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VOLTAGE STABILITY OF A PHOTOVOLTAIC DC MICROGRID WITH GaN-BASED BIDIRECTIONAL CONVERTER FOR EV CHARGING APPLICATION

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Abstract

The integration of electric vehicles (EVs) into modern energy systems presents a unique set of challenges, particularly in DC microgrid environments where voltage stability is paramount. This research investigates the application of Gallium Nitride (GaN) based bidirectional converters to enhance voltage stability within DC microgrids tailored for electric vehicle charging stations. Traditional power electronic converters, often based on silicon technology, are limited in their ability to efficiently handle the dynamic power flow demands of EVs. GaN power devices, known for their superior switching capabilities, offer a promising alternative. This study proposes a novel GaN-based bidirectional converter design optimized for EV charging applications, focusing on achieving high efficiency, reduced switching losses, and enhanced voltage regulation. Through PLECS simulation, the effectiveness of the GaN-based bidirectional converter in improving voltage stability is demonstrated. The converter's high-frequency switching capabilities enable rapid response to load fluctuations, ensuring a stable voltage profile even under challenging operating conditions. The findings of this research contribute to the advancement of DC microgrid technology, offering a scalable solution for the growing demand in EV charging infrastructure. The adoption of GaN-based converters not only enhances voltage stability but also paves the way for more efficient and reliable integration of electric vehicles into the grid, ultimately promoting sustainable transportation solutions

Keywords: *PV Array; DC Microgrid; Gallium Nitride Bi-directional DC-DC Converters; PI Controller; Electrical Vehicles; Voltage Stability, PLECS Software*

1. INTRODUCTION

The security and stability of the photovoltaic DC microgrid system are assessed by utilizing the bus voltage as a reference point [1]. However, the fluctuating and unpredictable nature of photovoltaic power generation, along with dynamic load changes, can lead to unexpected power disruptions during the operation of the PV DC microgrid, resulting in significant fluctuations in the bus voltage. Consequently, preserving the stability of the DC bus voltage and ensuring power quality have become crucial issues that require immediate attention [2]. Currently, energy storage devices (ESDs) are integrated into the DC bus through bidirectional DC/DC converters (BDCs) to compensate for these fluctuations [3]. The micro power source can provide energy, and the load can absorb power based on the quantity of load bus, thereby enhancing the system's resilience [4]. Incorporating ESDs into the DC bus through BDCs is a promising solution for maintaining voltage stability and ensuring power quality in photovoltaic DC microgrid systems, providing an efficient and effective means of managing power fluctuations.

The dual closed-loop control approach for voltage and current, or a modernized version of it, is typically used by energy storage unit converters nowadays. A classic control theory is the traditional dual closed-loop voltage and current control, which uses the bus voltage as the external layer of control and energy-storing inductive and current as the internal loop of control that is compensated by the PI controller [5]. This traditional way to control, while improving the dynamic response of the system, is unable to successfully reduce the large variations and influence of the DC bus voltage. As a result, alternative control methods are required to address these shortcomings and improve the stability and reliability of energy storage unit converters. More sophisticated and advanced control algorithms, such as adaptive and predictive control strategies, may be considered as potential solutions to overcome these issues and enhance the performance of energy storage unit converters in a variety of operating conditions.

To tackle this problem, several researchers have adopted a strategy that combines traditional dual closed-loop control with the feedforward control technique [6]. Depending on the feedforward variables used, these approaches can be categorized into power feedforward and current feedforward methods. For instance, three feedforward load current control strategies aimed at the boost converter's unstable zero point, which proved to be more effective than feedback control in limiting voltage changes and enhancing the system's stability when the output filter capacitance was decreased [7]. Furthermore, Hou et al. employed direct power control to integrate load current feedforward into the control link. The experimental and simulation results indicated a significant enhancement in the way DC converters react dynamically and the maintenance of a constant output voltage under sudden load changes. Additionally, Lu et al. introduced the establishment of a ripple compensation connection via load current feedforward to enhance the quality of the systematic output power and accelerate the inner loop dynamic reaction time of the existing inner loop control. While the current feedforward control approach mentioned above somewhat enhances the system's dynamic reaction capability, it still faces the issue of voltage and current loop delay, resulting in a slower response of the output current to the load disturbance

The power feedforward control method is utilized to reduce bus voltage fluctuations by introducing disturbance power into the control pathway [8]. A power feedforward compensation control strategy that uses classical dual closed-loop control to address the issue of bus voltage fluctuations resulting from the mismatch between output power and renewable energy load consumption in the microgrid. This method directs power disturbances into the controller via the feedforward channel, effectively limiting bus voltage fluctuations and improving the overall stability of the system [9]. Additionally, Song and Zhu introduced a practical direct power control strategy related to direct power feedforward control to enhance the bidirectional DC/DC converter's resistance to load disturbances. This approach eliminates the need to account for the energy storage inductance of the converter and changing ratio parameters of the transformer, thereby improving the overall system compatibility [10]. Moreover, power feedforward can help the system to respond more quickly to power disturbances, thereby improving its ability to regulate bus voltage fluctuations to a certain extent. Power feedforward has to move through the current inner loop, identical to current feedforward, which results in some delay in the output current compared to the load disturbance. Furthermore, it's important to note that feedforward control requires real-time monitoring of system parameters, which increases the system's cost and decreases its reliability. This is not beneficial for the expansion of the microgrid or the widespread adoption of plug-and-play capabilities. To address the issues with feedforward control. The use of a state observer eliminates the need for an exact mathematical model that includes the disturbance signal when evaluating the amount of disturbance. This approach simplifies model construction, avoids complex mathematical calculations, and satisfies the real-time property requirements of the system. However, the use of an observer to monitor the system's state variables introduces noise, even though the models are relatively simple.

