, GaN Systems, Panasonic and Transphorm, which have determined that the devices GaN exceeded in an outstanding manner the tests carried out [54], whose standards are originally designed for testing SiC devices, which conditions a little this aspect, because it is still questioned if these tests are suitable mainly for components of GaN, due to the completely different material. On the other hand, despite the fact that there is still much to be learned about the failure mechanisms related to technologies of GaN, there is supporting evidence that suggests excellent reliability of these devices, some of these records are presented in Figure 4, where reliability results are shown after 6 years of operation, demonstrating that GaN it has better characteristics than components made in silicon [55].

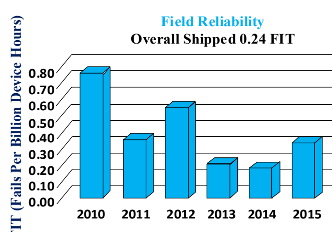

Fig. 4 GaN FET reliability over 6 years and 17 billion hours in the field [48]

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4.4 Complexity in use

Use of GaN devices is quite similar in behavior with the use of conventional MOSFETs (except for its superior performance), on the other hand, there are points to have in consideration, and such is the case to have special attention in the manipulation of component, due to its small size [56], therefore, they require more strict assembly tolerances. Nowadays the PCB circuit manufacturing technology, is improving, being able to find manufacturers that meet and exceed the capabilities necessary for an optimal performance.

According to the main questions in the use of new generation devices, many works reported in the literature have detailed throughout the last 5 years, interesting aspects as proposal to a solution of the problems related to low efficiencies, especially triggered by switching losses in converters, problems associated with amplifiers, applications based on current inverters, etc., Therefore, the GaN devices are presented as a candidate firm to give solution to them, due to its unique characteristics of operation.

Some of the main features and benefits of GaN devices have reported in the literature [57-64], are reviewed and mentioned below:

1. GaN devices present greater efficiency and power density, in addition, they are considerably smaller than their competitors made of Si and SiC.
2. GaN devices present lower power losses due to the high mobility of the carriers in the two-dimensional electron gas channel, so they do not have an inverse recovery charge.
3. GaN technologies are ideal for working in high frequency power electronic systems (between 200 kHz and 1 MHz).
4. They have less on-state resistance than any other devices made in Si or SiC.
5. They have much faster commutations, reducing switching losses.
6. The devices manufactured of SiC have an intrinsic diode, which in idle time remains active, causing power losses in the diode, associated with its voltage, GaN devices on the other hand, have a higher driving voltage in the third quadrant, this also means that there are losses during the dead time, but it is much smaller, guaranteeing smaller losses.
7. The devices manufactured on GaN, have lower parasitic capacitances, due to the same ignition resistance compared to any other device.

Each of the points mentioned above represent interesting facts and characteristics to explore, which suggest a generational change in the material construction of different types of components between SiC and GaN in the near future. These operation characteristics of operation have been achieved due to a marked progress of semiconductors in power electronics, for a host of applications, for this reason, some of the main works that present these characteristics are briefly detailed in the following section.

5. APPLICATIONS IN PV SYSTEMS

GaN power semiconductors are devices that have a high thermic conductivity and higher switching speed than conventional components fabricated of Si [65], and even those made of SiC. The advance of the GaN devices, offers greater advantages in the performance in power converters, because their switches are much more efficient than any other device today.

On the other hand, the use of this type of components is ideal in applications that require operator under frequency levels in the order of MHz, significantly reducing the size of passive components. Currently, the use of GaN devices in power converters is still at an early stage of development, but its widespread application is a close reality.

One of the areas of more development in recent years and which could benefit more from the use of GaN semiconductors are the systems of electric power generation through photovoltaic systems, because thanks to the features of these components, this type of systems would be benefit greatly from the point of view of efficiency and reliability.

Below are some works focused on the use of GaN devices in photovoltaic systems are presented the results demonstrate that GaN devices surpass the best Si devices and are broadly competent against front SiC devices technologies.

