Grid tied Renewable energy system- Solar, Wind and Hydro integration

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Introduction

The main objective of our project is the developmental idea of technological implementation, based on Simulink, related to grid connected power systems for energy production by using Renewable Energy Sources (RES), as clean and efficient sources for meeting both the environment requirements and the technical necessities of the grid connected power inverters. Another objective is to promote the knowledge regarding RES; consequently, it is necessary to bring contribution to the development of some technologies that allow the integration of RES in a power inverter with high energy quality and security. By using these energetic systems, the user is not only a consumer, but also a producer of energy. This fact will have a direct impact from technical, economic and social point of view, and it will contribute to the increasing of life quality.

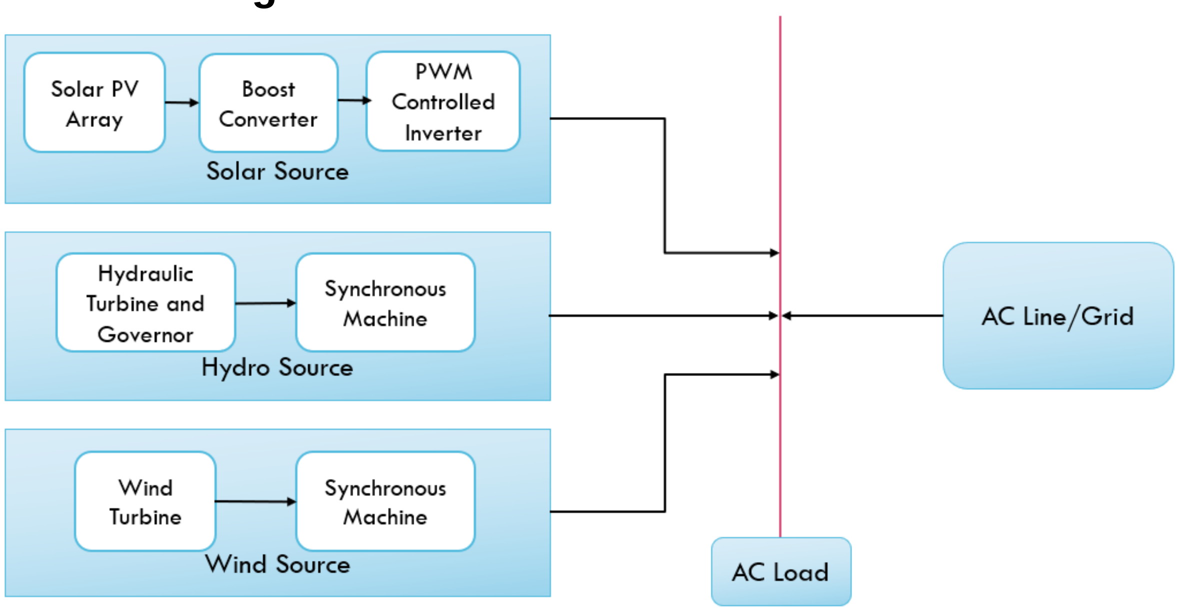
The main objective of this project-

- Development of grid tied Renewable Energy Source (RES), based on Simulink programming application.
- Power flow and consumption study of Grid-RES integrated system.

In this project, we used three Renewable Energy Sources-

- Solar Energy
- Hydro Energy
- Wind Energy

Work Flow Diagram:



Solar Source:

This is the most sophisticated and complicated source in our system. If we say it in the simplest term, when sunlight is incident upon PV array, energy of photon converts into electrical energy. Then the boost converter levels up the voltage, and the output goes to inverter, which yields 3 phase current and feeds the power to the load. The PWM Generation Block controls the inverter.

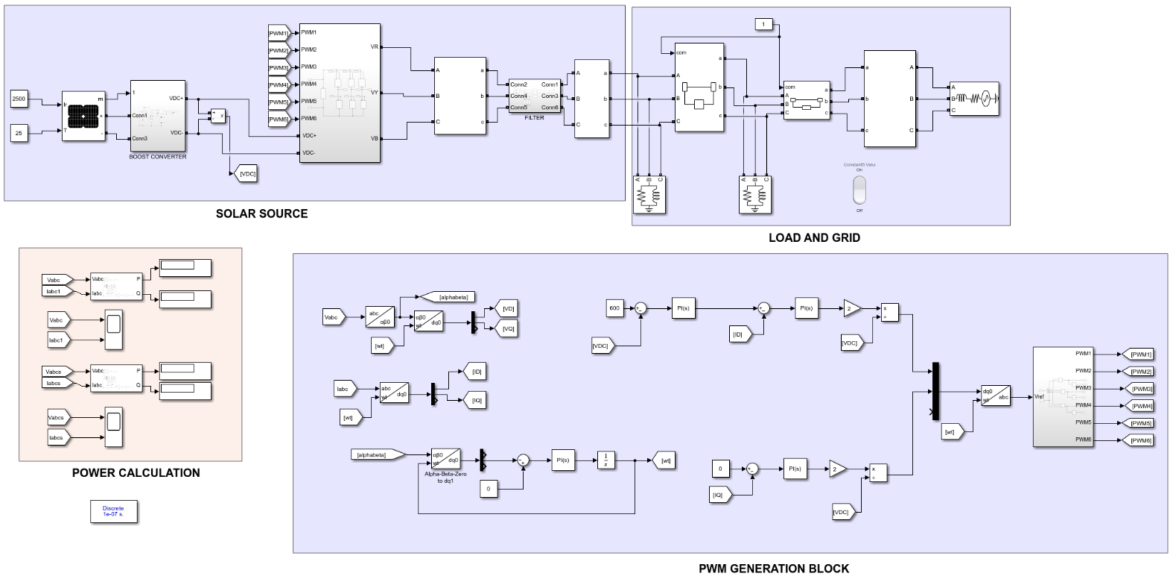


Figure: Solar Power System

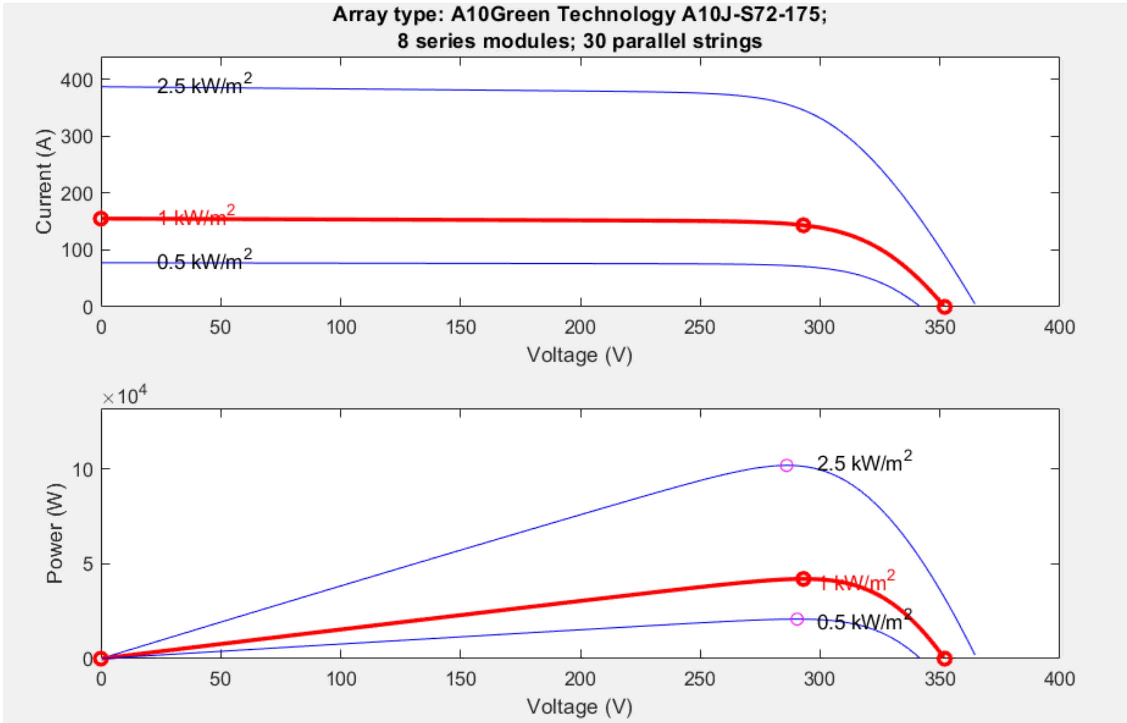
Now if we dive through the details, whole solar power generating system is made with many parts. And following are their mechanism and working system:

PV Array:

There are two input parameters in PV Array.

1. **Irradiance:** In radiometry, irradiance is the radiant flux received by a surface per unit area. The SI unit of irradiance is the watt per square metre. Average irradiance is 2700 W/m^2 in Dhaka, but we use 2500 W/ m^2 as input value for simulation which we can change if we want. Irradiance can vary upon weather, lower irradiance will produce lower power and higher irradiance will produce higher power.

2. **Temperature:** This also vary with weather; we keep it 25-degree Celsius for simulation.



In the above figure, first one is the plot of current vs voltage, second one is the plot of Power vs Voltage for different irradiance. It is clearly evident that, more irradiance can generate more power.

Specifications:

Parallel strings: 30
Series module per string:8
MPPT (Maximum Power Point Tracking) generation: 100KW
Grid: 400V L-L, 50Hz
irradiance: 2500W/m^2
Temperature: 25°C

Boost Converter:

Boost converter levels up the voltage level of PV array. Usually, voltage of PV array is never high enough to match with the Grid voltage, so boost converter is used. PV array usually doesn't produce high voltage because that is expensive.