Another important consideration to this end, is the emergence of wide band gap (WBG) semiconductors. Fundamentally due to reduced reverse recovery charge and higher electron mobility, gallium nitride (GaN) and silicon carbide (SiC) based transistors enable bidirectional operation and significantly higher switching frequency and efficiency compared to their Si based counterparts [11]. Although there are SiC transistors commercially available [12], GaN power transistors are still restricted to some voltage range [13]. Hence, in order to leverage the superior switching performance of GaN power transistors, catering to a wide output voltage range, multilevel switching circuits need to be considered.

In addition to topology and modulation technology, emerging power devices such as GaN HEMT offer superior static and dynamic performance that further improve the performance of power converters. GaN device outperforms Si device in terms of small output capacitance, no reverse recovery and low on-state resistance [14-21]. Applications that benefit from these features include the continuous current mode (CCM) totem pole power factor correction (PFC) rectifier [18,19] and other CCM applications [15,20,21]. Considering large reverse recovery charge (Q_{rr}), it is impractical to adopt the existing Si MOSFET. Meanwhile, the low Q_{rr}, low switching loss GaN HEMT power device enables this topology to achieve high efficiency. GaN device demonstrates its most important salient features in these applications.

The objective of this paper is to investigate the feasibility of a novel compact high efficiency bidirectional DC-DC converter with GaN HEMTs over traditional semiconductor devices for Electrical Vehicle charging applications.

2. MICROGRID DESCRIPTION

The microgrid being analyzed in this study operates at a voltage level of 48 volts, and it is depicted in Figure 1. In island mode, maintaining power balance is accomplished by controlling the distributed energy sources and compensating devices. The microgrid comprises three DC buses, each linked to its corresponding subsystem and governed by a regional controller (RC). Loads are connected to each bus and distributed throughout the system.

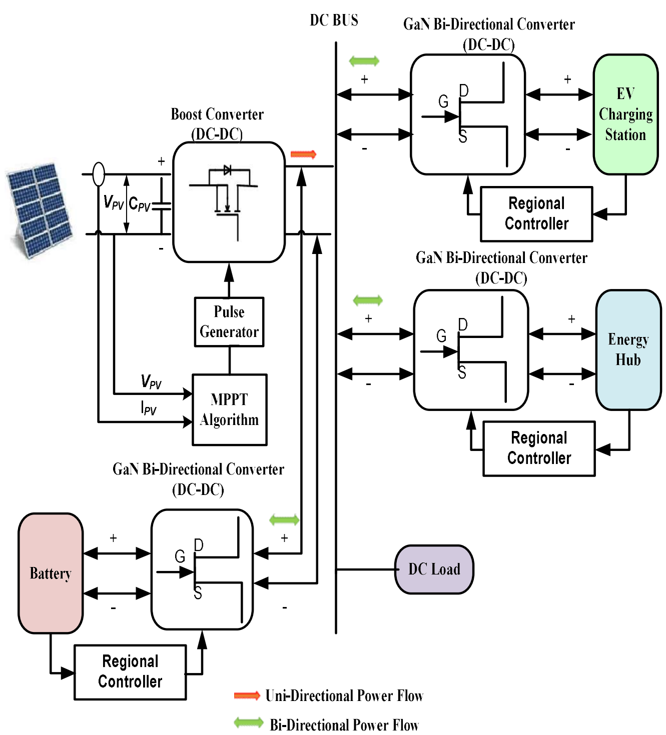

Figure 1: Solar PV based DC microgrid System

2.1 About Photovoltaic system (PV) System

The PV system is connected to the bus and exposed to changes in temperature and irradiance. It also has battery storage. A boost converter is used to use maximum power point tracking (MPPT) to increase the array's power output. This converter uses the incremental conductance (InC) approach and an additional integral regulator for robustness. When necessary, advanced MPPT techniques may be used. According to the InC method, the derivative of the Module power is assumed to be zero at the MPPT, positive to the left of the MPP, and negative to the right of the MPP [22]. When the system's InC and system conductance are equal, which corresponds to the lowest rate of change in PV power Ppv, the InC technique's search for the applied PV voltage ends. This can be mathematically represented.

$$\frac{dP_{PV}}{dV_{PV}} \approx 0 \quad (1)$$

Substituting for $P_{pv} = V_{pv} I_{pv}$ in (1), we get

$$\frac{d\left((V_{PV})(I_{PV})\right)}{dV_{PV}} \approx 0 \quad (2)$$

$$I_{PV}\frac{dV_{PV}}{dV_{PV}} + V_{PV}\frac{dI_{PV}}{dV_{PV}} \approx 0 \quad (3)$$

$$I_{PV} + V_{PV}\frac{dI_{PV}}{dV_{PV}} \approx 0 \quad (4)$$

$$\frac{dI_{PV}}{dV_{PV}} = -\frac{I_{PV}}{V_{PV}} \quad (5)$$

The InC algorithm-based DC-DC converter is in charge of modifying the operating point of the PV array to full-fill equation (5). The voltage of the bus is regulated by the battery, which operates its converter in a constant voltage mode. As a result, the converter can function in constant current mode (CCM), providing the microgrid with the highest attainable power output. Any excess energy generated is deposited in the battery storage, which allows the PV to work continuously in MPPT mode.

