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Simulink Based Modelling and Simulation of Solar Power Generation with Grid Interconnection System Using Matlab for Home Appliances

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Abstract: Solar energy is a vital resource that sustains life on Earth and offers an inexhaustible supply of clean energy. The utilization of solar cells in various industries and household appliances is on the rise due to the anticipated significant role of solar energy in future smart, distributed renewable sources. The amount of sunlight energy that reaches the Earth every hour is ample enough to meet the world's annual energy demand. In today's generation, the need for electricity persists on an hourly basis. This review presents a comprehensive electrical model for a 5.8 kW solar photovoltaic (PV) grid-connected power system. The aim is to effectively track the maximum power points considering the fluctuations in solar irradiation and temperature. Additionally, the project focuses on providing an analytical evaluation of the challenges associated with advanced grid-connected inverter systems. To validate the proposed 5.8 kW solar PV grid-connected power system, a modulation and simulation are conducted using MATLAB/SIMULINK.

Keywords: Solar power Generation; Sustainable Energy; Smart Grid; Energy Efficiency; Simulink

1. Introduction

The integration of renewable energy sources into the power grid has gained significant attention in recent years due to the need for sustainable and clean energy solutions. Solar power generation, in particular, has emerged as a promising technology with its abundant availability and environmentally friendly characteristics. The use of solar energy in residential settings has witnessed a remarkable growth, as it provides an opportunity to reduce dependence on fossil fuels and decrease carbon emissions .It aims to develop a comprehensive model and simulation framework for a solar power generation system connected to the electrical grid.

Renewable energy sources, including solar energy, fuel cells, batteries, and ultra-capacitors, have garnered considerable attention in the field of distributed power generation systems. In line with this, the present paper aims to put forward a comprehensive mathematical model for solar cells, followed by the implementation of a visually programmed simulation using MATLAB/Simulink software [1]. Bharathypriya D et al. conducted a study on the application of power electronic technology in diverse areas involving the generation and distribution of electrical power, particularly within solar photovoltaic panel systems. The research focused on the design and modelling of crucial parameters related to solar photovoltaic systems, including saturation current, photo current, reverse saturation, shunt resistor current, as well as voltage-current and voltage-power characteristics of solar photovoltaic cells. The simulation of these parameters was performed using MATLAB/Simulink software [2].

Jawairia Atiq et al. conducted a comprehensive analysis on the influence of solar irradiance and temperature on the overall power generation of a grid-connected PV system. The research focused on developing and modelling control strategies to ensure a constant voltage at the inverter output and synchronization of the output frequency with the electric utility grid. Specifically, a phase-locked loop and a regulator were designed and modelled for this purpose. The modelling approach employed in the study is straightforward and can be easily adapted to different temperature and solar isolation conditions. The proposed model encompasses a PV array, a maximum power point tracker, a boost converter, an inverter, and an LC filter [3]. The author introduces a promising and environmentally-friendly approach to power generation that offers economic benefits for future generations. The proposed method involves harnessing the DC output from photovoltaic panels and the rectified DC output from a wind energy conversion system. These two sources are combined and fed into a closed-loop boost converter, ensuring a constant output regardless of the prevailing environmental conditions [4].

Solar energy sustains life on Earth and represents an inexhaustible and environmentally-friendly source of power. Over the past five decades, extensive research has been conducted to explore various design aspects and performance characteristics of Photovoltaic (PV) cells. The ultimate objective has been to develop fully integrated PV modules that can effectively compete with conventional energy sources. There is a growing inclination towards utilizing solar cells in both industrial and residential applications due to the anticipated significant role of solar energy in future smart grids as a distributed renewable energy source [5]. The performance of solar modules is influenced by factors such as solar isolation and temperature. Elevated temperatures have a detrimental impact on the operational lifespan, technical characteristics, and efficiency of solar modules. As the temperature rises, the efficiency of the modules decreases. In order to study this relationship, a model of an autonomous solar power plant was developed using the MATLAB/Simulink program. The model takes into account the correlation between the temperature rise of the solar modules and their efficiency during operation. During the operation of the model, the batteries connected to the solar modules are charged, and the inverter converts the direct current (DC) generated by the modules into alternating current (AC) [6].