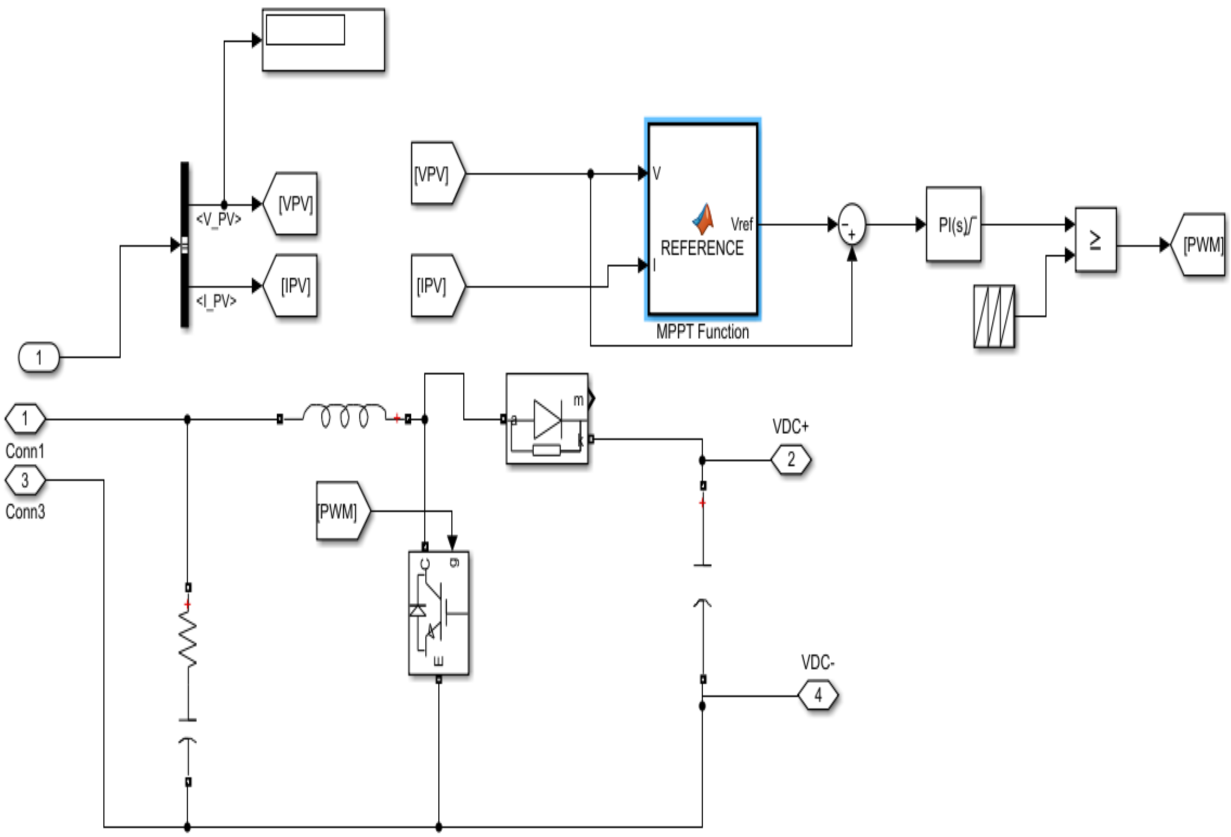
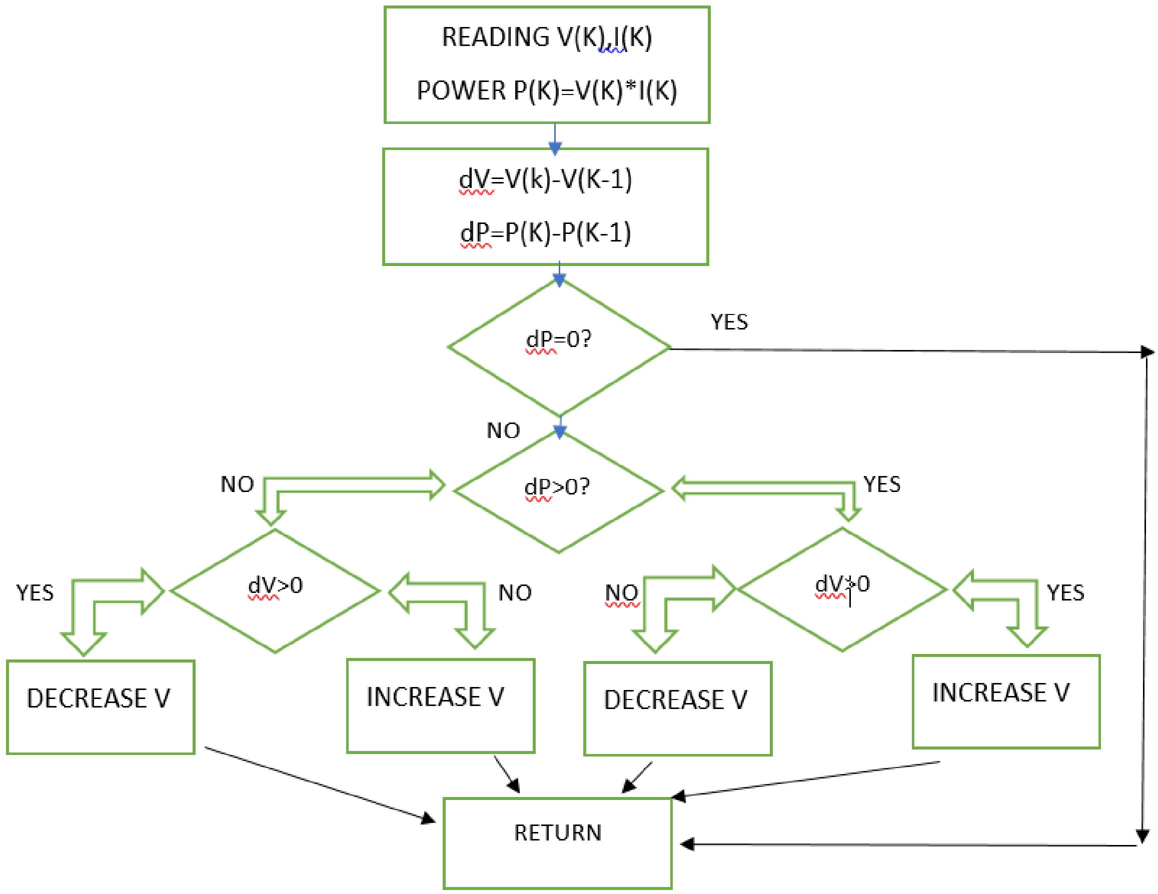


Figure: Circuit Diagram Inside Boost Converter

Inside boost converter, the voltage and current of PV array enters the MPPT controller. MPPT controller works upon MPPT function. Flow chart of the function is given below:



For the easiest explanation of function, let's say that there is an initial voltage and current for which we can calculate power. Now, let's increase the voltage a little bit. On the basis of that, if power increases, then MPPT controller will further increase voltage or else voltage will be decreased.

Then we can see that, output of MPPT function and voltage of PV array enters a PI controller. PI controller compares these two and finds the voltage which is required for maximum power output.

In the circuit of below part (where connection 1 and 3 is situated), we can see there is an IGBT (made of MOSFET and diode) which works like a switch. Let's assume first, the IGBT is on. In that case, capacitor will be charged. Again, when IGBT will be off, current will flow through short branch and there will be change of current through inductor. So, according to $V = L(di/dt)$ equation, we will find induced voltage across inductor which is the output voltage we find after boosting.

And IGBT switch on-off timing is controlled by PWM signal located in the circuit (rightmost). There is a triangular signal which is compared to the reference voltage, when triangular voltage is greater than reference voltage, the switch is on and else vice versa. Switch timing can be manipulated by changing the frequency of triangular signal.

Inverter:

Main purpose of inverter is to convert DC voltage to AC voltage.

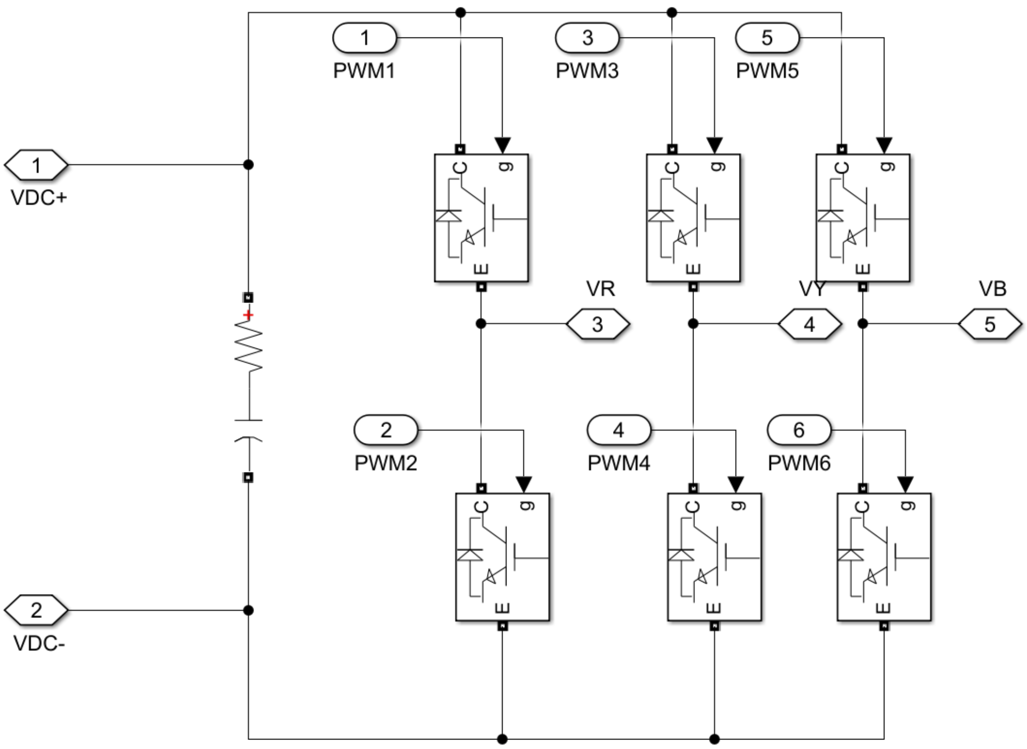
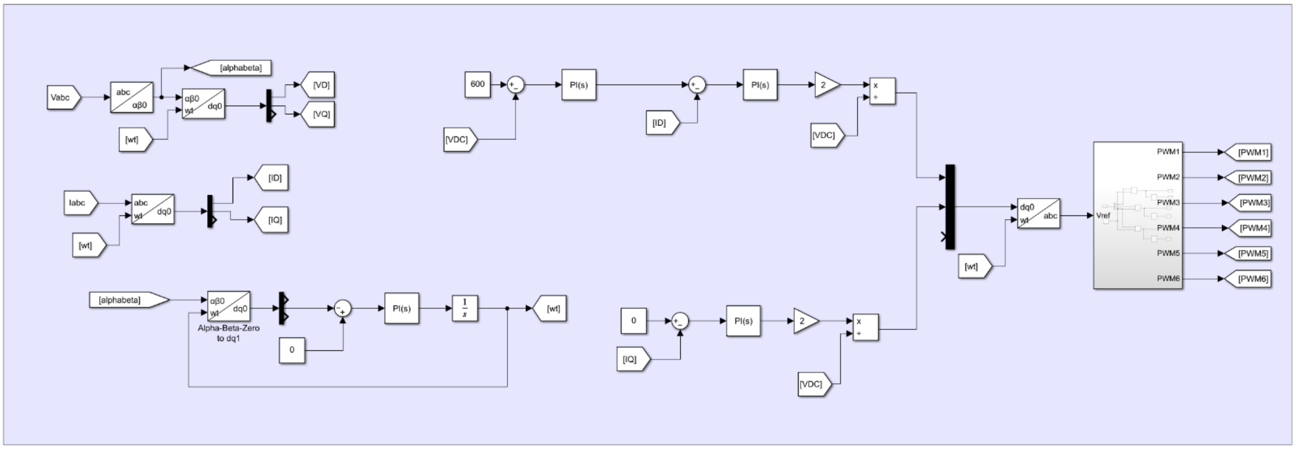