Figure 2 displays a detailed diagram of the subsystem. The unidirectional converter of the PV panel works MPPT mode, and the battery's bidirectional converter regulates the bus voltage with a proportional-integral (PI) controller. Excess power in the microgrid charges the battery storage, and the charging current is controlled to maintain a constant bus voltage.

2.2 GaN Bidirectional DC/DC Converter

DC-DC power converters are crucial components of DC microgrid systems because they convert electricity from various voltage levels to the appropriate output voltage level. Traditional DC converters, on the other hand, only handle unidirectional power transfer, limiting bidirectional power flow. To address this constraint, the suggested solution involves the use of sophisticated power devices, namely Gallium Nitride High Electron

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Mobility Transistors (GaN HEMT), which have improved static and dynamic properties, increasing the efficacy of power converters. GaN devices outperform their Silicon (Si) counterparts in important areas such as lower output capacitance, the lack of reverse recovery effects, and low on-state resistance, resulting in improved overall performance as shown in Figure 3, to enable the charging and discharging of storage devices like batteries and supercapacitors. This not only streamlines the process but also allows for more effective use of the stored energy, making the system as a whole more adaptable and robust.

The research contribution of a GaN-based DC-DC converter with SiC (Silicon Carbide) can be significant, particularly when evaluated in the context of recent studies and the state of the art in the literature. Here's a breakdown of how such a study could be classified and its significance justified:

2.2.1 Classification of Research Contribution:

a. Innovation: GaN (Gallium Nitride) and SiC technologies have been gaining attention due to their superior electrical properties compared to traditional silicon-based devices. Integrating these two advanced semiconductor materials into a DC-DC converter represents a forward-looking approach, aiming to leverage their unique characteristics for improved performance.

b. Performance Enhancement: The combination of GaN and SiC in a DC-DC converter could potentially offer benefits such as higher efficiency, higher switching frequencies, and improved power density compared to conventional silicon-based converters. These improvements can lead to smaller and more efficient power conversion systems, which are highly sought after in various applications ranging from consumer electronics to renewable energy systems.

c. Addressing Challenges: While GaN and SiC technologies offer advantages, they also pose challenges such as cost, reliability, and compatibility issues. A significant aspect of the research would involve addressing these challenges, possibly through innovative design approaches, material optimization, or integration techniques.

2.2.2 Justification of Significance:

a. Efficiency and Power Density**:** Recent studies have shown that GaN and SiC devices offer higher efficiency and power density compared to traditional silicon devices. By integrating these materials into a DC-DC converter, the study aims to capitalize on these advantages, potentially leading to significant improvements in overall system efficiency and compactness.

b. Reliability and Robustness**:** While GaN and SiC devices offer performance advantages, ensuring reliability and robustness is crucial for real-world applications. The study may focus on reliability assessments, failure mode analysis, or mitigation strategies to address these concerns, thereby enhancing the trustworthiness of the proposed converter technology.

c. Competitive Landscape: With the increasing demand for efficient power electronics solutions, the development of GaN and SiC-based converters can offer a competitive edge to industries involved in power electronics manufacturing. By staying at the forefront of technological advancements, the research contributes to maintaining or gaining a competitive position in the market.

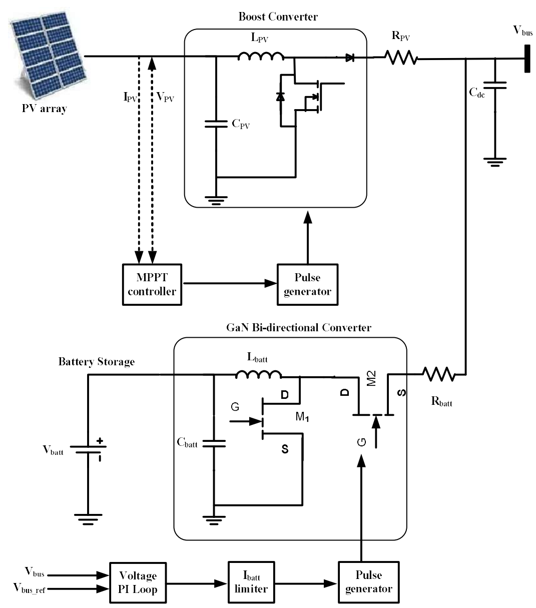
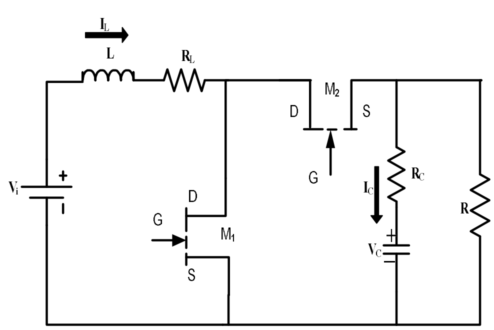


Figure 2: Implemented PV-Battery System.



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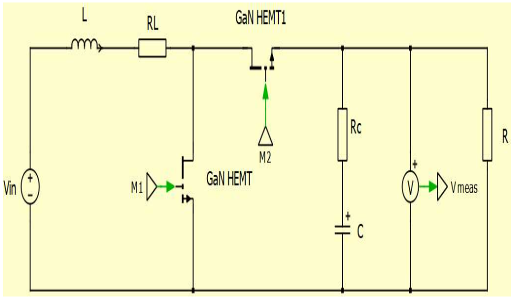

Figure 3. Implemented Gan Bidirectional DC-DC Converter With PLECS Software

The dynamic model of the converter includes parasitic resistances, which are identified as RL and RC, to characterize the inductor and capacitor characteristics, respectively.

