FOREX Publication
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International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 13, Issue 1 | Pages 178-185 | e-ISSN: 2347-470X

Implementation of DC-DC Boost & Luo Converters for Photovoltaic Applications

Veeranna G[1], Hussain M[2], Ramu Bhukya[3*], Durga Rao R[4], Azaharahmed MD[1]

[1]*Department of EEE, Sagi Rama Krishnam Raju Engineering college, Bhimavaram, Andhra Pradesh - 534 204, India*
[2]*Department of EEE, College of Engineering, King Khalid University, Abha, Saudi Arabia*
[3]*Department of EEE, Shri Vishnu Engineering College for Women (A), Bhimavaram, Andhra Pradesh - 534 202, India*
[4]*Department of EEE, JNTUH University college of Science and Technology, Kukatpally, Hyderabad -500085, India*

Correspondence: *ramu1632@svecw.edu.in*

ABSTRACT- Renewables are eco-friendly, of them solar photovoltaic (PV) systems are growing in popularity as a means to directly transform solar radiation into electricity. Installing a PV array is simple, and the ongoing decline in the price of PV modules provides a support as renewable energy source. As the globe continues to deplete its fossil fuel reserves, discussions about alternative, renewable energy sources are heating up. Due to its quiet operation, low maintenance requirements, and lack of emissions, the photovoltaic (PV) power system is quickly rising to the top of the renewable energy industry. Since a PV array is an expensive system to build, it is necessary to exploit all of the available output power. In this proposed system a comparative analysis between boost and LUO converter has been implanted, for attaining high output gain performance devoted to supply both linear and non-linear loads. The proposed scheme tracks Maximum Power Point (MPPT) from the solar panel by perturb and observe(P&O) and Incremental conductance method (INC). A comparative analysis is performed to attain maximum output. Based on the comparison the converter with maximum output voltage is considered as LUO converter. Finally, a hardware prototype using DSPIC30F4011 microcontroller is considered to validate the performance of the two converters.

Keywords: DC-DC converters, boost and Luo converters, Maximum Power Point tracking (MPPT), Photo voltaic, perturb and observe(P&O) and Incremental conductance method (INC)

ARTICLE INFORMATION
Author(s): Veeranna G, Hussain M, Ramu Bhukya, Durga Rao R, Azaharahmed MD;
Received: 28/10/2024; **Accepted**: 19/02/2025; **Published**: 30/03/2025;
e-ISSN: 2347-470X;
Paper Id: IJEER 2810-27;
Citation: 10.37391/ijeer.130123
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-13/ijeer-130123.html

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1. INTRODUCTION

Environmentally friendly energy alternatives must be implemented immediately as our traditional energy supplies continue to disappear. All of us are now relying solely on fossil fuels, which aren't going anywhere soon and constitute a major risk to future sustainability. Therefore, in the current climate, green energy is essential. photovoltaic systems, wind turbines, and energy storage systems are among the most common renewable energy options for generating power. Due to their wide range of applications in both residential and industrial settings, solar cells stand out as the most realistic option. Due to fewer losses, DC is chosen over AC The DC output of photovoltaic systems makes them more usable. Simulating and modelling photovoltaic devices is an important aspect of research in solar energy [1]. Despite being environmentally caring, solar systems have several fundamental faults. The most noticeable aspect is their efficient conversion of solar energy to electricity. This work addresses the drawback of using solar for producing electricity. To optimise the system, the perturb and observe approach was employed. This model may also be used as a foundation for implementing further MPPT approaches. An analogous circuit is used in modelling to simulate a photoelectric device with power electronics connections. Simulations help optimise systems before real implementation, making them cost-effective. A Photo Voltaic Generator is considered efficient if it transforms the greatest amount of available solar power at all times. To maintain the MPP [maximum power point] at its global maximum, the maximum power provided should align with prevailing parameters such as irradiance and temperature. A voltage converter and electronic MPPT system [2] work together to provide maximum power. Power output of PV modules is influenced by irradiance and temperature.

1.1. MPPT implementation in solar circuits

The operational point of a solar panel is rarely at peak power when it is directly linked to a load. The operating point of the solar panel is determined by the resistance that the panel perceives. Therefore, the operating point may be changed closer to the peak power point by changing the impedance that the panel recognizes [3]. A DC-DC converter is required to change the impedance of the source circuit to the load circuit since panels are DC devices. As can be observed from the panel, adjusting the duty ratio of the DC-DC converter causes a change in impedance. The operational point is the peak power transfer point at a given impedance (or duty ratio). When factors like temperature and radiance change in the atmosphere, the I-V curve of the panel might shift significantly. Since the working

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circumstances are always changing, it is not possible to specify the duty ratio [4]. The algorithms used in maximum power point tracking (MPPT) systems regularly sample the voltages and currents from the panels and then modify the duty ratio accordingly.

