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Power Management in Microgrid

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Abstract: *A microgrid is defined as an independent power network that uses distributed energy resources to provide grid backup or off-grid power to meet the load demand. Microgrids play an important role in managing and controlling the distributed generation. It is very important to maintain the quality of power for the organizations such as data centers, hospitals and airports that rely on 24/7 access to uninterrupted power to operate efficiently. Hence, in a microgrid, it is essential to maintain the power balance in load-demand for stability. Balancing the power becomes even more important as the microgrid is operating with a limited supply to the load demand. Control techniques are used for power balancing in microgrid also to have smooth and reliable operation. The proposed work involves in the development of power management scheme for microgrid comprising of solar and wind as the input sources along with battery for backup. As per load requirement, the detailed sizing of microgrid components was carried out using HOMER Pro software. Dual Input Single Output (DISO) DC-DC converter and an inverter were designed and simulated using MATLAB Simulink. To manage the power flow from source to load, local and global controllers were implemented. Local controller was used to control the dual-input converter switches. The battery with Bi-directional DC-DC Converter (BDC) was used to control the charging and discharging process of the battery and the inverter controller was used to control the inverter based on the output AC voltage. Finally, the global controller manages the control of the entire microgrid for efficient power management.*

Key Word*: Power Management; Microgrid; PV Panel; Wind Turbine; Dual Input Single Output (DISO) Converter; Bi-directional DC-DC Converter; Controllers and Inverter.*

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I. Introduction

The exponential population increase, economic expansion and increase of production capacity in the industrial sector needs increase in power demand. The application of distribution generation is growing widespread, as the use of renewable energy sources overcome the restrictions. Microgrid is a cluster of energy distribution and storage devices works either in grid mode or in islanded mode [1]. Microgrid is a new energy source and grid management technology that has emerged at the end of last century provides power with distributed generation systems and is capable to operate even under the failure of the main grid. In addition, the use of local sources of energy to serve local loads helps to reduce energy losses in transmission and distribution and hence improves the efficiency. Microgrid is often used as supplement to the main power grid during heavy demand [2].

Microgrid includes many sources like solar, wind, hydro, fuel cell, diesel generator etc., all these multiple sources increase the complexity of power system considerably. Each distributed energy source in a microgrid shares active and reactive power to maintain the systems voltage and frequency. It is critical to examine the overall system performance with various types of loads available on the distributed system. The distribution of load raises issues like power quality, power flow balancing and stability of microgrids [3]. There are different strategies for power management such as linear control and nonlinear control. Linear control methods are Proportional Integral (PI), Proportional Resonant (PR) and field-oriented controllers. Non-Linear controls such as artificial neural network-based algorithms, Adaptive Practical Swarm Optimization (APSO) algorithm, Fuzzy logic-based algorithm, Predictive algorithm etc. These controllers are used to monitor and balance the generation and consumption of energy in an electrical network [4]. The controller has to be fast enough to calculate and take necessary action with the least delay in case of automatic action. In microgrid, the power management system is essential for optimal use of distributed energy resources in intelligent, secure, reliable and coordinated ways.

II. Design & Analysis of Microgrid Components

Traditional microgrids are becoming strained as demand for energy is increasing. It is essential to maintain the power supply-demand balance for stability as it is difficult to predict power generation from renewable resources. The supply-demand balancing problem becomes even more important as the microgrid is operating in stand-alone mode with a limited supply. The objectives of the project are to optimize the sizing of microgrid components. To design, analyse and simulate dual input and single output DC-DC converter. And to develop controller for power flow management.

Sizing of Microgrid Components using HOMER

Sizing is first step in development of a power management strategy. The load of 25KWis considered here. A battery is used for backup purpose. Based on the load profile, the sizing of each component is calculated using a HOMER software. The load profile menu displays the graphical load data and summary statistics for the considered load. Electrical load data is modified based on the load requirement on the daily basis, hour-by-hour basis on the left side of the menu as shown in the Fig 1. Load profile window also shows the per day electricity consumption in the month of January. In detail the monthly consumption and the annual consumption data is also evaluated.