The state-space model of the converter can be represented as equations (6) and (7), where the system matrices are denoted as A, B, C and D.

$$x' = Ax + Bu \tag{6}$$

$$y = Cx + Du \tag{7}$$

The state-space model (SSM) of the converter can be obtained by taking the average of two discrete SSMs. The first SSM related to the case when M1 is ON and M2 is OFF for a duty cycle of d1, as shown in equation (8). The second SSM corresponds to the case when M1 is OFF and M2 is ON for a duty cycle of d2, which is equal to 1 minus d1, as shown in equation (9). The selected state variables are iL and Vc, represented by x1 and x2, respectively.

$$x'_{d1} = \begin{pmatrix} \frac{-R_L}{L} & 0 \\ 0 & \frac{-1}{C(R+R_C)} \end{pmatrix} x + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} u \tag{8}$$

$$x'_{d2} = \begin{pmatrix} \frac{1}{L}\left(R_L + \frac{RR_C}{R+R_C}\right) & \frac{-1}{L}\left(1+\frac{R_C}{R+R_C}\right) \\ \frac{R}{C(R+R_C)} & \frac{-1}{C(R+R_C)} \end{pmatrix} x + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} u \tag{9}$$

Equations (10) and (11) can be utilized to derive the averaged state-space model (SSM), resulting in equation (12).

$$A = d_1A_1 + d_2A_2 \tag{10}$$

$$B = d_1B_1 + d_2B_2 \tag{11}$$

$$\begin{pmatrix} \frac{1}{L}\left(R_L(1-2d)+\frac{RR_C}{R+R_C}.d'\right) & \frac{-1}{L}\left(1+\frac{R_C}{R+R_C}\right).d' \\ \frac{R(1-d)}{C(R+R_C)} & \frac{-1}{C(R+R_C)} \end{pmatrix} x + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} u \tag{12}$$

In a similar manner, the matrices C & D can be derived, resulting in equation (13) as shown below.

$$y = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} x + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} u \tag{13}$$

The obtained averaged SSM depicts the performance of the converter throughout a complete cycle having a period of Ts.

2.3 Energy Hub System

Microgrids require power compensation systems due of the inconsistent nature of renewable energy sources and changing demands. These systems serve two purposes: first, to serve as a power source when microgrid generation is insufficient to meet load demand, and second, to serve as a power sink when generation is at an excess. While traditional battery storage is one method of compensation, its slow dynamic response is not sufficient for rapid changes in load or renewable power. In contrast, supercapacitors (SCcap) offer advantages such as rapid response time and high instantaneous output power. Previous studies have highlighted the benefits of utilizing supercapacitors in various components of microgrids [23].

The proposed design aims to integrate Energy Hubs into the microgrid system for two primary purposes. Firstly, to ensure smooth power delivery during peak demand periods, the supercapacitor is utilized to absorb strong transients. Secondly, to maintain bus voltage, the battery system is employed. Typically, power regulation and balancing in microgrids are managed through generation unit outputs, such as PV units. However, during peak demand periods, generation units must operate at their maximum capacity, which can be challenging. Introducing an Energy Hub can take the pressure off the generation units and transfer control to other parts of the system, making it more efficient and reliable.

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As shown in Figure 4, the Energy Hub is composed of a SCap that is coupled to the same dc bus using bidirectional converters. The SCap control employs a cascaded PI system with an outside voltage loop and an inner current loop, whereas the battery control controls the bus voltage. The supercapacitor control makes sure that the isc value is zero during steady state.

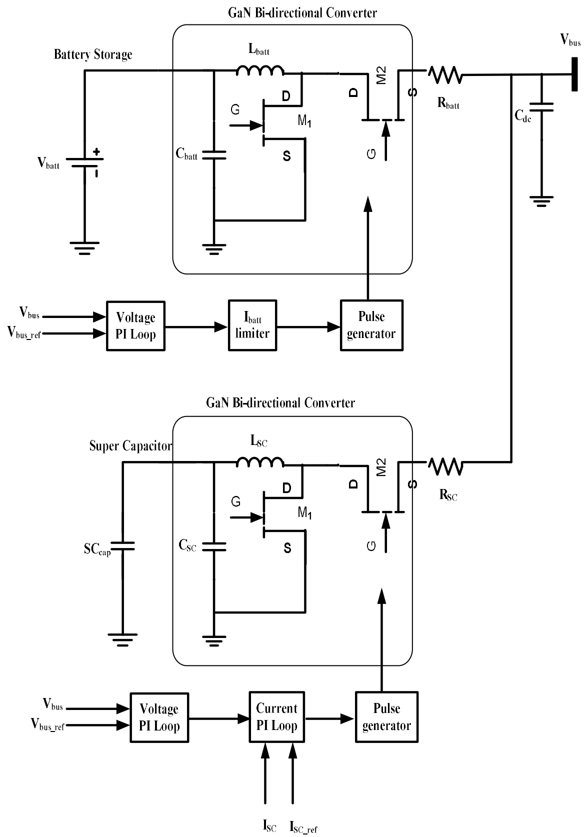

Figure 4: Implemented Energy Hub System

2.4 About Charging Station of Electric Vehicle

The integration of vehicle-to-grid technology into microgrids has opened up new possibilities for transferring the compensation load to electric vehicles connected to charging stations. The benefits and challenges of adopting this technology have been thoroughly analyzed in previous studies [24].

