



# A Three-Port DC-DC Converter Combined Configuration Method for PV-Battery Power Systems based on Prognostic Anticipating Controller Algorithm

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## Abstract

The Photovoltaic (PV) system is renewable energy developed nowadays in the power generation system and it is connected to the grid. This grid-tie PV system is used to generate power and utilize consumer applications, in the grid-tie PV system the output is not efficient because of the saturation of the sunlight in the PV array and it's affected the power quality and stability of this system. In this proposed Prognostic Anticipating Controller Algorithm (PACA) system, a DC synchronization with PV and ESS is proposed to achieve improved power quality and the losses are less to compare the existing method. Due to the concern with energy emergencies, the energy obtained from sunlight is considered the most capable conventional resource. Hence, the maximum power point tracking approach is necessary for obtaining enhanced efficiency from solar panels. In the case of Direct Current (DC) application, the output obtained from the Photovoltaic (PV) array cannot be directly connected to electronic devices. For regulating the output from the PV array, the DC-DC converter is provided in between the load and the array. The converter design plays a significant role in tracking the maximum power point of the solar panel. The PACA logic controller is employed in the generation of optimal control pulse for the DC-DC converter. Moreover, in the solar photovoltaic system, the steady-state operation is performed and the various solar irradiance results are analyzed.

**Keywords:** Solar Panel, Partially Isolated Multiport Converter, Three-Port DC-DC Converter, Battery Power Systems, Mat Lab Software.

## 1. Introduction

Sustainable energy sources (SES) including wind and solar photovoltaic (PV) have the greatest chance of supplying future electricity demands and tackling rural electrification. It is critical to consider the efficacy and efficiency of PV systems. This study presents a revolutionary three-port Forward-based DC-DC converter that is specifically made for freestanding solar systems to overcome these issues. This converter provides a small, one-unit solution that may be used in home and aerospace applications, with multiple modes of operation. Additionally, it improves the performance of Maximum PowerPoint Tracking (MPPT) and permits high step-up ratios. After a methodical investigation of the operating

modes, simulation, and experimentation are used. The primary focus of the study is on a comprehensive modulation strategy that manages output voltage and MPPT requirements for PV power systems [1].

## 2. Objective

To propose a better partly isolated multiport interface with the following specifications for connecting more than one source and a storage device to a DC load or grid. Component count was reduced while power density was increased. Component count was reduced while power density was increased. Reduced conduction losses and idle power loss by reducing freewheeling flow,

as well as increased efficiency and reliability. Reduced ripple content at renewable energy input ports, as well as bidirectional power transmission between the source and load sides. Using the suggested four port partly isolated converter, control the power of two different rated PV sources, battery and DC-load [2].

### 3. Proposed System

The system's distributed Prognostic Anticipating Controller Algorithm (PACA), which regulates solar output and enhances the energy storage system, is described in this suggested technique. The predictive control system of the multifunctional inverter is capable of transferring PV power while accounting for the necessary reactive power and grid current. This approach provides a simple PACA algorithm, reduces the number of switches needed, and is easy to apply in real-world circumstances because the load and inverter currents are not measured [3]. A zero-current switching Inductor-Capacitor-Inductor (LCL) Resonant Circuit (ZCS) is used for the primary switch. Instead of the converter's five programmable switches, the suggested converter utilizes three, and it charges a battery at the nominal voltage using the same renewable energy source. The Block Diagram is shown in Figure 1.

