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INTEGRATION OF SOLAR PVAND WIND ENERGY POWER GENERATION FOR RURAL UTILITY IN ETHIOPIA AMBIENCE

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ABSTRACT:

In this paper, a plan is proposed to design the Ideal Integration of wind-solar Energy for rural electrification, particularly for the village "Kelelamo7° 35' 0" N 37° 53' 0" E Ethiopia. Ethiopia has one of the lowest electrification rates in Sub-Saharan Africa, with under 20 percent of the nation's towns and villages electrified [1]. In rural areas where the usefulness of power brings in price is higher due to increased cost to transport the energy and due to a smaller number of consumers.

Consider a 243.51KWh/day power demand for the planned work. The wind-solar energy system is made to meet the electrical energy needs of rural consumers at a significantly reduced cost. The MATLAB 2020a Electric Renewable is utilized for the simulation procedure. The country metrological division and NASA provided the wind speed and sun irradiance data for the optimization software. The optimum outcome from the simulated model has decreased operational costs, the current cost of energy, and has also decreased CO2 and other environmentally hazardous gas emissions. In terms of sizing wind and solar PV arrays and generators to fulfil the energy demand of rural customers, the optimization findings from the simulated model are quite positive. The ideal Integrated model is extremely environmentally friendly.

Keywords: -Wind -Solar system, PV arrays, Matlab2020a

Subscripts:
AC Alternating current
COE Cost of energy
CO2 Carbon dioxide
CO Carbon monoxide
DC Direct current
NASA National Aeronautics and Space Administration
O & M Operation and maintenance
PV Photovoltaic
WT Wind turbine

1.INTRODUCTION

Designing the least priced power solution for electrical energy supply for villages and other remote areas is the most difficult work. If the electrical grids are located at a very distant place from the user's location, the transportation of the grid supply up to the consumers in the village proves to be very costly. In the proposed design, the focus is on optimized selection of solar PV and wind energy conversion schemes to get together the electrical energy order of the village users is done with the help of "MATLAB 2020a software tool. The present organization gives overview information of the villages having very less populations and the location of the village is very much far away from the grid; this reduces the environmental problems and increases the reliability of the usage of wind-solar energy systems. In villages, the Electrical energy demand is derived from fossil fuels which emit dangerous gases into the environment like CO, CO2, etc. To avoid environmental pollution, more encouragement given for the usage of the renewable integrated wind-solar PV scheme [2]. Many models study on wind solar energy system have been performed [3]. describes about the effect of sizing parameter of network linked wind solar PV scheme consisting of different types of energy consuming load and power storage devices.

1.2. STUDY LOCATION

Kelelamo is a village in South Region, Ethiopia, it is located in the South Nation Nationality of People's Region, at 7° 35' 0" N 37° 53' 0" E.

1.3. OBJECTIVE

General Objective

This study will evaluate resource potential and model the integration of solar PV and wind energy systems with the purpose of electrifying rural Ethiopian communities.

Specific Objective

- To examine the basic needs of the populace in rural Ethiopia in order to determine the power and ene rgy requirements of the population in the chosen rural areas.
- To use load forecasting to estimate community demand for the project's duration.
- The overall cost of installation, the contribution of renewable energy sources, and the cost of power per kWh, the goal is to select the most effective integrated model for supplying the community with electricity.

2.METHODOLOGY

In this study, the analysis of data from various data sources is used to model the standalone integrated system and analyze resource potential. These are carried out by examining the literature on integrated systems and using various concepts and approaches as necessary.

The primary work is field data collection, which includes data on the number of households and site observation to evaluate their living style. The power demand of each household has been estimated based on the need of the community and the application of numerical data using a Microsoft excel spreadsheet.

The Secondary Data is the wind speed and solar radiation of the selected sites are collated from different sources such as: The National Metrological Service Agency of Ethiopia (NMSA), National Aeronautics and Space Administration (NASA), Previous works by other scholars and others. Finally, the integrated system is modeled and simulated using the **MATLAB 2020A** tool suggests system investigation of the model.

2.1. MATHEMATICAL MODEL OF SOLAR CELL

This module contains a paralleled connected current resource, as shown in Figure 1 The current output (I) is provided by

$I = I_{PV} - I_D$

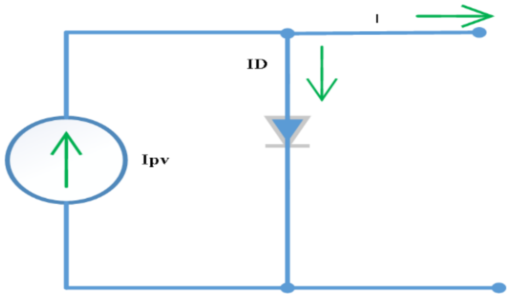

Figure 1. Ideal solar cell model

Where,

I_{pv} - Current in photon,

I_d - Current in a diode.

From Shockley's diode equation, Id is given as: $I_d = I_o$ [exp $(\frac{qv}{dkt})$-1]

$I_d = I_o$ [exp $(\frac{V+IRS}{nVt})$-1]

$0 = Isc - Io[\exp\left(\frac{q*Voc}{\alpha KT}\right) - 1$

$ISC = Io[\exp\left(qvc\frac{qvCc}{\alpha KT}\right) - 1$

$ISC = ISC[exp(\frac{qVcc}{\alpha KT}) - 1]$

If the value, Isc, is known in standard test condition (STC), Go=1000 W/m2, T=25C, the generated current at another irradiance is specified by

$$I_{ScatG} = [\left(\frac{G}{G_o}\right) - 1]I_{ScatGo}$$

The simplest simulated model in MATLAB 2020a yield plot shown in Figure 2 for 2 insolation values such as 500 and 1000 w/m^2 This indicates that cell current directly relational

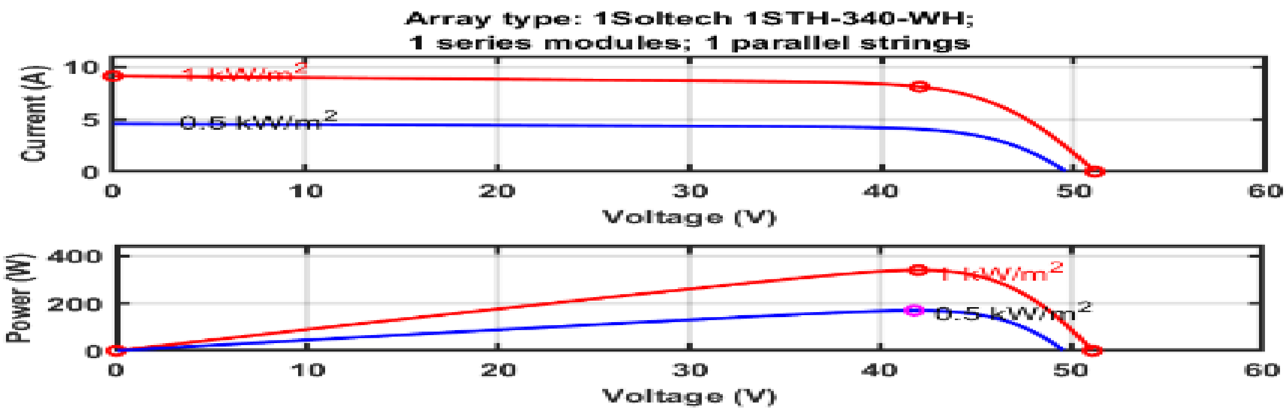

Figure 2. **Isolation Value**

2.2. MAXIMUM POWER POINT TRACKING (MPPT)

The maximum electrical power generation is obtained using MPPT. Maximum Power Point Tracking is algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The array efficiency is maximized by functioning at the maximum set point conditions in the PV module.[4] The solar system current and voltage are continuously controlled using MPPT irrespective of the load. Many MPPT techniques are available, on this paper only P and O technique is discussed below.