Name: Electric Load #1

January Profile

Hour	Load (kW)
0	1.110
1	1.110
2	1.110
3	1.110
4	1.110
5	1.110
6	1.110
7	1.110
8	1.110
9	1.110
10	3.125

Time Step Size: **60** minutes

Random Variability

Day-to-day (%): 10

Timestep (%): 20

Peak Month: **None**

Metric	Baseline	Scaled
Average (kWh/day)	42.76	25
Average(kW)	1.78	1.04
Peak (kW)	5.64	3.3
Load factor	.32	.32

Load Type: ● AC ○ DC

☐ Efficiency (Advanced)

Efficiency multiplier: 1

Capital cost ($): 0

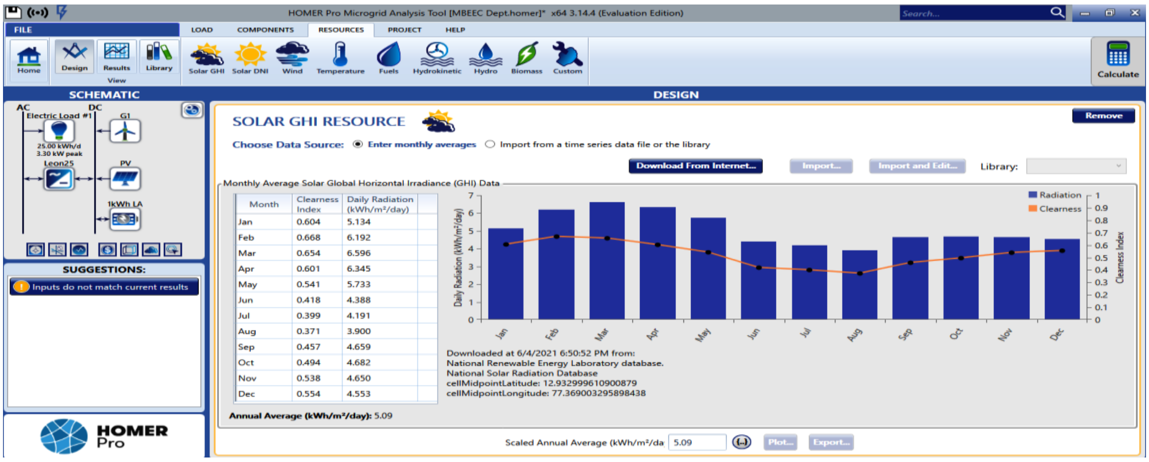
Lifetime (yr): 10

Scaled Annual Average (kWh/day): 25.00

Figure 1: Electrical Load Page in HOMER

Solar Global Horizontal Radiation (GHI) Resource

The solar GHI resource window allows to specify the GHI for each time step in the HOMER simulation. The GHI is the total amount of solar radiation striking the horizontal surface on the earth. HOMER calculates the global solar radiation incident on the surface of the PV array is shown in the Fig 2.



Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.604	5.134
Feb	0.668	6.192
Mar	0.654	6.596
Apr	0.601	6.345
May	0.541	5.733
Jun	0.418	4.388
Jul	0.399	4.191
Aug	0.371	3.900
Sep	0.457	4.659
Oct	0.494	4.682
Nov	0.538	4.650
Dec	0.554	4.553

Downloaded at 6/4/2021 6:50:52 PM from:
National Renewable Energy Laboratory database.
National Solar Radiation Database
cellMidpointLatitude: 12.932999610900879
cellMidpointLongitude: 77.369003295898438