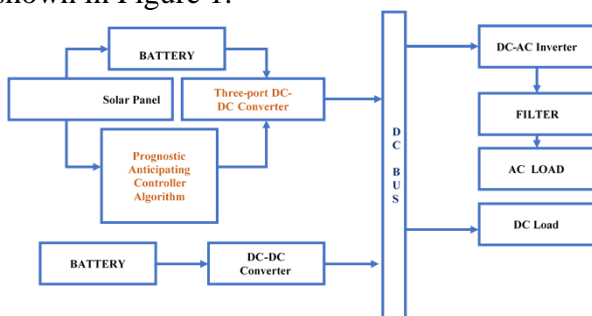


Figure 1 Block Diagram

#### 3.1. Solar Panel

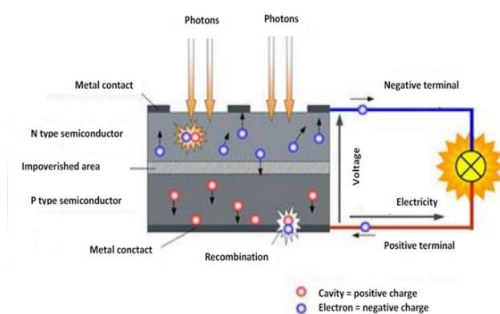


Figure 2 Functioning of the Photovoltaic Cell

The most well-known method of using solar energy is through PV systems, which transform solar energy into electrical energy. As semiconductor devices, solar photovoltaic cells share many processing and manufacturing processes with other semiconductor devices like computers and memory chips. The standards for semiconductor device purity and quality control are fairly stringent, as is widely known. Due to cheap manufacturing costs, the whole industry of solar cell manufacture has grown with today's production, which has scaled up significantly. The devices that capture solar radiation and transform it into heat or power are called solar panels. A solar panel is made up of several solar cells, also known as photovoltaic cells, which work together to produce electricity. On the surface of solar panels, these cells are organized in a grid-like configuration. These panels can withstand a great deal of wear and strain. The lifespan of solar panels is incredibly slow [4]. Their efficacy drops by only 1% to 2% in a calendar year (at times, even lesser). The functions of the photovoltaic cell are shown in Figure 2.

#### 3.1.1. Three-port DC-DC Converter

An energy storage system, several non-isolated DC-DC three-port converters (TPCs), and a current-reversible DC bus are suggested to offer more variable power flow. The majority of reported non-isolated topologies in this field only take into account a load that consumes a lot of electricity. However, applications like hybrid electric vehicle braking systems and DC microgrids need also take into account the load power-producing capacity. One unidirectional port and two bidirectional ports make up the proposed three-port family. From the perspective of power flow, they are therefore appropriate for photovoltaic (PV)-battery-DC bus systems, since they combine a variety of well-known power converters and consider the voltage's polarity. It is recommended to use a three-phase PV-battery-DC bus system with a reversible power flow channel. Battery life may be increased by further recycling braking system energy with the help of the supercapacitor. The bi-directional power flow



function for bi-directional TPCs is accomplished using isolated transformers. Switches are used in place of the traditional rectifier diodes on the secondary side to enable Bi-directional power flow. Although electrical isolation is a feature of transformer-based TPCs. An integrated multiport converter construction is shown in the chapter before for integrating numerous sources, energy storage, and load. This chapter offers a literature review based on the different multiport converter topologies. To select the best topology for the requested application, a comparison study of three kinds of multiport converters from the literature was conducted. Additionally, research has been done on the control techniques used in multiport converter systems to govern power flow. The goal of the study effort is defined from the constraints of the existing topologies and control mechanisms that are determined by the literature review. Numerous multiport converter topologies have been developed and are being used in the processing of renewable energy sources because multiport converters have such remarkable benefits as high power density, high efficiency, and a less complicated design. The three connecting principles are electrical coupling (DC-linking), magnetic coupling employing transformers, and combined DC and magnetic coupling, according to the information accessible from the writers. The characteristics of each of these groups are described in the sections below. Because of DC-linking in these topologies, only sources with comparatively similar operating voltages can be linked over common ground. To build non-isolated multiport networks, basic topologies like buck, boost, or buck/boost converters are frequently utilized. They often result in a construction that is compact and tiny, which helps to achieve high power density because they don't use a transformer for isolation and share certain devices among the ports. a non-isolated multiport structure's layout. Non-isolated topologies have a limited voltage gain that is solely based on the switches' duty cycle [5]. Therefore, voltage-raising techniques are needed to increase gain, which further oversimplifies the schematic diagram. Multiport converters use a multi-winding transformer to use magnetic coupling to connect the converter's various

