International Journal of Science, Technology and Management (IJSTM) ISSN (online): 2321-774X
Volume 10, Issue 1, 2023

Modeling of Conventional Dc-Dc Boost Converter And Modified Sepic Boost Converter Based Grid Connected PV Array System

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ABSTRACT

Currently, solar energy is gaining popularity as a preferred renewable energy resource due to factors such as environmental concerns, government support, and its abundant availability. However, integrating solar energy with the utility grid poses several challenges for researchers. These challenges include dealing with complex electrical equipment, DC/AC conversions, multiple voltage levels, adherence to grid codes, and selecting appropriate modeling techniques for specific applications. Additionally, there is a need to enhance the performance of solar energy systems to match the capabilities of other energy resources. In this study, a dynamic model of a grid-connected PV system is developed.

Keywords: Solar Energy, Voltage Levels, On-Grid, PV System

INTRODUCTION

In the future, renewable energy sources (RES) will play a crucial role in meeting power demand due to the limitations of non-renewable energy sources (NRES) like fossil fuels. Fossil fuels, which took hundreds of millions of years to form, have been rapidly consumed in the past 2000 years, depleting reserves and causing significant impacts on climate change. If production continues at current rates, most non-renewable resources will be exhausted within the next 50 years, and even sooner within 25 years if production rates increase [1]. However, as the human population grows, the demand for electricity also increases proportionally, necessitating alternative solutions. Currently, fossil fuels dominate global electricity generation, but their finite availability calls for the exploration of other sources to replace their role. Implementing renewable energy sources, such as [2], emerges as the most viable solution to address this issue.

- Wind power
- Bioenergy
- Geothermal energy
- Hydropower
- Solar energy
- Fuel cells, etc.

Solar Energy

The inclination towards renewable energy stems from the ongoing advancements in technology. Among the various alternatives, solar energy emerges as one of the most promising and feasible options.

FIG 1*: Solar energy growth per year in India*

Solar energy is considered the optimal investment choice among renewable energy sources, particularly in countries like India, due to its widespread availability throughout the year. Additionally, solar energy is less dependent on specific geographical sites, although it does require substantial free space. These factors collectively contribute to making solar energy a superior resource when compared to other renewable energy sources. [4]

PV Cell

Silicon, a semiconductor material, plays a crucial role in solar cells due to its unique properties. This is achieved by creating an electrical imbalance within the solar cell, which acts as a slope or pathway along which the electrons can flow in a specific direction [5].

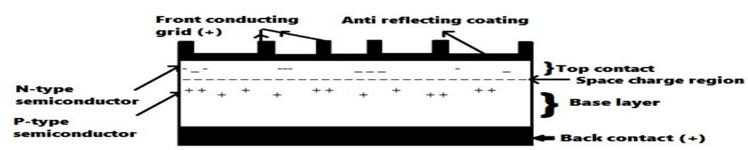

FIG 2*: Schematic diagram of PV cell*

The creation of an electrical imbalance within a solar cell is facilitated by the internal structure of silicon. The n-type silicon contains excess electrons, while the p-type silicon has electron deficiencies, resulting in holes [6]. These two types of silicon are placed adjacent to each other within the solar cell.

2.0 LITERATURE REVIEW

This research work focuses on addressing the research problem of modeling and implementing a modified SEPIC boost converter system within a grid-connected PV array system. To mitigate the adverse impacts of rising temperatures, renewable energy sources are often considered as the most effective solution [1-11]. Given the growing urgency of global energy issues, there is a significant emphasis on the development of new energy sources and related technologies. Both power grids and PV power plants must address these challenges as they navigate this evolving landscape [12]. Among these, the perturb and observe (P&O) and incremental conductance (INC) algorithms are the most commonly used methods in PV systems. Although the INC MPPT algorithm is more complex compared to the P&O method, advancements in microchip devices have made it easier to implement in controller systems [13-14].

To address this issue, maximum power point trackers (MPPT) are employed to optimize the utilization of PV modules and minimize power loss due to environmental conditions [15]. This droop controller incorporates bounded voltage dynamics and a constant virtual resistance to ensure system stability and achieve the desired limitations in a closed-loop configuration [16].

On the other hand, active schemes introduce disturbances into the grid and monitor their effects, which may impact the power quality [17]. These limitations are in place to prevent saturation of distribution transformers. While this solution does not directly resolve the issue of DC injection, it simplifies the grounding of the PV modules [18-19].

