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Switching loss and temperature analysis of MPWM controller for solar PV inverter

Sivaraj Panneerselvam[1], Karunanithi Kandasamy[1], S. Sivakumar[1], N. Vignesh Prasanna[2], R. Hushein[2]
[1]Department of Electrical and Electronics Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai, India
[2]Department of Electronics and Communication Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai, India

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ABSTRACT

Despite the fact that temperature affects how much power is produced by solar panels, a temperature that exceeds a certain threshold results in a reduction in output. Additionally, there are losses when switching is controlled in inverters using different control approaches like pulse width modulation (PWM), sinusoidal pulse width modulation (SPWM), and multiple pulse width modulation (MPWM). The type of control method and temperature have an impact on these losses. Here, the MPWM approach is used to analyze it at various temperatures. A metal-oxide-semiconductor field-effect transistor or MOSFET-based and an insulated gate bipolar transistor (IGBT)-based inverter are also planned. Their switching losses at various temperatures are contrasted. For a range of temperature values, the IGBT-equipped inverter is discovered to be a low-loss inverter. Compared to an IGBT inverter, the MOSFET inverter has a comparatively higher loss.

Corresponding Author:

Sivaraj Panneerselvam
Department of Electrical and Electronics Engineering
Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology
No.42, Avadi-Vel Tech Road, Avadi, Chennai, Tamil Nadu 600062, India
Email: psivaraj@veltech.edu.in

1. INTRODUCTION

The Inverters have losses like switching, conduction losses, and gate charge losses. [1]-[4]. The conduction losses depend on the type of semiconductors used for the inverter and can be reduced based on the selection of switches for the appropriate application [5]-[7]. However, the switching losses vary with the switching technique and switching frequency [8]-[11]. The pulse width modulation (PWM) technique is most commonly used for switching and has a few drawbacks like harmonics [12]-[14]. MOSFET and insulated gate bipolar transistor (IGBT) are the most used switches, which have different conduction losses and switching losses [15]-[17].

Instead of using a single PWM for switching, multiple PWM signals have proven to be more efficient [18]-[24]. The multiple pulse width modulation (MPWM) signal is obtained by comparing the sawtooth signal with the square pulse signal. The MPWM switching with MOSFET and IGBT inverter are tested in simulation for loss calculation. Conduction and switching losses are calculated. Switching and conduction losses are calculated with different load conditions, as loads also have some impact on switching losses. As more switching is used, harmonics increase much. Selective harmonic elimination can also be implemented in the future, which will help reduce harmonics much better [25].

2. MPWM GENERATOR

As illustrated in Figure 1, the carrier signal takes the form of a sawtooth wave, while the reference signal adopts a square wave shape. Through the utilization of the relational operator (specifically, greater than or equal), these signals undergo comparison. This comparative analysis initiates the activation of a specific set of switches within the inverter. Either a second generator similar to the first is created for the opposite set of switches, or the MPWM signal from the first generator is sampled later.

Figure 2 depicts the modified pulse width modulation (MPWM) generator designed within Simulink. It employs a square pulse with an average amplitude, period, and width all set to one unit. In this setup, the carrier wave manifests as a sawtooth wave characterized by an amplitude of 2 and a period of 0.5. The comparison between these two signals is facilitated by the relational operator "greater than or equal". Whenever the amplitude of the reference signal surpasses that of the carrier signal (sawtooth wave), the relational operator generates output pulses. These output pulses possess an amplitude identical to that of the reference wave and a frequency equivalent to that of the carrier wave. Figure 3 delineates two distinct sets of switches on the inverter's output MPWM signal.