Figure: Circuit Diagram Inside Inverter

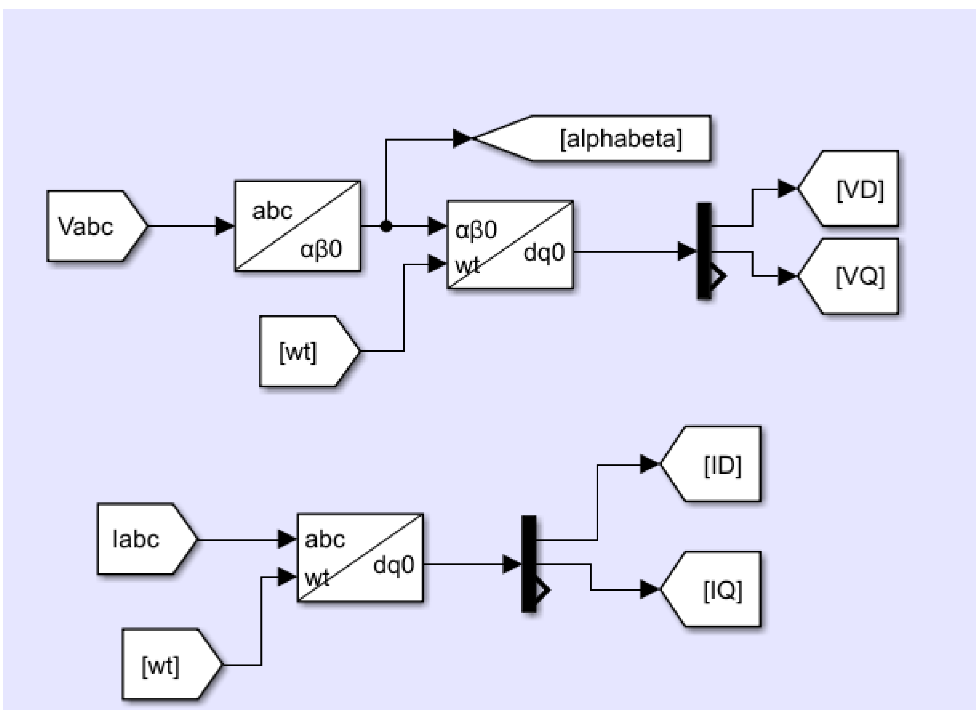
Here we can see, there are 6 IGBT switches which can be controlled by PWM inputs. Thus, direction of current can be changed by these manipulations and we can get a sinusoidal output. This output will become smoother when it is passed through a filter. And how the PWM inputs are controlled are determined by PWM generation block.

PWM Generation Block:

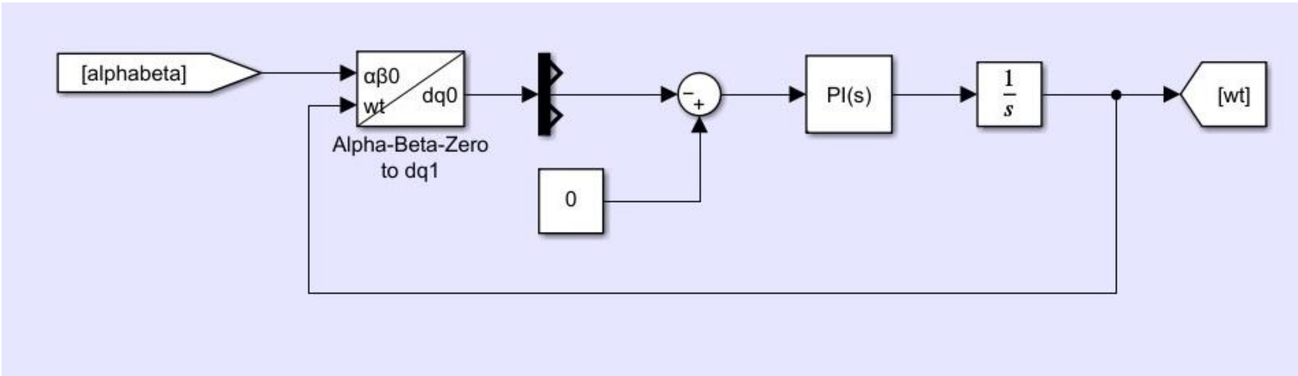


PWM GENERATION BLOCK

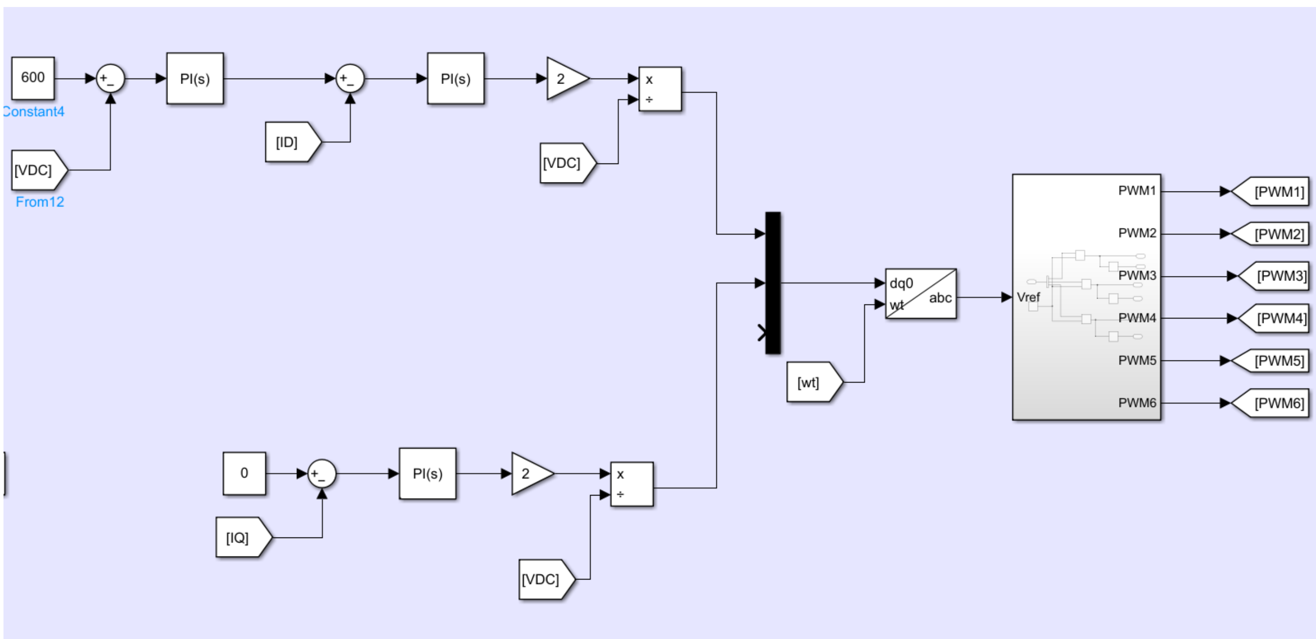
Above is the simulation diagram of whole PWM generation block. Workflow and incidents of this circuit is described below:



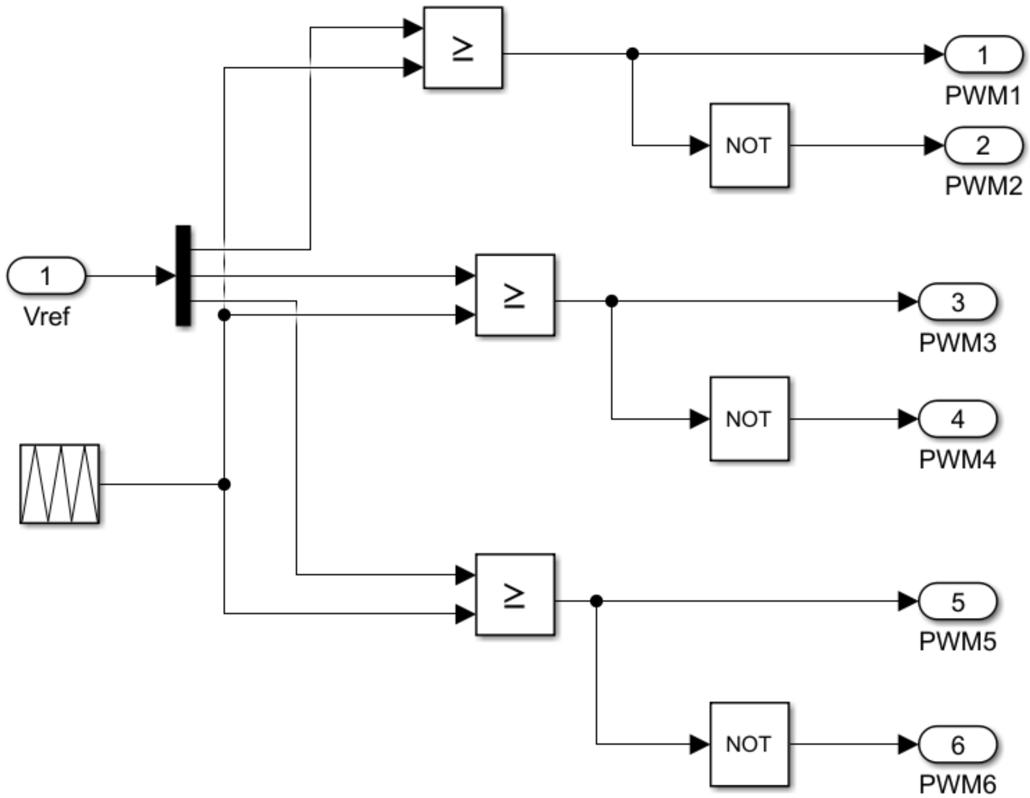
Input of inverter is DC input but the grid is AC. Now, comparing AC and DC is not feasible. So, AC is taken to such a coordinate system (dq0 axis) where AC will behave like DC. The axis dq0 can rotate with w angular velocity, so AC voltage is relatively motionless in that axis and thus behaves like DC. Now, V_{abc} is in three phase co-ordinate system, so it is first taken to **α**β0 two phase co-ordinate system. Then it is taken to dq0 co-ordinate system and finally we get output V_D and V_Q. In similar process, we can get I_D and I_Q from I_{abc}. Now the wt is calculated from [alphabeta] of following circuit.



The PI controller in above circuit is controlled in such way that the voltage axis and V_D axis gets aligned. In such way, wt can be found as output which is fed into axis transformation circuit mentioned before. And VQ is treated 0 in this circuit so that current and voltage gets aligned and maximum power output can be confirmed.