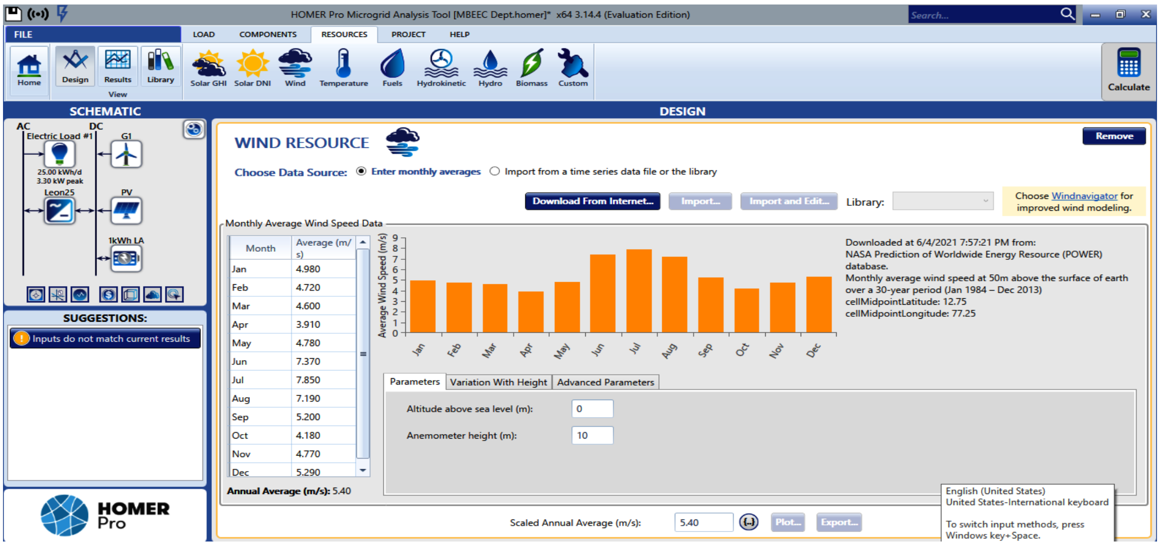
Annual Average (kWh/m²/day): 5.09

Scaled Annual Average (kWh/m²/da 5.09

Figure 2: Solar GHI Resource in HOMER

Wind Resource

The availability of wind speed annually is shown in the Fig 3. HOMER uses these data to calculate the output of the wind turbine in each time steps. The annual average wind resource data is available on the HOMER. HOMER displays the annual average wind resource calculated using baseline data in the table and graph.



Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Choose Windnavigator for improved wind modeling.

Month	Average (m/s)
Jan	4.980
Feb	4.720
Mar	4.600
Apr	3.910
May	4.780
Jun	7.370
Jul	7.850
Aug	7.190
Sep	5.200
Oct	4.180
Nov	4.770
Dec	5.290

Annual Average (m/s): 5.40

Downloaded at 6/4/2021 7:57:21 PM from:
NASA Prediction of Worldwide Energy Resource (POWER) database.
Monthly average wind speed at 50m above the surface of earth over a 30-year period (Jan 1984 – Dec 2013)
cellMidpointLatitude: 12.75
cellMidpointLongitude: 77.25

Altitude above sea level (m): 0
Anemometer height (m): 10

Scaled Annual Average (m/s): 5.40

English (United States)
United States-International keyboard
To switch input methods, press Windows key+Space.

Figure 3: Wind Resource in HOMER

Schematic Circuit of Microgrid

The connection of components in the microgrid includes PV panels, wind turbine and battery that are connected to DC bus. Battery is bidirectional. The converter is connected between DC and AC bus. Load is taken from AC Bus bar as shown in the Fig 4.

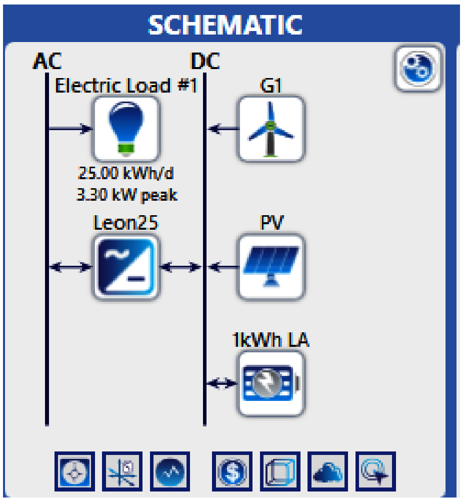


Figure 4: Components Connection in Microgrid

Design of Dual-Input Single Output Buck Converter

Dual-input single output DC-DC converter simultaneously draws energy from two sources and provides single output power. The power ratios are derived from each source and maintained constant. A non-isolated DI DC-DC buck converter in continuous conduction mode (CCM) is designed [9]. Two inputs are combined to form dual-input DC-DC converter. The Table 1 shows the specification of dual-input buck converter used for a proposed microgrid. The specification values are selected according to the HOMER results.