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The performance that GaN devices present in comparison with conventional technologies in semiconductors, has already been reported in the literature in previous years, through its use in DC-DC converters, works on it through analysis in a boost converter were presented [66-70], as well as studies focused on dual active bridge converter [71].

PV system applications, specifically on DC-DC converters, could greatly benefit from GaN technology, these converters could have an increase of efficiency and performance, as well as a reduction of losses, derived from the switching of their switches.

Unfortunately, in conventional photovoltaic systems, not only a higher efficiency in the DC-DC converter is sought, but also other aspects related to the efficient extraction of energy by the solar cells, due to this a large part of the effort devoted by the academic and scientific area for this type of applications, is focused on finding solutions to aspects related to environmental conditions, orientation of the module, shading, dirt, misalignment, monitoring of the maximum power point tracking (MPPT), increase in reliability among some others [72-81].

In recent years the optimization and evolution of photovoltaic systems have increased, nowadays the companies or sectors related to this application offer more optimized power converters. The increase in performance of commonly used DC-DC converters should be optimally designed according to the requirements of the system. The available solutions reported in the literature to increase the efficiency and improve the problems associated with this power stage for photovoltaic systems proposes optimized solutions for the converters that are used every year, but which they are regularly viewed under the same evaluation criteria.

Applications based on photovoltaic systems, have 3 specifications in the design of DC-DC converters [82], which from the point of view to the use of new technologies in semiconductors, can be addressed, these aspects are related to the electrical, thermal and technological part, same as mentioned briefly below.

a. Electric specifications.

The main aspect of an electric design, is the performance requirements of the PV system, with the objective to have the lowest number of losses of energy in the operation of the system, this is related directly with the size of the final prototype, relating in turn to use of the switching frequency, this parameter is very important because at lower switching frequency, the requirements for the thermic design can vary, while an increment of the switching frequency, leads to the decrease of the passive components that are in the system, so the use of GaN components, represents the advantage of operates in the order of MHz. Therefore, for any topology with this conjecture, the switching frequency represents the main equilibrium parameter, between the power density of the system and the behavior of the temperature.

b. Thermic specifications.

Thermic specifications are related with the temperature of the photovoltaic panel, because the panel can easily reach 70 °C with it operation of more. On the same way not only the panel suffers of this excessive heating, another stage of the system with the same problem is the DC-DC converter, because part of the heat due to power losses are directly related to their components, which when operating at elevated temperatures, they see more diminished their useful life, compromising the operation of the system. In this case from the point of view of semiconductor devices one proposal is the use of new generation devices, which together with an optimized thermic design can help to decrease high temperatures reached in DC-DC converter.

c. Technological requirements.

Technological requirements for a good performance are related to efficiency, performance, reliability and volume that design presents considering these parameters, in addition the use of materials that help to satisfy these aspects as much as possible. From the aforementioned parameters, use of GaN devices could have benefits related to the efficiency and reduction in the final size of the required converter, obtaining stages with a reduced final volume, helping not only in aspects related to size, but also in aspects relate to reliability, because they have better performance, than semiconductor devices fabricated on Si and SiC.

One work focused on the comparison between GaN and SiC semiconductor devices is presented in [83], by a topology designed with a QZS-CMI (Quasi Z-Source Cascaded Multilevel Module) for a power output of 1

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MW, the work proposes two possible solutions, the first one through the use of GaN devices and the second one through the use of SiC devices, the topology proposed, is shown in Figure 5.

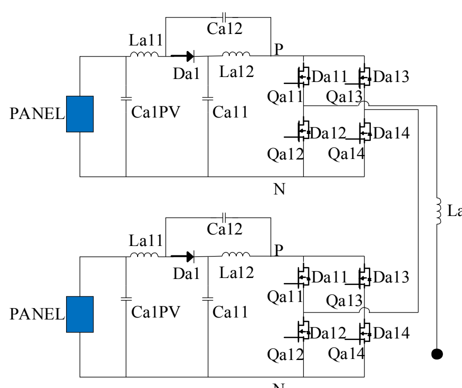

Fig. 5 Topology for 1 MW/11 kV QZS-CMI

Topology on Figure 5 presents two alternative solutions for a photovoltaic application through the use of GaN and SiC devices, the presented work shows the performance of both materials and the benefits that they offer in this application, and how they help to increase or reduce the electrical properties in the system.