The thorough review of literature concludes the objective that PV array, DC-DC boost converter, inverter with transformer and filter are the main components of the PV system connected to grid, which are being used to convert solar energy into electrical energy. Clear understanding of the characteristics and accurate modeling of their dynamic performance of these components are of fundamental importance for analysis of grid connected PV array system. Therefore, one of the objectives of this work is to implement accurate dynamic modeling of PV connected grid system.

3.0 METHODOLOGY

In recent years, there has been a substantial increase in the demand for renewable energy this is primarily due to advancements in power electronic technologies and the abundant availability of solar energy, especially in countries like India, where it is freely accessible.

PV Array

Photovoltaic (PV) sources have gained significant popularity in various applications due to their maintenance-free and pollution-free nature. Solar energy can be harnessed in two different ways. The first approach involves utilizing stand-alone systems where the harvested energy is stored in batteries for supplying nearby loads.

The PV array, DC-DC boost converter, three-phase inverter, filter, transformer, and grid are the key components of a grid-connected PV array system. Therefore, it is crucial to accurately model the various components of the grid-connected PV array system. Understanding their characteristics and precisely modeling their dynamic performance are fundamental for studying power dynamics and steady-state operation.

DC-DC Boost

Traditionally, conventional DC-DC boost converters have been employed to increase low voltage levels. Typically, conventional DC-DC boost converters require high duty cycles to achieve high output voltages [15]. However, this results in high switching voltage stress and substantial inductor current ripple, which adversely impact conversion efficiency and voltage gain [16]. Hence, to enhance the efficiency of power conversion, it is necessary to develop a well-designed DC-DC boost converter capable of effectively regulating the output voltage.

RESULTS & DISCUSSIONS

This section discusses the results obtained by modelling the using the described methodology in the previous section to solve our problem statement.

Grid Connected PV Array system

Initially, photovoltaic systems were primarily utilized as independent systems to supply electricity to remote rural areas lacking alternative energy sources. However, advancements in technology and growing concerns regarding global warming have prompted both utility companies and consumers to increasingly adopt grid-connected PV array systems [12].

Standards such as IEEE [18] and IEC [19] have imposed restrictions on the maximum permissible level of DC current injected into the grid. A grid-connected PV array system consists of several components, which can

International Journal of Science, Technology and Management (IJSTM) ISSN (online): 2321-774X
Volume 10, Issue 1, 2023

be categorized into two sides: the DC side and the AC side.

The PV array system connected to the grid primarily consists of a configuration of PV arrays that convert sunlight into DC power. This DC power is then converted to AC power through a power conditioning unit. The resulting AC power is injected into the grid and can be utilized by local loads. In certain situations, storage devices may be incorporated to enhance the availability of the power generated by the PV system.

Figure 3 illustrates the schematic diagram of the various components comprising a detailed 100 kW grid-connected array system, including a conventional DC-DC boost converter and its control mechanism. The mathematical modeling of the system is outlined as follows:

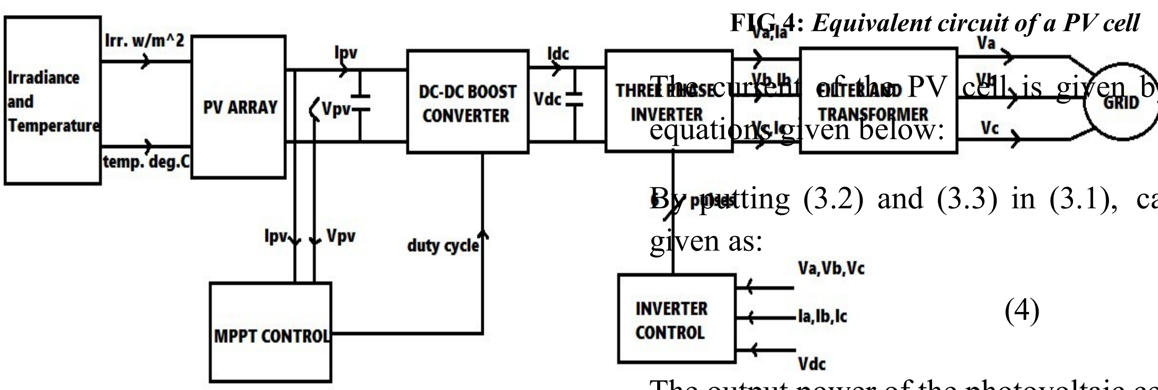

FIG 3 ***Schematic diagram of grid connected PV array system with conventional dc-dc boost converter***

PV array

A solar panel, also referred to as a solar module, is comprised of silicon cells, a metal frame, a glass casing, and wiring that enables the flow of current from the silicon cells. [20]. To mathematically model the PV array, a single diode equivalent circuit of a PV cell is considered, as depicted in Figure 4. Applying Kirchhoff's Current Law (KCL) to the ideal photovoltaic cell, the generated output current of the cell can be expressed as the difference between the photon current and diode current, as shown in equation (1).