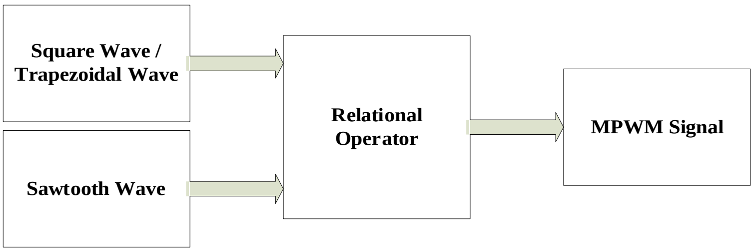

Figure 1. Block diagram of MPWM generator

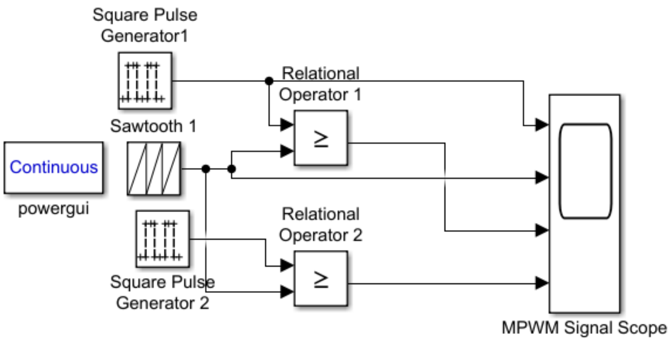

Figure 2. MATLAB-Simulink MPWM generator

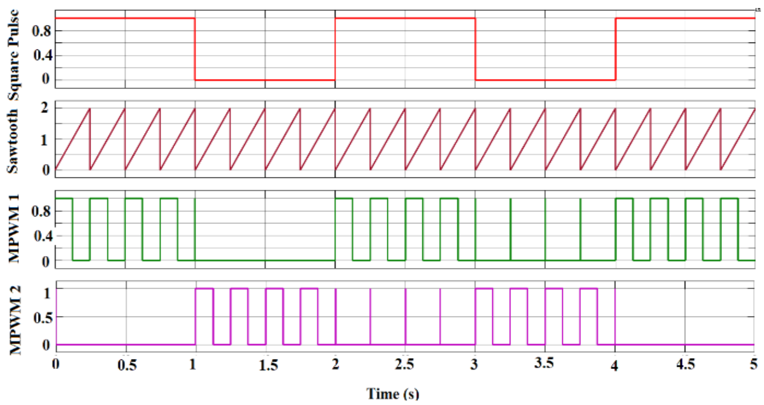

Figure 3. MPWM signal

3. MOSFET INVERTER BASED ON MPWM

In the given scenario, a solar photovoltaic (PV) module with a short-circuit current capability of 36 A and an open-circuit voltage capability of 360 V is integrated with a MOSFET inverter. The inverter configuration comprises four MOSFET switches, with two switches present on each bridge limb. These switches are controlled to open and close based on the modified pulse width modulation (MPWM) signal.

The MOSFET switches, driven by the MPWM signal, regulate the flow of current from the solar PV module to the resistive load connected to the inverter. This modulation technique effectively converts the DC power generated by the solar module into AC power suitable for the resistive load. Throughout this process, the inverter ensures efficient power conversion by synchronizing the operation of the MOSFET switches with the MPWM signal, thereby controlling the flow of current and voltage to meet the requirements of the connected resistive load. Figure 4 shows the general blocks of the MOSFET based inverter -PV system.

Figure 5 displays the MATLAB and Simulink-made MOSFET inverter model. For the simulation, solar radiation of 800 W/m^2 at 35 °C is used. The MOSFET inverter and the solar module's output are connected. By turning on one pair of the inverter's four switches while leaving the other pair of MOSFET switches off, the positive half cycle of the AC output is produced using MPWM pulses from the MPWM generator. After stopping the first set of switches, the second set of switches receives the MPWM pulses. Figure 6 displays the output current and voltage. Instead of being a continuous wave, each half cycle of the AC output is made up of several components.