2.2.1. PERTURB AND OBSERVE (P&O) ALGORITHM

For MPP tracking P&O algorithm is utilized in solar systems. It is depending on the perturbation of the voltage than the observed rate of change of power. A process flow describing the procedure is presented in figure 3.

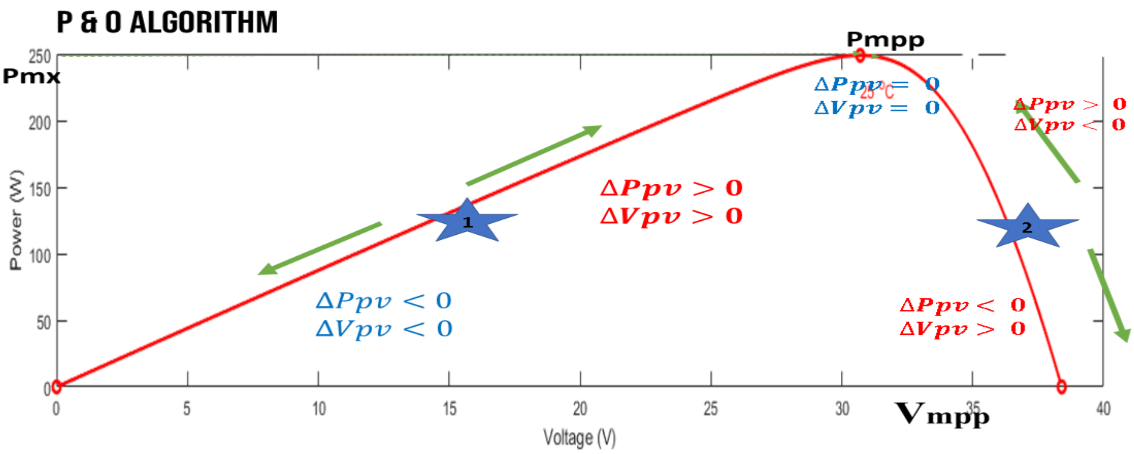

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Figure 3. P and O Algorithm

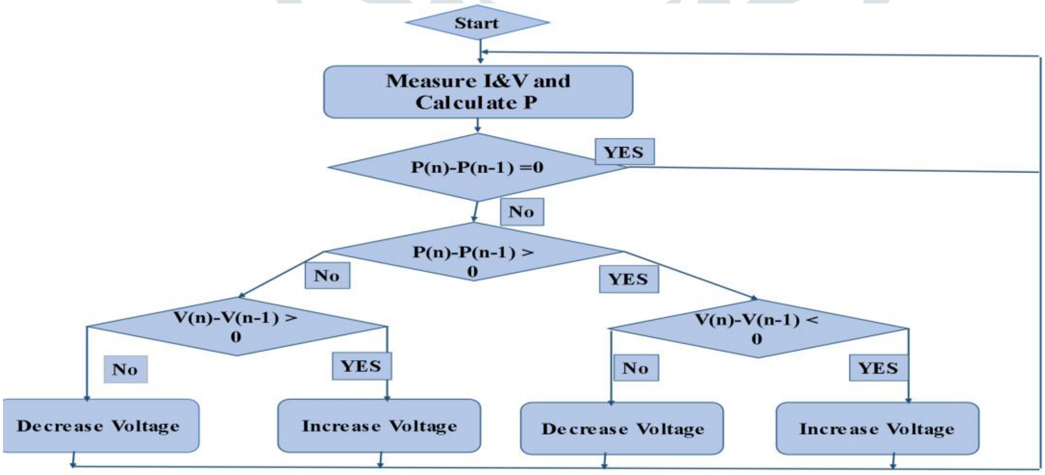

Figure 4. Flow Chart of P and O Algorithm procedure

2.2.2. MATHEMATICAL MODEL OF BOST CONVERTOR

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load) [6].

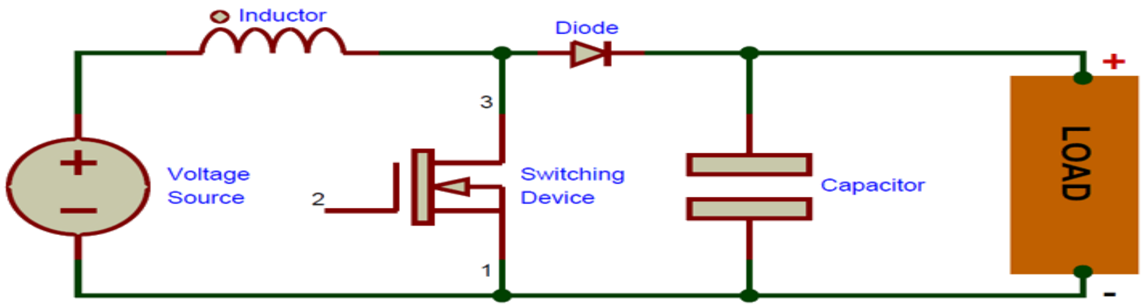

Figure 5. Boost Convertor

Its operation is mainly of two distinct states:

i) During the ON period, switch is made to close its contacts which results in increase of inductor current.

ii) During the OFF period, switch is made to open and thus the only path for inductor current to flow is through the fly-back diode 'D' and the parallel combination of capacitor and load. This enables capacitor to transfer energy gained by it during ON period.