In this part of PWM Generation Block, to keep the boost converter output voltage at a constant value irrespective of load, we compare the output voltage with 600V DC by (As $400*\sqrt{2}$ = 565V, we are taking 600V considering loss) a PI controller. Later the output is compared with DQ axis output and later divided by VDC/2 to produce sinusoidal pulse width modulation index.



After that modulation index transfers into ABC axis so that it can be compared with a reference signal to generate PWM signal.

Filter Block:

A filter block is used after the inverter output and before connecting to the AC load and grid. This filter circuit is shown here. The series inductors are with inductance = $500\mu H$. Inductance of parallel inductors is $100\mu H$. Both series and parallel resistance, used here, is $1m\Omega$.

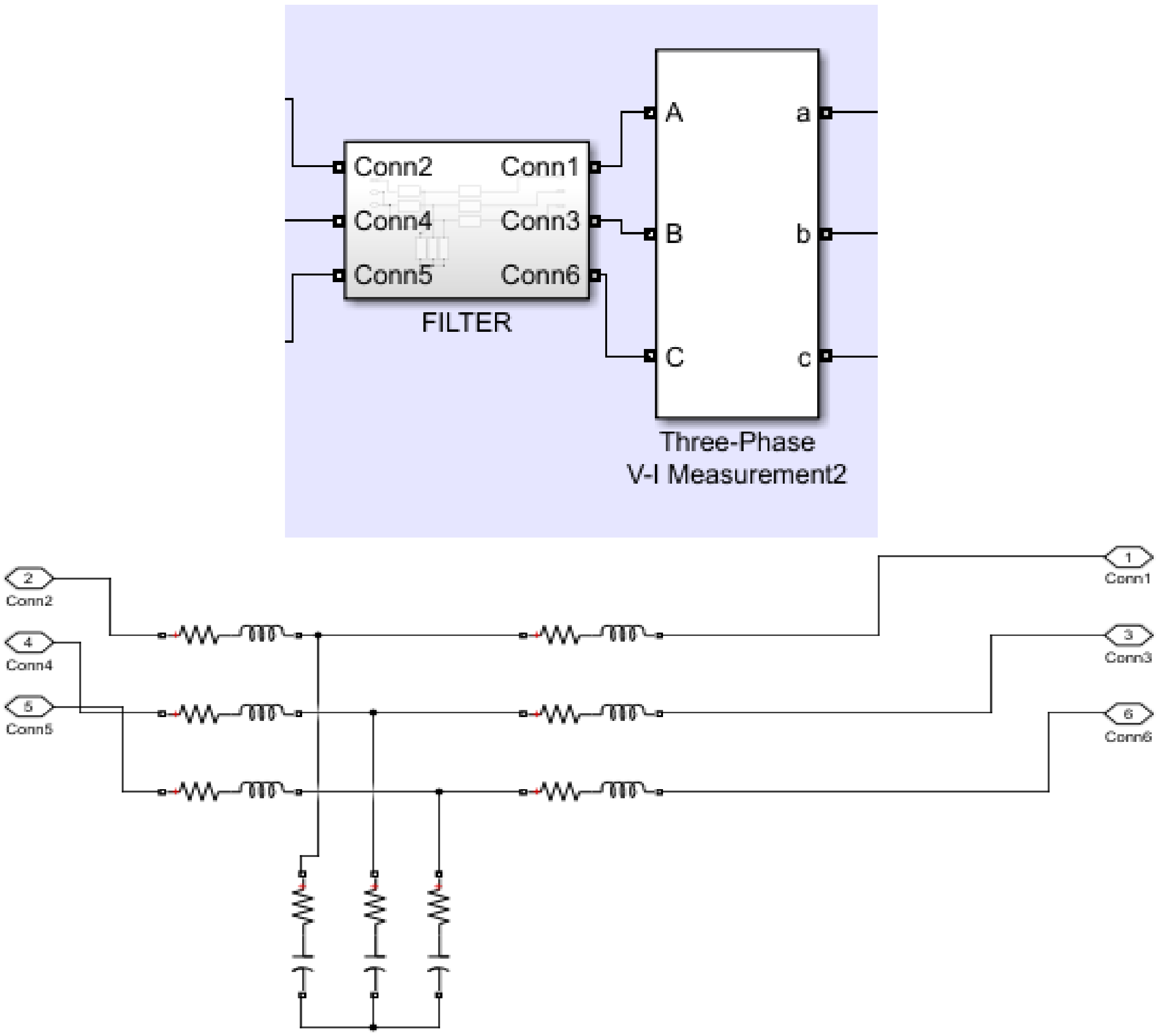
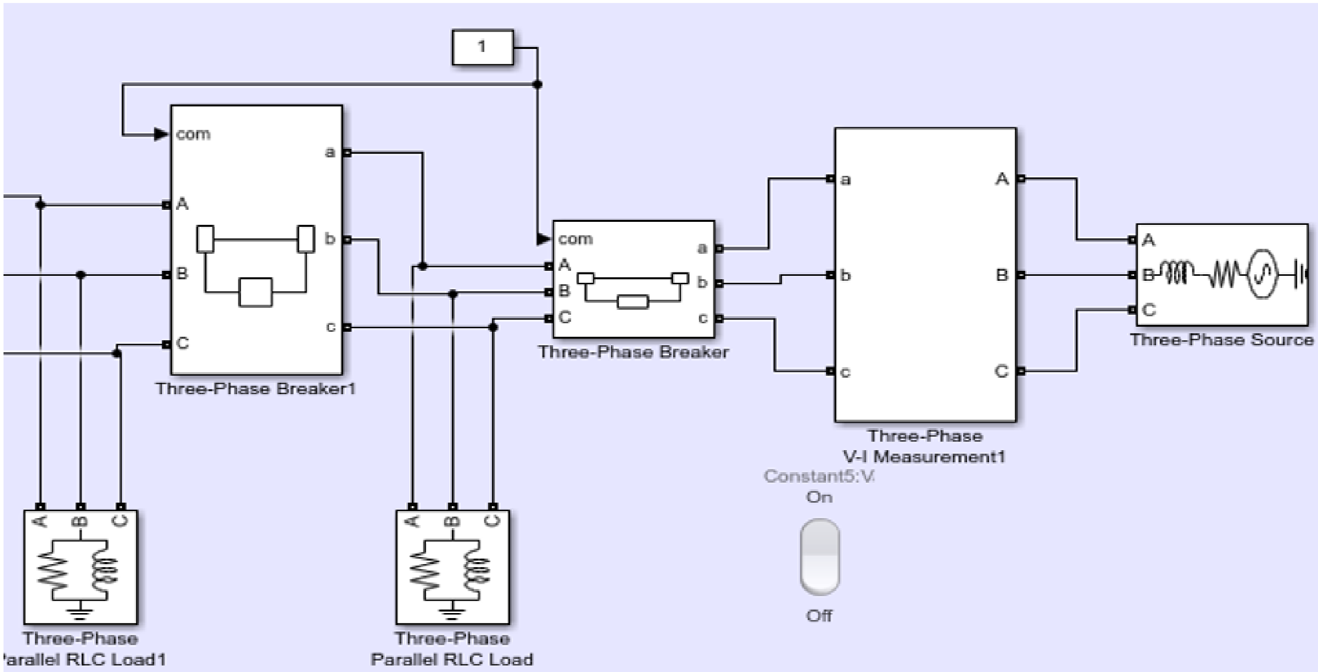


FIG: FILTER BLOCK

Load and Grid Block:

Complex AC load is used here. Grid line used here is 400V L-L, 50Hz. In power calculation box, Vabc-Iabc1 refer to grid supply and V_{abcs}-I_{abcs} refer to solar source supply. Load values are:



LOAD AND GRID

We can see, there is an on-off switch in the Load and Grid Block. By putting off the switch, we can model grid failure. Then, solar system will take the whole responsibility of the load.

Three Phase Load	Total KVA Rating	Active Power, P	Inductive Power QL (positive var):	Power Factor	Configuration
Critical RLC Load	$100kVA$	$90kW$	$40kVAR$	0.9	Y(grounded)
RLC Load1	$100kVA$	$90kW$	$40kVAR$	0.9	Y(grounded)
Total	$200kVA$	$180kW$	$80kVAR$	0.9	-

Solar System Power Calculation:

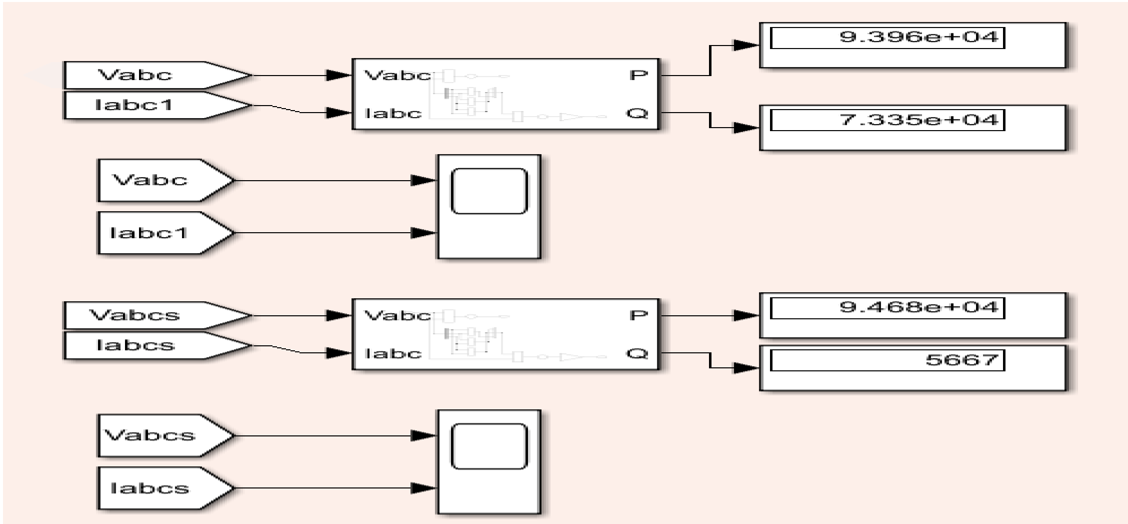
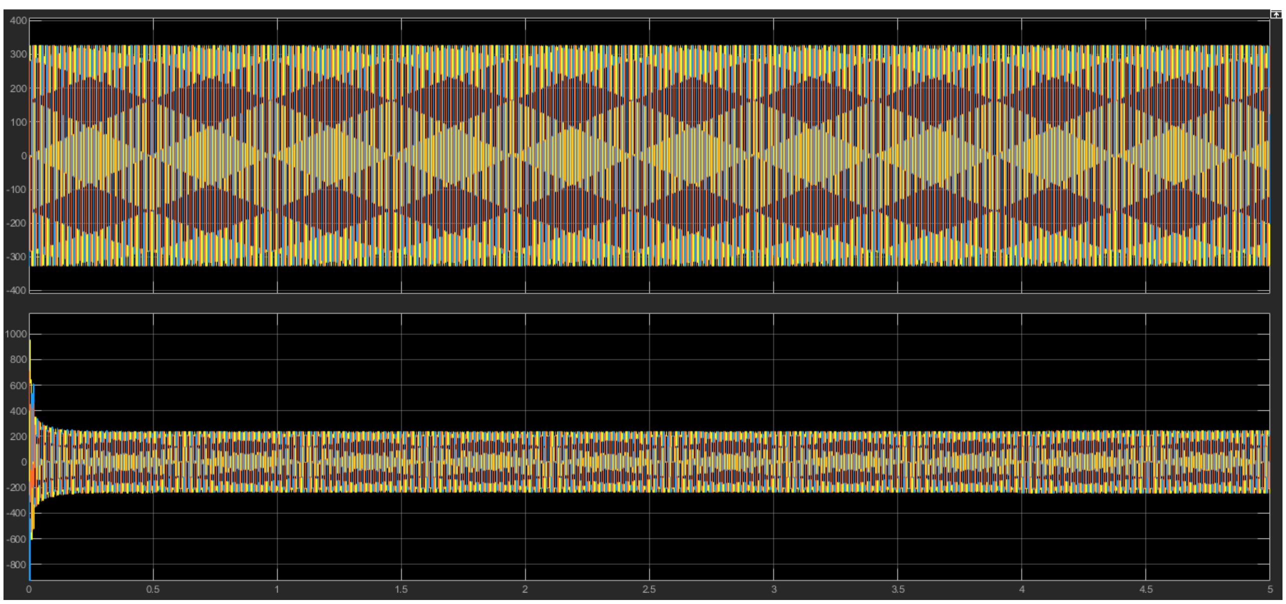