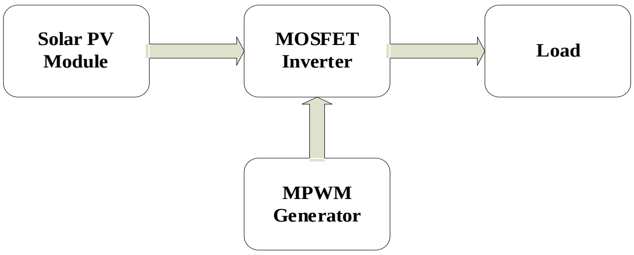

Figure 4. Block diagram of MPWM based MOSFET inverter

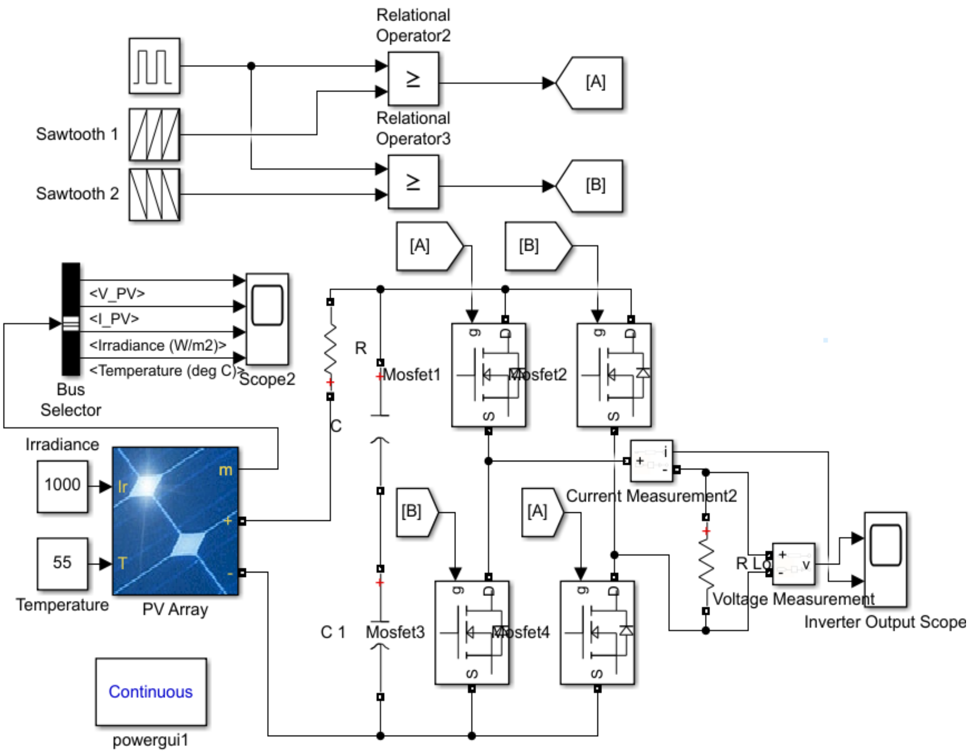

Figure 5. MATLAB-Simulink built MPWM based MOSFET inverter

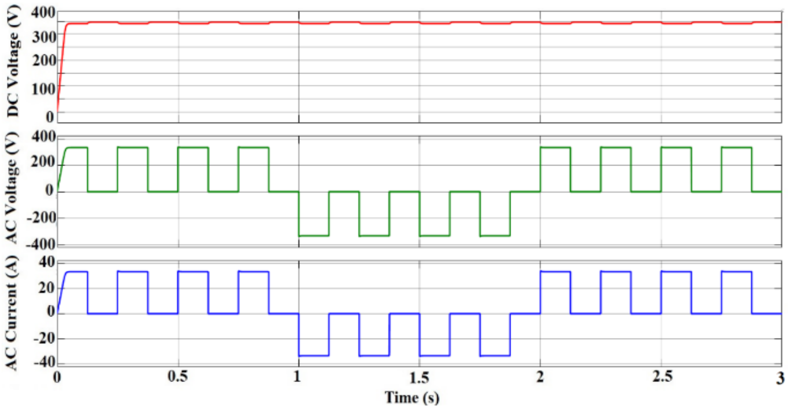

Figure 6. Output of MPWM based MOSFET inverter

4. IGBT INVERTER BASED ON MPWM

With a short circuit current of 36 A and an open circuit current of 360 V, an IGBT inverter is linked to a solar PV module. On each limb of the bridge-type inverter, there are two IGBT switches, giving the inverter a total of four. The MPWM signal causes the IGBT switches to turn on. The inverter is linked in parallel with a resistive load. Figure 7 shows the general blocks of the IGBT based inverter -PV system.

In Figure 8, a MATLAB and Simulink simulation showcases an MPWM-driven insulated gate bipolar transistor (IGBT) inverter. This setup likely demonstrates the operation of an inverter circuit where IGBTs are controlled using MPWM signals to regulate the output waveform. Figure 9 illustrates the resulting output voltage and current waveform from the inverter. Unlike a continuous sinusoidal wave, the AC output comprises multiple components for each half cycle. These components might arise due to the modulation technique employed (such as PWM), circuit characteristics, load variations, or other factors affecting the output waveform. The non-continuous nature of the AC output suggests that the inverter operation might involve pulse-width modulation (PWM) techniques, where the width of the pulses determines the output voltage level. This approach allows for efficient control of the output waveform and can be advantageous in various applications such as motor control, renewable energy systems, and uninterruptible power supplies.

