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Modeling And Control for Smart Grid Integration of Solar/Wind Energy Conversion System

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keywords: Smart grid, MATLAB Simulation, PV & WECS integration

Introduction

1. This paper focuses mainly on the smart grid integration of PV/WT hybrid system (grid optimisation and distribution generation). India had set an ambitious target of reaching 175 GW of installed capacity from renewable energy sources by the year 2022, which included 100 GW of solar and 60 GW of wind power capacity. Various policy initiatives were taken to achieve this target. At the end of 2017-18 the total renewable power installed capacity in the country was almost 70 GW. The existing wind farms have scope of adding solar PV capacity and similarly there may be wind potential in the vicinity of existing solar PV plant. Suitable policy interventions are therefore, required not only for new wind-solar hybrid plants but also for encouraging hybridization of existing wind and solar plants. To smoothen the wind solar hybrid power further, appropriate capacity of battery storage may also be added to the project.

1.2 Based upon the above prevailing need for the upgradation and development of the new technology a detailed dynamic model, control and simulation of a smart grid-connected PV/WT hybrid power generation system is proposed. Modeling and simulation are implemented using MATLAB/SIMULINK software packages to verify the effectiveness of the proposed system.

Literature survey

2. The combination of renewable energy sources, wind & solar are used for generating power called as wind solar hybrid system. This system is designed using the solar panels and small wind turbines generators for generating electricity. Solar Energy is available only during the day time whereas wind energy is available through out the day depending upon the atmospheric conditions. Wind and solar energy are complementary to each other, which makes the system to generate electricity almost throughout the year. The main components of the Wind Solar Hybrid System are wind aero generator and tower, solar photovoltaic panels, batteries, cables, charge controller and inverter. The Wind - Solar Hybrid System generates electricity that can be used for charging batteries and with the use of inverter can be used to fed the grid.

2.1 The implementation of wind solar hybrid system will depend on different configurations and use of technology. Battery storage may be added to the hybrid project for the following :

a. To reduce the variability of output power from wind solar hybrid plant.
b. To provide higher energy output for a given capacity (bid/ sanctioned capacity) at delivery point, by installing additional capacity of wind and solar power in a wind solar hybrid plant.
c. To ensure availability of firm power for a particular period

2.2 Wind-Solar Hybrid- AC integration

In this configuration the AC output of the both the wind and solar systems is integrated either at LT side or at HT side. In the later case both system uses separate step-up transformer and HT output of both the system is connected to common AC Bus-bar. Suitable control equipment are deployed for controlling the power output of hybrid system.

2.3 Wind-Solar Hybrid- DC integration

DC integration is possible in case of variable speed drive wind turbines using convertor-inverter. In this configuration the DC output of the both the wind and solar PV plant is connected to a common DC bus and a common invertors suitable for combined output AC capacity is used to convert this DC power in to AC power. Battery storage may be added to the hybrid project (i) to reduce the variability of output power from wind solar hybrid plant; (ii) providing higher energy output for a given capacity (bid/ sanctioned capacity) at delivery point, by installing additional capacity of wind and solar power in a wind solar hybrid plant; and (iii) ensuring availability of firm power for a particular period.

2.4 Solar potential of India

Urbanization and economic development are leading to a rapid rise in energy demand in urban areas Several Indian cities and towns are experiencing 15% growth in the peak electricity demand. The local governments and the electricity utilities are finding it difficult to cope with this rapid rise in demand and as a result most of the cities/towns are facing severe electricity shortages. During 2010–19, the foreign capital invested in India on Solar power projects was nearly 20.7 billion US$. The International Solar Alliance (ISA), proposed by India as a founder member, is headquartered in India. India has also put forward the concept of "One Sun One World One Grid" and "World Solar Bank" to harness abundant solar power on global scale. With about 300 clear and sunny days in a year, the calculated solar energy incidence on India's land area is about 5 quadrillion kilowatt-hours (kWh) per year (or 5 EWh/yr). The solar energy available in a single year exceeds the possible energy output of all of the fossil fuel energy reserves in India.

2.5 Wind Power System

Wind energy simply means kinetic energy of air in motion. Wind power is the use of air flow through wind turbines to mechanically power generators for electric power. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land. The net effects on the environment are far less problematic than those of non-renewable power sources. Once the turbines are installed and there is no much maintenance required for long time. Wind energy electricity generation system takes some land for installation but most of the land they are on can be still farmed or used to crop animals. So land is not a big issue for wind turbine generating system. In most of the cases, wind plant is installed at the good height to obtain sufficient wind to produce electricity.