The ideal outcome and optimal balance of efficiency, performance, and dependability can only be attained by meticulous design. In addition, the system is controlled by software and a microprocessor, which are always tries for the attaining a position to extract power from the solar array.

Some of the commonly used techniques are [5]:
• Perturb and Observe (P&O)
• Incremental Conductance (INC)

2. LITERATURE ASSESSMENT

A boost converter-based MPPT PV battery charging system was presented in the reference [6]. This approach is determined and implemented utilising non-linear dynamics and fast-scale stability analysis. Incorporating these ideas primarily helps the MPPT system with its control features, such as: (i) assured stability with strong resistance to changes in parameters and (ii) quick dynamic reactions in the face of dynamically changing environmental circumstances. Traditional digital or analogue MPPT controllers need elaborate controller design and constant parameter adjustment to achieve this.

By iteratively applying the Voltage Lift (VL) method on the prototype, Archana Nath. S. et al. created LUO converters. Converting DC to DC voltages, these converters have a simple design, a high efficiency, and a high-power density. They have a high output voltage with tiny ripples, among their numerous benefits, and are unique among DC-DC step-up converters [7]. Industrial applications and computer peripherals, particularly those requiring a high output voltage, make extensive use of these converters. The system's output voltage increases step-by-step along the geometric progression thanks to the Improved Positive Output Super-Lift LUO Converter. In order to circumvent parasitic components that reduce the output voltage, the converter employs the Voltage Lift (VL) method. This article presents the IPOSLC, an improved positive output super-lift LUO converter that makes use of the Super-Lift approach [8]. They have successfully developed the Voltage Lift method; however the output voltage can only be increased in an arithmetic progression. Additional Super-Lift technology is used to enhance efficiency; this approach boosts the output voltage in a geometric progression. The primary distinction between the conventional circuit and lift of output voltage in this converter is the inclusion of an additional inductor and diode.

Recent progress in solid-state semiconductors has led to the creation of medium-voltage power converters. These converters could do away with the need for step-up transformers in green energy systems. Modular multilevel cascaded converters are promising candidates for medium voltage converter development; however, they impose a number of separate balanced dc supply. A transformer coupled multilevel inverter based on sinusoidal pulse width modulation (SPWM) is simulated in this work to get integrated with the grid, and a DC voltage regulator is implemented for a PV panel utilising the suggested Luo converter [8]. At nighttime, the voltage is drawn from the battery, which is supplied with the output of the PV panel. A novel technology that has been suggested is this work to provide immense possibilities for smart grid applications and renewable generating systems in the future [9]. The main intention of this work was to enhance the efficiency of solar PV generation initially with considering MPPT techniques and comparative analysis with MPPT techniques has made to attain maximum output. The generated DC output from solar is provided as an input to basic boost and Luo converter which further increases the PV generation for diverse applications. Moreover, a Hardware implementation has been done, and comparative analysis has been conducted with simulation results. Developed hardware provides practical analysis of PV systems for available converters and applications in various fields.