The differences between MOSFET and IGBT inverters' input and output voltages are shown in Table 1. The difference between the input and output of a MOSFET inverter is 6.7 V, but that of an IGBT inverter is only 0.1 V. The differences between MOSFET and IGBT inverters' current and power are shown in Table 2. While the IGBT inverter only loses 6 W of power, the MOSFET inverter loses 448 W. There is only a 440 W difference between the power output of MOSFET and IGBT inverters.

Table 1. Comparison of input and output voltages of MOSFET and IGBT inverter

Inverter	Input voltage (V)	Input current (A)	Input power (W)	Output voltage (V)
MOSFET	340.9	34.1	11614.5	334.2
IGBT	340.8	34.1	11611.1	340.7

Table 2. Comparison of output power and current of MOSFET and IGBT inverter

Inverter	Output current (A)	Voltage loss (V)	Output power (W)	Power loss (W)	Efficiency in %
MOSFET	33.4	6.7	11166.0	448.5	96.14
IGBT	34.1	0.1	11605.0	6.1	99.95

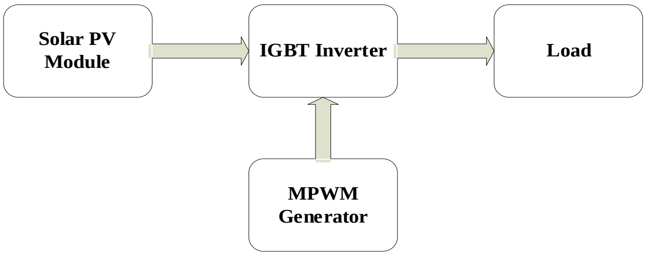

Figure 7. Block diagram of IGBT inverter based on MPWM

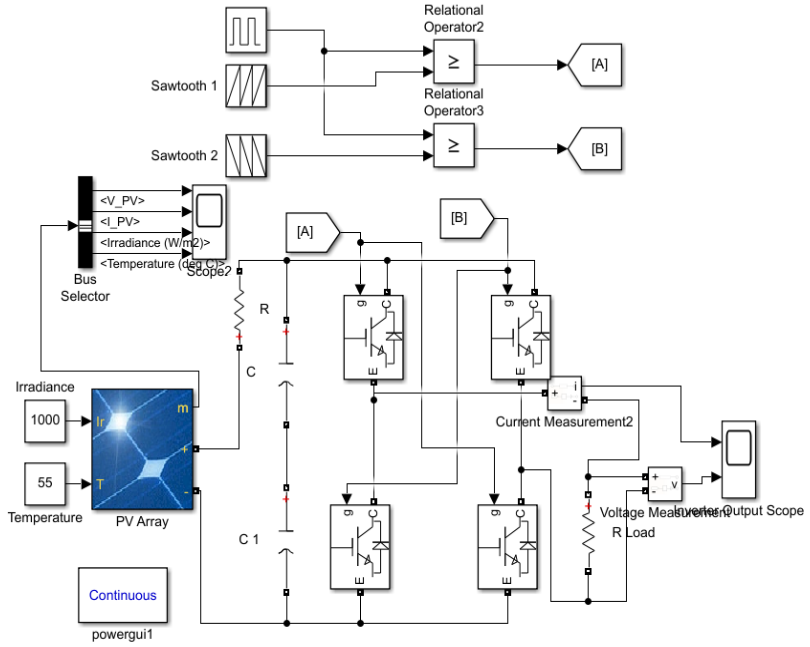

Figure 8. MATLAB-Simulink built MPWM based IGBT inverter

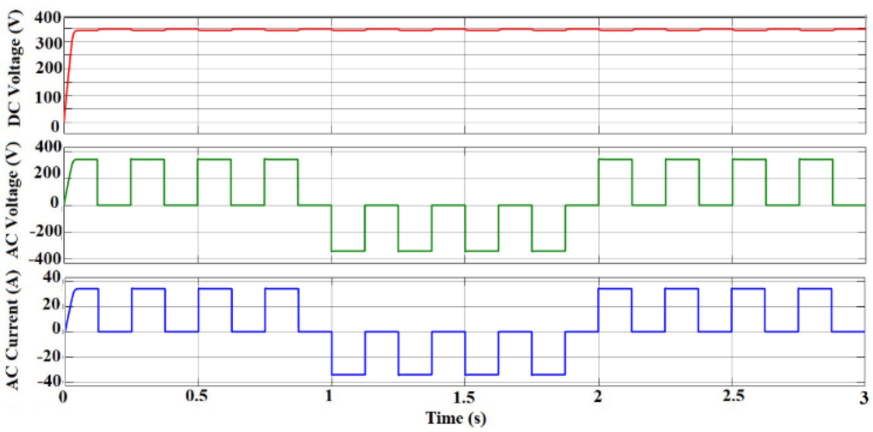

Figure 9. Output of MPWM-based IGBT inverter

Figure 10 shows how the MOSFET and IGBT inverters differ in terms of power output. IGBT inverters have an output power of 11605 W, which is 440 W greater than MOSFET inverters at 11166 W. In Figure 11, the output voltages of MOSFET and IGBT inverters are displayed. IGBT inverters offer a 340.7 V output voltage for the same amount of input voltage as MOSFET inverters. MOSFET inverters drop over 6 V, but IGBT inverters drop 0.1 V. The voltage drop across the transistors during inversion is depicted differently in Figure 12. Figure 13 displays the power loss at each switch. Compared to the IGBT switch, the MOSFET switch loses more than 200 W of power.

Figure 14 displays the MPWM inverters' output currents at various PV module temperatures. For all of the temperature values depicted in Figure 14, the output current from the MOSFET inverter is lower than the IGBT inverter. However, as the temperature of the PV module rises as is shown in Figure 14, the output current of MOSFET and IGBT inverters drops.

Figure 15 compares the output voltages of MOSFET- and IGBT-based inverters at various PV module temperatures. As can clearly be seen in the image, the IGBT inverter generates a higher output voltage than the MOSFET inverter. Additionally, both MOSFET inverters and IGBT inverters significantly reduce their output voltage in response to every variation in the temperature of the PV module.

Figure 16 compares the output power of MPWM inverters with MOSFET and IGBT technology at various PV module temperatures. It is extremely obvious from the figure that the IGBT-MPWM inverter has more output at all temperature points. Additionally, it demonstrates that when the temperature of the PV module rises, the output power of the MOSFET- and IGBT-inverters drops.