A grid-connected solar photovoltaic system utilizes a DC-DC boost converter and a DC/AC inverter to supply electric power to the utility grid. The PV cell model employed in this system is both straightforward and precise, as it incorporates external temperature and solar radiation as influential factors. The simulation results demonstrate the impact of variations in solar radiation on the power output of any PV system. Additionally, they showcase the control performance and dynamic behavior of the grid-connected photovoltaic system [7]. In certain circumstances, it may not be feasible to physically validate the performance of a PV-based power system using a DC-DC converter due to practical limitations. To address this, a simulation of a mathematical model for a photovoltaic (PV) module and a DC-DC boost converter is conducted. The simulation focuses on the behavior of the DC-DC converter, and the results are obtained by comparing a constant DC supply-fed converter with a PV-fed converter [8].

The outcomes of this project are expected to contribute to the understanding of solar power generation systems and their effective integration into the existing electrical grid infrastructure. The insights gained from this study will facilitate the adoption and optimization of solar power systems for residential applications, thereby promoting sustainable energy practices and reducing the environmental impact of conventional energy sources.

2. Proposed Methodology

The solar energy that reaches the Earth's surface within an hour and a half possesses the capacity to fulfill the global energy consumption for an entire year. Solar technologies harness this energy by converting sunlight into electrical energy using photovoltaic (PV) panels. When sunlight strikes a solar panel, the PV cells within the panel absorb the energy from the sunlight. This absorption prompts the creation of electrical charges within the cells, which in turn generate an electric current due to the internal electrical field of the cell.

In standalone systems, which are not connected to the grid, it becomes necessary to incorporate a battery bank for energy storage. This enables the storage of excess energy produced during periods of high sunlight for later use when sunlight is insufficient. However, in grid-connected systems, any surplus energy generated beyond the immediate requirements of the end user can be transmitted back to the utility grid. This surplus energy is then utilized in areas experiencing energy shortages. Consequently, in grid-connected systems, the communal electricity grid functions as both an energy source and a storage mechanism. The block diagram for the solar power generation is shown in Figure 1.

A solar panel is comprised of series and parallel strings. The determination of the number of series-connected solar panels in a string involves considerations such as the supply voltage, voltage drop across the line inductor, supply voltage fluctuation, and the dependence of open circuit voltage on temperature and irradiance. On the other hand, the number of solar panel strings connected in parallel is determined based on the power rating of the entire plant. It is worth noting that connecting multiple panels can potentially impact simulation performance by increasing the number of elements within the model, as depicted in Figure 2.

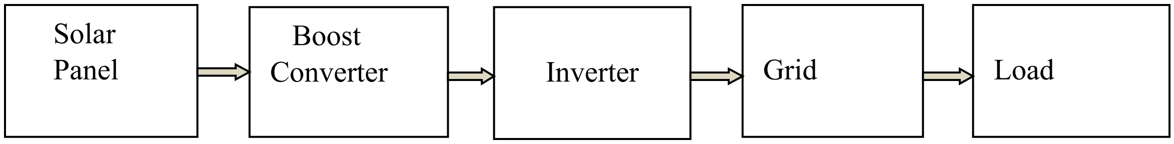

Figure 1 Block diagram for solar power generation

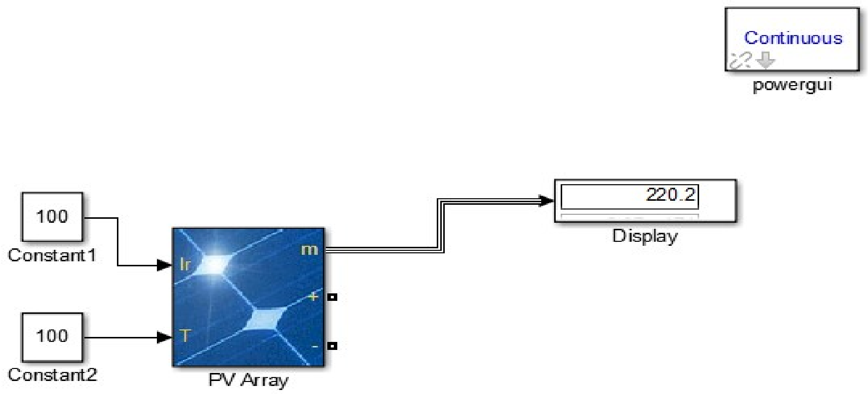

Figure 2 MATLAB Simulink Circuit for PV array

To achieve a boosted and regulated output voltage from the photovoltaic (PV) array, a DC-DC boost converter is employed, as illustrated in Figure 3. This converter also facilitates the implementation of maximum power point tracking. The output voltage of the converter is determined by the equation V0 = Vin / (1 - D), where V0 represents the output voltage, Vin denotes the input voltage, and D signifies the duty cycle value. The selection of the inductor and capacitor in the circuit involves specific equations as