ports. All of the converter's ports are isolated from one another thanks to this multiple-winding transformer; these topologies are known as fully isolated topologies. Either full-bridge converter circuits, half-bridge converter circuits, or a combination of the two are the source of these topological structures. A multi-winding transformer in this topological architecture connects voltage sources or loads to the ports. The development of mixed DC link and magnetically coupled topologies addresses the drawbacks of DC-linking and magnetically coupled architecture. For connecting several ports, this type of converter makes use of both electrical and magnetic coupling. In this design, the load is linked through a transformer, which offers isolation and variable voltage handling capabilities, and the voltage sources with closer operating voltages are connected by DC-linking with common grounding. These topologies are referred to as partly isolated topologies because only some of their ports, often the load ports, are separated. These topologies are created by merging converter circuits that are isolated and non-isolated. These topologies simply employ a transformer with a single primary and a single secondary winding to separate source ports linked through DC linking from load ports. When compared to totally isolated topologies, this architecture offers active and passive device sharing using DC-linked ports, hence lowering component count and maintaining a compact circuit layout. This topological topology can accommodate a less complicated circuit construction while also supporting variable voltage levels at the load ports. This topology's voltage gain is influenced by the transformer's turns-to-duty ratio and the switching device's duty cycle [6].

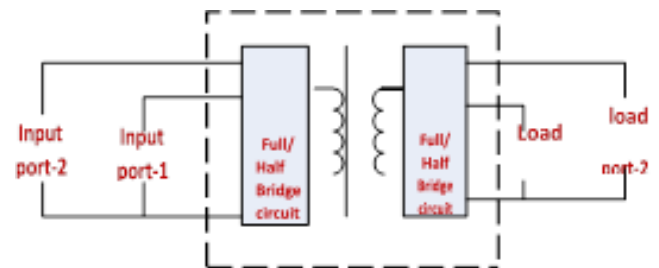
### **3.1.2. Partially Isolated Multiport Converter**

The integration of many renewable energy sources into one or more loads can be accomplished using non-isolated direct link connections or time-sharing devices. The direct connection approach links several sources to a single bus using converter cells. A bidirectional converter was suggested for use with fuel cells. This topological structure's drawback is that it can't be utilized to

link voltage sources with large voltage ranges. The circuit diagram of the Three-port DC-DC Converter is shown in Figure 3.

Time-sharing of devices produced the steady-state and dynamic properties of a two-input buck-boost type converter. The experimental setup and performance of the converter validated the concept of the multi-input converter. In fully isolated multiport topologies, magnetic coupling technology can be used to link multiple sources with multiple loads. Partially isolated topologies are hybrid topologies made up of both fully isolated and non-isolated topologies. They are made by merging isolated and non-isolated circuits or by fusing the concepts of magnetic and DC-linking. In this arrangement, a transformer with a single primary and secondary winding is used to isolate the isolated load port from sources that are connected to the common ground. Because these topologies share circuit components and enable a multiple-input bidirectional DC-DC

converter for fuel cells, supercapacitors, and load integration, they offer higher power densities than fully isolated and non-isolated topologies. Compared to a fully isolated converter, this architecture is simpler in structure and contains fewer components. Two programmable ports are added to a four-port converter to form an integrated multiport structure for power generation units using renewable energy [7-8].