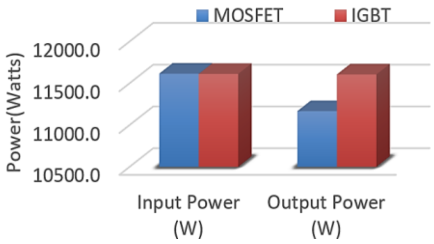

Figure 10. Input-output power comparison of MOSFET and IGBT inverter

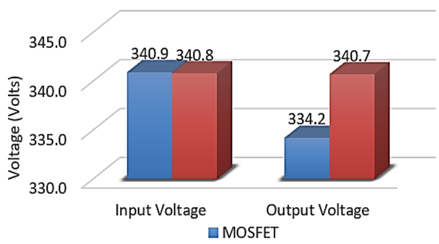

Figure 11. Input-output voltage comparison of MOSFET and IGBT inverter

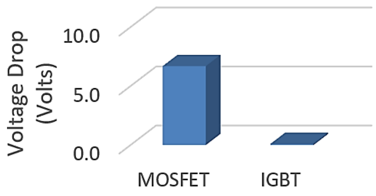

Figure 12. Voltage drop comparison of MOSFET and IGBT switches

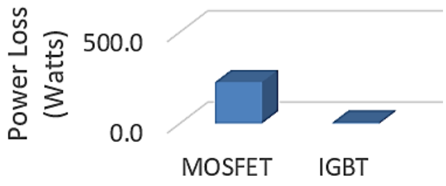

Figure 13. A comparison of power loss in MOSFET and IGBT inverters

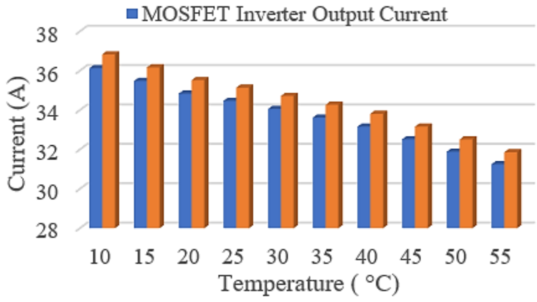

Figure 14. Output current of SPWM inverter at different temperature of PV module

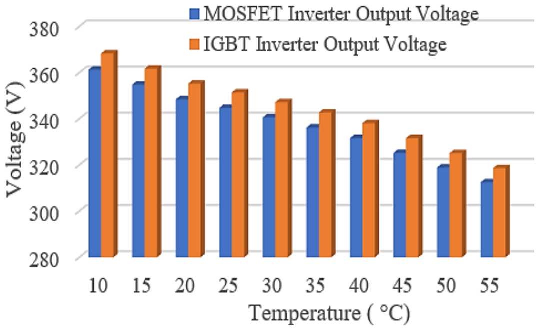

Figure 15. Output voltage of SPWM inverter at different temperature of PV module

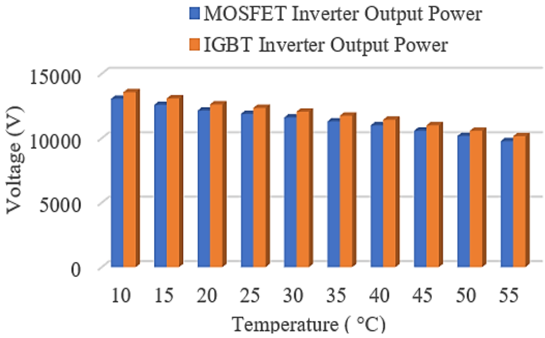

Figure 16. Output power of SPWM inverter at different temperature of PV module

5. CONCLUSION

The experiment detailed above illustrates the contrasting output characteristics between MPWM-controlled MOSFET and IGBT inverters. When comparing the two, it becomes evident that the IGBT inverter yields a notably higher output voltage in contrast to its MOSFET counterpart. This divergence arises primarily from the distinct behavior of the inverter's switching components, specifically the insulated gate bipolar transistors (IGBTs), which undergo diminished voltage losses during operation.

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BIOGRAPHIES OF AUTHORS

Sivaraj Panneerselvam is an assistant professor in Electrical and Electronics Engineering Department at the Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai, Tamil Nadu, India. He received his B.E. degree in Electrical and Electronics Engineering and M.E degree in Energy Engineering from Anna University, India, in 2007 and 2010 respectively. His research interests include the field of solar PV, power electronics, motor drives, and renewable energy. He can be contacted at email: psivaraj@veltech.edu.in.

Karunanithi Kandasamy is graduated from the Institution of Engineers (India), Kolkata in Electrical Engineering in 2005. He obtained his master of engineering in Power Systems Engineering in 2009. He was awarded his Ph.D. in the Faculty of Electrical Engineering from Kalasalingam University, Srivilliputur in 2016. He has more than 20 years of teaching experience in Electrical and Electronics