Within the microgrid being examined, the charging station is connected to the bus, and its primary role is to recharge the electric vehicles (EVs) that connect to it. Nevertheless, during times of ultimate demand, the EVs can also function as a power source to help regulate the microgrid. The dc voltage at the bus is adjusted by altering the value of Vev, which occurs when several EVs connect or disconnect from the charging station node, as depicted in Figure 5.

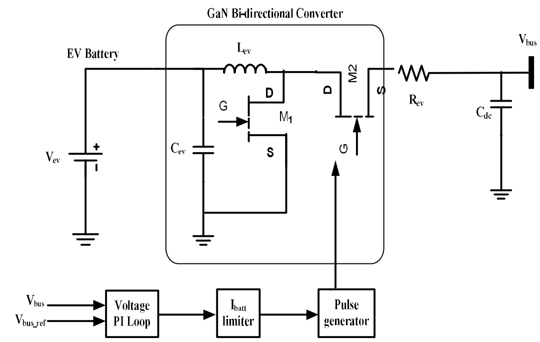

Figure 5: Implemented EV Charging Station System

3. PROPOSED CONTROL TECHNIQUE

The aim of this article is to present a method of energy optimization in a DC decentralized power network using a distributed control technique. This approach does not rely on a communication network. Instead, power flow from individual sources is regulated through interconnected DC/DC converters.

3.1 PI Controller

The PI controller generates the necessary duty cycle based on the output error, similar to the PID controller. In contrast, the PI controller is considerably less susceptible to such disruptions and produces an oscillation-free duty cycle. Moreover, the PI controller outperforms the PID controller in terms of offset and steady-state error [25]. Therefore, this paper utilizes a PI controller rather than a PID controller, taking into account all of these factors. The mathematical analysis of the PI controller is shown in the equation below.

$$U(t) = K_i \int_0^t e(t)\,dt + K_p e(t) \tag{15}$$

The error signal e(t) is the difference between the bus value and the reference signal Voltage (V_{bus}) and reference voltage (V_{bus_ref}).

$$e(t) = V_{bus} - V_{bus\_ref} \tag{16}$$

The dual-loop control method involves the use of two PI controllers - one for the voltage loop and the other for the current loop. The first controller receives direct feedback from the converter's output and its output is then passed on transferred to the second controller, which creates the necessary duty cycle.

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when converter parameters like input voltage and output current are affected by nonlinear or continually changing circumstances, and output filter performance, tuning the PI controller becomes a cumbersome and time-consuming task. In addition, conventional PI tuning lacks a right-half plane zero, resulting in a limited understanding of the converter's behavior [25].

3.2 Gallium Nitride HEMT Transistor

In the context of a Zero Voltage Switching (ZVS) configuration, medium and high-voltage Silicon (Si) Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) manifest escalated switching losses and, on occasion, operational malfunctions, as documented in the literature [26]. The prolonged reverse recovery duration exhibited by the inherent body diode under conditions of low reverse voltage is regarded as the principal instigator of these deleterious MOSFET failures [27]. It is imperative to underscore that once the body diode enters the phase of reverse recovery, it can instigate the failure mode through the agency of either the peak reverse recovery current (IRRM) or the rate of voltage alteration during the turn-off process (dv/dt). These intricacies are a direct consequence of the intrinsic structural attributes characterizing super-junction MOSFETs, characterized notably by a substantially magnified PN junction area. Despite successive iterations aimed at amelioration, the persistence of this unsatisfactory reverse recovery phenomenon persists as an enduring and formidable challenge.

Furthermore, it's crucial to emphasize that, under conditions of minimal or no load, an alternative failure mechanism comes into play within Zero Voltage Switching (ZVS) super-junction Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs). In this particular scenario, the parasitic output capacitor retains a partially charged state, persisting above voltage levels of zero. Intriguingly, this challenge persists despite attempts to mitigate the inherent diode recovery effects. Referred to as the "Cdv/dt shoot-through problem," this phenomenon specifically occurs within the leg designated for short-circuiting.

To compound this challenge, stored energy within the output capacitor dissipates as it transfers into the device during its activation, thereby introducing additional complexity to the situation. Of significant note, the non-linear characteristics exhibited by the output capacitance (Coss) pose a formidable obstacle to achieving Zero Voltage Switching (ZVS). This formidable hurdle arises due to the fact that the power MOSFET's output capacitance undergoes an exponential increase as the drain-source voltage approaches the zero threshold. Consequently, this exacerbates the challenge of promptly discharging the output capacitance, ultimately resulting in prolonged discharge intervals.

Table 1. PI Control Parameters

Mode	K_{pv}	K_{iv}	K_{pi}	K_{ii}
Battery	0.2	2.45	0.45	2.8
Supercapacitor	0.1	4	0.27	3.2
PV-Battery	0.1	4	10	4

In summary, Silicon (Si) MOSFETs have a number of drawbacks, including a long reverse recovery time, a significant reverse recovery charge, and significant output capacitance. These characteristics combined indicate a slow switching speed and high switching losses. As a result, while selecting a power switch for deployment within a bidirectional converter, it is critical that the power switch exhibit the following fundamental characteristics [28]:

a. Fast reverse recovery of body diode especially at lower reverse voltage;
b. Less reverse recovery charge of body diode;
c. Less output capacitance *Coss*;
d. Less *Qgd/Qgs* ratio;
e. High threshold voltage.