$Inductace(L) = \frac{V_{in\_}min*D}{F_S*\Delta IL_{max}}$

$Capacitance\ (C) = \frac{I_{omax}*D}{F_S*\Delta VC}$

2.3. MATHEMATICAL MODELLING OF WIND TURBINE (WT)

Based on the tower height nature, the WTs operate in two configurations. The axis of the rotor is fixed on the tower for the upwind configuration and followed by the direction of the wind rotor is located beside the tower for downwind configuration. The WT is modelled by the consideration of wind passing into the turbine blades [7]. The Power developed in the WT can be derived by the following equations

$\rho S_1 V_1 = \rho SV = \rho S_2 V_2 = m = constant$

The power specified as: $P = \frac{1}{2} m(V_1^2 - V_2^2)$ where, m-air mass

$\rho = \rho SV(V_1^2 - V_2^2)$ where V denoted the wind speed flow through rotor blades of the wind turbine.

$$P = \frac{1}{2}\,\rho SV(V_1^2 - V_2^2) = \rho SV^2(V_1 - V_2)$$

Considering, the average wind speed at the turbine from the literature [8], we get

$V = (\frac{V_1 - V_2}{2})$

Since Force and power in terms of downstream & upstream velocities can be expressed as

$$F = \rho SV(V_1 - V_2) = \rho S(\frac{V_1^2 - V_2^2}{2})$$

$$P = \rho SV^2(V_1 - V_2)$$

$$P = \frac{1}{4}\rho SV(V_1 + V_2)(V_1 - V_2)$$

$$P = \frac{1}{4}\rho SV(V_1 + V_2)^2(V_1 - V_2)$$

In terms of downstream velocity factor $B = \frac{V_1}{V_2}$

$$P = \frac{\rho SV_1^3(1 + b)(1 - b^2)}{4}$$

$$P_f = \frac{P}{S}$$

$$P_f = \frac{\frac{1}{2}\rho SV^3}{S}$$

$$P_f = \frac{1}{2}\rho V^3$$

The kinetic content of power for upstream undisturbed wind with over S will result in

$$W = \frac{1}{2}\rho V_1^3$$

3.ELECTRICAL LOAD DATA AND COST OF A RURAL VILLAGE FOR DESIGNING THE INTEGRATION SYSTEM

As a case study, a rural Kelelamo of around 20 houses that hamlet 47 KM away from Hosanna city is taken into consideration. There are 20 homes in this rural community, and an energy audit conducted there revealed that each home uses an average of 243.52 KWh of electricity per day, with a maximum usage of 44 KW. The information was derived from the hourly daily electrical usage of a specific location in a hamlet. The rural villagers were found to require electricity for 8 hours.

I.PV financial data

solar PV coexist in series and are both financially feasible. The amount of electricity the PV array generates depends on how much sunlight hits it. The PV array employed in the suggested setup has a 340W size. Each capacity costs BIRR 110,000 & BIRR 112,000 including battery. A "derating issue of 80% & land reflection is 20%" will ensure healthy performance for 25 years. The PV array is oriented with a west-facing slope angle of 35 degrees, zero azimuth, and optimistic value.

II. Wind turbine

The input from wind turbines the wind-solar power system uses a BWC- EXCEL-RL/48 type WT" generator. BWCEXCEL-RL/48 (XLR) has a 14.2kw DC maximum power. The wind turbine produces electrical energy from the kinetic energy of the wind. The fluctuation in wind velocity affects how much electrical energy the turbine produces. Used wind turbine cost is BIRR.250,000, as are servicing and maintenance fees. 142, 500, and 1,700,000 BIRR, respectively including power convertor. The anemometer is situated 30 meters above the tower, and a good performance is anticipated for 25 years.

3.1. WIND AND SOLAR ENERGY RESOURCE

The renewable sources are naturally obtainable and clean but not available continuously. Renewable energy sources possess the first preference to supply electrical energy to meet the demand of village users. The climate information for the selected village location for renewable wind PV solar is very vital to understand the possibility of the past, which is the secret data. The data for wind and solar sources of selected village location is supplied by NASA [9].

3.2. SOLAR ENERGY RESOURCES OF KELELAMO VILLAGE

Most parts of Ethiopia have a daily solar radiation which varies from 5 and 7 kWh/m^2.day [10]. The results found from Metronome shows that the daily solar global irradiation of Kelelamo village is 5.33 KWh/m^2 day. To determine the amount of energy for Kelelamo Village that can be attained by means of solar PVs, the radiation data for the coordinates indicated below is considered.

Sunlight irradiance information of every hour is recorded from the location of the village. Long-standing standard yearly supply scale (5.531). These statistics are measured. Figure 11 shows all 12 months PV output power present, based on the solar radiation. It is observed that solar energy is more abundant in the summer months in comparison to the months of winter. Table2 tabulates the Month-wise solar insolation and wind speed information.

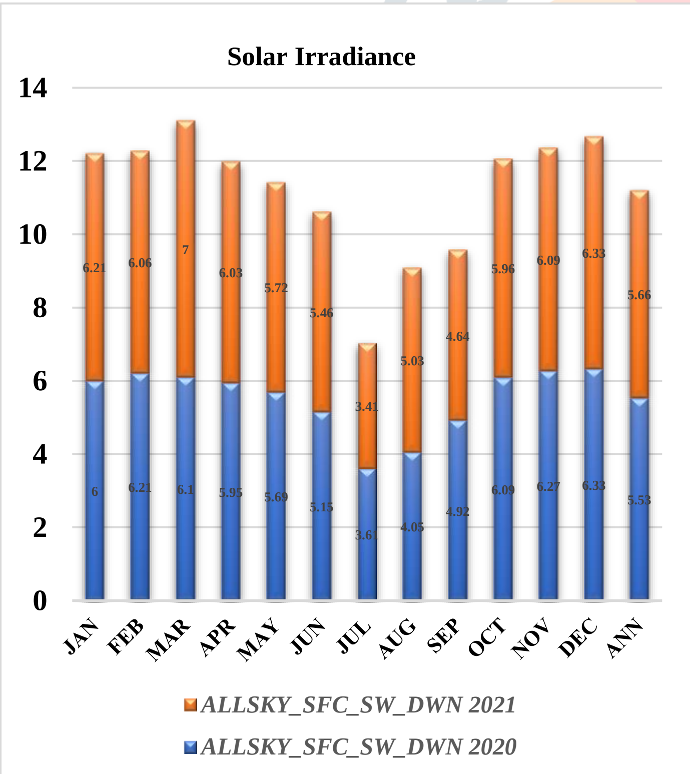

Figure 6. Irradiance (kW-hr/m^2/day)

Table 1:Temperature data

MONTH	TEMPERATURE(°C)
JAN	18.68
FEB	21.33
MAR	24.93
APR	22.64
MAY	19.53
JUN	19.53
JUL	18.14
AUG	18.86
SEP	19.01
OCT	18.76
NOV	19.15
DEC	20.69
ANN	**20.1**