3. PROPOSED SYSTEM

3.1. Representation of block diagram

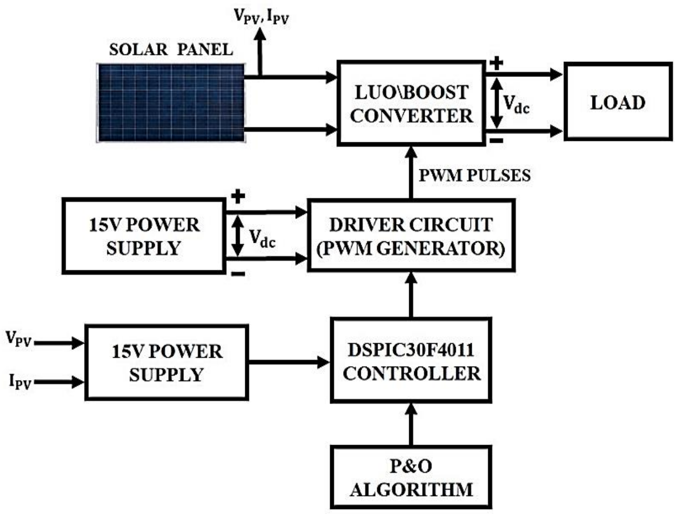

Figure 1. Proposed system Block diagram representation

The use of solar photovoltaic (PV) systems, which directly transform sunlight into clean, sustainable electricity, is on the rise. Solar photovoltaic (PV) arrays are becoming more attractive due to their low upfront cost and ease of installation compared to other renewable energy sources. The depletion and eventual usage of fossil fuels has made renewable energy sources an increasingly pressing global issue. Clean, low-maintenance, and silent, the photovoltaic (PV) power system is quickly rising to the position of most accessible renewable energy source. Utilizing the full output power of a PV array is essential due to the high initial investment required to build the system. To obtain high output gain performance dedicated to feeding both linear and non-linear loads, Figure 1, illustrates proposed system which incorporates a comparison of boost and Luo converters [10]. In order to monitor the solar panel's Maximum Power Point (MPP), the suggested strategy use the P&O observe approach. To maintain a steady output voltage

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International Journal of
Electrical and Electronics Research (IJEER)
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from a converter while increasing its efficiency, the suggested converter (LUO converter) is utilized. Lastly, in order to verify the two converters' functionality, and a hardware prototype will be created utilizing the DSPIC30F4011 Microcontroller. [11].

3.2. Components required

3.2.1. Solar panel

A Solar panel, commonly known as "PV panels," turn sunlight into electricity that can power electrical loads. Solar panels turn sunshine into electricity, which is subsequently utilized to power electrical loads. Solar panels are made up of layers of silicon, phosphorous (negative charge), and boron (positive charge). Solar panels capture sunlight and generate electricity. Photons strike the solar panel surface, releasing electrons from their orbits and creating an electric field that pulls them into a current. It's called the Photovoltaic Effect. Many more solar panels than are needed to power a typical home can be installed on the roof. The extra electricity produced is fed into the main power grid, which offsets its usage during the night. Solar panels are a useful approach to generate electricity for various applications [12]. The obvious choice is off-grid life. Off-grid living refers to living in areas without access to the main electric grid. A well-maintained solar electric system can produce power for up to three decades, thereby saving money. Solar panels not only enable off-grid generation but also provide a clean and renewable source of electricity. *Table 1* shows the rating of solar panel utilized for the work.

Table 1. PV Module Specifications

Power Rating	10 W
Operating Voltage	12-18V
Panel Technology	Poly Crystalline
Wattage (Wp)	10W
Current At Max Power	0.56A
No. Of Cells	36
Operating Temperature	(-10 to +40)

3.2.2. Boost converter

Figure 2 illustrates a boost converter which is a basic form of switch mode converter. As implied by its name, this device takes an input voltage and amplifies or raises it. You can get quite excellent MOSFETs these days, so that's what it is. Other than that, it's just an inductor, a diode, and a capacitor. Additionally, a periodic square wave source is required. The boost converter's functionality relies on the idea of an inductor storing energy. A change in the electric current passing through an inductor will result in a corresponding voltage drop across it [13]. The circuit configuration functions in a way that aids in preserving a regulated and elevated dc output at the load. A solid-state component that functions as a switch, like a power MOSFET, is linked across the source in a boost converter circuit. A diode serves as a secondary switch. The diode is linked to both the capacitor and the load.

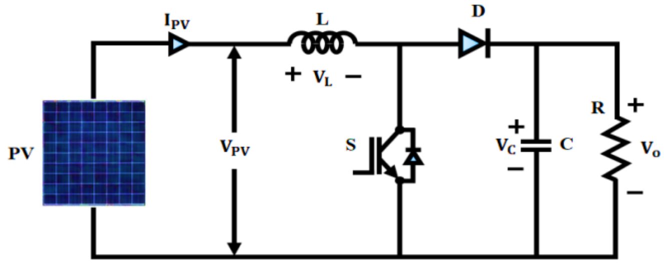

Figure 2. Circuit diagram of a Boost converter

With the inductor linked in series with the power source, the input current remains constant. The boost converter and the loads both provide a steady flow of current and voltage, respectively. Pulse width modulation (PWM) is used to activate and deactivate the controlled switch *S*. Time-based or frequency-based PWM is possible. Because of its ease of construction and application, time-based modulation is commonly employed for Boost Converter. In this form of pulse width modulation, the frequency stays the same. The rating of components used in boost converter is tabulated in *table 2.*

Table 2. Specifications of boost converter

Input voltage	12-40 V
Output Voltage	24- 80 (adjustable)
Output current	Rated current 2A, Maximum 3A
Switching frequency	40Hz
Operating temperature	Industrial grade (-45 to +85)

3.2.3. Luo converter

A novel family of DC-DC step-up (boost) converters called LUO-converters [1] was built from the ground up utilizing the voltage lift technique. With a simple design illustrated in *Figure 3*, great efficiency, and a high-power density, these converters increase the voltage from DC to AC. These Luo converters can be either switched inductor type or switched capacitor type, and they both function in a push-pull condition. The inductors and transformers are absent from the switched capacitor type Luo converter. This enables Controlled energy transfer from an uncontrolled source to a regulated output voltage. The Positive Output Super Lift Luo converter (POSLC) is a powerful DC-DC converter that transforms a positive source voltage to a positive load voltage, resulting in higher positive voltage ranges compared to traditional versions. The rating of components used in Luo converter is tabulated in *table 3*.