**Figure 3** Circuit diagram of Three-port DC-DC Converter

**Table 1** Comparison of three categories of multiport converters

Features	Non-isolated	Partially isolated	Fully isolated
1) Derived from	Buck, boost, buck-boost circuits	Half and full-bridgescircuits	Half and full-bridgescircuits
2) Coupling betweenports	DC linking	DC linking and magnetic coupling	Magnetic coupling
3) Circuit size	Compact due to a minimum number ofactive switches	Smaller than fullyisolated due to device sharing	Larger due to a greater number of active switches
4) Cost	Low	Lower than fullyisolated	High cost
5)Power density	Highest	Higher than fullyisolated	Lower

These sources and storage are connected to the loads using power electronic converters. Recently, the concept of a microgrid has been developed to provide electricity to isolated areas where extending the grid infrastructure is not practical. Microgrids also require storage components and rely on locally available renewable energy sources. Power electronic converters are therefore essential for linking various sources, storage to the grid, or loads. The remainder of this chapter covers the use of direct current distribution (DC microgrid) and its advantages for power generation systems, as well as the use of power converters in power production systems. A comparison of three categories of multiport converter features is shown in Table 1.

### 3.1.3. Prognostic Anticipating Controller Algorithm (PACA)

A photovoltaic (PV) system's Maximum Power Point (MPP) must be continuously tracked to maximize the system's output power. The temperature of the panel, the connected load, and the irradiation conditions all affect the MPP. Maximum power point tracking (MPPT) algorithms, which can be used in a range of hardware and software configurations, are theoretically capable of helping solar panels achieve their MPPT. Rarely do PV systems without MPPT run at maximum power point performance (MPPP). For this reason, when a load is connected, the solar panel's rated power is rarely

realized. With a tight budget, the project's objective was to quickly design, build, and test a functional solution to the MPP problem. Due to the rapid development, the team had to first review the current. A semiconductor-based power converter is called an inverter. An apparatus that converts direct current to alternating current is called a DC-AC inverter. In general speaking, an "inverter" is a piece of equipment that combines a DC-AC inverter with an AC-DC converter, which changes alternating current into direct current, which generates unlimited voltages and frequencies. AC energy is supplied to residences, workplaces, and factories at a variety of voltages and frequencies, including 50 Hz/100 V and 60 Hz/220 V. Electric motors require the main supply to be adjusted to the correct voltage and frequency to run effectively. In the case of a power loss, such as a windstorm, emergency power systems convert mains AC electricity into DC power [9].

#### 4. Battery

An electron flow occurs in a circuit when one or more cells combine chemically to form a battery. A battery's anode (the "-" side), cathode (the "+" side), and electrolyte of some type are its three fundamental parts (a substance that chemically reacts with the anode and cathode). An anode-to-electrolyte chemical reaction occurs when a battery's cathode and anode are linked to a circuit. In the cathode, where another chemical reaction occurs, electrons from this reaction move back into the circuit. Chemical energy is converted to electrical power in an electrolytic cell. Free energy shift and cell potential are related. An electrochemical cell's mechanism operates [10]. The circuit diagram DC-AC Inverter & the battery management system are shown in Figures 4 and 5.

##### 4.1. MAT LAB Software Description

Programming, calculation, and visualization are all combined in the high-performance technical computing language Standard mathematical notation is used to explain problems and answers in MATLAB's intuitive environment. In the role of a prototype setting, the main objective is to make development easier by providing functionality not found in performance-oriented languages like FORTRAN and C, such as interactive debugging and linguistic flexibility. There are ways to make Mat lab run faster, even though it might not be as quick as C right now. wish to cut down on the amount of time spent creating, testing, executing, and getting results. An array is the fundamental data element of this interactive system and does not require dimensioning. It can resolve a lot of technical computing problems in a short amount of time, especially those involving matrix and vector formulations [11].