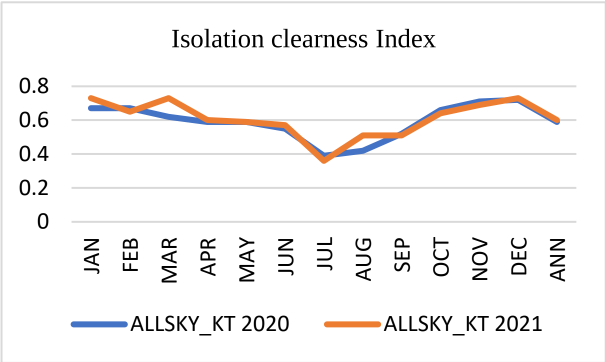

Figure 7.Clearness Index Data

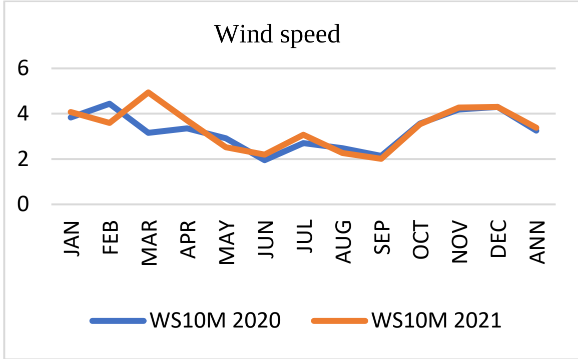

Figure 8.Wind speed Data

4.SYSTEM CONFIGURATION INTEGRATING PV AND WIND ENERGY

The integration power plant has both solar and wind energy generators. Two energy sources are combined to create electrical energy. The combination charge regulator is coupled to this combined electrical energy. In order to support the peak load for the necessary backup hour, the combined energy from the charge controller is subsequently stored in a high efficiency, low self-discharge, C10 rating, gel tube battery with a correctly predicted AH rating. After that, a high-efficiency, pure sine wave inverter with the necessary VA rating is attached to the battery's output to drive the load. The inverter receives the battery's DC energy as an input, transforms it to AC, and then drives the load based on demand. Figure (9) presents a construction block diagram of an integrated solar and wind power system.

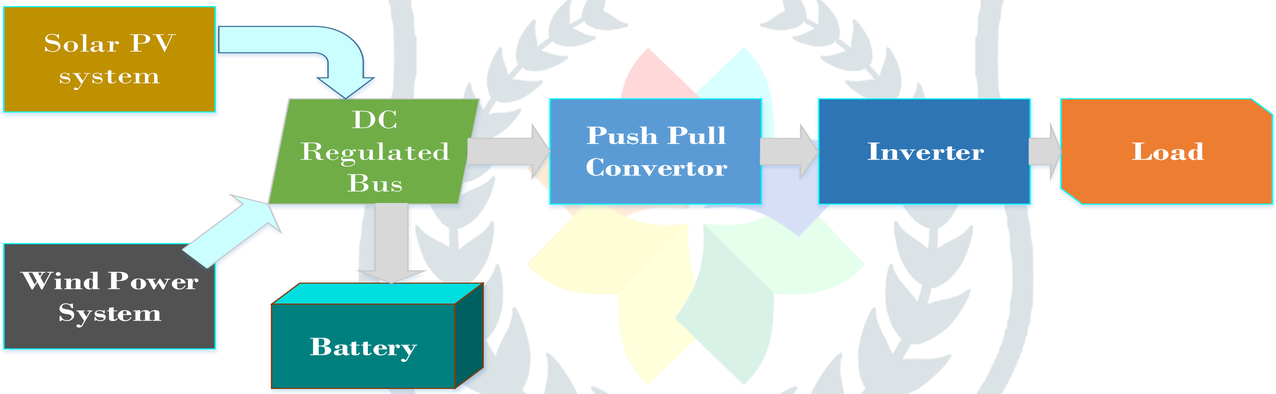

Figure 9.Block diagram of the wind-solar integration power system

4.1. INCREASE IN THE INTEGRATION SYSTEM'S SIZE

Both solar PV and wind energy are abundant, free, and healthy for the environment. The low speed and greater unpredictability of wind energy systems may prevent them from being technically feasible at all locations. As a result, combining the usage of various renewable energy sources is becoming more and more popular as a substitute for energy derived from oil. These renewable energy technologies' economic features are sufficiently promising to be taken into account for increased power generation capacity in developing nations. An array of solar PV and wind turbines make up the intended integrated system, and a diesel generator and battery bank make up the backup system. The mentioned Integration system is developed for the off-grid plan in the remote region. For performing optimal sizing of the wind PV solar system, the "MATLAB 2020a software tool" is utilized based on the following main tasks. They are the Study of: - Simulation, Sensitivity and Enhancement.

The following characteristics are utilized in MATLAB/Simulink:

- ✓ For the WES model, the Sim Power system toolkit application library
- ✓ The MPP algorithm and PV system are simulated using the Sim power system and Simulink blocks.
- ✓ The PS model and grid are created using Sim Power system toolkit.

4.2. MATLAB SIMULINK MODEL OF A SYSTEM SOLAR PV AND MPPT

The detailed simulated model of standalone PV System is implemented using in MATLAB/Simulink software. The PV system is modeled using the mathematical modeling described in the above.

Table 2.Specifications and Parameters of PV System

Quantity	Value
PV Panel parameters	
Module Type	1Soltech 1STH-340-WH
No. of cells/module	80
No. of series connected modules/string	8
No. of parallel strings	10
Output power of PV panel	28.5KW
Module specification under Standard Test Condition (STC)	
Open circuit voltage	51.1V
Short circuit current	9.12A
Maximum power voltage	42V
maximum power current	8.09A
Boost Converter parameters	
Switching Frequency	5KHZ
Capacitor	15Mf
Inductor	170Mh
MPPT controller gain	7.2