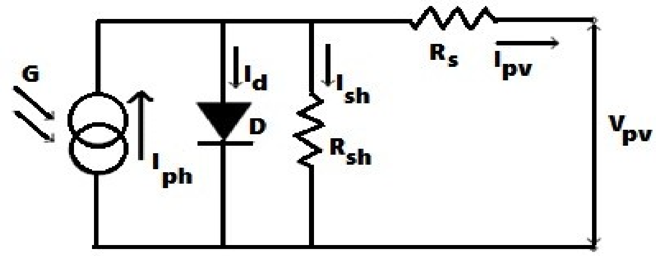

FIG 4: ***Equivalent circuit of a PV cell***

The current of the PV cell is given by the equations given below:

By putting (3.2) and (3.3) in (3.1), can be given as:

(4)

The output power of the photovoltaic cell is given by:

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(5)

Where,

denotes the diode current, denotes the photon current, denotes the cell current, denotes the saturation current of diode, denotes the electrical charge, denotes the ideality factor, denotes the cell temperature in Kelvin, denotes the Boltzmann constant, denotes the terminal voltage of the array, denotes the series resistance, denotes the shunt resistance

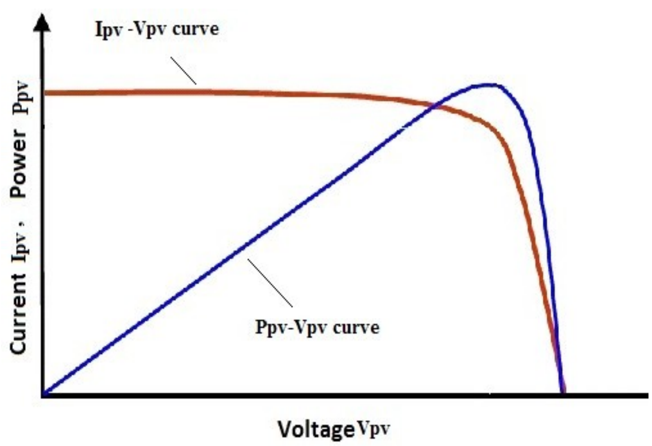

FIG 5 ***Characteristics of PV cell***

Hence, the mathematical model of a PV array is derived by incorporating equations (1) to (5), which account for the configuration of parallel and series cells, as well as the losses associated with resistances.

DC-DC boost converter

The primary goal of incorporating a DC-DC converter in the Maximum Power Point Tracker (MPPT) is to achieve the following objectives:

- Regulating the input voltage at the PV MPP and
- For providing load matching for the maximum power transfer [18].

DC-DC converters come in various types, including isolated and non-isolated topologies. Isolated topologies provide electrical isolation between the input and output, making them suitable for applications such as switch mode DC power supplies. In the context of PV systems, isolated topologies are commonly used in grid-tied systems to ensure safety and compliance [19].

Furthermore, a boost converter, also known as a step-up converter, is a type of DC-DC power converter that increases the output voltage while decreasing the input current. In PV grid-connected arrays, boost converters with a frequency range of 5 KHz to 500V are utilized. To mitigate voltage ripple, filters consisting of capacitors, sometimes in conjunction with inductors, are commonly employed at the output (load-side filter) and input (supply-side filter) of such converters.

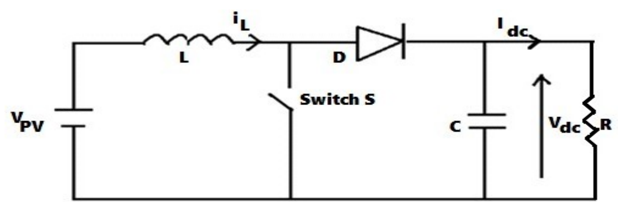

FIG 6 ***Circuit diagram of conventional dc-dc boost converter***

This circuit depicted in Figure 6 is specifically designed to function in the continuous conduction mode, wherein it operates in a cyclical manner between two loops. When the switch is in the "ON" state, the current flowing through the inductor increases, resulting in energy being stored within it. Simultaneously, during this period, the capacitor C discharges through the load resistor R, following a relationship that can be described as follows:

MODIFIED SEPIC CONVERTER

The SEPIC (single-ended primary-inductor converter) is a DC-DC converter that offers the flexibility to have an output voltage greater than, less than, or equal to its input voltage. The control of the SEPIC's output is achieved by manipulating the duty cycle of the control transistor (S) [15].

