[1] Abdullah Sami Assaf
[2] Sefer Kurnaz

Modelling and Analysis of High Performance for Solar Power Injection with Distribution Networks

Journal of Electrical Systems

Abstract: - Given the growing emphasis on environmental consciousness, there is a spike in the integration of solar photovoltaic energy into contemporary distribution networks. Interestingly, there is a non-linear relationship between the energy production of solar modules and changing external environmental conditions. In response, this study aims to increase the effectiveness of solar photovoltaic systems (SPVS) by putting out a careful analysis to ascertain the ideal performance criteria for the integration of renewable energy sources into distribution networks. The use of a Maximum Power Point Tracker is crucial to this assessment (MPPT). The model provides important insights into the possible increases in energy efficiency, making it a strong tool in this optimization process. In addition, the research conducts a comparison analysis, examining the distribution system properties in relation to different levels of solar PV system penetration. This aspect of the research illuminates the consequences of harmonic-induced distortions in current and voltage on the feeder networks in the distribution system. The simulation findings clearly show that as the penetration capacity of the PV system increases, so does the amount of harmonic dispersion that is introduced into the network. This suggests that it would be wise to incorporate the photovoltaic (PV) array only as far as the network can support it in order to prevent any possible performance reduction. Using MATLAB/SIMULINK as a computational tool, the research carefully examines the important characteristics from the technical data in order to examine the overall model. Further testing of the model's flexibility and resilience under a range of weather scenarios and partial shade conditions offers a thorough assessment of the model's performance dynamics. Positively, the investigation concluded with results that were satisfactory and confirmed the system's exceptional performance capabilities, which are supported by the MPPT. This result reflects a positive trend toward maximizing the integration of renewable energy sources into distribution networks, which will help to create a more sustainable and environmentally friendly energy landscape.

Keywords: High Performance, solar photovoltaic systems, Distribution Networks, Solar Power Injection.

I. INTRODUCTION

Renewable energy sources like wind, tidal, solar, biomass, etc. are given a fresh impetus due to the depletion of fossil fuel supplies and the daily rise in pollution caused by global warming [1]. Due to their numerous advantageous qualities, including low maintenance requirements, the ability to be deployed in distant locations, and the ability to function as a stand-alone system, photovoltaic, or PV, systems are becoming increasingly common. Due to the photovoltaic system's unrestricted access to solar energy on the earth's surface and recent advancements in power electronics will soon overtake all other renewable energy sources as the most significant one. The sun's energy fluctuates during the day since it depends on temperature and air radiation. Connecting to the PV module requires a battery backup in order to guarantee supply continuity to the utility grid [2]. When the output of the PV system surpasses the total amount of demand, the excess power will be utilized to charge the battery. The amount of solar energy that can be produced during the day varies depending on the temperature and other characteristics of the atmosphere. Attaching the battery as a backup will allow the utility grid to be powered continually. These days, a PV system with power return can feed an AC grid system directly [3]. The network application is offered with the bi-directional adaptor in [4]. Solar energy is immediately converted into electrical energy by solar panels and inverters. Low-efficiency silicon and germanium semiconductors are used to build these panels [5]. A solar photovoltaic system may be one of the finest renewable energy sources if correctly regulated. The Maximum electricity Points Controller (MPPT) is employed for the PV module to provide the most electricity. When managed optimally, the solar module will produce its maximum output. many optimization technologies, including Fuzzy Logic Controllers (FLC), Altitude climb Problem Monitoring, etc . It may monitor a photovoltaic module's maximum output [6]. Anxiety and observation produce better results in many cases than other optimization strategies because they are simple to use and can follow the maximum point with less variation about the maximum

[1] Electrical and Computer Engineering Department/ Engineering College/Altinbaş University /Istanbul, Turkey.

Email: abdullah1993sami@gmail.com

[2] Electrical and Computer Engineering Department/ Engineering College/Altinbaş University /Istanbul, Turkey.

Email: sefer.kurnaz@altinbas.edu.tr

power points (MPP) [7]. A well-regulated output is provided for the grid-connected solar system by the P&O, which exhibits a quick dynamic reaction. Numerous pieces of equipment, including photovoltaic modules, boost converters, power-supporting batteries, inverters, etc., are incorporated into the solar power system, increasing the amount of power electronics parts and escalating the photovoltaic system's power quality issues.