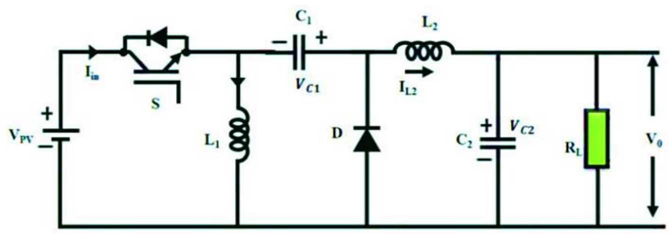

Figure 3. Circuit diagram of LUO Converter

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Research Article | Volume 13, Issue 1 | Pages 178-185 | e-ISSN: 2347-470X

Table 3. Specifications of Luo converter

Input voltage	12-40 V
Output Voltage	48- 160 (adjustable)
Output current	Rated current 2A, Maximum 3A
Switching frequency	40Hz
Operating temperature	Industrial grade (-45 to +85)

Table 4. Boost & Luo Converter Parameters Calculations

Boost Converter	Luo Converter
$\text{Duty ratio} = 1 - \left(\frac{Vin}{Vo}\right)$	$Duty\ ratio = \frac{2Vo}{Vin+2Vo}$
$Inductance = \frac{Vin(Vo-Vin)}{\Delta IL*fs*Vo}$	$Inductance = \frac{(Vo-Vin)*D*(1-D)}{2fs*\Delta IL}$
$Capacitance = \frac{Iomax*D}{fs*\Delta Vo}$	$Capacitance = Vi - \frac{Vo}{8*L*f^2}$

4. SIMULATION ANALYSIS

4.1. Simulation procedure

1. Open MATLAB → Simulink →New Model (.mdl file)
2. Connect the circuit as shown in Simulink model as follows
3. Go to Simulink library browser → Simscape → Power systems → Specialized Technology →Renewables→ Solar → and (drag) add PV Array to working (new) model file.
4. Go to Simulink library browser → Simscape → Power systems → Specialized Technology →Fundamental Blocks → Electrical Sources (Controlled voltage source, etc.) → Measurements (Voltage, current measurement, etc.)
5. Take a controlled voltage source block with ramp control.
6. Go to Simulink library browser →Simulink→ Commonly used blocks→ Sources (Ramp, clock, constant, etc...) → Sinks (Scope, XY Graph, Display, Workspace, etc.)
7. Open (double click) PV Array block and modify the parameters as per the given PV specifications.
8. Run the model and observe the plots.

4.2.1. Boost converter using P&O and INC

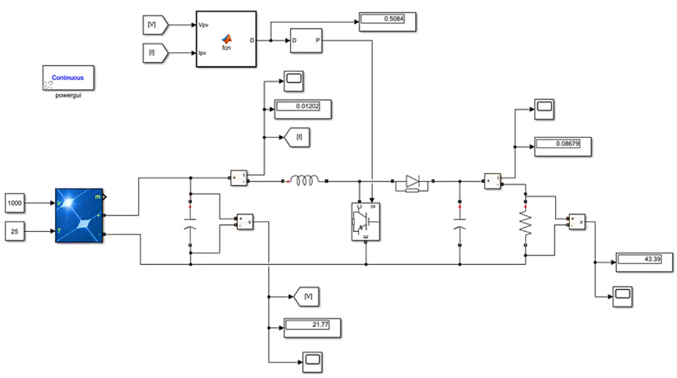

Figure 4. Boost converter using perturb and observe and Incremental Conductance

4.2.2. Luo converter using P&O and INC

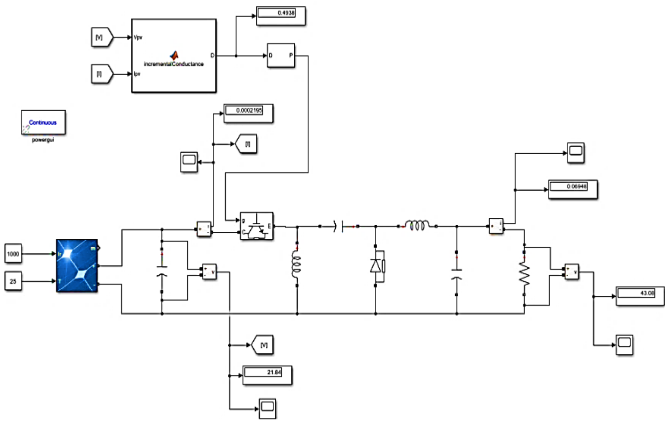

Figure 5. LUO converter using Incremental Conductance

The proposed system for simulating the P&O algorithm and Incremental Conductance [16] for MPPT is shown in *figure 5*. The results are shown in the figure and displayed in the below *table 4*.