2.6 Wind Power Generation Wind power is the use of air flow through wind turbines to mechanically power generators for electricity. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land. The net effects on the environment are far less problematic than those of nonrenewable power sources. Wind farms consist of many individual wind turbines, which are connected to the electric power transmission network. Onshore wind is an inexpensive source of electric power, competitive with or in many places cheaper than coal or gas plants. Offshore wind is steadier and stronger than on land and offshore farms have less visual impact, but construction and maintenance costs are considerably higher. Small onshore wind farms can feed some energy into the grid or provide electric power to isolated off-grid locations.

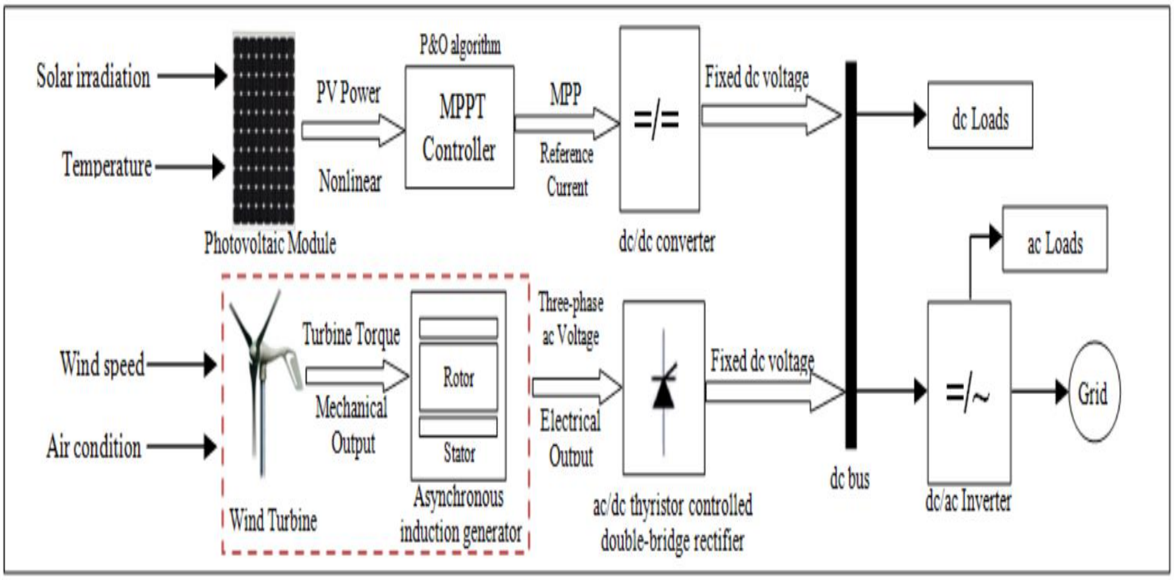
2.7 Generator characteristics and stability

2.8 Capacity factor

Since wind speed is not constant, a wind farm's annual energy production is never as much as the sum of the generator nameplate ratings multiplied by the total hours in a year. The ratio of actual productivity in a year to this theoretical maximum is called the capacity factor. Typical capacity factors are 15–50%; values at the upper end of the range are achieved in favourable sites and are due to wind turbine design improvements.

Methodology

3. Smart grid is a system consists of three layers: the physical power layer, the control layer and the application layer. In this section, the dynamic simulation model is described for photovoltaic/wind turbine hybrid generation system. The developed system consists of a photovoltaic array, dc/dc converter with an isolated transformer, designed for achieving the MPP with a current reference control (Iref) produced by P&O algorithm, wind turbine, asynchronous induction generator, and ac/dc thyristor controlled double-bridge rectifier.