Problems related to power quality, such as poor power factor, distorted voltage harmonics, current waveforms, etc., pose serious challenges to the research community. Filters in the solar system were employed in the literature [8] to solve the issue of low power quality. But it increases the overall expense of the system. Wave producing techniques, both active and passive, are used in many PQI applications. Because of passive wave creation, the system is complex and costly (multi-pulse, multi-level, etc.). Active wave forming, sometimes referred to as pulse width modulation, is an effective technique for managing power quality [9]. Since external circuits cannot regulate the power quality gauges, an effective controller tuned by PWM technology is needed to maintain all of the photovoltaic system's control parameters. However, the system can be controlled with comprehensive system information [10].

II. RESEARCH METHOD

A. Construction of PV grid-connected system

Photovoltaic systems' effectiveness and correct operation depend on several variables. Environmental factors and system design are among the most important of these. These significantly impact the system's effectiveness and power quality [11]. Four categories may be used to group the various grid-connected PV system installations. The figure 1.a depicts the creation of the center arrangement. The network's strong harmonic injection is one issue with the central configuration, which is an older design. Each chain uses a dedicated reflector to supply the network, as shown in Figure 1b.

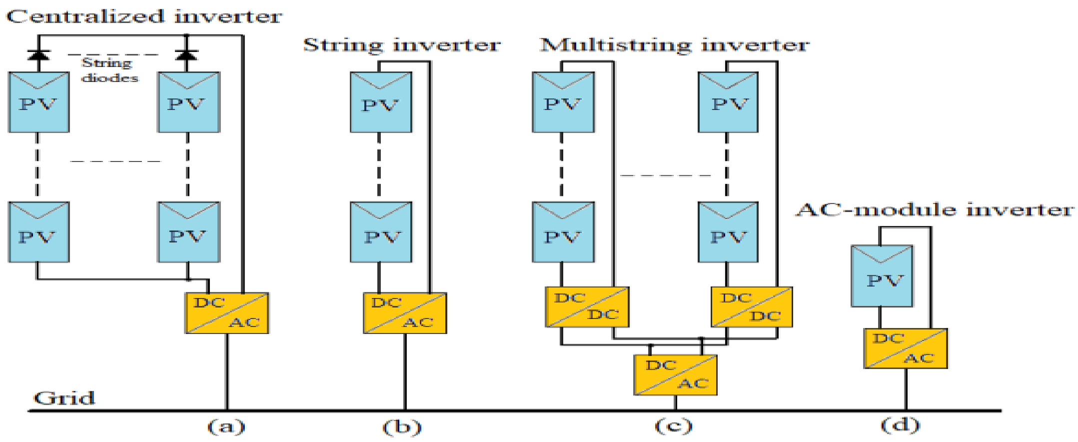

Figure 1: Different configurations of grid-connected PV systems. (a) Centralized approach (b) String approach (c) Multi-string approach (d) AC- module approach [12].

The multithreading arrangement is displayed in Figure 1.c. This system has a DC to DC converter in each series that operates using the MPPT approach. By supplying the grid with extra energy and sharing the power from the strings with the inverter through the DC connection, the inverter regulates the voltage level at the direct current link. The AC system, seen in the image, receives the final connection. 1.d [13] is an example of an intricate electrical per-unit interface.

Comparison of the four connected to the grid photovoltaic (GCPV) panel designs' efficiency, dependability, possibility for power mismatch, and scalability revealed that the centralized solution was the least effective. However, it has been suggested that the multi-string inverter architecture is the most effective and dependable for medium-range and utility GCPV systems [14].

B. PV Power Model

A PV's equivalent circuit is seen in Figure 2 while light is being emitted. Over the ideal properties of the diode, the parallel resistance Rsh indicates the leaking resistance described by the continuous resistance [15]. Since PV voltage and current have a substantially nonlinear connection, modeling of the PV is necessary before performing a full system design simulation that can produce correct system properties.

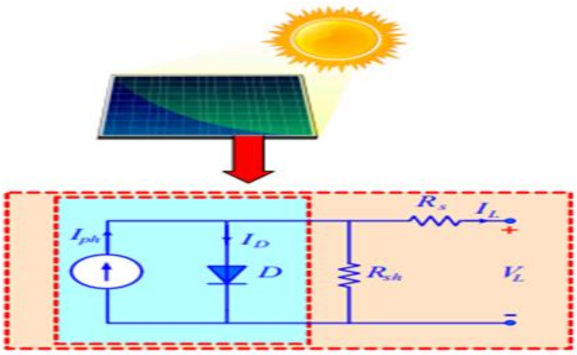

Figure 2: Photovoltaic (PV) equivalent circuit [15] .