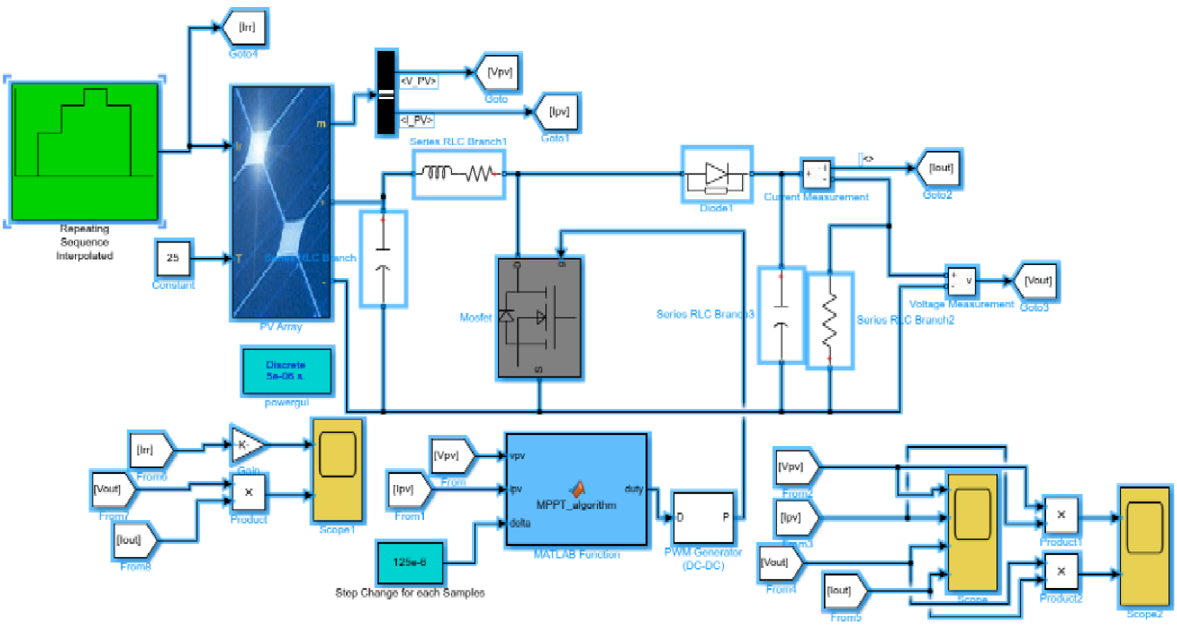

Figure 10.Mppt P&O Algorithm

A standalone PV system's comprehensive model is made up of numerous states and non-linear building parts, including power electronics components. As a result, the created electrical system has a fixed-step to minimize computing requirements. For the power system and power conditioning system, the simulation is run in discrete mode at 1e-6 step size with the Tustin/backward Euler solver.

To increase simulation performance and accuracy, multi-level control blocks like the VSC controller and MPPT controller use a configurable step size of 100e-6. Figure 11. depicts a simulation of the PV panel subsystem. Solar irradiance (W/m2) is sent to the PV panel as its input by the signal builder block of the Simulink library. The PV system is suggested for Kelelamo village Ethiopia.

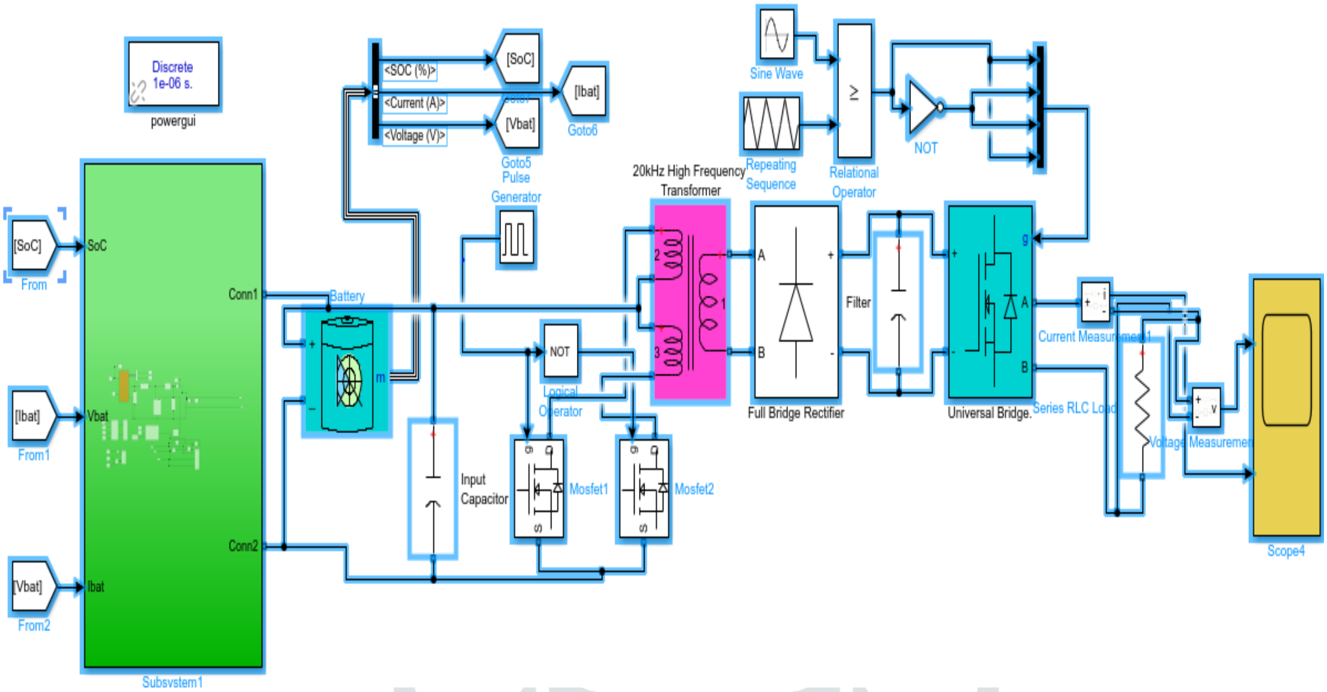

Figure 11.Simulated Model of Standalone PV System Using MATLAB

The DC power output of the system is used to MPPT in order to get the maximum DC energy from the PV. The inverter uses the MPPT's highest harnessed DC power output as input before delivering the synchronized AC power output to the load. Similar to this, a DC charging unit is connected for battery charging in DC applications.