Figures of Merit (FOMs) are valuable tools for assessing and comparing device performance, particularly in early design phases [29-31]. Previous studies introduced FOMs for hard-switching and soft-switching applications [29]. These FOMs consistently demonstrate Gallium Nitride High Electron Mobility Transistors (GaN HEMTs) outperforming Silicon (Si) Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) in high-frequency and high-voltage scenarios, including hard and soft-switching circuits, regarding conduction and switching losses

Additionally, a novel FOM designed for evaluating reverse-recovery characteristics during synchronous rectification was proposed [30]. A comprehensive comparison between 650V GaN HEMTs and Si MOSFETs in [31] consistently favored GaN HEMTs across both FOMs. This superior performance can be attributed to GaN HEMTs' inherent properties, particularly the absence of minority carriers in conduction, eliminating reverse recovery charge. However, as with Si MOSFETs, it's essential to minimize body diode conduction. In these applications, GaN devices excel.

Problems in GaN HEMT Modeling

Circuit models have to provide accurate results with fast simulations. An important additional target for manufacturers is developing these models quickly. According to the analyses the use of MOSFET models to reach these targets has the following strengths: The approaches used for modeling the OC (Output Characteristics) and TC (Transfer Characteristics) of MOSFET can be easily adapted to GaN HEMT models by using the approach proposed in this paper to handle the MOSFET ZTC (Zero Temperature coefficient) when the GMOS of the GaN HEMT has to be obtained. Regarding the static R_{DSon}, all the models used for Si MOSFET and some models used for SiC MOSFET can be used for GaN HEMT modeling. Finally, the comparison and the literature analyses have highlighted that the exploitation of the MOSFET modeling experience is useful for modeling the TQ and small-signal capacitance blocks of GaN HEMT. On the other hand, there are some weaknesses to such an approach. GaN HEMT presents the current collapse phenomenon that must be taken into account in the circuit model, but if this phenomenon is absent in MOSFET, then there is no previous modeling experience that can be exploited. Moreover, recent studies have highlighted that the use of the datasheet information for modeling the output parasitic capacitance of MOSFETs and GaN HEMTs can lead to misleading simulation results, especially in high-frequency soft-switching applications. Although this phenomenon is also present in MOSFETs, it has only been discovered recently, so it has not been considered in MOSFET circuit models so far. Consequently, in this case, there is no previous modeling experience that can be exploited for GaN HEMT. In the following, these key problems in GaN HEMT modeling have been investigated

4. RESULTS AND DISCUSSION

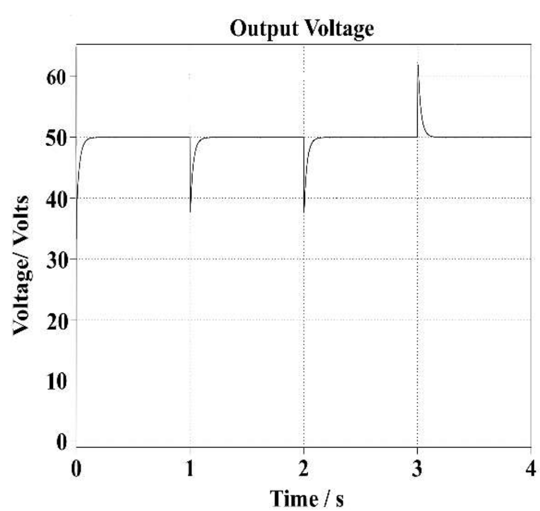
The suggested control approach was evaluated for its ability to regulate bus voltage and optimize load balancing with both effectiveness and precision, and tested for resilience under various scenarios. Detailed descriptions of the outcomes for each test can be found in the subsequent sections.

4.1 Dynamic Load Changes

The efficacy of the suggested power management system was assessed for sudden changes in load characterized by a rapid increase and subsequent decline with PI controller with GaN converter. During these tests, regional controllers employed their specific control algorithms to counteract bus voltage fluctuations. As power generation decreased, the Energy Hub introduced power into the microgrid, with the supercapacitor handling abrupt power transients until the batteries could achieve the new steady-state value. The outcomes depicted in Figure. 6 indicate that the PI control approach handles sudden changes in load proficiently, ensuring effective bus voltage and power regulation

4.2 Communication Delay

The control method proposed in this study was tested for its ability to respond to controller communication delays in a distributed microgrid mode. A 200 ms communication latency was imposed between each regional controller in the system, and the strategy was simulated. The results are presented in Figure 7, where the suggested PI control method with GaN converter demonstrates faster voltage stabilization, with a voltage stabilization time of 0.15 s. This suggests that the projected control can stabilize bus voltage even if there is a communication delay between the regional controllers due to the distributed mode.



(a)

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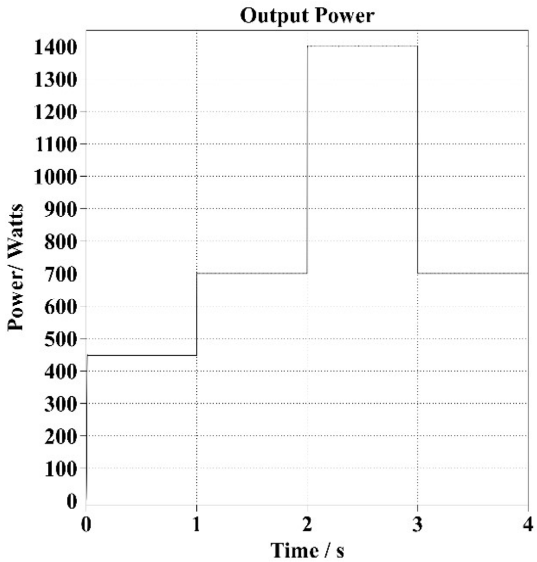