The number of parallel and series-connected cells determines the voltage of the open circuit and the short current of the circuit in a solar array .

$$V_{OC} = N_s\, V_{oc} \tag{1}$$

$$I_{SC} = N_p\, I_{sc} \tag{2}$$

The PV has P-V and I-V characteristics can be obtained as :

$$I_{ph} = I_{sc} S_N + I_t (T_c - T_r) \tag{3}$$

$$I_d = I_o \left[\exp\left(\frac{q(V_L + I_L R_s)}{AkT} \right) - 1 \right] \tag{4}$$

$$I_o = I_{or} \left[\frac{T_c}{T_r} \right] \cdot \exp\left(\frac{qE_g}{Bk} \left(\frac{1}{T_r} - \frac{1}{T_c} \right) \right) \tag{5}$$

$$I_L = I_{ph} - I_d - \frac{V_L + I_L R_s}{R_{sh}} \tag{6}$$

For a certain radiation dose SN and operating cell temperature Tc, equation (3) is true. Measuring the PV, current, voltage, and power will yield. Figure 3 shows various radiation levels' P-V & I-V parameters at constant cell temperature [15].

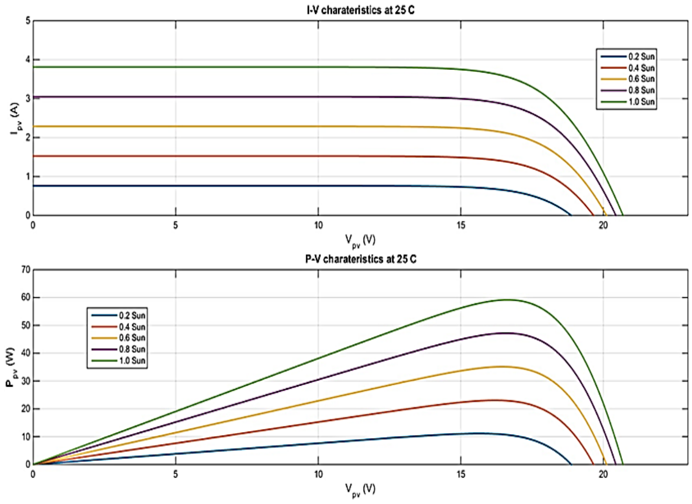

Figure 3: Features of the voltage-current & power-current relationships include variable irradiation rates and constant temperature [15] .

III. MODELING OF VOLTAGE CONTROLLED SYSTEM

A. DC to DC Converter

Estimates of the DC output voltage from the PV module studied in this article fall short of the precise control required [16]. This is the correct technique to increase the voltage and have the transformer run in a boosted mode. Inductor L, output capacitor C, IGBT switch D, diode D, and load R are the fundamental components of the step-up transformer in the power current flowing from left to right in the schematic picture [17]-[20]. The essential elements of a push transformer are shown in Figure 4. Pulse Width Modulation (PWM) indicates the control phase, specifically in relation to the voltage and current inside the inductance compared to the power phase [21]. The boost converter's signals are shown in Figure 5; the time range and timeout during operation are also made apparent.

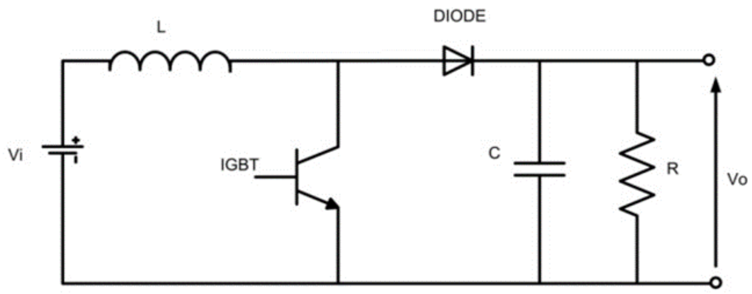

Figure 4: The circuit at boost converter [22].