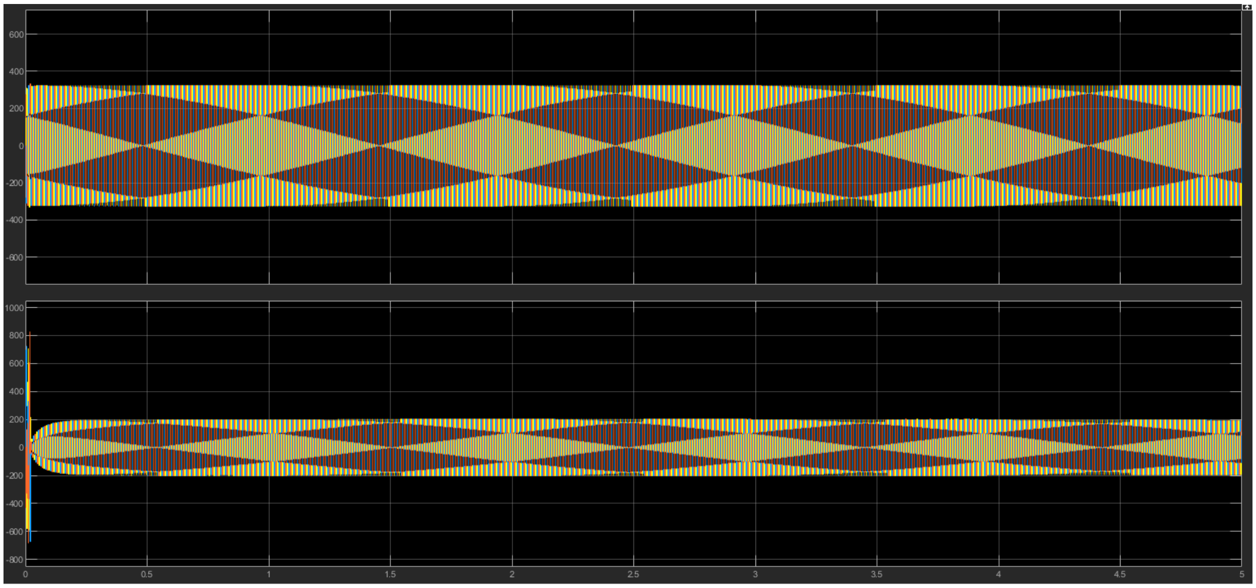
Figure: Power Calculation Block

Solar System Output Plots:

Grid supplied Voltage and Current plot for 5 seconds:



Solar source supplied Voltage and Current plot for 5 seconds:



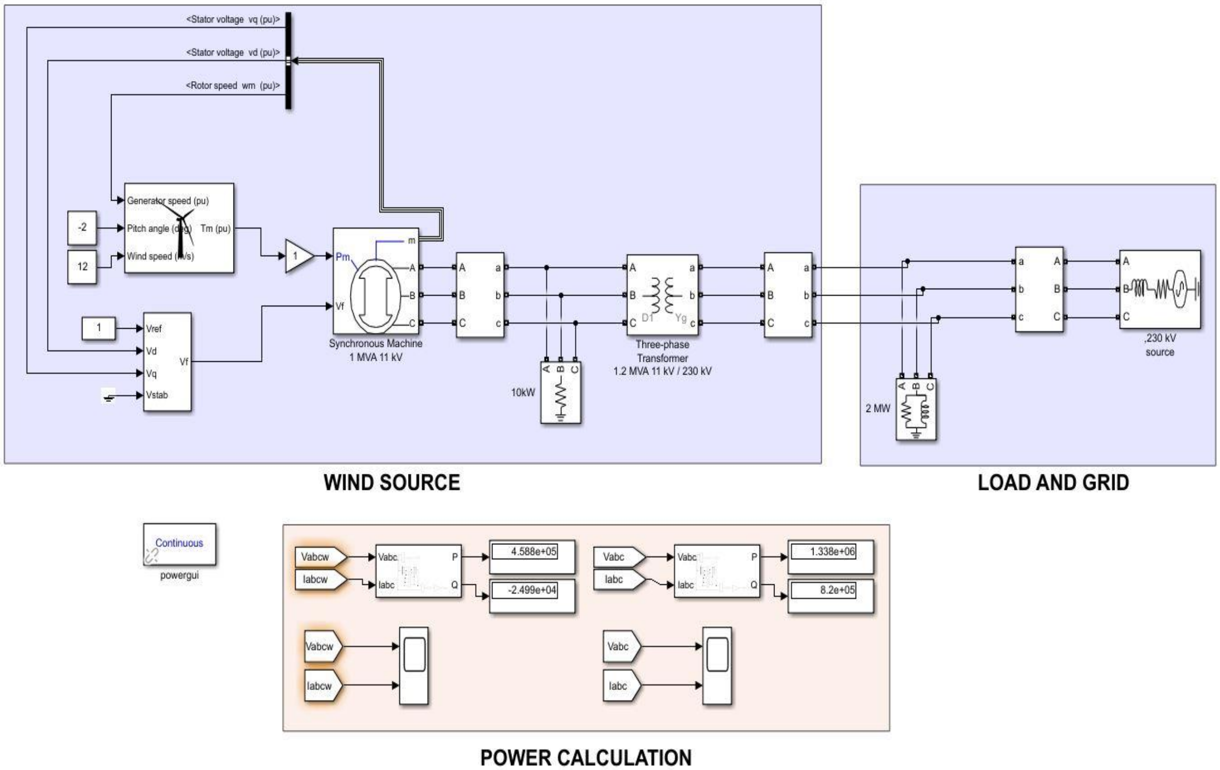
Power supply calculation table:

Source	Active Power, P	Inductive Power, QL	Apparent Power, S	Total Power	Contribution Percentage
Grid	$9.396 \times 10^4 W$	$7.335 \times 10^4 VAR$	$11.92 \times 10^4 VA$	$21.4 \times 10^4 VA$ $= 214 kVA$	55.688%
Solar	$9.468 \times 10^4 W$	$5667 VAR$	$9.485 \times 10^4 VA$		41.312%

So, we can see that, Solar source is contributing 41.312% of the load which is quite significant. Also, we can rely on that as a back up in case the grid fails.

Wind Source Power Generation:

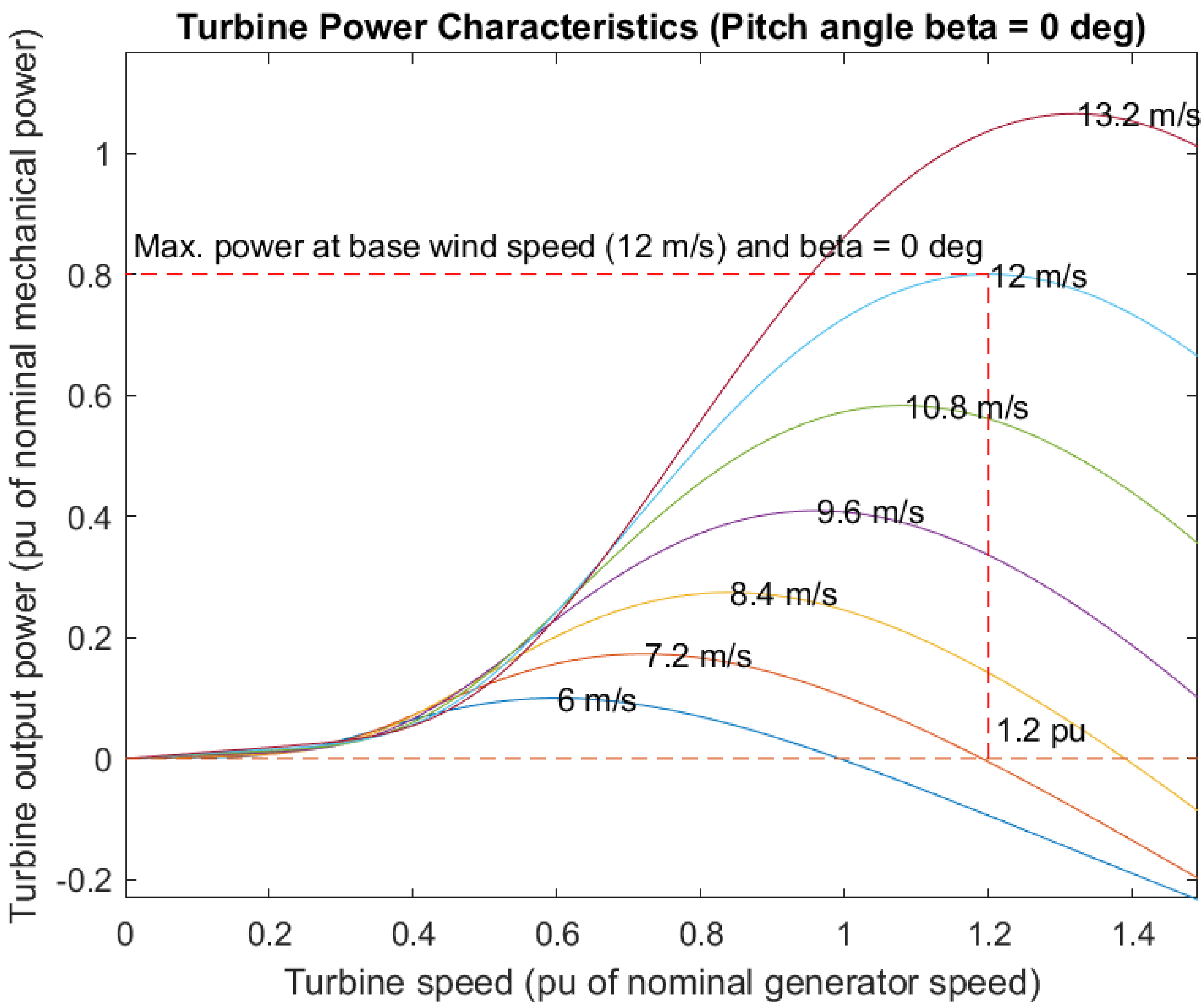
Schematic Diagram:



Block by Block analysis:

Wind Turbine:

Wind turbine feeds mechanical torque through gain = 1 and output is mechanical power. Pitch angle is taken to be -2. Wind speed is 12 m/s. Base rotational speed is 1.2 pu. Turbine power characteristics is shown here-



Excitation System & Synchronous Machine:

Reference voltage is taken to be 1 pu. Feedback loop supplies direct axis and quadrature axis voltage components in the excitation system. Also, a ground connection is taken as input.