(b)

Figure 6 PLECS Simulation Results With Step-Load Change In (A) Voltage (B) Power

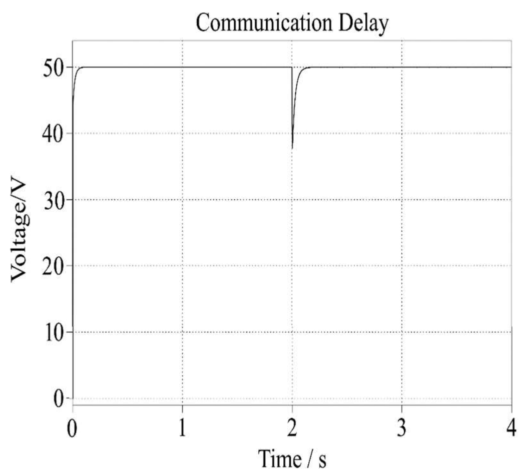

Figure 7. PLECS Simulation With Communication Delay Of 200 Ms

5. CONCLUSIONS

In this paper, the GaN-based bidirectional DC-DC converter is proposed for a microgrid. The paper applies PI controller technique in the microgrid, which depends upon a bidirectional DC-DC converter-based Hybrid Energy Storage System (HESS) to enhance the stability of the DC voltage. Specifically, solar energy is considered as the input source to provide continuous power to the microgrid. Both the Supercapacitor (SC) and Battery units within the HESS are charged from solar energy.

The GaN-based converter system's performance was assessed using PLECS Software. It was determined that the proposed approach can effectively control the bus voltage at the desired level and rapidly regulate the output power in response to changes in the reference or load. This study suggests that the envisioned technique can be efficiently applied within a DC microgrid to ensure voltage stability for Electric Vehicle charging applications.

On the other hand, this paper has also pinpointed the main problems in modeling key static and dynamic quantities of the GaN HEMT. furthermore, there is not any previous MOSFET modeling experience that can be used for GaN HEMT. Neglecting them in circuit models used to simulate GaN-based power converters can lead to inaccurate results involving a non-optimal design that, in turn, lowers efficiency and can involve reliability issues. Therefore, the challenge for researchers involved in GaN modeling is the development of behavioral models of the dynamic RDS,on, large-signal capacitance, and capacitive hysteresis. These models have to be both accurate and computationally low-cost. Another key challenge is the development of models that enable quick computation of the model parameters while simultaneously being endowed with good accuracy and fast simulation

REFERENCES:

[1] Q. Yang, D. An, W. Yu, Z. Tan, and X. Yang, "*Towards stochastic optimization-based electric vehicle penetration in a novel archipelago microgrid*," Sensors, vol. 16, no. 6, p. 907, 2016.

[2] B. Li, S. Huang, and X. Chen, "*Performance improvement for two-stage single-phase grid-connected converters using a fast DC bus control scheme and a novel synchronous frame current controller*," Energies, vol. 10, no. 3, 2017.

[3] Benfei Wang, Liang Xian, Ujjal Manandhar, Jian Ye, Xinan Zhang, Hoay Beng Gooi, Abhisek Ukil,, "*Hybrid energy storage system using bidirectional single-inductor multiple-port converter with model predictive control in DC microgrids*", Electric Power Systems Research Volume 173, 2019, Pages 38-47, https://doi.org/10.1016/j.epsr.2019.03.015.

[4] Z. Lei, F. Wang, Y. Gao, and Y. Ruan, *"Research status and application analysis of bidirectional DC-DC converters in DC micro-grids*," Transactions of China Electrotechnical Society, vol. 31, no. 22, pp. 137–147, 2016.