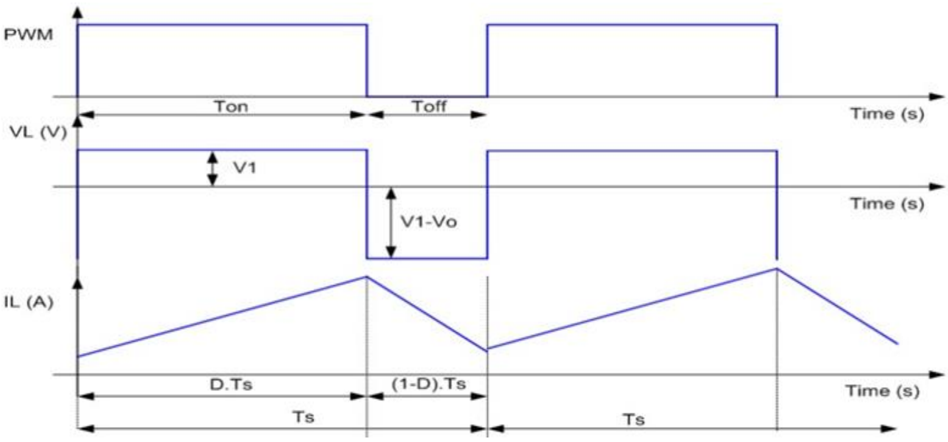

Figure 5 :Boost converter signals [22].

This section contains the most crucial equations and allows the reader to follow along with the whole numerical analysis of the lifting transformer [23] - [24].

$$v_c = \frac{1}{c}\int_{t_2}^{t_1} i_c \, dt \qquad (7)$$

The relationship between the connection and the inductor current is calculated as follows.

$$i_L = \frac{1}{L}\int_{t_2}^{t_1} v_L \, dt \qquad (8)$$

The condition $v_L = v_1$ *with* T_{on} and $v_L = v_1 - v_0$ and at ng T_{off}

The relationship between voltage changes in the lift transformer's CCM is:

$$v_0 = v_i \frac{1}{1 - D} \qquad (9)$$

Constant current mode (CCM) of a step-up transformer, given average quality, connection between inductor current and return current, is:

$$i_L = i_0 \frac{1}{1 - D} \qquad (10)$$

As a result, this connection will be between the exterior and the current internal [25]-[29]:

$$i_0 = i_1(1 - D) \qquad (11)$$

B. Structure of voltage control system

Solar energy has witnessed a sharp increase in popularity recently and is now widely regarded as one of the most promising forms of renewable energy. There are a lot of parallels drawn between solar energy and other energy sources [30] . The amount of solar radiation that reaches Earth in a single day is more than sufficient to provide the world's energy needs for a full year. Because solar power has no adverse effects on the environment, it is perfect and sustainable. There are numerous applications for producing electricity from solar energy. The residential, transportation, aerospace, aviation, and maritime sectors are the main markets for solar energy [31] . The photoelectric effect is the cycle by which a photovoltaic cell transforms solar energy into usable electricity. Light absorbed by a photovoltaic cell generates electricity, while light that is reflected, assimilated, or completely absorbed does none of those things. As shown in Figure 6, the electrons in the molecules of a photovoltaic cell receive the light energy that has been absorbed. With their increased kinetic energy, these electrons leave their usual hangouts in the PV material's semiconducting atoms and join the flow of electricity. Because of its unique electrical property known as a "built-in electrical domain," a photoelectric cell may generate enough current to power an external "load" like a light bulb [32]-[37].