##### 4.2. Working on the MATLAB

**THE LANGUAGE:** High-level matrix/array language MATLAB has facilities for object-oriented programming, functions, data structures, input/output, and control flow instructions. It enables you to quickly write short programs for both little and large programming tasks that you don't plan to use again. Large-scale programming can also be used to create complex application

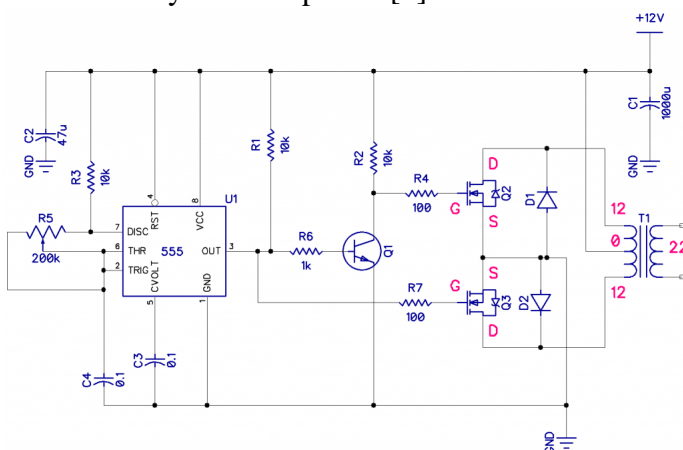


Figure 4 Circuit Diagram DC-AC INVERTER

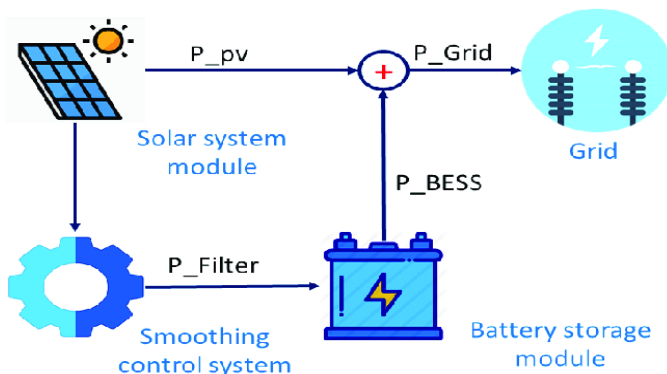


Figure 5 Circuit Diagram of the Battery Management System



programs that are intended to be reused.

**GRAPHICS:** Rich graphing features for vectors and matrices are offered by MATLAB, together with the option to annotate and publish these graphs. It offers sophisticated tools for two- and three-dimensional data visualization, animation, presentation graphics, and picture processing. It also comes with low-level facilities that let you create complete graphical user interfaces for your MATLAB applications and completely change the look of graphics.

**EXTERNAL INTERFACES:** Writing C and Fortran applications that communicate with MATLAB is possible with the library of the external interface. It contains MATLAB functions that can be used to read, write, and call computational engines from files. procedures (dynamic linking).

**ARRAY PRE-ALLOCATION:** Rows and columns can be dynamically enhanced using Mat Lab's matrix variables. For instance, in

- $A(2, 6) = 1,$
- $a = 2\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 1$
- and  $a = 2$

The matrix is automatically resized by Mat Lab. A greater reallocation of the matrix data memory must occur inside. Resizing a matrix repeatedly, such as in a loop, might result in a considerable overhead. Use the zeros command to reallocate the matrix to prevent frequent reallocations.

**JIT ACCELERATION:** The Just-In-Time (JIT) Accelerator is a feature of Mat lab 6.5 (R13) and later helps speed up M-functions, especially those that use loops. A little bit of knowledge about the accelerator will help you get better results. By default, the JIT Accelerator is turned on. Enter "\feature accel off" to turn it off and "\feature aces on" to turn it back on in the console. As of Mat lab R2008b, acceleration is available for just a subset of the Mat lab language. Acceleration processing returns to the non-accelerated assessment when it encounters an unsupported feature. When substantial contiguous sections of code are supported, acceleration works best.

**TYPES OF DATA:** To speed up the code, it must use the following data types: double (both real and complex), char, logical, int8 ~32, and uint8 ~32. Supported handles include strut, cell, class def, and

function handles. Sparse arrays are not eligible for acceleration.

**ARRAY SHAPES:** You can use any size array form that has three dimensions or less. Acceleration ends when an array's form or data type changes. A few specific scenarios involving 4D arrays are expedited.