Excitation system feeds field voltage to synchronous generator (1MVA ,11kV,50Hz) that produces three-phase ac voltage.

Three phase transformer and measurement:

Output of synchronous generator passes through a three-phase measurement and then through a three phase step up transformer for transmission. The primary side of the transformer is wye connected and the secondary side is delta connected. Transformer rating is 1.2 MVA, 11kV/230kV at 50 Hz. Then it is passed again through a three-phase measurement.

A resistive load of 10kW is connected parallel to the transmission line here as line loss (I^2R loss).

Grid:

Grid source of 230 kV (phase voltage) and 50 Hz frequency has source resistance = 0.529 ohm and source inductance = 0.014 H.

Load:

Complex AC load of 2 MVA rating having active power = 1.8MW and reactive power of 0.8 MVAR with 0.9 lagging power factor is used. The load has wye configuration with neutral line grounded.

Wind System Output Plot:

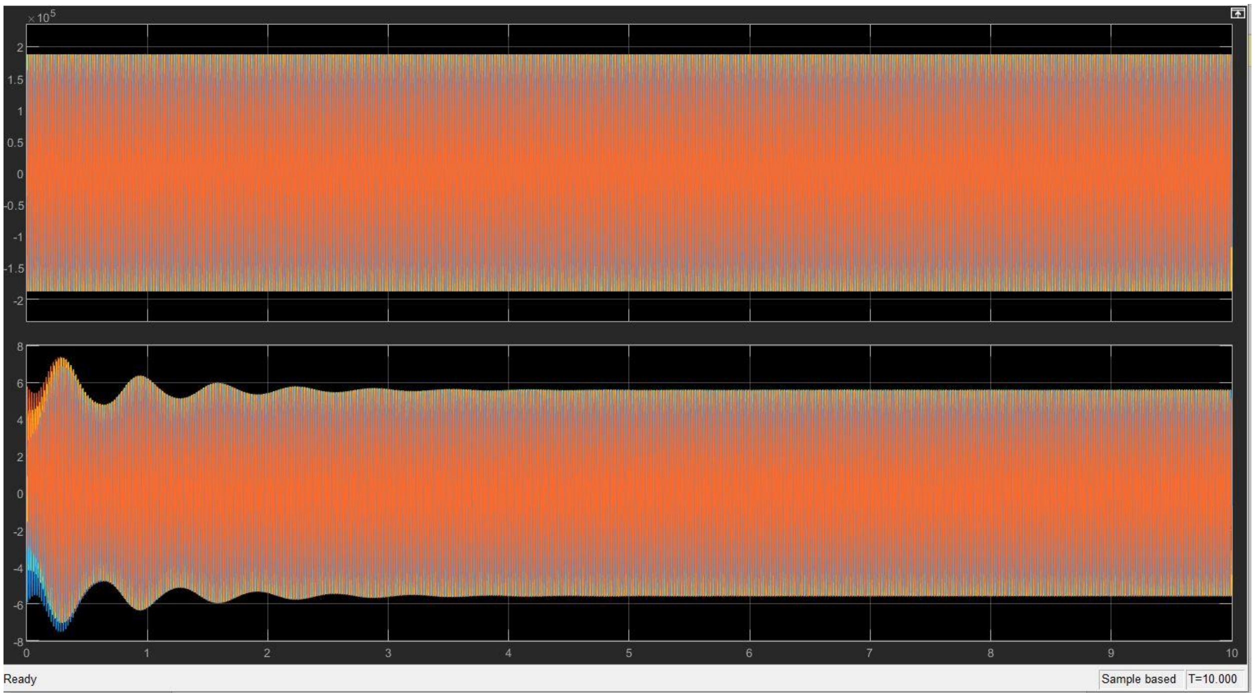


Figure: Grid supplied Voltage and Current plot for 10 seconds

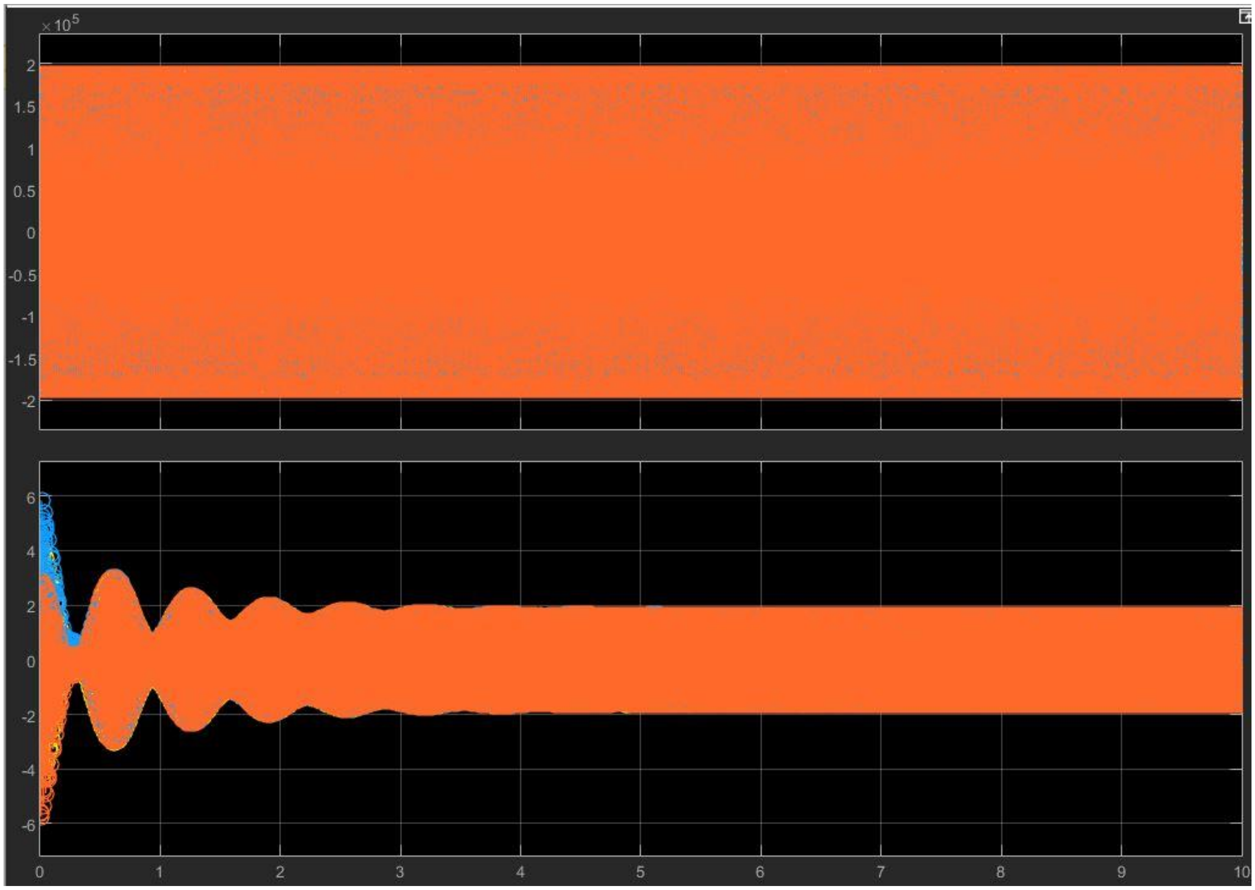


Figure: Wind source supplied Voltage and Current plot for 10 seconds.

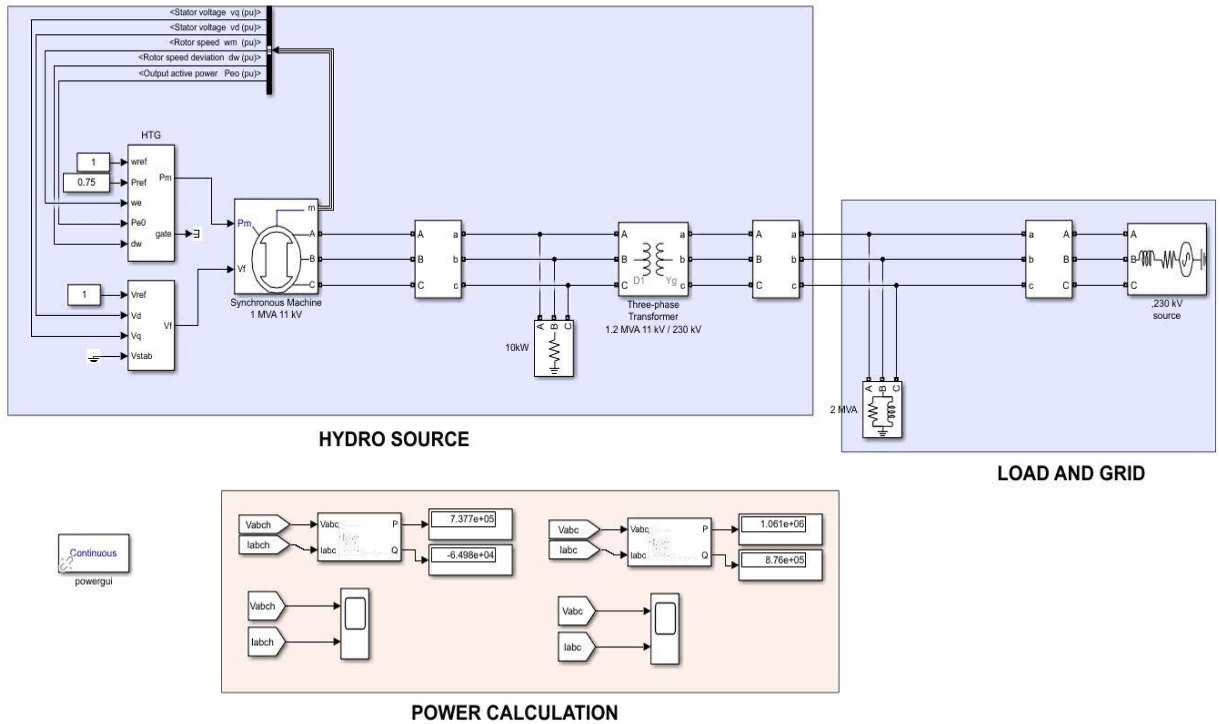
From both figures, it is seen that steady-state current is observed after 4 seconds.