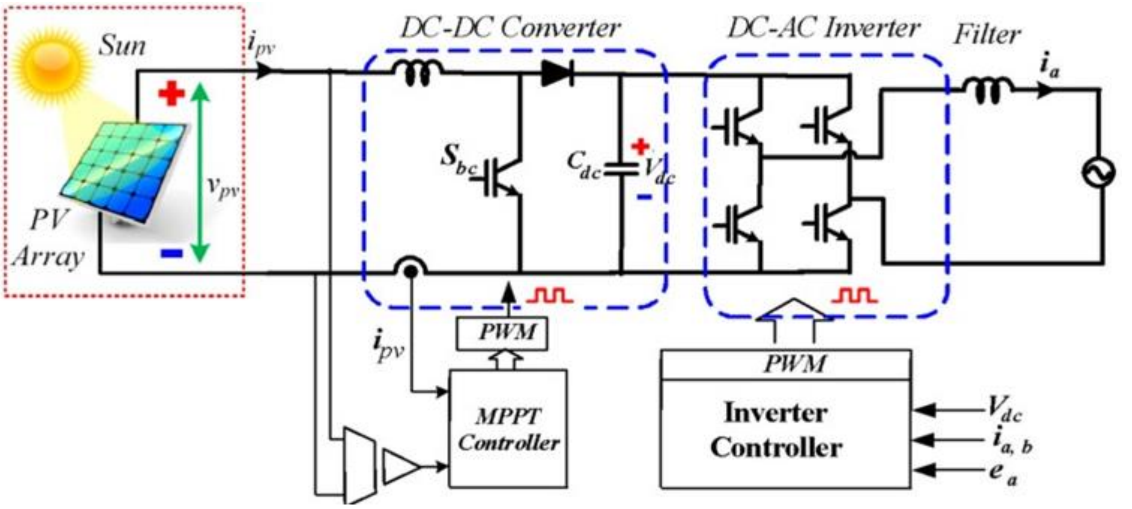

Figure 6: PV grid-connected system [15].

The grid-tied inverter's output stage is where the DC crossover current control and voltage control are finished. The voltage source tag (vpv*) produced by the MPPT calculation is followed by the control module of the standard step-up transformer. Only the entry label for the current regulator may be used with the key [38].

The DC link voltage and current are controlled by the inverter's output stage when grid-connected. In a typical boost converter, the MPPT algorithm produces a voltage reference signal (vpv*), which is then used to direct the controller's actions. Figure 7a depicts the switch being operated by a gate signal from the current control unit [39].

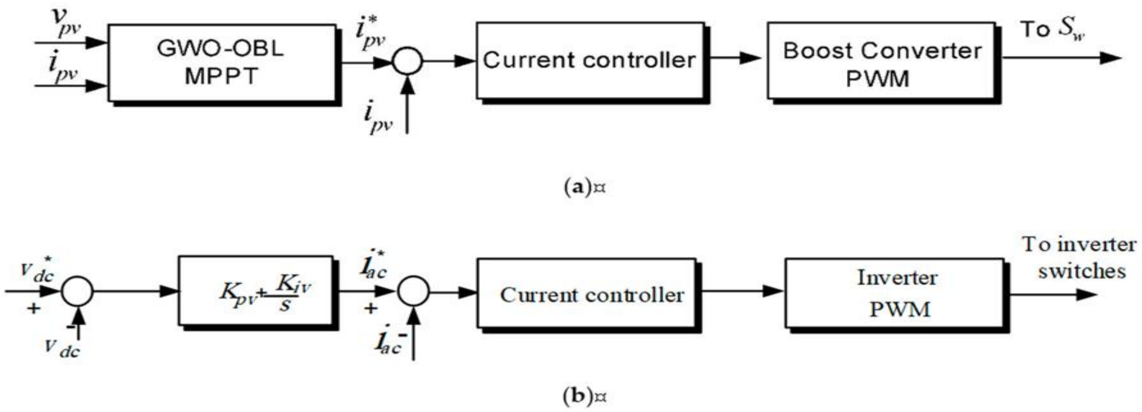

Figure 7: Control circuit: (a) the boost converts, (b) the DC to AC inverter [15].

The inverter transforms direct current (DC) into alternating current (AC) that is then supplied to utility or household loads. Additionally, it controls the DC connections' voltage level and ensures the o/p current correlates to the grid voltage [40]. The block diagram of Figure 7b schematically depicts the inverter system of controls. This control system consists of two distinct loops: an outer loop that regulates voltage and an inner loop that regulates current. The inverter's capacity to synchronize its current output with grid voltage is one of its most crucial features since it allows controlling the DC link voltage and maintaining module power easier [41].

IV. SIMULATION RESULTS, ANALYSIS AND DISCUSSION

The block diagram of the simulation for the overall system PV grid-connected, shown in Figure 6, is presented in Figure 8. The simulation starts with a supply of varying irradiation levels and a fixed temperature of the PV system. To continually change the voltage to match the maximum power point (MPP) of a solar energy system (PV panel) to maximize output. The MPP, which fluctuates with the level of light, temperature, and other factors, is the voltage generated at which the solar panel produces the greatest power. The simulation of this event is seen in Figure 9 as the MPPT controller monitors the panel's current and voltage and modifies the current and voltage related to preserve the MPP. This maximizes the quantity of electrical power that can be harvested from the photovoltaic system and improves its efficiency.