$$L > \frac{V_{in} x D}{f x \Delta I}$$

$$C1=C2= \frac{V_{out} D}{2 f \Delta V_{out} R_{load}}$$

The inductor value (L) must exceed a certain threshold, which is determined by other factors not specified here. The capacitance values of C1 and C2 are set to be equal. Additionally, other variables related to the converter include the converter frequency (F), the current ripple (I), the output voltage ripple (Vout), and the load resistance (R), which is derived from Vout divided by Iout.

Grid-connected systems consist of essential components, namely the PV array and the inverter, as depicted in Figure 4. The PV array serves the purpose of converting solar energy into DC power, while the inverter plays a vital role in converting this DC power into AC power. Subsequently, the generated power can be utilized by the load or, alternatively, redirected back to the utility grid. Consequently, the array of solar panels and the inverters are recognized as the fundamental building blocks of grid-connected systems.

3. Results and Discussion

Home appliances cannot directly utilize the electricity stored in battery systems without converting it into alternating current (AC). This is because batteries and solar panels operate on direct current (DC). Hence, inverters play a crucial role in ensuring the proper functioning of any solar panel system. Solar panel inverters serve as a vital safety mechanism for the system as well. They are designed to detect any anomalies or irregularities in the system's operation and promptly shut off the power supply. This protective feature safeguards the home from potential electrical issues, equipment malfunctions, and other related risks. The waveform of the inverter can be observed in Figure 5 .