Table -1: Dual Input Converter Specification

	Solar plant	Wind plant	Unit
Input Voltage	800	750	V
Output Voltage	640	640	V
Output Power	6.5	5.5	KW
Switching Frequency	150	150	KHZ

Design of Load Resistor R_L and Output Current I_o

The output current and load resistance are calculated using output voltage and power as described in specification Table 1.

Load resistance (R_L) = $\frac{Vo^2}{Po} = \frac{(640)^2}{25000}$ = 16.38 ohms (1)

Load current (I_o) = $\frac{Po}{Vo} = \frac{25000}{640}$ = 39.06 Amps (2)

Duty Ratio

The key to the analysis of the duty ratio is to check the inductor current and voltage flow in the switch for D cycle and for (1-D) cycle. The required duty cycle is higher to compensate for the voltage drop across the switch, diode and inductor in order to regulate output voltage. The duty cycle is a ratio of output voltage to input voltage is calculated as follows

$$D = \frac{Vo}{Vin} = \frac{640}{800+980} = 0.35 \qquad (3)$$

Design of Inductor

The inductor L, is chosen such that the inductor ripple current Δi_L is practically 30% of the load current. It must also meet the L_{min} inductance requirements.

$$L_{min} = \frac{(1-D)*R_L}{2*fs} = \frac{(1-0.35)*16.38}{2*150*10^3} = 35.5\mu\,\mathrm{H} \qquad (4)$$

$$L = \frac{(Vs-I_oR_{DS}-I_or_L-Vo)*D}{\Delta I_L * \mathrm{fs}} = \frac{(1780-(39.06*1.45)-(39.06*0.005)-640)*0.35}{11.7*150*10^3} = 216\,\mu\,\mathrm{H} \qquad (5)$$

Design of Capacitor

The capacitor of a buck converter is calculated as

$$C = \frac{(Vo+Vf+Io*rL)*(1-D)}{8L*\frac{\Delta Vo}{Vo}*fs^2} = \frac{(640+1.1+39.06*0.005)*(0.65)}{8*216u*\frac{64}{640}*(150*10^3)^2} = 107.21\,\mu\mathrm{F} \qquad (6)$$

Selection of the IGBT

In any application, the appropriate IGBT considers the reduction of losses. Losses are affected by current, duty cycle, switching frequency, switching rise and fall times. The selection of an IGBT is typically based on the device rating and its ability to handle the systems power. The required high breakdown voltage V_{CE} is ≥ Vin, and the collector current I_C is ≤ I_O, based on the above analysis.

Selection of the Diode

The reverse breakdown voltage V_{rr}, the forward voltage drop V_f and the forward current I_f are the factors influences for diode selection. The OFF time of the diode is critical in high frequency applications in terms of efficiency. It is necessary to have a high reverse breakdown voltage $V_{rr} > V_{in}$ (diode stress as the switch is closed). It is necessary to have a lower forward voltage drop V_f and a higher forward current I_f.

Design of Bi-Directional DC-DC Converter (BDC)

Specification values are selected according to HOMER results.

Table -2: Specification of Bidirectional converter in Battery system

	Symbol	Value	Unit
Input Voltage	V_{in}	300	V
Output Voltage	V_o	640	V
Output Power	P_0	25	KW
Switching Frequency	f_s	30	KHZ

- The capacitor value is calculated as follows

  $$C = \frac{1}{8\Delta V_C}\Delta I_L T = \frac{1}{8*0.64}*12*0.05\mathrm{m} = 117.18\,\mu\mathrm{F} \qquad (7)$$

- The inductor is chosen based on the circuit's working mode (CCM or DCM) and the current ripple demand.

  $$L = \frac{(1-0.5)T^2}{8C*\frac{\Delta V_C}{V_O}} = \frac{(1-0.5)(0.05m)^2}{8*117.18\mu*\frac{0.64}{640}} = 1.33\mathrm{mH} \qquad (8)$$

Proportional Integral (PI) Controller

A P.I Controller is a feedback control loop that calculates an error signal by subtracting the difference between a system's output and the set point, in case the power drawn from the battery. The set point is the power level at system to operate ideally. And the system is made to operate near maximum power without triggering the power limiter. The transfer function is implemented directly in the software package like MATLAB Simulink this allows to simulate the system and find the right proportional and integral constant parameters for the controller. The Fig 5 shows basic PI controller model.