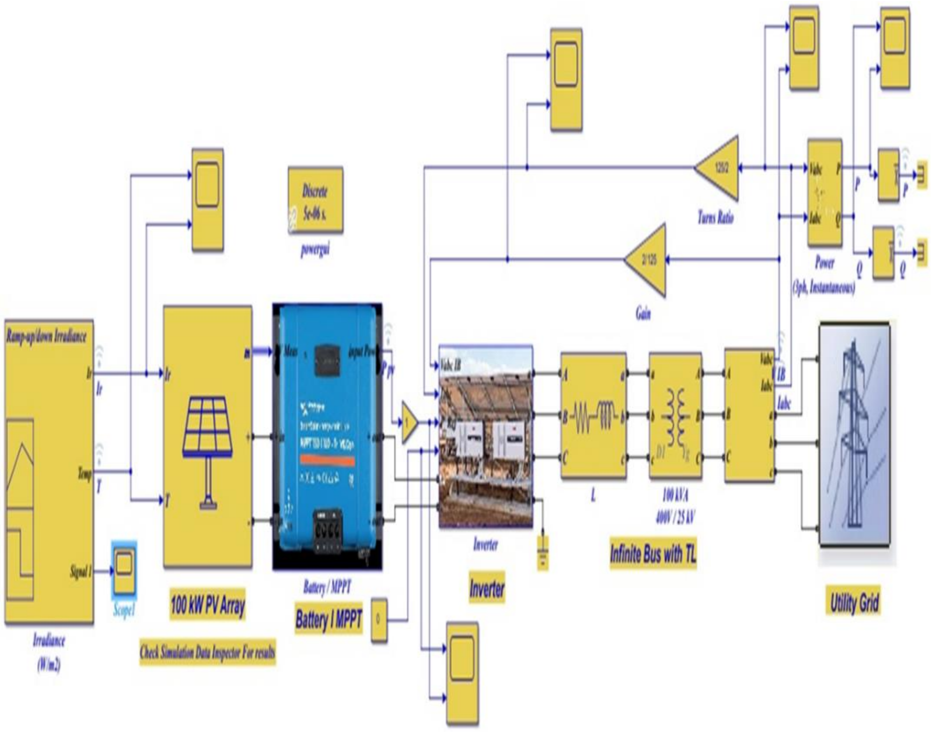

Figure 8: Block diagram of simulation for overall PV grid-connected system.