The possible solutions propose the following components: the first one proposes the use of a GaN device of 650 V, model E-HEMT GS66516T of GaN Systems like switch, and a diode of SiC of 650 V model C5D50065D of Cree operating at 20 kHz, on the other hand, the second option proposes the use of a SiC component of 1200 V model CAS120M12BM2 of Cree operating at 10 kHz, the components used in both solutions are shown in Table 5.

TABLE 5. Components of both solutions

First Solution	**Second Solution**
Components	Components
GaN E-HEMT	SiC half-bridge module
Gate Driver	Gate Driver
SiC Schottky diode	SiC Schottky diode
qZS inductor	qZS inductor
qZS capacitor	qZS capacitor
Output filter inductor	Output filter inductor
Output filter capacitor	Output filter capacitor
PV terminal capacitor	PV terminal capacitor

The first solution according to the switch model chosen in GaN requires two components with anti-parallel diodes to satisfy the current requirement, with a margin of 44%, the second one presents a current margin in the SiC module of approximately one 62%, the negative element visible in the proposed topology from the use of GaN components is reflected in the need to use a greater number of components, in order to satisfy the operational requirements of the selected topology, on the other hand, part of the benefits that the use of GaN components entails consists of having lower ignition resistances and less parasitic capacitance.

An exhaustive analysis is presented in [83] obtaining the total losses in one and another solution, based on the operating principle of the proposed topology. As a summary, Figure 6 shown the distribution of losses in both cases operating with a frequency of 20 kHz, noting that despite having a greater number of components in the option using GaN better benefits are obtained from the point of view of efficiency.

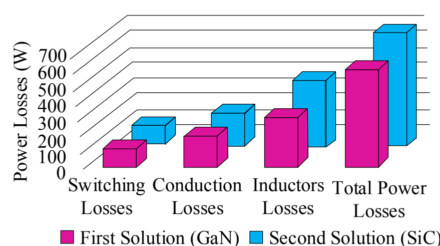

Fig. 6 Comparisons of power losses between GaN and SiC

Figure 6 shown both options operating at a frequency of 20 kHz, concluding that although the switching losses in the first solution is twice than the second, the first solution still shows power losses in each module, but given the better switching characteristics in GaN power devices, switching losses are much lower than in the second option using SiC semiconductor components.

The power losses on the semiconductor devices is improved by 13.6% through the use of GaN semiconductors, therefore in terms of energy management and efficiency of the switching stages, the GaN semiconductors are superior than SiC devices. Another important aspect to take into account in the choice of any power device is the economic part, this point results in a negative aspect of the use of GaN components, the article similarly performs this exercise, obtaining that under a scheme using GaN devices the investment is $ 93,825 and under a scheme using SiC devices, the investment is $ 65,940 (price in dollars).
In the aspect related to costs, it is concluded that the price per module, for the solution through GaN is 31.18% less than that presented by SiC, however, the total cost of the solution system in GaN is much higher than the solution in SiC, due to the greater number of components necessary to satisfy the operating parameters.

Another work focused on evaluating the use of GaN semiconductor components in photovoltaic applications, is the one shown in [84], presenting a performance comparison in a DC-DC converter using GaN and Si components for an output power of 117 W, noting that gallium devices outperform the best components based on Si, the topology and the system used are shown in the following figure.