Table 4. Simulation results of Boost and Luo converters

Parameters	Boost converter		LUO converter	
	P&O	INC	P&O	INC
Input Current	0.01202	0.09054	0.002510	0.0002195
Input Voltage	21.77	21.41	20.75	21.84
Output Current	0.6679	0.0851	0.09737	0.06948
Output Voltage	43.39	42.55	60.37	43.08

A MATLAB simulation shown in *figures 4* and *5* depict the effect of changing irradiance of the system is done. The simulation results are obtained with considering boost and Luo converters for different MPPT techniques. These values obtained shows the variation considering diverse Converter and MPPT techniques. With converters consideration Luo provides better results with both MPPT techniques in terms of output voltage. Moreover INC-MPPT techniques provides better results comparative to P&O method.

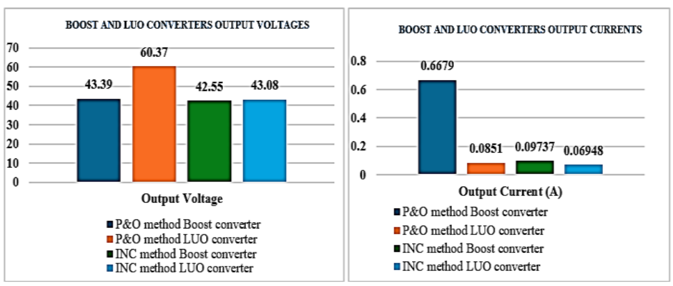

Figure 6. Comparison of Boost and Luo Converter Outputs

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Both converters can achieve high efficiency when properly designed. However, Luo converters have an edge due to their topology which can reduce losses under certain conditions. The output of Luo converter with P&O is high compared with boost with same MPPT. The efficiency will also depend on how well each MPPT technique tracks the maximum power point. INC generally provides faster tracking speed compared to P&O because it uses both voltage and current changes. INC minimizes oscillations better than P&O for both Boost and Luo converters. P&O is simpler but less accurate compared to INC. Ultimately, the choice between a Boost converter and a Luo converter along with either P&O or INC MPPT technique depends on specific application requirements such as cost constraints, complexity tolerance, desired efficiency levels, and environmental conditions. For high power output PV applications Luo converter is considered with INC-MPPT techniques compared with boost converter which provides better results.

5. HARDWARE IMPLEMENTATION

5.1. Driver Circuit

To control another circuit or component, like a high-power transistor, an electrical circuit or other electronic component is employed as a driver in electronics. *Figure 7* illustrates Schematic arrangement of Driver Circuit. They are typically used to regulate the flow of current through a circuit or to control other parameters such as other circuit components or devices. The gate driver circuit is a fundamental component of power electronics converters that drives power semiconductor devices such as IGBTs and MOSFETs. The output of DC-DC converters is mostly determined by how the gate driver circuits work. Therefore, your proposed DC-DC converter's output won't meet your requirements if the gate driver circuit doesn't drive the gate of the MOSFET device correctly. Consequently, power electronics converter design is heavily dependent on gate driver circuit design [17].

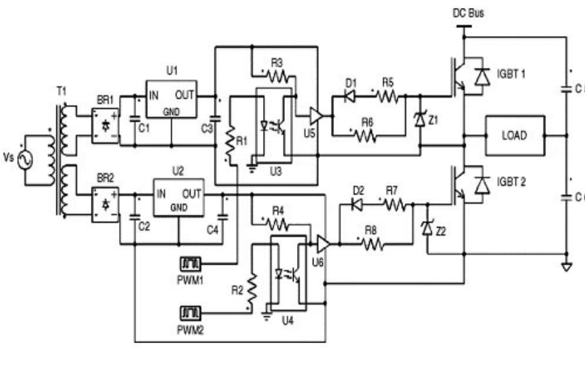

Figure 7. Schematic of Driver Circuit

5.2. DSPIC 30f4011 Controller

The regulated DC output is ripple-free and exceptionally smooth. Typically, two sorts of regulators are employed. Specifically, the regulators can be categorised into positive and negative types. The 78** series of controllers are utilized for positive type regulators. Regulators from the 79** family are utilized for negative type regulators. The selection of the regulator IC depends on the voltage and type of voltage. Due to the industry, education, health, defence, communication, and other factors, microcontroller goods have started to gain attention in recent years. These fields have seen technological advancements, and the need for increasingly sophisticated electronics is growing. A solution for mixed control systems has been built within the microcontroller hardware [17].