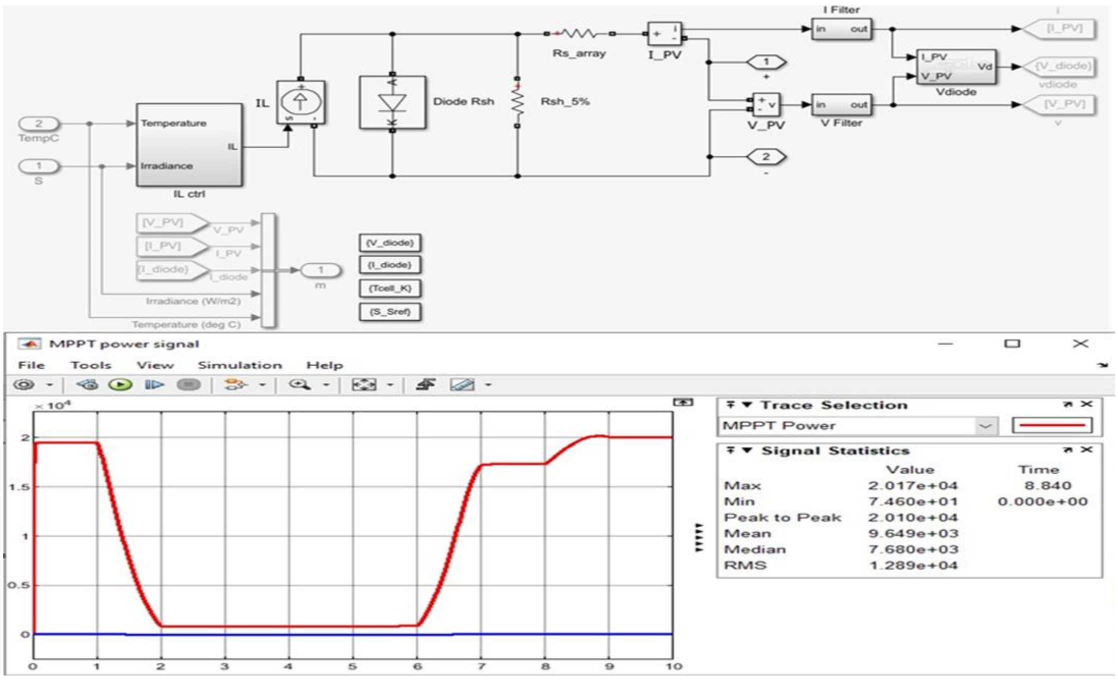

Figure 9: Simulation for MPPT controller for PV panel.

In off-grid situations where the system's efficiency and dependability are crucial, MPPT is frequently employed in solar power systems. A device used in solar energy systems that transforms the DC voltage generated by the photovoltaic cells into AC voltage is a converter with a DC-DC converter, which is the next phase in the suggested system's architecture. Before it is transformed to AC voltage, the DC voltage produced from the PV panels is optimized using the DC-DC converter that is located in the inverter.

The maximum power point (MPP) of the solar energy system is reached by varying the voltage, as demonstrated in Figure 10's simulation of the conversion device with DC-DC converter presets. This process is similar to the MPPT methodology used in PV systems. The electrical machinery that is powered by the AC voltage output of the inverter can then be used or fed back into the grid. Using an inverter with a DC-DC converter improves the efficiency of the PV system and maximizes the amount of electricity generated by the solar panels.

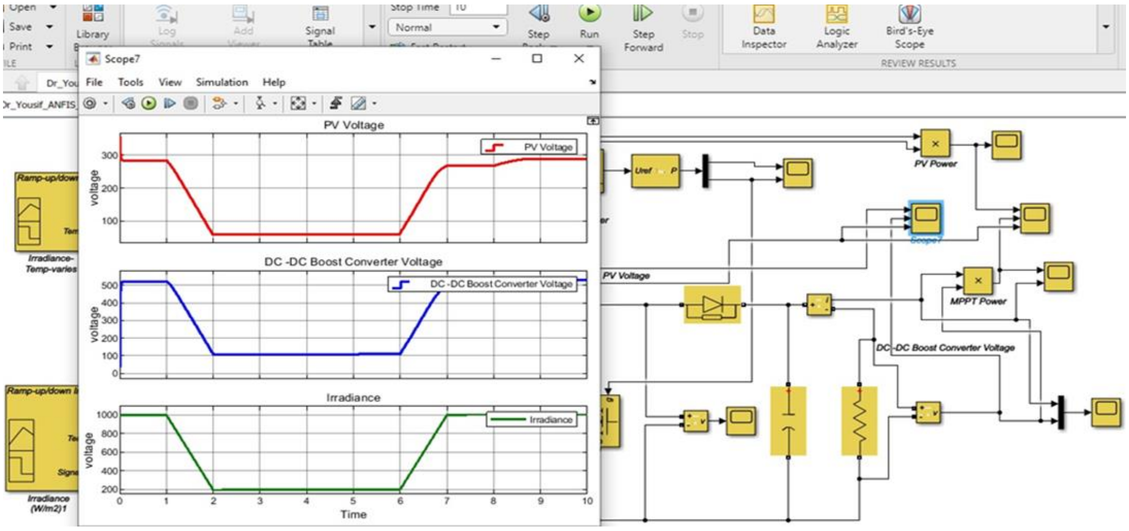

Figure10: Simulation of inverter with DC-DC converter.

Figure 11 illustrates the simulation, which includes simulating the PV panels, inverter, and other system parts and examining how they function under various circumstances including varying weather and load demand. Power injection into the grid, which must be done carefully to prevent harm to the system or other equipment, is one of the simulation's key components. The simulation can aid in system design optimization and guarantee that it will function effectively and safely in various scenarios.