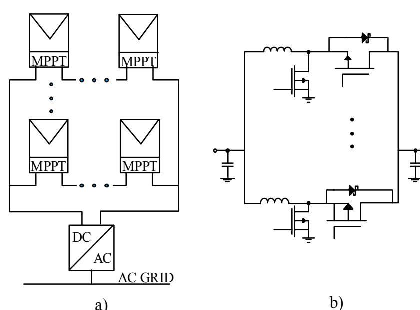

Fig. 7 (a) System, (b) Converter topology

The comparative study was developed with the objective to observe the performance and operation that converter presents, due to the effect of “on resistance” and “parasitic capacitance”. The characteristics of the components used are presented in Table 6.

TABLE 6. Device Selection

Device	Model	V_{DSS}	$R_{DS(ON)}$	I_D
GaN	EPC2001	100V	7mΩ	25A
Si	IPB26CN10	100V	25mΩ	35A

The obtained results by using GaN devices present better performance in terms of efficiency in the complete system, observing that due to the increase of the switching frequency, the value of the passive components are reduced, the adjustment and the components used in the design are shown in Table 7.

TABLE 7. Specifications of used components

Parameter	f_{sw} Hz	L $[\mu H]$	C_{in} $[\mu F]$	C_{out} $[\mu F]$
Si Converter	300	8.3	2.8	5.7
GaN Converter	600	4.2	1.5	3

Finally, the distribution of the switching losses in comparison with the operating characteristics of the components used is presented, in Figure 8, in which a better performance is presented by the GaN devices.

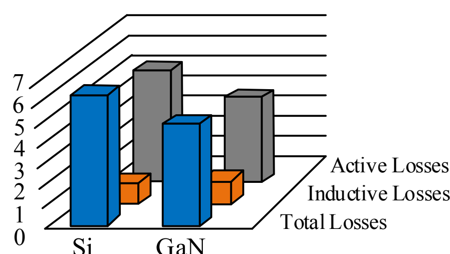

Fig. 8 Converter Losses

Due to the superior switching characteristics, the widespread use of the GaN components in power electronics is a closer reality, part of the improvements in switching would improve the most efficient energy conversion, while allowing a switching frequency greater that helps decrease the final volume of the system. In this aspect, from the point of view of photovoltaic systems, aspects related to efficiency, reliability and volume would be improved, they are fundamental aspects at present, because represent important requirements in their constitution of this type of applications.

The previous works shown only some of the comparisons that have been reported in the literature under conventional schemes in photovoltaic systems, up to this point it has been mentioned that one of the main advantages that involves the use of GaN components is related to increase the switching frequency, decreasing the size of the passive components such as inductors and therefore an increase of power density.

Currently there is a small number of works [85-92] related the use of current source inverters CSI for photovoltaic systems, which according to their authors, have interesting characteristics compared to the use of voltage inverters VSI, more employees for this type of topology.

However, part of the main problems associated with the use of CSI in photovoltaic systems are related to low efficiency, because they use bulky components that make them prone to present losses due to their design, right here it is important to mention part of the advantages that would bring the use of GaN power semiconductors in this type of schemes for photovoltaic systems, due to the advantage of being able to operate under much higher frequency levels than in any other device.

A related work in this aspect, is presented in [36], it proposes a topology and control scheme with an energy decoupling circuit for single-phase applications based on a current inverter, the proposed scheme complies with the electric norms stipulated for this type of applications, avoids the use of electrolytic capacitors and emerges as an interesting option to the problem of the reliability present in this type of systems.

The proposed inverter is shown in Figure 9 and consists of a switch, two diodes and a small capacitor, so the size and the number of components are reduced in comparison with the conventional circuits.

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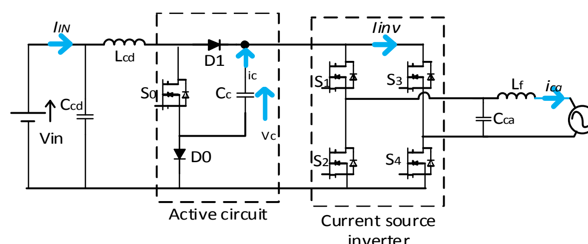

Fig. 9 Photovoltaic inverter presented in [36]

The inverter shown in Figure 9 decouples the energy through a small film capacitor, in this sense, is the same inverter that can control the DC input voltage and achieve the MPPT, providing a sinusoidal current to the grid with a less number of components.