[5] N. Korada and M. K. Mishra, “Grid adaptive power management strategy for an integrated microgrid with hybrid energy storage,” *IEEE Transactions on Industrial Electronics*, vol. 64, no. 4, pp. 2884–2892, 2017.
[6] C. He, G. Hu, F. L. Lewis, and A. Davoudi, “A distributed feedforward approach to cooperative control of AC micro- grids,” *IEEE Transactions on Power Systems*, vol. 31, no. 5, pp. 4057–4067, 2016.
[7] X. Li, L. Guo, S. Zhang, C. Wang, and Y. W. Li, “Observer- based DC voltage droop and current feed-forward control of aDC microgrid,” *IEEE Transactions on Smart Grid*, vol. 99, p. 1, 2017.
[8] Y. Li, Q. Sun, D. Wang, and S. Lin, “A virtual inertia-based power feedforward control strategy for an energy router in a direct current microgrid application,” *Energies*, vol. 12, no. 3, 2019.
[9] Zhang, Yu,Wei, Shuhao,Wang, Jin,Zhang, Lieping" Bus Voltage Stabilization Control of Photovoltaic DC Microgrid Based on Fuzzy-PI Dual-Mode Controller" *Journal of Electrical and Computer Engineering*, https://doi.org/10.1155/2020/2683052,2020.
[10] P. Song and W. Zhu, “*Virtual direct power control strategy of dual active bridge DC-DC converter*,” Electrical Measurement & Instrumentation, vol. 55, no. 5, pp. 125–131, 2018.
[11] X. Huang, Z. Liu, Q. Li, and F. C. Lee, “Evaluation and application of 600 V GaN HEMT in cascode structure,” *IEEE Trans. Power Electron.*, vol. 29, no. 5, pp. 2453–2461, May 2014.
[12] Wolfspeed, “CREE SiC MOSFET Gen2 40mOhm datasheet,” 2022. [Online]. Available: https://assets.wolfspeed.com/uploads/2020/12/C2M0040120D.pdf
[13] H. Amano et al., “The 2018 GaN power electronics roadmap,” *J. Phys. D: Appl. Phys.*, vol. 51, no. 16, Mar. 2018, Art. no. 163001. [Online].Available: https://doi.org/10.1088/1361-6463/aaaf9d
[14] Reusch, D.; Strydom, J., "Evaluation of Gallium Nitride Transistors in High Frequency Resonant and Soft-Switching DC-DC Converters," Power Electronics, IEEE Transactions on, vol.30, no.9, pp.5151,5158, Sept. 2015.
[15] B. J. Baliga, “Integral Diode,” in *Advanced Power MOSFET Concepts*. New York, NY: Springer, 2010, ch. 8, sec. 4, pp. 472–476.
[16] Costinett, D.; Hien Nguyen; Zane, R.; Maksimovic, D., "GaN-FET based dual active bridge DC-DC converter," Applied Power Electronics Conference and Exposition (APEC), 2011 Twenty-Sixth Annual IEEE , vol., no., pp.1425,1432, 6-11 March 2011.
[17] F. Xue, R. Yu, W. Yu and A. Q. Huang, "Distributed energy storage device based on a novel bidirectional Dc-Dc converter with 650V GaN transistors," 2015 IEEE 6th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Aachen, 2015, pp. 1-6.
[18] L. Zhou, Y. Wu, J. Honea and Z. Wang, "High-efficiency True Bridgeless Totem Pole PFC based on GaN HEMT: Design Challenges and Cost-effective Solution," PCIM Europe 2015; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management; Proceedings of, Nuremberg, Germany, 2015, pp. 1-8.
[19] Z. Liu, F. C. Lee, Q. Li and Y. Yang, "Design of GaN-based MHz totem-pole PFC rectifier," 2015 IEEE Energy Conversion Congress and Exposition (ECCE), Montreal, QC, 2015, pp. 682-688.
[20] Hughes, B.; Lazar, J. etc., "GaN HFET switching characteristics at 350V/20A and synchronous boost converter performance at 1MHz," in Applied Power Electronics Conference and Exposition (APEC), 2012 Twenty-Seventh Annual IEEE, vol., no., pp.2506-2508, 5-9 Feb. 2012.
[21] Seeman, M.D.; Bahl, S.R.; Anderson, D.I.; Shah, G.A., "Advantages of GaN in a high-voltage resonant LLC converter," in Applied Power Electronics Conference and Exposition (APEC), 2014 Twenty-Ninth Annual IEEE, vol., no., pp.476-483, 16-20 March 2014.
[22] A. K. Gupta and R. Saxena, “Review on widely-used MPPT techniques for PV applications,” *in Proc. Int. Conf. Innov Challenges Cyber Secur.*, Noida, India, 2016, pp. 270–273.
[23] Mangipudi Sreedevi, Carmel Tensy Pereira, K. Jyothi Bojjamma, 2015, Simulation Model of a Hybrid Photo Voltaic/ Fuel Cell/ Ultra-Capacitor System for Stand Alone Applications, International Journal of Engineering Research & Technology, Volume 04, Issue 06, 2015, http://dx.doi.org/10.17577/IJERTV4IS060914.
[24] Y. Zhou and X. Li, "Vehicle to grid technology: A review," *2015 34th Chinese Control Conference (CCC)*, Hangzhou, China, 2015, pp. 9031-9036, doi: 10.1109/ChiCC.2015.7261068.

[25] Toub M, Bijaieh MM, Weaver WW, Robinett RD III, Maaroufi M, Aniba G. "Droop Control in DQ Coordinates for Fixed Frequency Inverter-Based AC Microgrids". *Electronics*. 2019; 8(10):1168. https://doi.org/10.3390/electronics8101168.

[26] J. Hiltunen, V. Väisänen, R. Juntunen and P. Silventoinen, "Variable-Frequency Phase Shift Modulation of a Dual Active Bridge Converter," in IEEE Transactions on Power Electronics, vol. 30, no. 12, pp. 7138-7148, Dec. 2015.

[27] X. F. He, Z. Zhang, Y. Y. Cai and Y. F. Liu, "A variable switching frequency hybrid control for ZVS dual active bridge converters to achieve high efficiency in wide load range," Applied Power Electronics Conference and Exposition (APEC), 2014 Twenty-Ninth Annual IEEE, 2014, pp. 1095-1099.

[28] B. Zhao, Q. Song, W. Liu and Y. Sun, "Overview of Dual-Active-Bridge Isolated Bidirectional DC–DC Converter for High-Frequency-Link Power-Conversion System," in IEEE Transactions on Power Electronics, vol. 29, no. 8, pp. 4091-4106, Aug. 2014.

[29] B. J. Baliga, "Integral Diode," in *Advanced Power MOSFET Concepts*. New York, NY: Springer, 2010, ch. 8, sec. 4, pp. 472–476.

[30] Costinett, D.; Hien Nguyen; Zane, R.; Maksimovic, D., "GaN-FET based dual active bridge DC-DC converter," Applied Power Electronics Conference and Exposition (APEC), 2011 Twenty-Sixth Annual IEEE , vol., no., pp.1425,1432, 6-11 March 2011.

[31] F. Xue, R. Yu, W. Yu and A. Q. Huang, "Distributed energy storage device based on a novel bidirectional Dc-Dc converter with 650V GaN transistors," 2015 IEEE 6th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Aachen, 2015, pp. 1-6