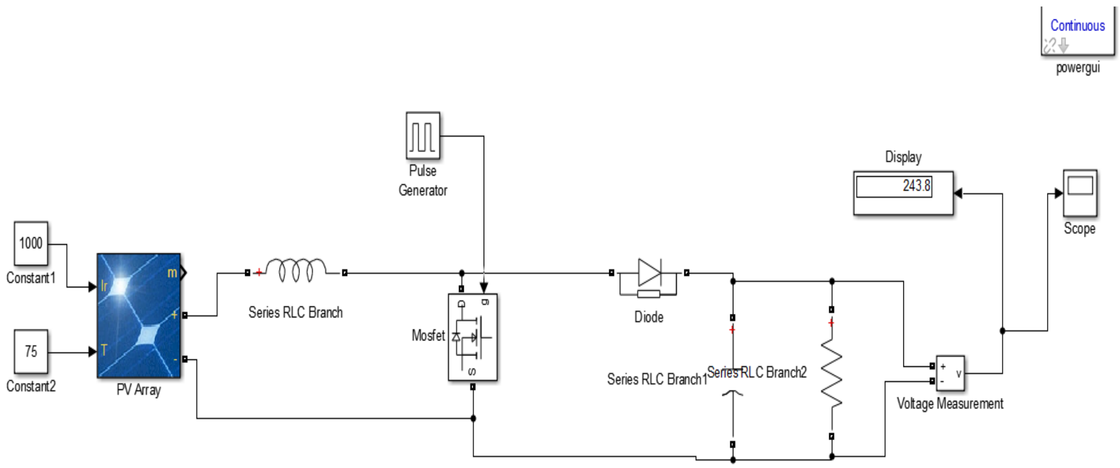

Figure 3 MATLAB Simulink Circuit for Boost converter

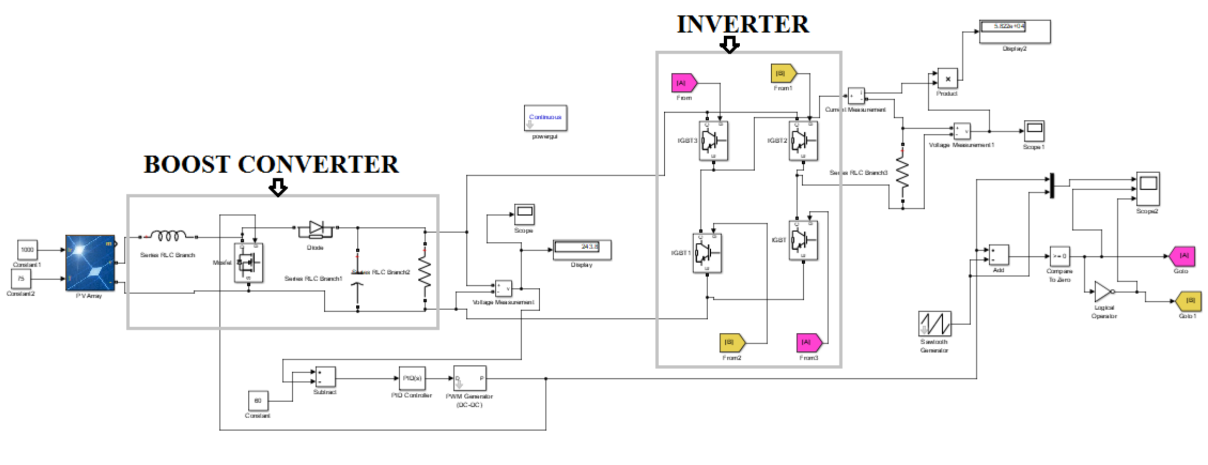

Figure 4 MATLAB Simulink Circuit for Inverter

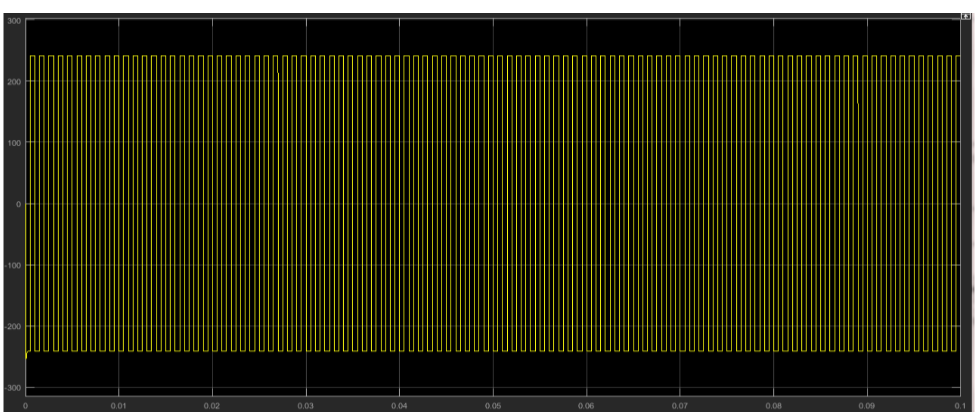

Figure 5 Waveform for inverter

In a typical household, the power consumption of essential items typically ranges from 5000 to 7000 watts. Starting watts refer to the additional power required for a brief period of two to three seconds to initiate motor-driven devices. If the running watts are not specified for a particular tool or appliance, an estimation can be made using the following equation:

Watts = Volts * Amps

Table 1. Calculation of power for home application

Appliance	Hours	No of appliance	Watts	Total watts
Light	10	1	80	800
Fan	6	1	75	450
Fridge	24	1	500	1200
TV	3	1	250	750
Mixer	0.40	1	500	200
Grinder	0.75	1	500	375
Washing machine	1	1	500	500
			Total	4,275kw/h

The total power consumption of the appliances in a given period is calculated to be 4,275 kWh as in Table 1. It allows us to infer that the combined energy usage of the listed appliances over the specified duration is significant. It is important to note that these calculations provide an estimation of power consumption and may vary depending on the specific models and usage patterns of the appliances. Proper monitoring and management of energy usage can contribute to more efficient and sustainable electricity consumption in a household.

4. Conclusion

This project focuses on the modelling of a 5.8 kW grid-connected photovoltaic (PV) system using MATLAB/SIMULINK. The system presented comprises several components, including a solar PV array, a PID controller used to regulate the power from the PV array, a DC-DC boost converter employed to regulate and amplify the output of the PV array, an inverter responsible for converting the DC power into AC power, and an LC filter designed to filter current harmonics from the inverter's output current. The successful modelling and simulation of the grid-connected PV system using MATLAB/SIMULINK provide a solid foundation for further exploration and advancement in this field. Future research endeavours may involve investigating and optimizing the system's performance under varying environmental conditions, integrating energy storage systems for enhanced grid resilience and stability, exploring advanced control strategies for improved power management, and evaluating the system's performance in real-world scenarios. Additionally, advancements in PV technology and the integration of smart grid concepts can contribute to the ongoing development of efficient and sustainable grid-connected PV systems.

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