Power Calculation Table:

Source	Active Power, P	Inductive Power, Q_L	Apparent Power, S	Total Power	Contribution Percentage
Wind	6.384×10^5W	-4.877×10^4 VAR	6.4×10^5 VA	2.084×10^6 VA	30.71%
Grid	1.172×10^6W	8.442×10^5 VAR	1.444×10^6 VA		69.29%

Hydro Source Power Generation:

Schematic Diagram:



Block by Block Analysis:

HTG, excitation and synchronous machine:

Hydraulic turbine and governor system feeds mechanical power and excitation system feeds field voltage to synchronous generator which produces three-phase ac voltage. Generator rating is 1 MVA,11 kV, 50 Hz.

Feedback loop is used to connect direct axis and quadrature axis voltage components of stator voltage into excitation & rotor speed, output power and speed deviation into HTG as input.

For HTG, reference speed is taken to be 1 pu, reference power is taken to be 0.75 pu. For excitation system reference voltage is taken to be 1 pu and a ground connection is also included as input.

Three phase transformer and measurements:

Output of synchronous generator passes through a three-phase measurement and then through a three phase step up transformer for transmission. The primary side of the transformer is wye connected and the secondary side is delta connected. Transformer rating is 1.2 MVA, 11kV/230kV at 50 Hz. Then it is passed again through a three-phase measurement.

A resistive load of 10kW is connected parallel to the transmission line here as line loss (I^2R loss).

Grid:

Grid source of 230 kV (phase voltage) and 50 Hz frequency has source resistance = 1 $\mu\Omega$ and source inductance = 1 μH.

Load:

Complex AC load of 2 MVA rating having active power = 1.8MW and reactive power of 0.8 MVAR with 0.9 lagging power factor is used. The load has wye configuration with neutral line grounded.

Hydro System Output Plot:

Figure: Grid supplied Voltage and Current plot for 15 seconds

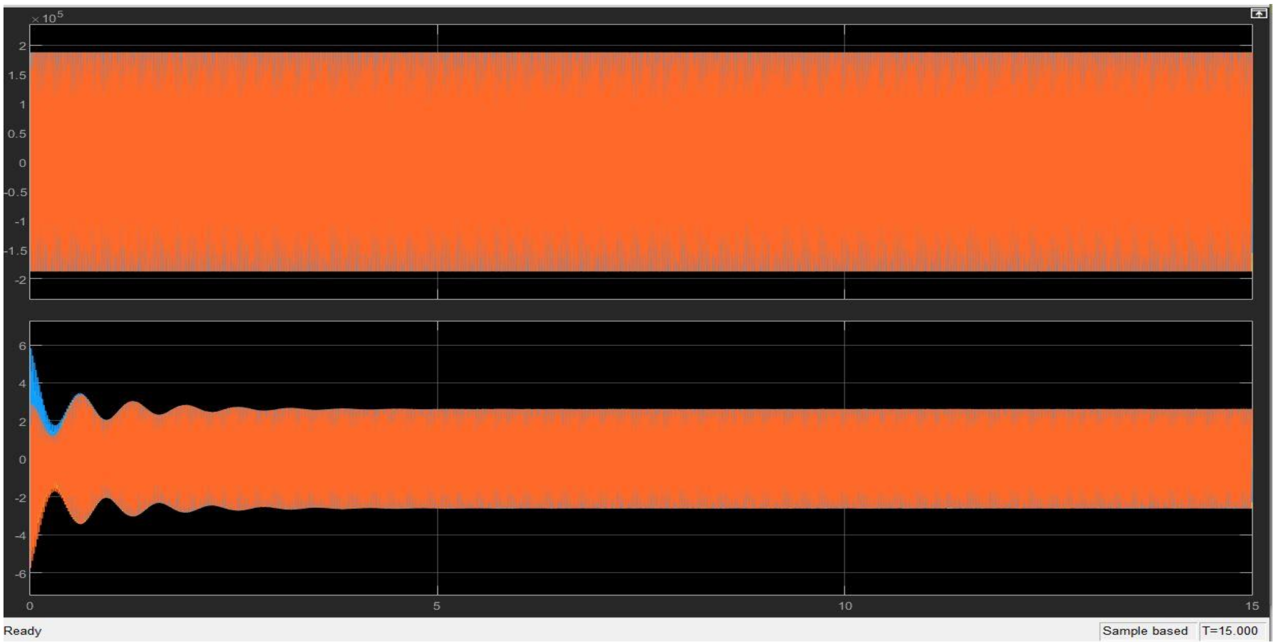


Figure: Hydro source supplied Voltage and Current plot for 15 seconds.

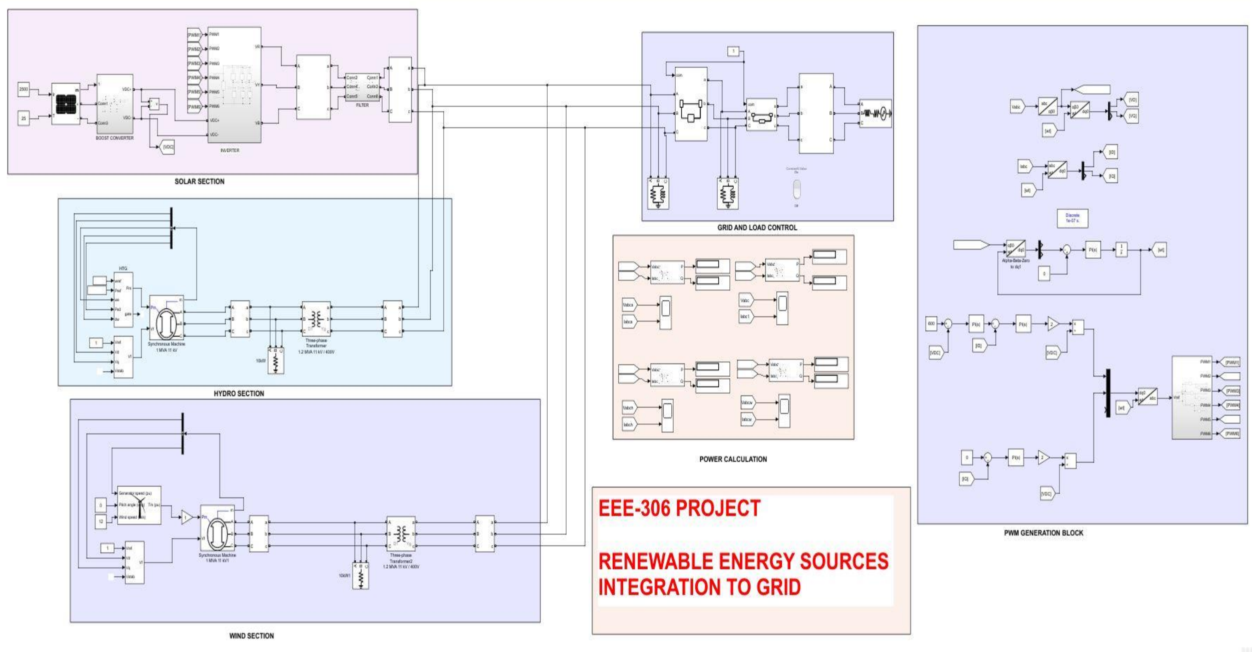
From both figures, it is seen that steady-state current is observed after 4 seconds.

Power Calculation Table:

Source	Active Power, P	Inductive Power, Q_L	Apparent Power, S	Total Power	Contribution Percentage
Hydro	7.377×10^5W	-6.498×10^4 VAR	7.406×10^5 VA	2.226×10^6 VA	34.972%
Grid	1.061×10^6W	8.76×10^5 VAR	1.376×10^6 VA		65.028%

Grid-Renewable energy source Integrated system & output analysis:

Schematic diagram:



Complex Load:

Here, the complex loads are slightly changed than the individual system.

Three phase complex loads	Total kVA rating	Active power, P	Inductive Power, Q_L	Power Factor	Configuration
Critical RLC load	1.5 MVA	1.35 MW	0.6 MVAR	0.9	Y(Grounded)
RLC load	2 MVA	1.8 MW	0.8 MVAR	0.9	Y(Grounded)
Total	3.5 MVA	3.15 MW	1.4 MVAR	0.9	Y(Grounded)

Small changes are made in this integrated system than the individual RES-Grid tied system.

1. Transformers' ratings are taken 11kV/400V instead of 11kV/230kV in this integrated system.

2. Grid line voltage is 400V L-L. This grid line doesn't exist, normally a π-line and a transformer are used after grid line that convert the higher grid line voltage into 400V L-L. As this operation huge simulation time and memory in Simulink, 400V L-L grid is used directly.