Block Diagram of Proposed System

3.1 Modelling and Design of a Photovoltaic Module The general mathematical model for the solar cell has been studied over the past three decades. The circuit of the solar cell model, which consists of a photocurrent, diode, parallel resistor (leakage current) and a series resistor; is shown in Fig. 5. According to both the PV cell circuit shown in Fig. 3 and Kirchhoff's circuit laws, the photovoltaic current can be presented as follows:

$$I_{pv} = I_{gc} - I_o \left[\exp^{\left(\frac{ev_d}{KFT_c}\right)} - 1 \right] - \frac{v_d}{R_p}$$

Where Igc is the light generated current, Io is the dark saturation current dependant on the cell temperature, e is the electric charge = 1.6 x 10-19 Coulombs, K is Boltzmann's constant = 1.38 x 10-23

J/K, F is the cell idealizing factor, Tc is the cell's absolute temperature, vd is the diode voltage, and Rp is the parallel resistance. The photocurrent (Igc) mainly depends on the solar irradiation and cell temperature, which is described as [13]

$$I_{gc} = \left[\mu_{sc}\left(T_c - T_r\right) + I_{sc}\right] G$$

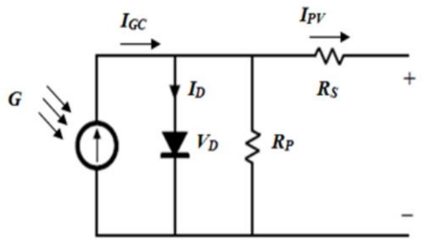


Figure 5 : Solar Cell Model

Where μsc is the temperature coefficient of the cell's short circuit current, Tref is the cell's reference temperature, Isc is the cell's short circuit current at a 25o C and 1kW/m2 , and G is the solar irradiation in kW/m2 . Furthermore, the cell's saturation current (Io) varies with the cell temperature, which is described as:

$$I_o = I_{o\alpha}\left(\frac{T_c}{T_r}\right)^3 \exp^{\left[\frac{ev_g}{KF}\left(\frac{1}{T_r}-\frac{1}{T_c}\right)\right]}$$

$$I_{o\alpha} = \frac{I_{sc}}{\exp^{\left(\frac{ev_{oc}}{KFT_c}\right)}}$$

Where Ioα is the cell's reverse saturation current at a solar radiation and reference temperature, Vg is the band-gap energy of the semiconductor used in the cell, and Voc is the cells open circuit voltage. In this study, a general PV model is built and implemented using MATLAB/SIMULINK to verify the nonlinear output characteristics for the PV module. The proposed model is implemented. In this model, whereas the inputs are the solar irradiation and cell temperature, the outputs are the photovoltaic voltage and current. The PV models parameters are usually extracted from the manufactures data sheet.The feedback is done through a meter to monitor power. Photovoltaic wattage may be less than average consumption, in which case the consumer will continue to purchase grid energy, but a lesser amount than previously. If photovoltaic wattage substantially exceeds average consumption, the energy produced by the panels will be much in excess of the demand. In this case, the excess power can yield revenue by selling it to the grid.

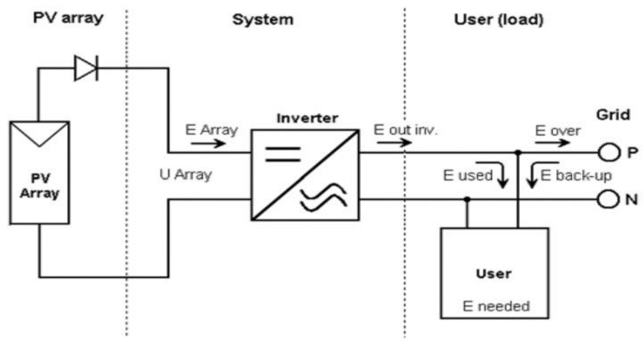


Figure 6 : Block Diagram of Grid Connected PV System

5.2 Modeling and Design of a Wind Turbine

Figure 7 shows the characteristic parameters of a wind turbine which is essential in choosing an appropriate turbine. Cut-in speed is the minimum wind speed required to overcome the friction of the turbine blades to rotate the blades. The rated speed is the minimum wind speed at which the turbine generates the rated power output. Rated power output is the maximum power generated by the generator without damaging the generator and batteries. Pitch angle adjustment of the blades limits the output power by varying the aerodynamic forces acting on the blades at higher wind speed [3]. Cut-out speed or furling speed is the maximum wind speed at which the generator will continue to generate electricity before shutting down to protect the turbine. Any wind speed above the cut-out speed will cause damage to the turbine and therefore the braking mechanism will be activated and shut down the turbine.