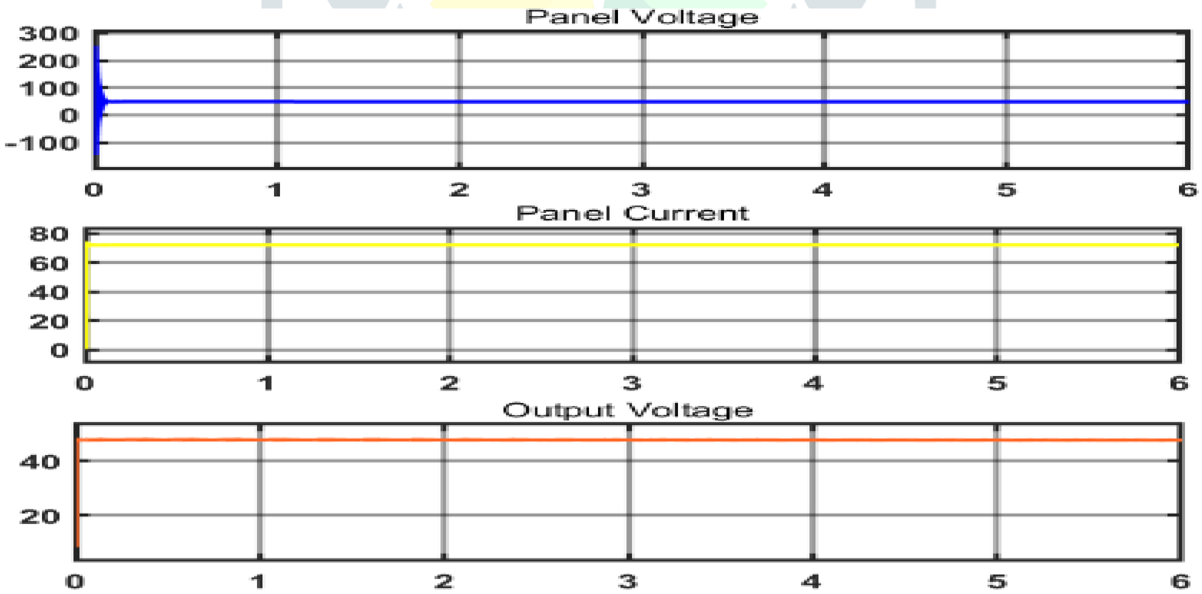

Figure 12.Panel Voltage, Current and output Voltage

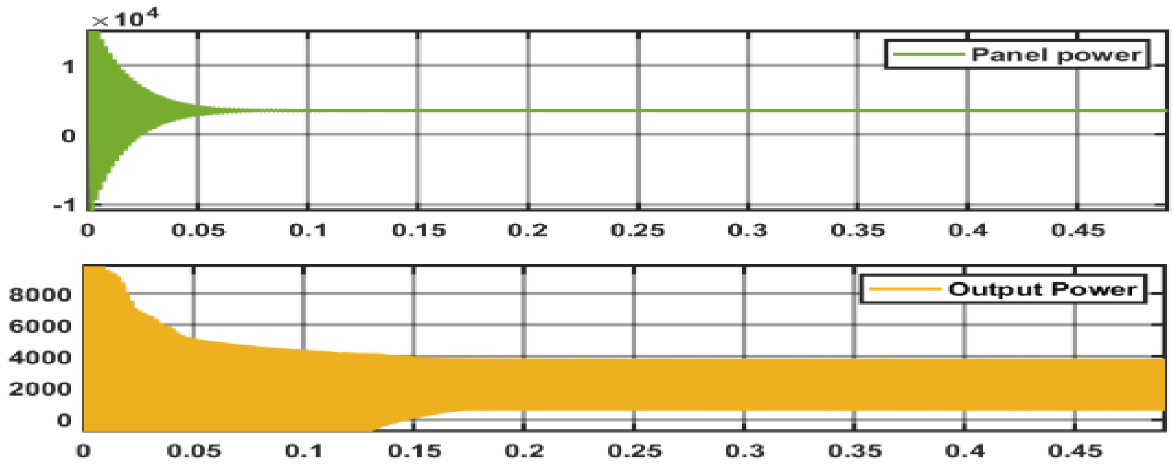

Figure 13.Panel output power and System output power

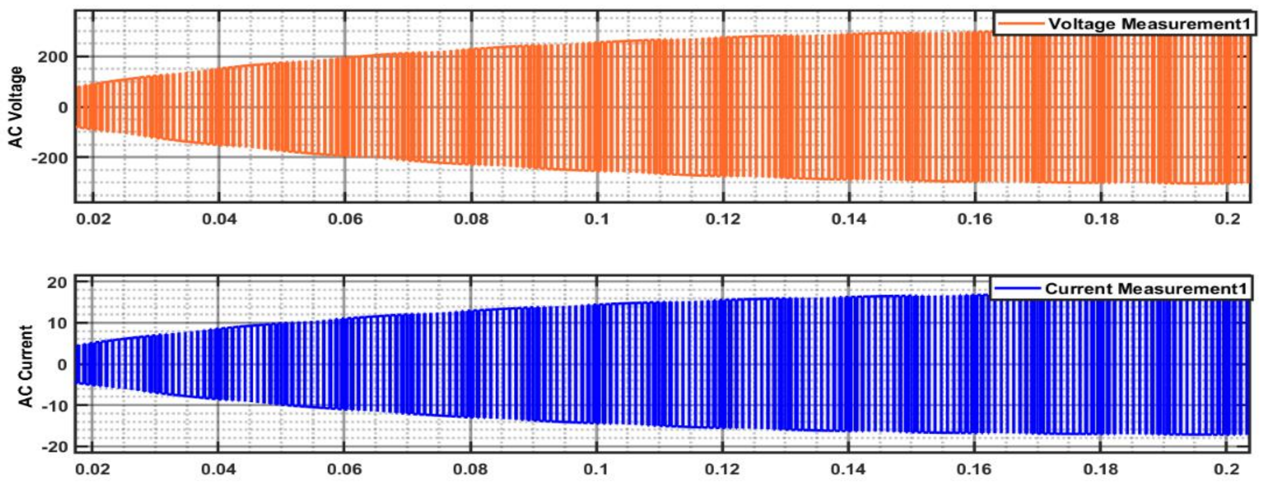

Figure 14.AC Voltage and Current output

4.3. SYSTEM SIMULATION FOR WIND ENERGY

The Sim Power systems block in the MATLAB/Simulink environment is used to create the model of a variable speed wind energy conversion system composed of a pitch-regulated wind turbine and a self-excited induction generator. Figure 23 depicts the simulated hybrid system created by MATLAB.

Table 3.Wind Energy Specification

Quantity	Value
Output Power	28.5kW
Capacitor bank	4kVar
Rated voltage	230V
Rated current	26A
Rated speed	1500rpm
No. of pole	4
Frequency	50Hz

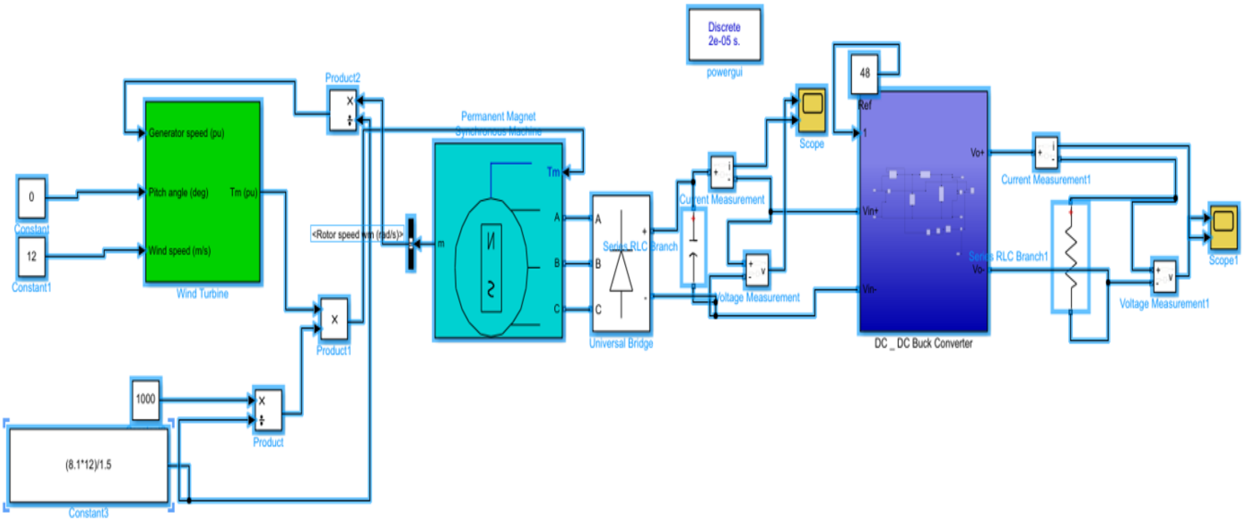

Figure 15.MATLAB Simulink model of WES with SEIG

The wind speed and load variations influence how much voltage the SEIG generates. Therefore, the terminal voltage is controlled via the asynchronous connection, also known as an AC-DC-AC converter.