**FUNCTION CALLS:** M-functions and integrated features are called more quickly. Calls to the Java and MEX functions stop the acceleration. See page 14 for details on inlining simple routines.

**CONDITIONALS AND LOOPS:** The conditional expressions if, else if, and simple switch statements are available if the conditional phrase evaluates to a scalar. If all of the code inside the loop is supported, loops of the format The while, for k=a: b: c, and for k=a: b: b loops will execute more quickly.

#### 4.3. In-Place Computation

It is possible to compute in place the operators (+, \*, etc.) that operate on elements, along with a few other functions; these were covered in Mat lab 7.3. (R2006b). That is, one can do an internal calculation like  $x = 5*\text{sqrt}(x.^2 + 1);$  and accumulate the result without needing to store it temporarily. It is also possible to compute the M-function in place if there is a match between one of the input arguments and the output argument.

```
Function x = my fun; x = my fun(x) (x)
    x equals 5 * sort (x.^2 + 1);
    Return;
```

The in-place operation to enable in-place computing is contained in an M-function (and the function itself needs to be called within an M-function for an in-place function). MEX functions do not currently support in-place calculation [12].

#### 4.4. Multithreaded Computation

Mat lab 7.4 introduced multithreaded computing for multi-core and multi-processor platforms (R2007a). Using multithreaded processing speeds up the application of some linear algebra functions in the BLAS library as well as several per-element functions (such as ^, sin, and exp). Select File! to activate it. With the Parallel Computing Toolbox, you have a lot more control over parallel processing.



#### 4.4.1. Features

- **The System MATLAB:** These are the principal components of the MATLAB system:
- **Workstation Instruments and the Development Context:** The purpose of the MATLAB tools and resources in this section is to help you make the most out of MATLAB files and functions. Graphical user interfaces are present in several of this equipment. It contains files, additional tools, code analyzers, an editor, a debugger, the MATLAB desktop and Command Window, and browsers for looking up assistance [13].

#### 4.5. Simulink Description

**SIMULINK:** A block diagram environment for model-based design and multi-domain simulation. It facilitates continuous testing and verification of embedded systems, simulation, system-level design, and autonomous code generation. To describe and simulate dynamic systems, Simulink offers a graphical editor, solvers, and block libraries that can be tailored. Because of its integration with MATLAB, you may export simulation results to MATLAB for additional analysis and embed MATLAB algorithms into models. Using the same core techniques that you used to generate the basic model in this tutorial, you can utilize those same techniques to create more complex models that mimic the dynamic behavior of the original system. This simple model requires four Simulink blocks to construct. A system's mathematics and features are specified by its model elements or blocks.

**MODELLING:** To use block diagrams to represent physical systems and algorithms. Both linear and nonlinear systems can be modeled, taking into account actual occurrences like hard stops, gear slippage, and friction. You can construct models with the aid of an extensive library of prefabricated blocks. The Simulink Editor is used to add blocks from the library to your model. Use signal lines to join blocks in the editor to create mathematical links between the various parts of the system. To further personalize how users interact with the model, you may also apply masks and improve the model's appearance. You can create hierarchical models by dividing blocks into groups called subsystems. With this method, you may create discrete parts that accurately

represent your actual system and model how those parts interact.

**BLOCK LIBRARIES:** The primary building blocks in Simulink are called blocks, and you may explore and search the block libraries using the Library Browser. Once the desired block has been located, incorporate it into your model.

**SIMULATION:** It allows you to simulate your system interactively and view the results on scopes and graphical displays. The modeling of continuous, discrete, and mixed-signal systems can be done with a variety of fixed-step and variable-step solutions. Solvers are integration algorithms that compute the dynamics of a system over time. You may use MATLAB commands to execute unattended batch simulations of your Simulink models thanks to the integration of Simulink and MATLAB. This article demonstrates how to use Simulink® software to simulate a dynamic system and then utilize the simulation findings to refine the model. Once the model is ready for simulation, measured system data and room temperature can be entered using an interface.