5.3 Components in a WECS

Wind energy conversion system as shown in Figure 8 can be divided into the blades, generator, power converter and controller. The turbine blades are responsible of converting the kinetic energy from the wind into mechanical power that rotates the turbine shaft. The mechanical power of the shaft is converted into electrical energy via the generator. Drive train is used to increase the rotational speed of the turbine shaft to power the generator. The converter and inverter will convert noisy AC power generated by the variable speed generator into clean and reliable AC power.

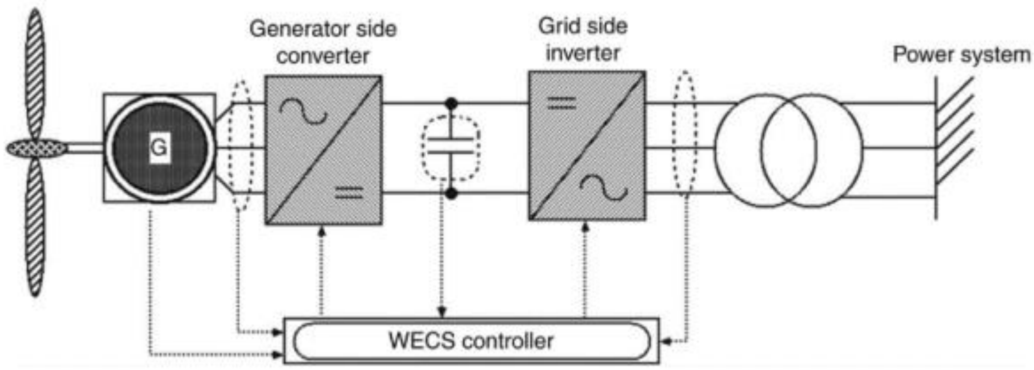


Figure 8 : Wind Energy Conversion System

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Simulation

6.1 Simulink Model

Simulink model consists of the following:

(a) Wind turbine simulation.

(b) PV model simulation.

(c) Battery storage system with bidirectional DC/DC Converter.

(d) Grid connected full bridge inverter.