By utilizing microcontrollers in electronic circuit designs instead of analogue control elements, it becomes feasible to eliminate several circuit elements and hardware modifications through the use of programmed algorithms. Additionally, analogue circuits have an advantage due to the fact that they can set desired values via a computer and transfer measured values *via* a microcontroller to the computer environment [18]. Microchip launched the DSPIC microcontrollers in 2005. *Figure 8* illustrates Schematic arrangement of DSPIC 30F4011 controller.

These blend the control features of microcontrollers with the computing power and efficiency of DSPs in a single embedded system. Many applications have begun to favour DSPICS Low price and price performance balance in recent years due to its many advantages, including improved and flexible interrupt execution, a large function library for digital and analogue peripherals, different clock frequencies, arbitrary code protection, full debugging capability, real-time simulation at full speed, and more. Microchip introduced and upgraded the dsPIC30F4011, a 16-bit RISC microprocessor, in 2005. The motor is intended to be controlled by the dsPIC30F motor control family. Compared to standard PIC controllers, DSPICS process data far more quickly. It is equipped with high-speed analogue to digital converters and a motor control pulse width modulation (MCPWM) module. Six PWM generators and eight output pins make up the MCPWM modulator. Additionally, the dsPIC30F4011's DSP engine is capable of performing the necessary mathematical calculations. An analogue to digital converter with 10 bits and 1 MSPS is built in.