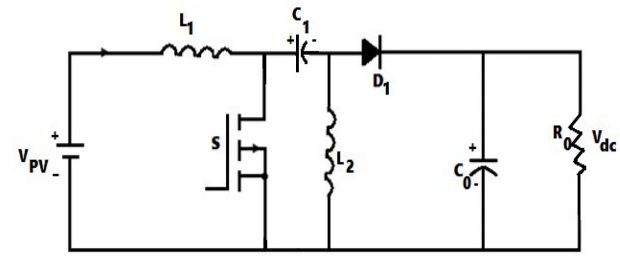

FIG 7 ***Circuit diagram of conventional SEPIC converter***

A SEPIC converter can be seen as a combination of a boost converter and an inverted buck-boost converter, providing certain advantages over a traditional buck-boost converter. These advantages include a non-inverted output (same polarity as the input), the use of a series capacitor for improved response to short-circuits, and the ability to achieve true shutdown when the switch S is turned off sufficiently. The schematic diagram of a basic SEPIC converter is shown in Fig.7. Like other DC-DC converters, the SEPIC converter transfers energy between capacitors and inductors to convert between different voltages. The amount of energy transfer is controlled by the switch S, typically implemented as a transistor such as a MOSFET.

To enhance the performance of the SEPIC converter for PV systems, a modified SEPIC converter is developed by combining a conventional SEPIC converter with a DC-DC boost converter and a diode-capacitor circuit. This modified converter offers several advantages, including high voltage gain, low switching voltage stress, and low conduction losses. One key advantage of the modified SEPIC converter circuit is its ability to achieve high gain for a given duty cycle.

The modified SEPIC converter incorporates a diode-capacitor circuit in series and utilizes MOSFETs with low voltage ratings and low resistance. This design choice effectively reduces the voltage stress across the MOSFETs and diodes, resulting in increased conversion efficiency for the proposed model. The modified SEPIC converter topology is particularly suitable for renewable energy-based applications that operate with low input DC voltage.

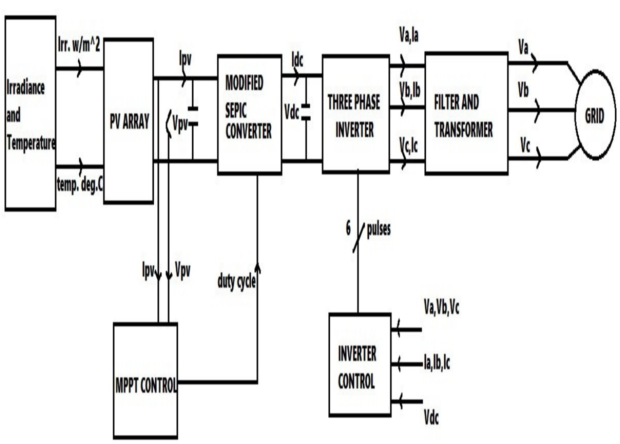

FIG 8 ***Schematic diagram of grid connected PV array system with modified SEPIC converter***

The proposed converter's circuit topology is illustrated in Figure 8. It comprises several components, including a DC voltage source (V_{dc}), a main switch (S), three diodes (D_1, D_2, and D_3), three capacitors (C_1, C_2, and C_3), two inductors (L_1 and L_2), an output diode (D_0), and an output capacitor (C_0). To enhance the static voltage gain, a diode-capacitor-based SEPIC converter is proposed by combining it with a boost converter. The inclusion of diode-capacitor elements helps alleviate stress on the switch. Capacitor C_2 is charged with the converter's output voltage, and during the conduction period of power switch S, the voltage from capacitor C_2 is applied to inductor L_2, thereby increasing the voltage gain compared to a conventional DC-DC boost converter.

5.0 CONCLUSIONS

In addition to the primary objective of this work, which is the detailed modeling of the power circuit and control circuitry of the grid-connected PV system, several significant conclusions have been drawn, including:

- The designed parameters of the modified SEPIC converter are:

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- The grid-connected PV system equipped with a conventional boost converter achieves an efficiency of 93.5%, whereas the designed boost converter enhances the system's efficiency to 96.2%.

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