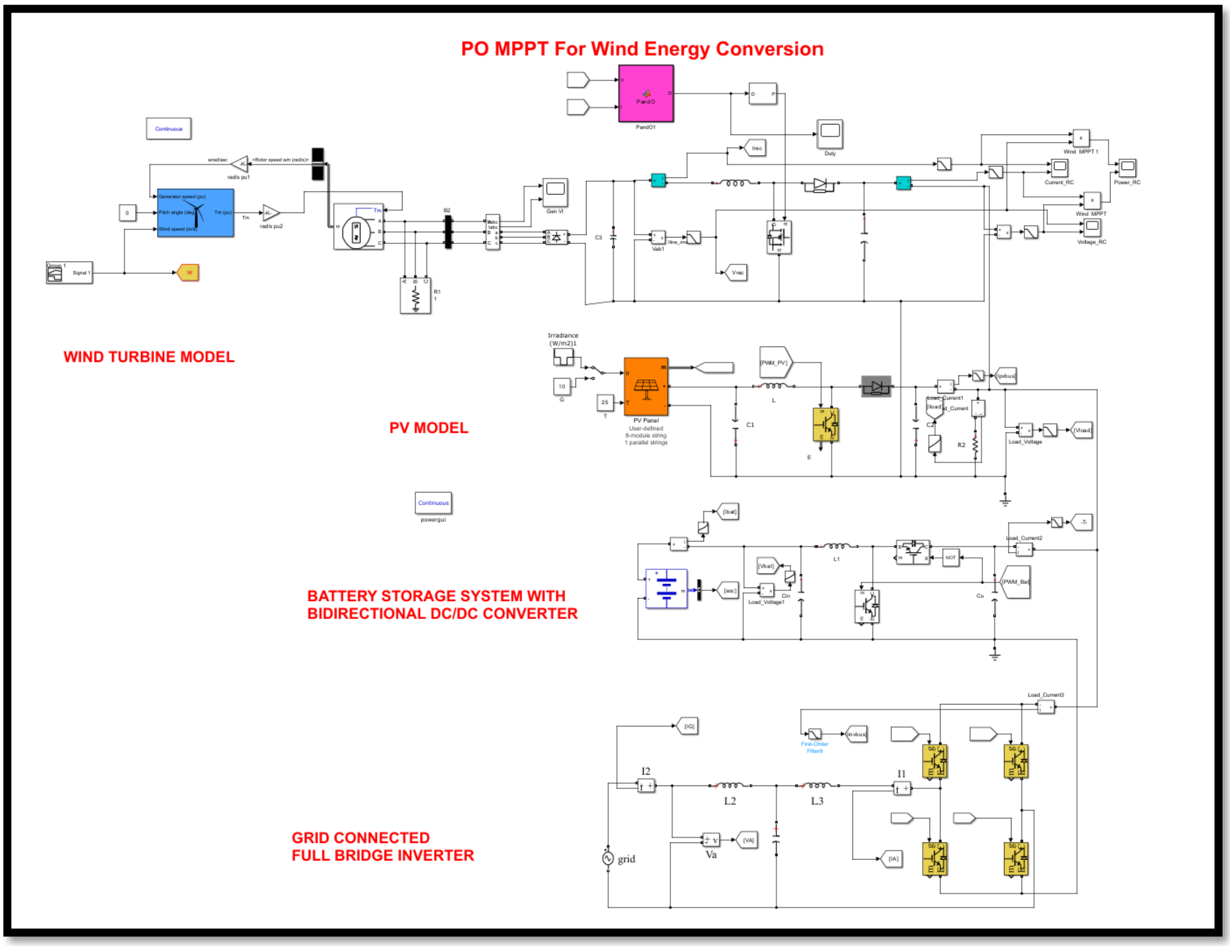
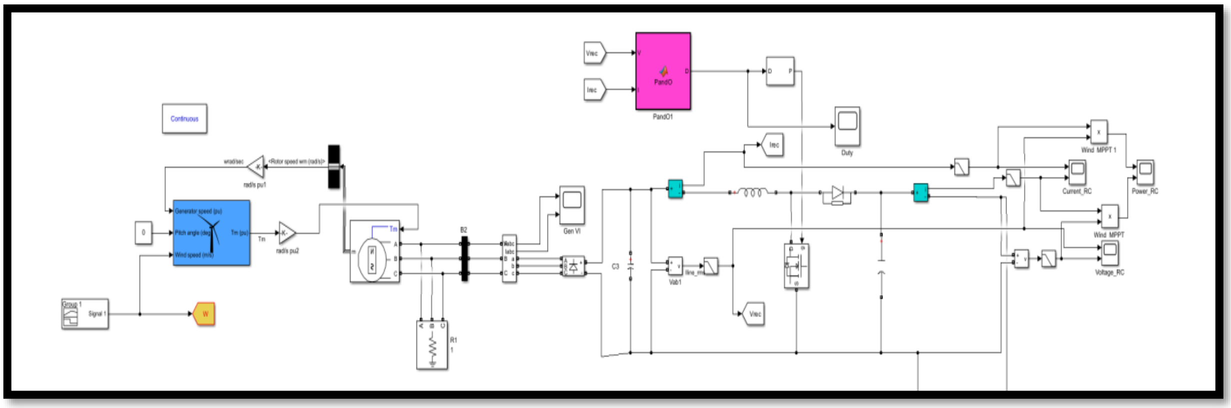
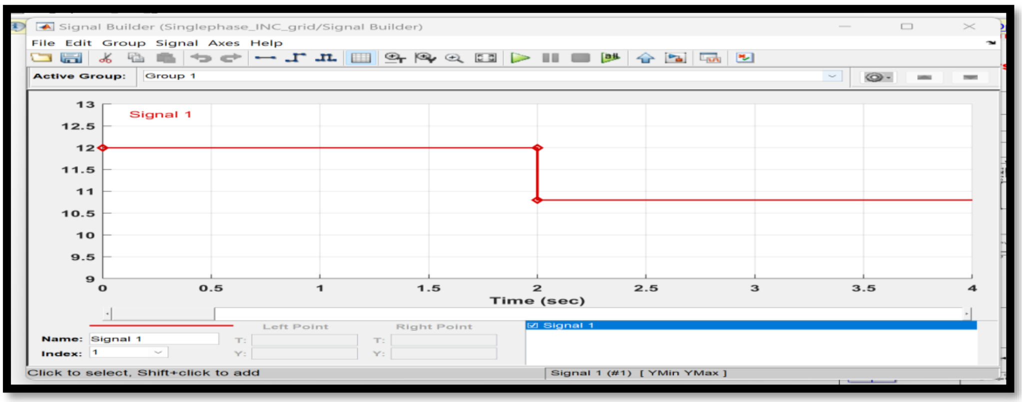