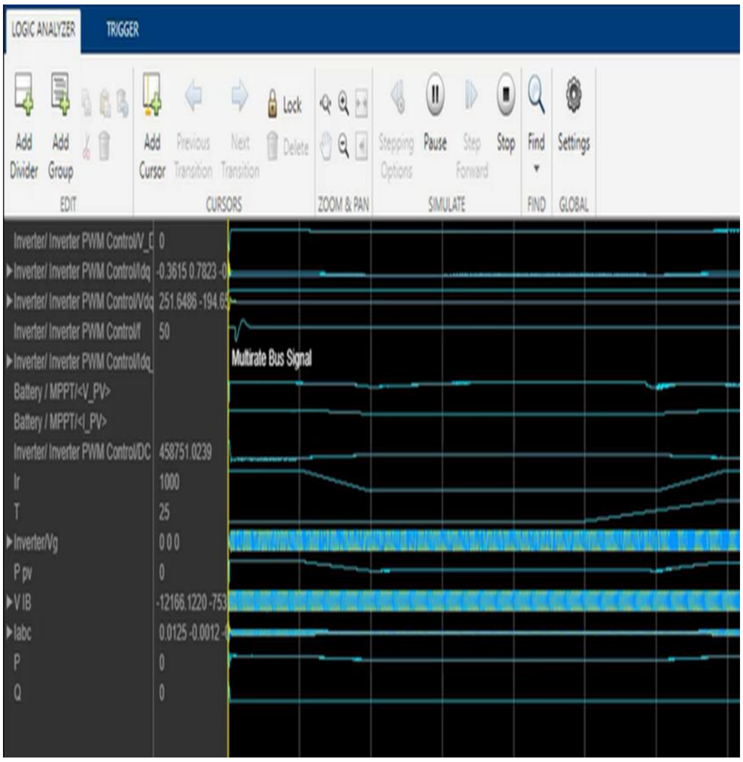

Figure11: The simulation for all parameters in proposed design system.

The explanation for detail results that presents in Figure 11, the video in the following link explain the details simulation process for all proposed system design as:

https://drive.google.com/file/d/1-0keUJSmPuDR4gixkpBu-xE2_tXhnd1P/view?usp=sharing

V. CONCLUSION

Researchers are working to attain maximum power point tracking (MPPT), a crucial component of solar systems, through a variety of approaches in an effort to maximize the use of solar systems. This work presents a novel model that performs significantly faster than conventional methods like the progressive conduction technique and the constant voltage method.

The simulation results show that this novel model reaches and sustains its maximum power in an astounding 0.03 seconds. Utilizing a DC-DC converter, a crucial component in the isolated photovoltaic (PV) system's design, is key to this accomplishment. The PV array is isolated from the load by a high-frequency transformer that is included into the converter. This function significantly increases the energy system's overall efficiency.

To further substantiate the model's efficiency, the research examines the integration levels of the solar PV system into the grid, focusing on the potential for harmonic distortion. It posits that the integration of the solar PV system into the distribution network should be calibrated to leverage only the highest thresholds of the network's carrying capacity. After a thorough analysis that takes into account variables such overall voltage distortion and variations in current demand, it has been determined that the ideal penetration level is roughly 0.5 percent. Past this point, there is a noticeable drop in the system's performance.

Moreover, the study finds that the negative effects on the performance are only marginally noticeable up to the determined maximum penetration level, exhibiting negligible overall distortions of the voltage and current demand. It is important to remember that adding subpar solar PV systems to the distribution network is typically the first step towards power quality problems.

This study stands as a significant stride towards advancing solar energy systems, proposing an accelerated and more efficient pathway to achieving maximum power point tracking, thereby paving the way for a more sustainable energy future.

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NOMENCLATURE

I_{ph} The Photocurrent.

I_d The Diode saturated current.

A Diode ideal factor of the solar cell.

V_{oc} Open cell voltage.

V_{OC} Open voltage PV array.

I_{sc} Shorted cell current.

I_{SC} Shorted PV array current.

Ns No. of series solar cells.

Np No. of parallel solar cells.

I_o Reversing saturated current [A] with certain temperature of solar cell.

k Boltzmann const.

q Charge value[C].

R_{sh} The parallel resistance.

S_N Solar irradiance per unit.

B Manufacture constant.

I_t Coefficient of Shorted cct. Current with surface temperature rising [A|K].

T The ambient temperature[K].

T_c Temperature of solar cell [K].

T_r Reference temperature of solar cell [K].

E_g Band gab energy.

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