Power Supply Calculation:

Source	Active Power, P	Inductive Power, Q_L	Apparent Power, S	Total Power	Contribution Percentage
Grid	1.354×10^6 W	4.037×10^5 VAR	1.413×10^6 VA	3.087×10^6 VA = 3.087 MVA	45.767%
Solar	9.463×10^4 W	5141 VAR	9.477×10^4 VA		3.07%
Hydro	7.326×10^5 W	3.845×10^5 VAR	8.274×10^5 V		26.8%
Wind	6.382×10^5 W	3.98×10^5 VAR	7.52×10^5 VAR		24.363%

Grid-Renewable energy source Integrated system Output Plot:

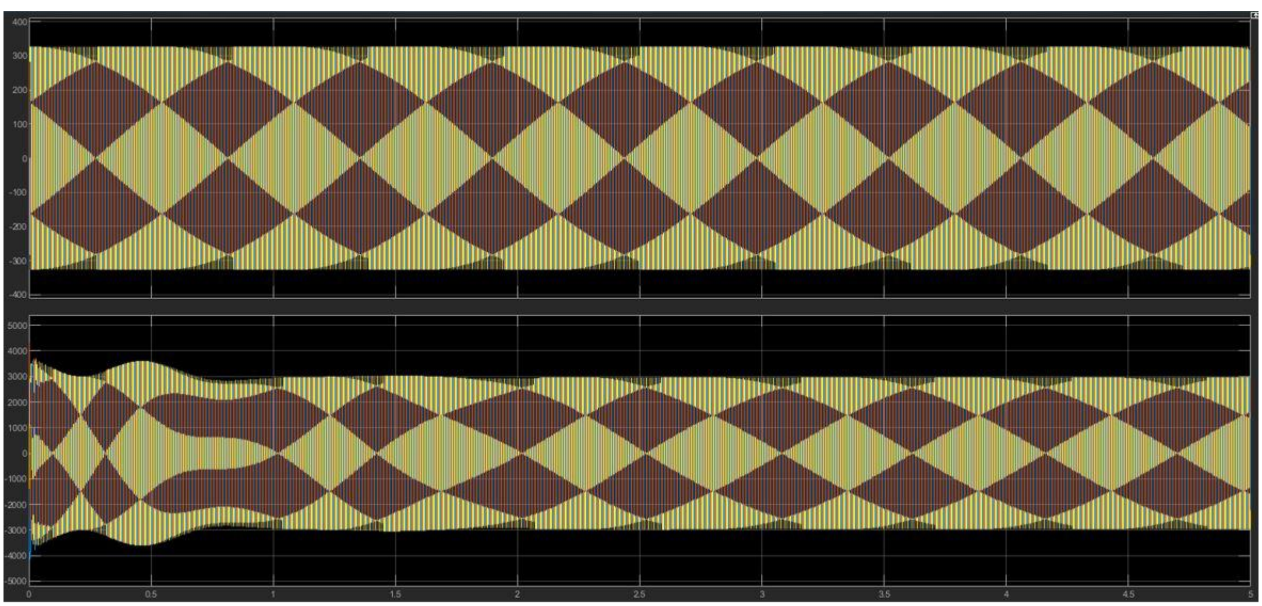


Figure: Grid supplied Voltage and Current plot for 5 seconds

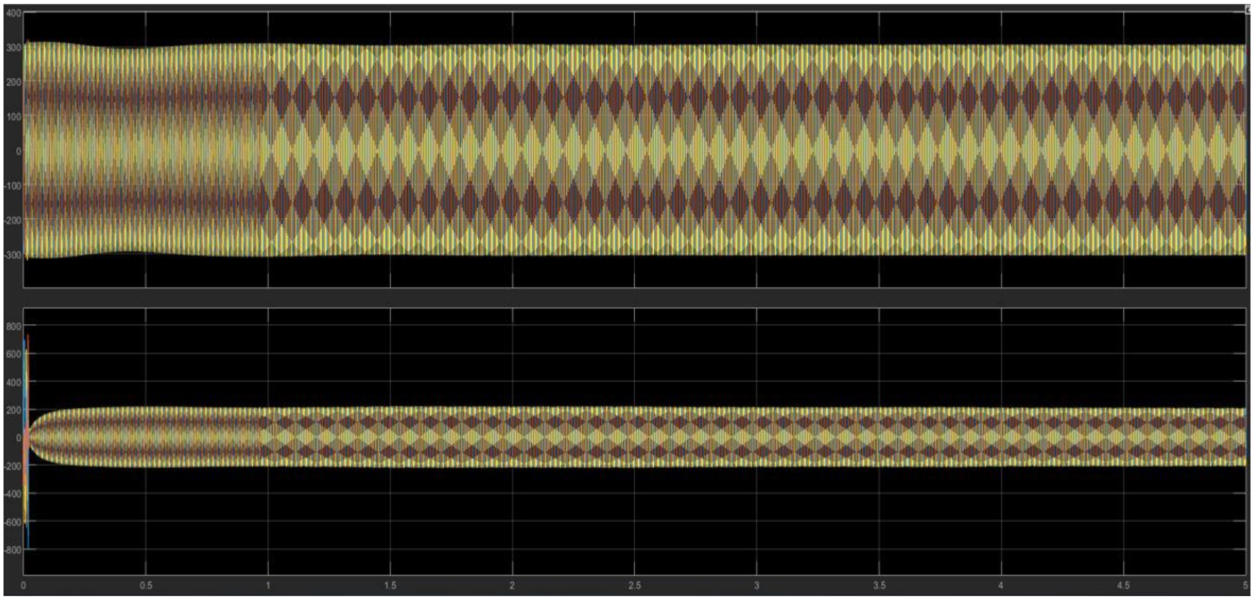


Figure: Solar supplied Voltage and Current plot for 5 seconds

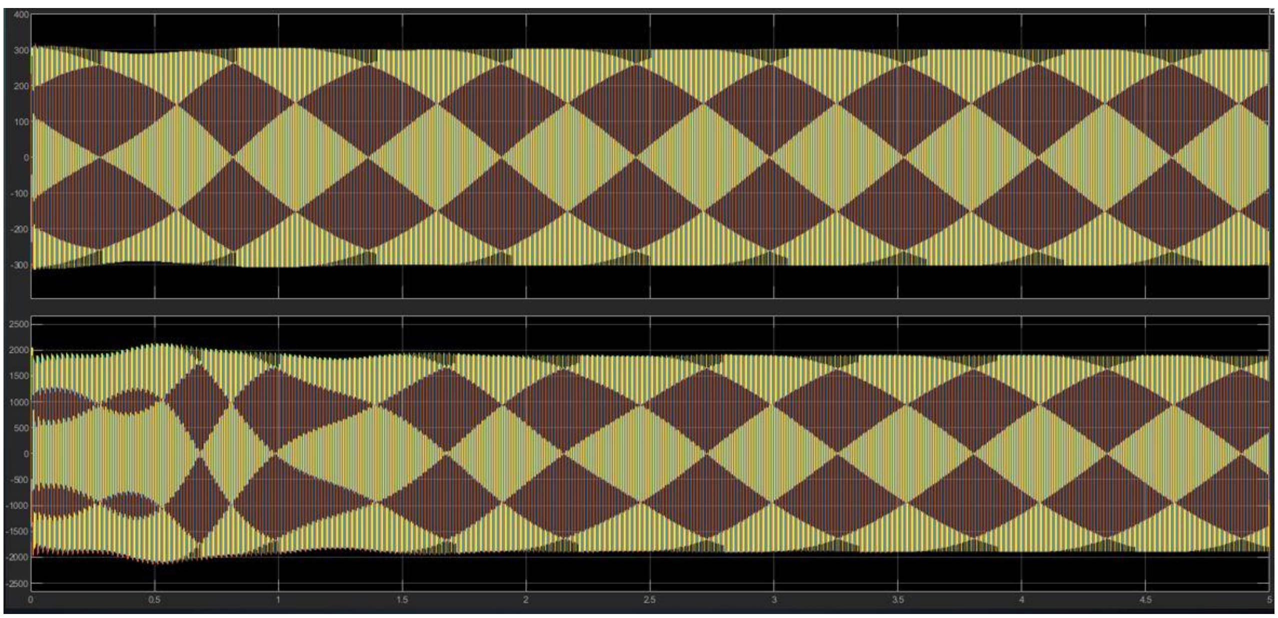


Figure: Hydro supplied Voltage and Current plot for 5 seconds

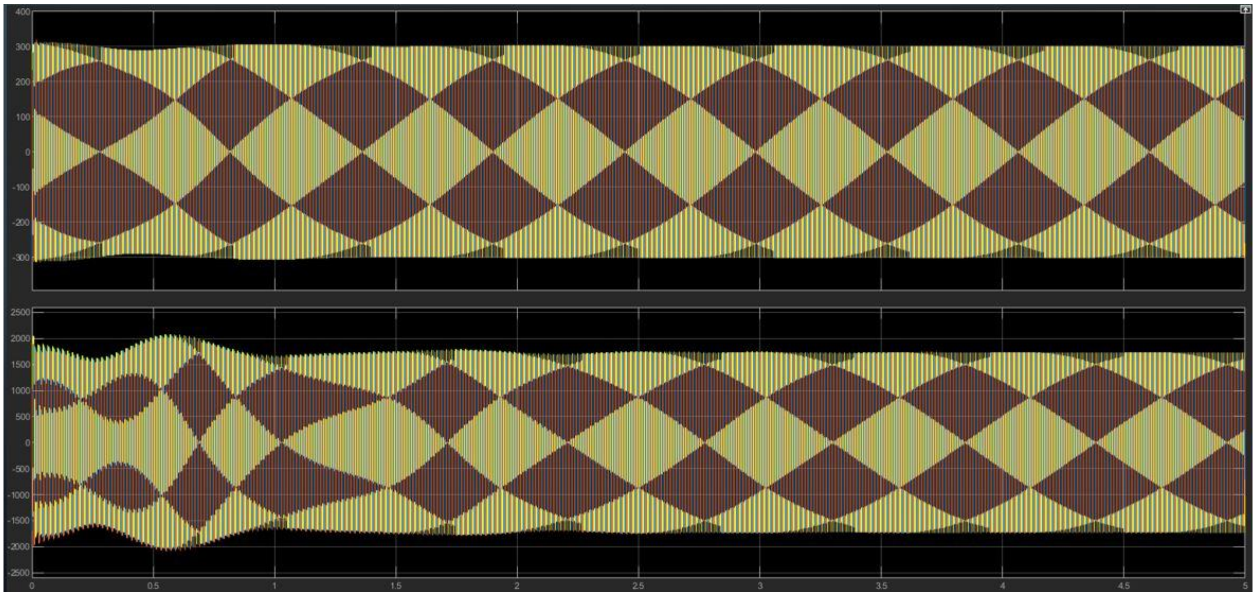


Figure: Wind supplied Voltage and Current plot for 5 seconds

Conclusion:

Renewable Energy Sources (RES) are always a good support to powerplant in case of power supply system. It helps reduce the dependency on natural resources which are used to generate electric power in powerplant. Not only that, but this RES-grid combination also can be very useful for household and small-medium industry when AC grid line goes blackout. The more efficient the grid-tied RES system is, the more helpful and effective the power supply system becomes.

This project provides good insight and simulation models of grid-tied RES system. Here we used three RESs-

- Solar Source (Solar PV arrays)
- Hydro Source (Hydraulic Turbine and governor)
- Wind Source (Wind turbine)

We built three individual models using these three resources individually tied with grid and providing power to the load.

The most important side of this project is, we combined all three resources and built an RES-grid integrated system which can be a big addition to power supply system for our country. We simulated the integrated system and found efficient result while supplying power to load. The advantages of this system are-

- The dependency on AC powerplant/grid line reduces in good number.

- When grid power supply goes down, there are three alternative resources- solar, hydro, wind to provide power supply medium-small industry and household loads.
- If one/two of the RES goes down, one/two other RES are going to be there to help/share the power supply with main grid line. But these one/two RES going down is much unlikely to happen.
- Finally, one of the biggest positive sides of this integrated system is, a complete blackout of power supply is not going to be any option, anymore. There are four supplies, resources in total, in parallel. So, a complete blackout requires shutdown in all four of the resources which is very much unlikely to happen, probably a probability here is tends to zero.