**PERFORMANCE:** A Simulink model with excellent performance compiles and simulates rapidly. You can accelerate the model simulation by using the methods Simulink offers. Use Performance Advisor as a starting point for enhancing simulation performance. Performance Advisor looks for factors that could be causing your simulations to run more slowly. To handle these conditions, the tool can automatically modify your model; alternatively, you can manually examine and implement proposed adjustments. Performance Advisor can examine your model to find settings and conditions that can cause the simulation to run more slowly. It can run simulations in accelerator mode for you, make modeling optimization recommendations, and apply them automatically. To accelerate the simulation without altering the model itself, use the Accelerator and Rapid Accelerator modes. Utilize some of these manual techniques to expedite the simulation process for your models.

#### 4.6. Component-Based Modeling

Modular design and modeling based on

components. Your model can be divided into design components, and each component can then be separately modeled, simulated, and verified. Individual parts can be saved as standalone models or as subsystems in a library. After that, team members can work concurrently on those components. Large modeling projects can be managed with Simulink Projects by employing source control, maintaining and distributing files and settings, and locating necessary files. A subassembly, unit-level object, or portion of your design that you can work on without requiring the higher-level model parts is called a component. Organizing your model into components is the process of componentization. Organizations that create big Simulink models with several functional components might profit greatly from componentization [14].

**MODELING GUIDELINES:** Using Model-Based Design with Math Works products, these modeling guidelines assist you in creating models and producing code. Your models' readability, consistency, and clarity can all be enhanced by following these recommendations. You may also find model settings, blocks, and block parameters that influence code production or simulation behavior by using the recommendations. The table provides a summary of the high-integrity principles together with the related Model Advisor checks. Automation of the guideline-checking process is not feasible for guidelines without Model Advisor inspections. rules without an analogous one.

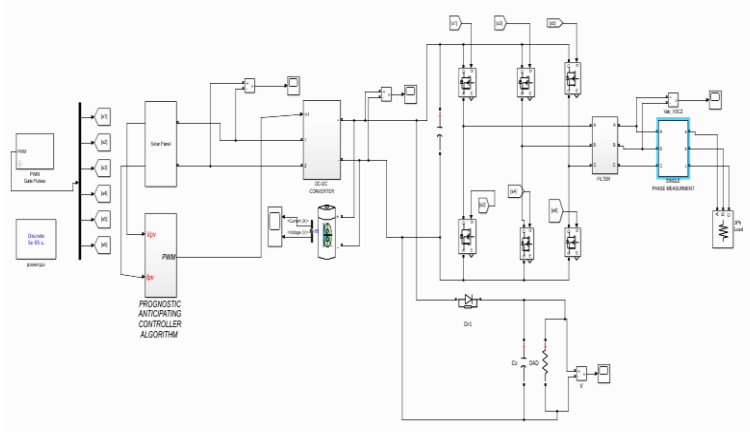
**BLOCK CREATION:** You can make custom blocks and add them to the Simulink Library Browser

by using the modeling functionality that Simulink has built in. From a MATLAB function, a custom block can be made. You can define custom functionality using the MATLAB language by using function blocks in MATLAB. A decent place to start is with these blocks.

- It is simpler to represent custom functionality using a MATLAB function than a Simulink block diagram; the custom functionality is already modeled by an existing MATLAB function.
- Adding C, C++, or FORTRAN code, or masking a subsystem of other blocks are examples of continuous or discrete dynamic states that are not included in the custom functionality [15].

#### 4.7. Advantages

PV cells were created for use in space, where replacement is exceedingly expensive, if not impossible. Photovoltaic systems are silent and visually unobtrusive. Almost all satellites in orbit are still powered by photovoltaic cells (PV) due to their long operating life and low maintenance requirements. One locally accessible renewable resource is solar energy. It is not required to be brought from abroad or from different parts of the nation. This also lessens the negative effects of transportation on the environment. The size of a photovoltaic system can be tailored to meet specific energy needs. PV systems can enlarge or move if energy needs change. The proposed simulation work is shown in Figure 6.