Engineering courses. At present, he is serving as a professor in the Department of Electrical and Electronics Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Avadi, Chennai. His research interests include power system planning, electric vehicles, battery management system and design of microgrid. He can be contacted at email: drkkarunanithi@veltech.edu.in.

S. Sivakumar is an associate professor in the Department of Electrical and Electronics Engineering at Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, Avadi, Chennai, Tamilnadu, India. He received his B.E. degree in Electrical and Electronics Engineering and M.E. degree in Embedded System Technology from the Anna univeristy, India, in 2007 and 2009 respectively. He got the Ph.D. degree in the area of renewable energy with cloud computing. His research interests include smart grids, renewable energy systems, cloud computing, the internet of things, embedded system networking, and machine learning. He can be contacted at email: ssivakumar@veltech.edu.in.

N. Vignesh Prasanna is an associate professor in the Department of Electronics and Communication Engineering at Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, Avadi, Chennai, Tamilnadu, India. He received his B.E. degree in Electronics and Communication Engineering and M.E. degree in Embedded System Technology from the Anna University, India, in 2007 and 2009 respectively. He got the Ph.D. degree in the area of underwater communication. He can be contacted at email: vigneshprasanna@veltech.edu.in.

R. Hushein is an associate professor in Electronics and Communications Engineering Department at the Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai, Tamil Nadu, India. He received his B.E. degree in Electronics and Communication Engineering from Pallavan College of Engineering (affiliated to Anna University) and M.Tech. degree in Robotics from SRM University, India, in 2009 and 2012 respectively. He completed his doctoral degree from Vel Tech University in 2022. His research interests include the field of robotics, 3D printing, energy harvesting, and graphene. He is currently working in the office of the dean of academics and he is the coordinator for academic regulations and statutory. He can be contacted at email: rhushein@veltech.edu.in.