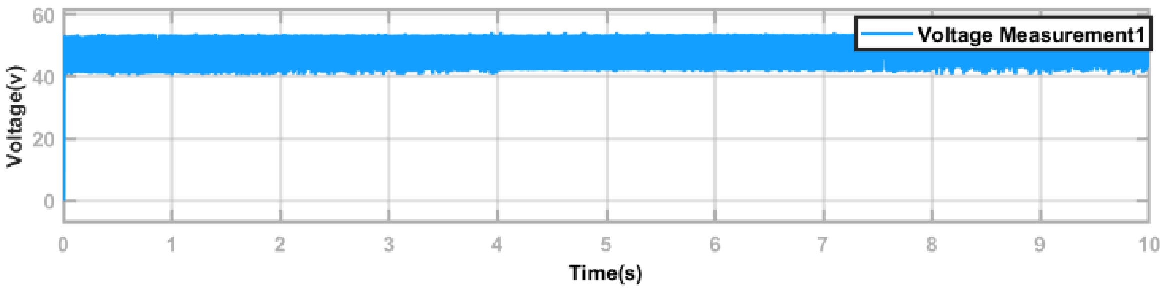

Figure 16.wind turbine voltage output

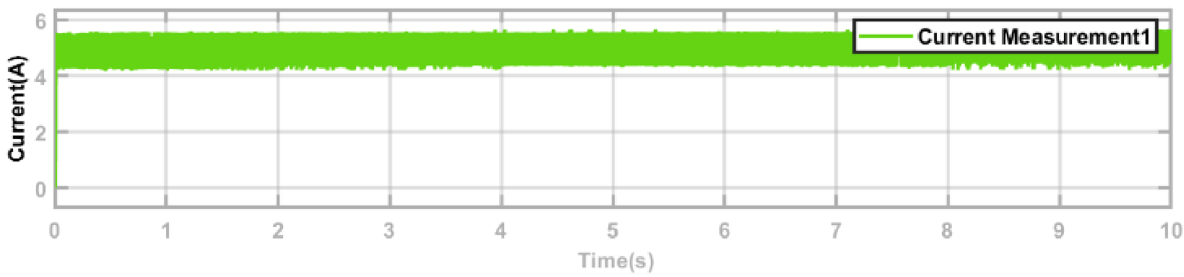

Figure 17.wind turbine current output

4.4. MATLAB SIMULINK MODEL OF INTEGRATION SYSTEM

In this section, the functional building block diagram of the wind-solar system is shown in Figure.

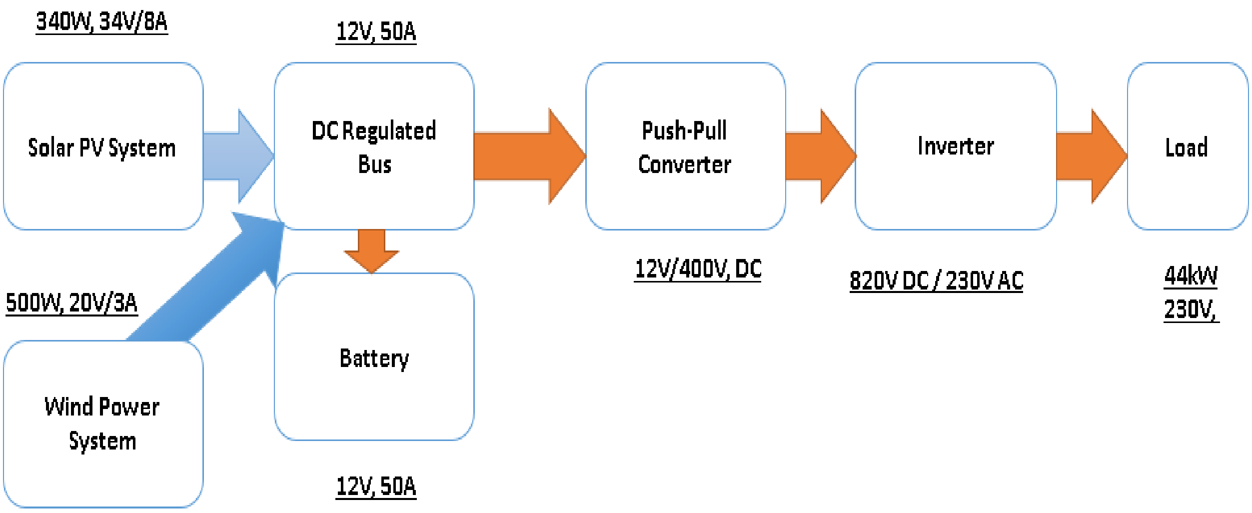

Figure 18.Functional Block diagram

The Sim Power tool of the MATLAB Simulink software simulates the entire MATLAB representation of a wind-solar structure with the building blocks of a wind-solar power system, namely wind energy arrangement building block, PV building block, battery storage system block, and DC to DC converter subsystem design building block.

Table 4. Parameters for a Wind-Solar System in MATLAB Simulation Model

NO.	MATLAB Simulation Blocks	Parameter
1.	PV Solar system	Output Power = 28.5KW
2.	Wind power System	DC Current Produced = 100Amp; AC Output developed = 28.5KW
3.	Battery system	D. C. Voltage = 720V; D.C. AH rating = 750Amp-Hr.
4.	(AC to DC Converter)	Snubber resistance r=5000 ron=1Ω
5.	Transformer	Nominal power = 73,000VA; Cycles per second = 50 c/s; Transformer input voltage = 75,000V; Transformer output voltage = 2400V.
6.	AC Generator	Cycles per second = 50; c/s short circuit level = 50,000VA; Transformation ratio = 7.
7.	Electrical Load	voltage; Vn= 420V; Nominal cycles/sec f= 50 c/s; Active power = 20KW; Inductive reactive power = 200 VAR;