**Figure 6 Proposed Simulation Work**



#### 4.8. Result and Discussion

Each DC-DC converter is connected to multiple inputs or outputs as part of a multi-port converter. Next, instead of being coupled to separate energy storage components that are connected to a bus, each DC-DC converter is coupled to a single overall energy storage element (traditional topology). One controller is then in charge of each DC-DC converter, controlling the amount of power that comes from each input. Hybrid cars have a variety of inputs and outputs; therefore, this topology is starting to gain traction. Given that hybrid autos have two voltage buses—14V and 42V—this wish makes sense. Afterward, the 14V bus, connected to the primary 42V bus, is powered by a DC-DC converter. These voltages are currently supplied via multi-level changers [16-19]. A DC-DC converter with three ports and a high step-up for a separate power source. Single-phase AC Voltage & DC Voltage are shown in Figures 7 and 8.

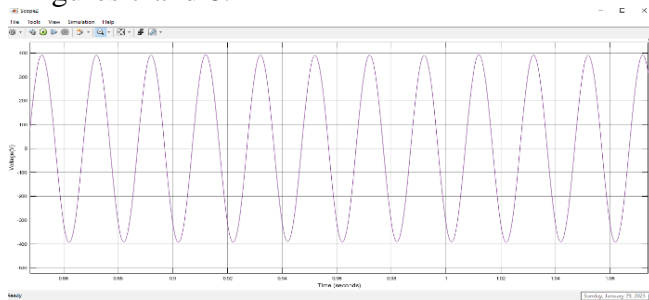


Figure 7 Single-phase AC Voltage

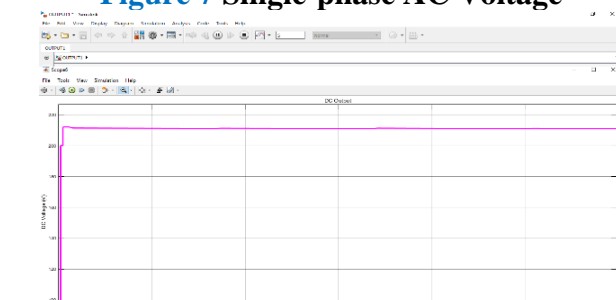


Figure 8 Single-Phase DC Voltage

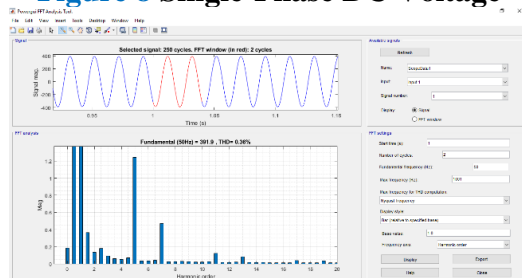


Figure 9 THD (Total Harmonics Distortion)

Measuring the total harmonic distortion of an amplifier is one way to assess its linearity (THD). The output spectrum is used to assess harmonic distortion by using specific circuit settings (e.g., bias conditions, output amplitude or output power level, frequency, etc.) to apply a spectrally pure sine wave to the amplifier. THD (Total Harmonics Distortion) is shown in Figure 9.

#### Conclusion

The impact of distribution on grid-connected solar power generation network power quality is examined by the Power Quality Analysis and enumerates the requirements for user-side PV power stability-related power quality issues. The Prognostic Anticipating Controller Algorithm (PACA) system that is recommended improves the power quality of this particular system. MATLAB simulates every parameter of the system. A set of DC-DC three-port converters (TPCs) between a renewable energy source, an energy storage device, and a current-reversible DC bus. However, for applications such as photovoltaic (PV) and battery storage systems, the capacity to generate load electricity should also be taken into account. There are two bidirectional ports and one vertical port in the proposed three-port family [20].

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