The results obtained by Yoshiya Uhnuma present interesting characteristics of efficiency and power factor with respect to the output power, where is observed a maximum efficiency of 94.9%, these results are compared with conventional topologies using a VSI, which are presented in Figure 10.

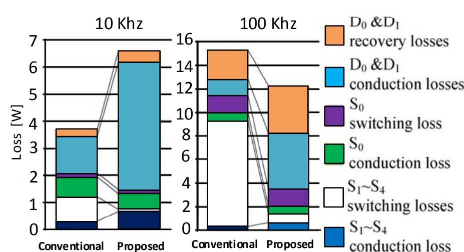

Fig. 10 Comparison of losses at different operating frequencies

Figure 10 shows the losses distribution present in a conventional topology (VSI) and the proposed scheme (CSI), it is observed that when the switching frequency is about 10 kHz, in the proposed circuit the conduction losses of the diodes is higher, on the other hand by increasing the switching frequency, the losses are lower using CSI, achieving important results, but that is still somewhat below the efficiencies presented by the most of the VSI currently, where estimated efficiencies are superior than 97%.

Under these types of topologies and from the point of view of new generation components developed on GaN, they could increase the benefits of the use of CSI in photovoltaic systems, because part of the main problems associated with these investors are linked to problems of efficiency in the switches and the great bulk in its passive components, which can be benefited or improved only by the replacement of semiconductor components.

In summary, based on the analysis of energy losses between the components of GaN and SiC, it is concluded that although the first solution shows lower power losses, there is a substantial increase in the final cost of the system when using GaN, same that conditions a wider use of this emergent technology at the present time, on the other hand, given the promising innovations in the GaN devices, it is totally possible to expect that the price of components elaborated in GaN diminish in the near future, existing a possible generational change reality in the use of the material for the mass manufacture of semiconductor devices, which is currently led, at the moment by components based on SiC.

6. CONCLUSIONS

There are many advantages that lead to the use of power semiconductor devices based on GaN, part of them highlights the increase in the efficiency of any system compared to Si and SiC devices, the data show, for example, a reduction in noise for the use in robust amplifiers, eliminating the need for limiters of a diode as protection against overexertion, additionally, due to its physical characteristics and its high mobility of electrons, it grants special properties for applications in high power and frequency.

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The sensitivity of ionizing radiation for this type of devices is the lowest that any other device currently, so not only complies as a component for "normal" applications, but also for military and space applications due to its stability in environments of radiation, have lower ignition resistances, lower parasite capacitances, do not present inverse recovery time, help in the reduction of conduction losses and switching in converters, help to reduce robust components thanks to the fact that they operate in high frequency, in addition to a series of aspects that in comparison with Si and SiC devices make them more profitable.

Another important point that the GaN devices are presenting in front of any other device currently is the fact of having a higher reliability, helping applications that require a long lifetime, such is the case of power LED systems or photovoltaic systems, which need components with high reliability.

On the other hand, aspects related to its cost and the fact of operating at lower temperatures than SiC devices, positions them a bit below currently as leading components in applications related to power electronics. The positive part of this, as a recent technology there is still much room for improvement, this suggests that the components developed in GaN can be the super component that helps mitigate many of the problems associated with switches in power electronics, in this sense it is well known that many companies, distributors, designers and researchers are in various stages of adoption towards this new technology in semiconductors, while there is another more conservative sector that expects to find more compelling reasons to bet on them.

With a view to the near future, the devices developed in GaN will have a decrease in their price, which will help to better see the performance and advantages they have over the current power devices. So this may be translated as a generational change of components in applications where Si and SiC devices are commonly used, making current applications faster, more efficient, more reliable, smaller and with higher energy density.

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