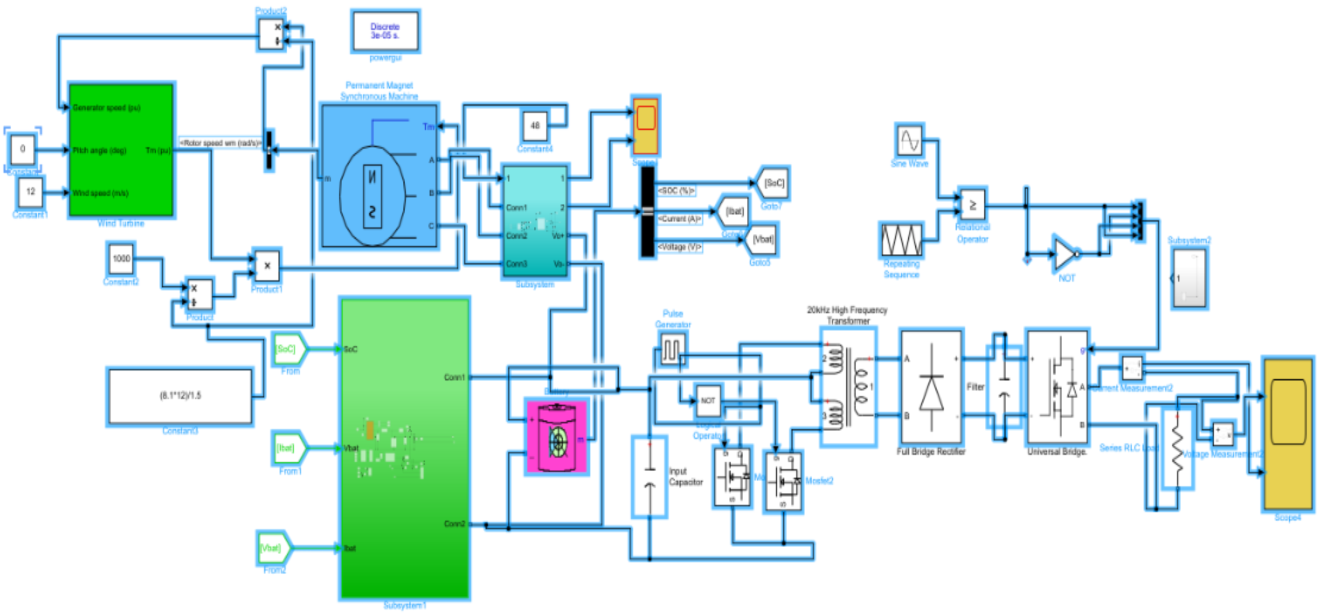

Figure 19.Wind-PV power structure representations

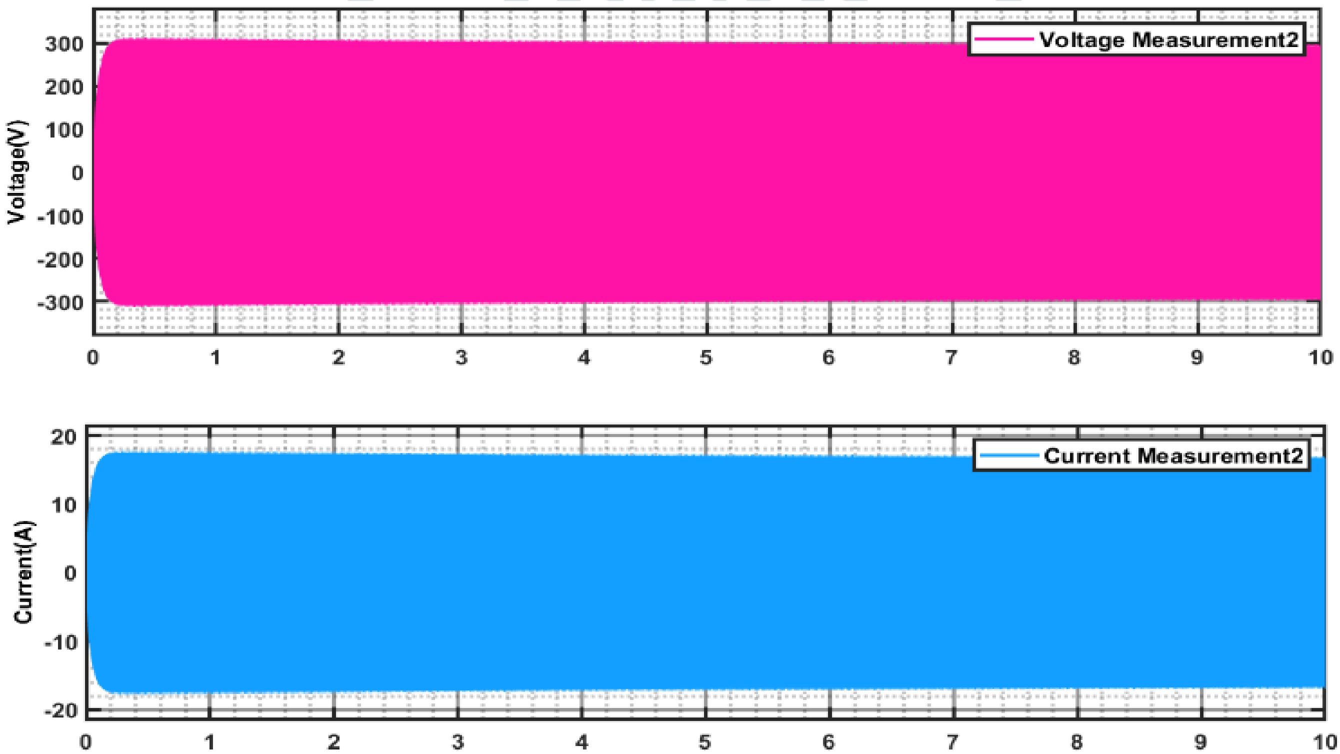

Figure 20.AC Voltage and Current of Integration System

5.RESULTS AND CONCLUSION

Throughout the entire year, a rural village receives uninterrupted power from wind and solar sources. Take into account several sensitivity factors for the inquiry, such as battery price, wind speed, and sun radiation. The integrated wind solar system is seen to be the greatest option for supplying an isolated village's energy needs. The optimal model is simulated based on the hourly time series data to supply the electricity for all twelve months of the year. The MATLAB 2020a software's recommended configuration includes a PV panel, a boost converter, a wind turbine, and a battery. Under a calculated load, the integration of the PV and wind systems has been carried out and studied. The reported findings unmistakably show that the proposed controllers and the proposed systems are effective and trustworthy for remote and rural locations, respectively

Ethiopia has one of the lowest electrification rates in Sub-Saharan Africa, with under 20 percent of the nation's towns and villages electrified. For such a remote village, combined wind and solar systems are the greatest option for rural electrification. This method is both affordable and able to provide electricity throughout the entire year. The research of the pre-viability of an integrated solar photovoltaic (PV) and wind power system is based on a substation in a remote area of Ethiopia. The most environmentally friendly and economically advantageous options for the majority of the challenging remote locations were discovered to be the remote rural village site base station powered by the wind solar with battery support. Whether the system is implemented in crowded areas or remote parts of a hamlet, hybrid wind-solar systems are beneficial to the environment. Additionally, the wind solar system lowers hazardous gases like CO_2.

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