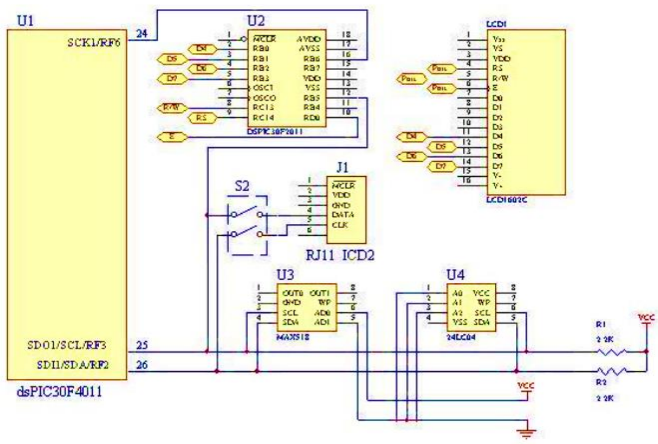

Figure 8. Schematic of DSPIC 30F4011 controller

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5.3. Hardware Outlook

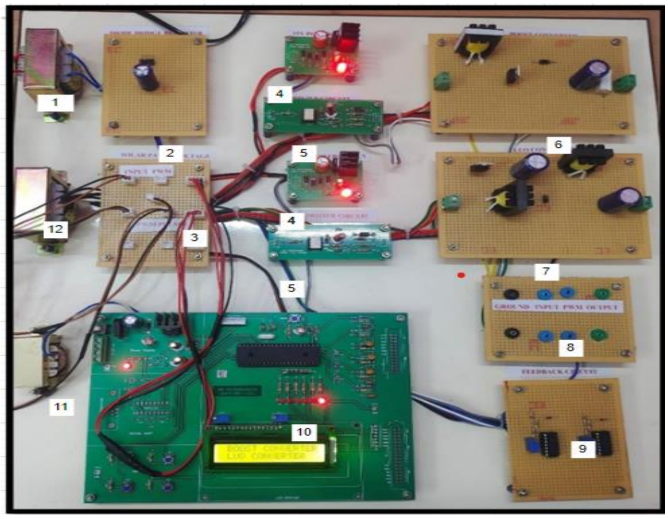
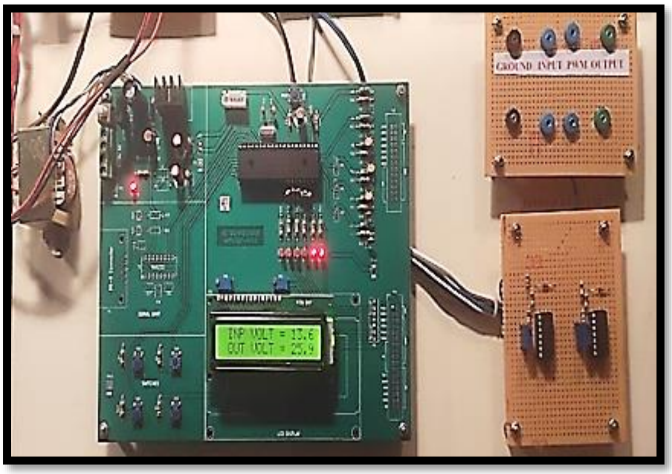
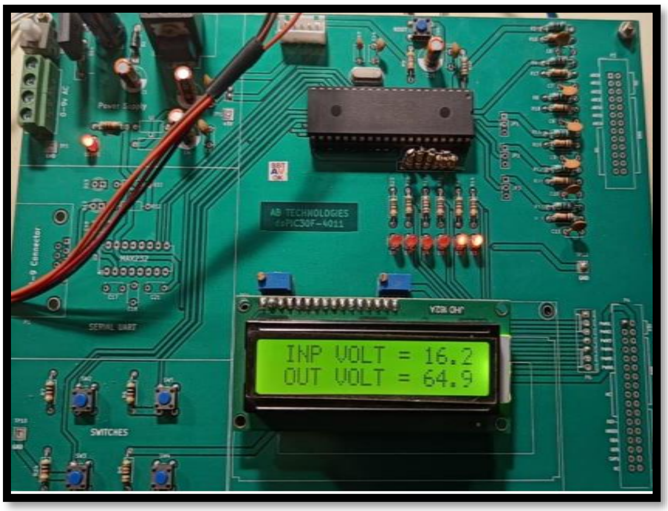


Figure 9. Hardware View with components description



(a)



(b)

Figure 10. (a) Boost converter Hardware (b) Luo converter Hardware implementation

Table 5. Hardware Components detail

S. No.	Name of the component
1	Step down transformer(230/12V)
2	Diode bridge rectifier
3	Voltage divider for PWM
4	Stable DC Supply-15V to converters
5	Driver circuit to each Converter
6	Boost Converter
7	Luo Converter
8	PWM Comparator
9	Feedback circuit to Controller
10	DSPIC 30F4011 Controller
11	Supply transformer for controller
12	Auxiliary Transformer

Figure 11. Overall, Hardware setup with PV input

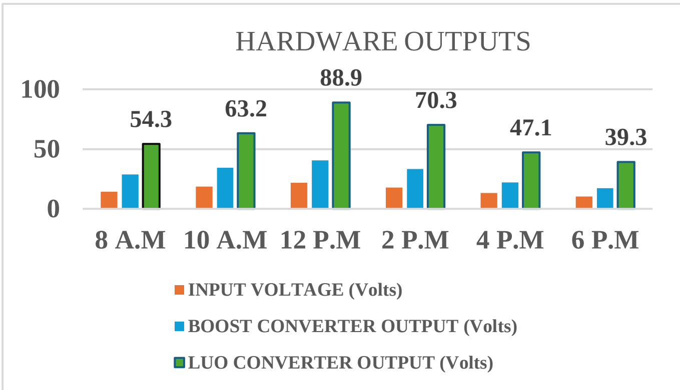


Figure 12. Hardware output for Boost and Luo Converter for different PV inputs

Overall setup is exposed to sunlight from 8 A.M to 6 P.M. As the solar radiations are intermittent the output obtained will vary with time. Initially PV out is obtained with solar radiations as an input is given to boost converter and Luo converter at the same time. As seen from simulation analysis performance of Luo is good compared with boost converter in terms of output voltage the same can be seen with practical setup. At 12 P.M a maximum output voltage is obtained with Luo compared with boost with same input is given for both the converters. Moreover, the hardware setup results concludes that Luo converter provides better performance compared with boost converter, as it varies with design.

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Table 6. Observations for Various Irradiation with Hardware

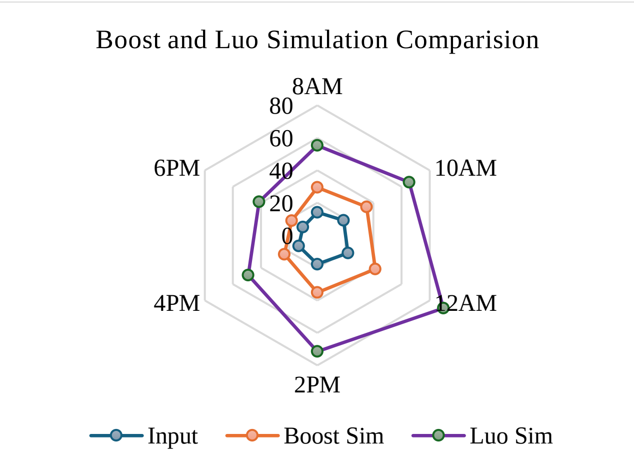
Time	Input Voltage	Boost Converter Output (Volts)	Luo Converter Output (Volts)
8 A.M	14.2	28.7	54.3
10 A.M	18.6	34.5	63.2
12 P.M	21.8	40.4	88.9
2 P.M	17.7	33.3	70.3
4 P.M	13.2	22.2	47.1
6 P.M	10.3	17.4	39.3