Figure 9 : Simulink Model of Wind/PV Grid Connected System With Battery Storage

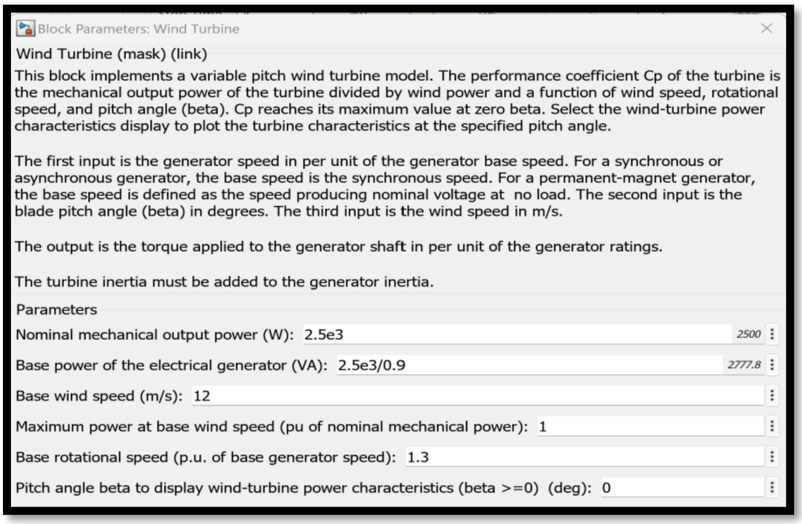
6.2 Wind Turbine Model



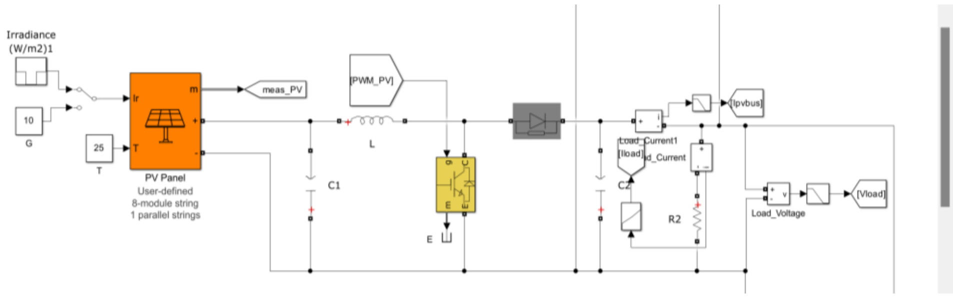
6.2.1 Wind Parameters



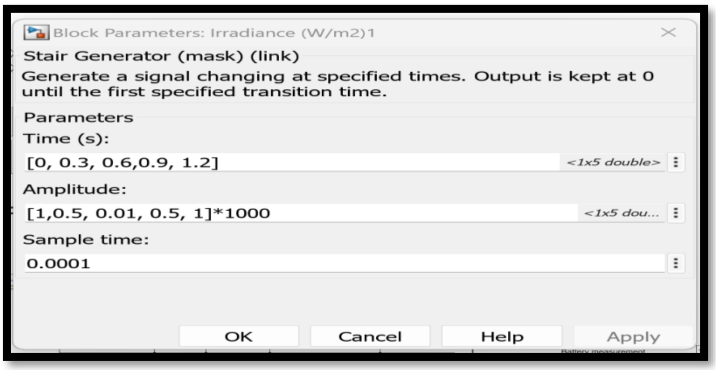
6.2.2 Turbine Parameters



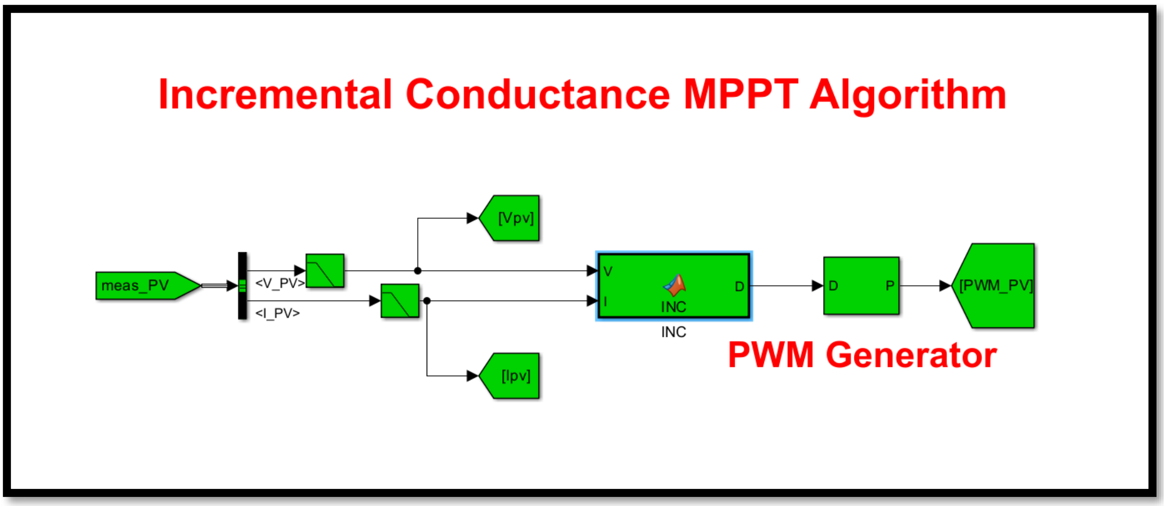
6.3 PV Model



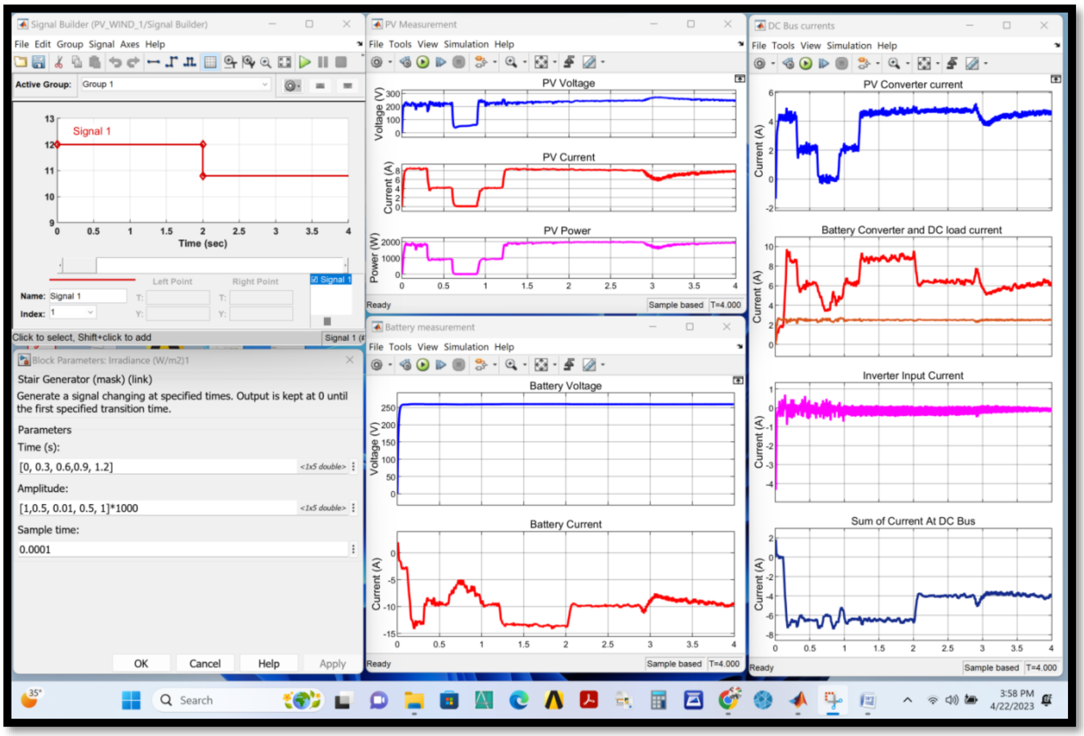
6.3.1. Input Irradiance



6.3.2 MPPT Algorithm



6.4. Simulation Results



CONCLUSION

In this paper, a PV/WT hybrid power system is designed and modelled for smart grid applications. The model has been implemented using the MATLAB/SIMULINK software package, and designed with a dialog box like those used in the SIMULINK block libraries. The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency of the PV system, the PV module was integrated with the wind turbine system. The dynamic behavior of the proposed model is examined under different operating conditions. The developed system and its control strategy exhibit excellent performance for the simulation of a complete day. The proposed model offers a proper tool for smart grid performance optimization.

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