With intermittent nature of solar radiations which directly effects the solar output and the raise in temperature which terms as inversely related with output voltage. The *figure 12* shown as a tabulated value in *table 6*. The solar radiations are a dependent variable on several aspects like seasons, day-night and temperature. The output voltage of converter obtained depends upon input voltage which obtained from solar conversion in PV. The converter output is affected directly with input voltage and indirectly with solar radiations.

5.4. Comparative Assessment with Discussions

Table 7. Comparative analysis and Discussions

Time	Input voltage (volts)	Boost converter Output voltage (volts)		Luo converter Output voltage (volts)	
		Simulink	Hardware	Simulink	Hard ware
8 A.M	14.2	29.5	28.7	55.3	54.3
10 A.M	18.6	35.2	34.5	65.4	63.2
12 P.M	21.8	41.3	40.4	89.7	88.9
2 P.M	17.7	35.2	33.3	71.5	70.3
4 P.M	13.2	23.4	22.2	49.1	47.1
6 P.M	10.3	18.2	17.4	41.4	39.3



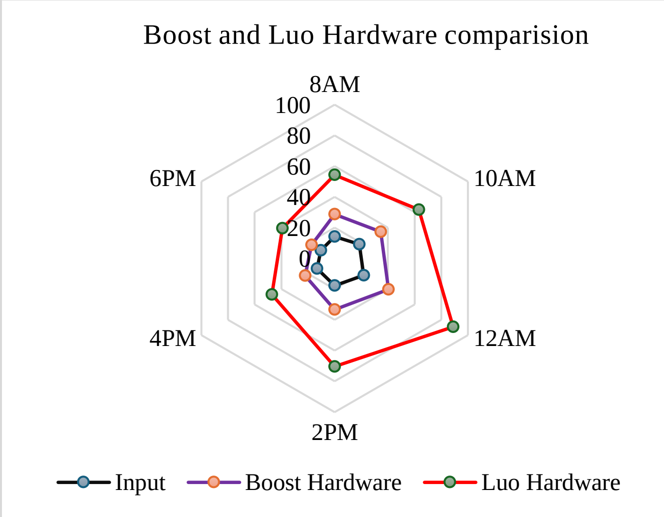


Figure 13. Boost and Luo Converter Comparative assessment for different PV inputs

From the above *figure 13* it can be assessed that the hardware implemented is almost nearer to the Simulink values and discussed for Incremental conductance technique which provides better results. As the output from the solar is not continuous due to its intermittent nature the generation is also not continuous. The PV generation depends upon the time and seasons. There is a need of continuous and constant power supply to the battery to store energy from the PV. For different time interval of a particular day the PV generation is noted and considered as an input voltage for various converters along with MPPT techniques. The output of Boost and Luo converters provided better results based on their switching operation as shown in *table 7*. In this work the hardware implementation provides the enhanced output for the generation from PV with considering various topologies like boost and Luo converters. To extract maximum solar power various MPPT techniques has been implemented and future the output PV is enhanced with converters for various applications. The novelty of hardware design to achieve maximum power output from solar helpful for further studies and can attain more output with change in converter topology based on the application.

6. CONCLUSION

This has made a valuable contribution to this field by demonstrating the effectiveness of MPPT algorithms for extracting maximum power from solar energy. By optimizing the tracking of the maximum power point, it has shown that these algorithms can significantly improve the efficiency of the PV system, resulting in a more cost-effective solution for generating renewable energy. In addition, benefits of using the DC-DC Luo converter for small DC loads, which can further improve the performance and reliability of the PV system. Comparative analysis of various MPPT techniques provides valuable insights into their advantages and disadvantages, which can inform future research and development in this area. This analysis can help researchers and practitioners to identify the most effective MPPT techniques for different applications and to develop new and innovative solutions to improve the performance of solar PV system. It has shown that by employing advanced technologies and techniques, and that improved the efficiency and cost-effectiveness of solar PV systems and accelerate the transition to a more sustainable future.

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