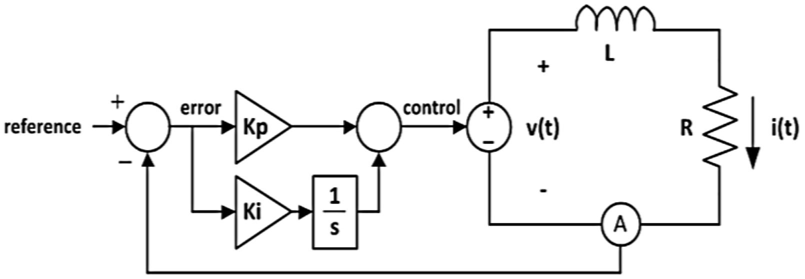


Figure-5: PI Controller

Controller Algorithms

The algorithm for the battery controller, local controller and complete microgrid as shown in the form of a flow chart in Fig 6, Fig 7 and Fig 8 respectively.

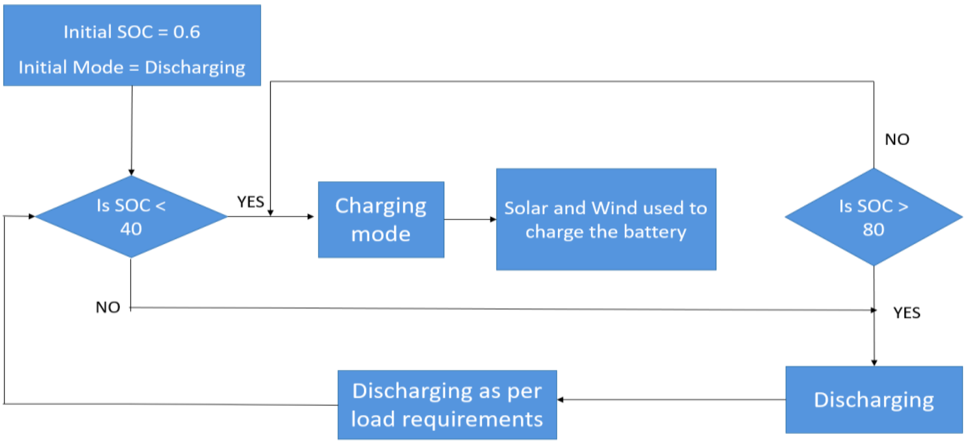


Figure-6: Battery Controller Flow Chart

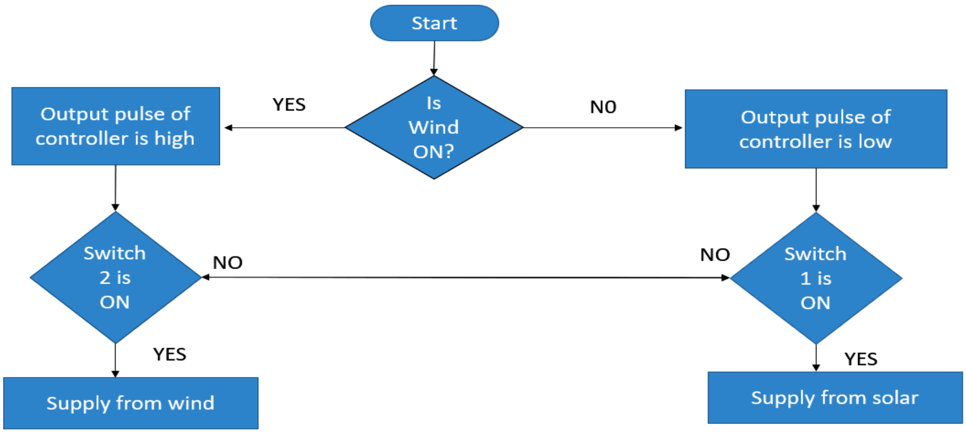


Figure-7: Local Controller Flowchart

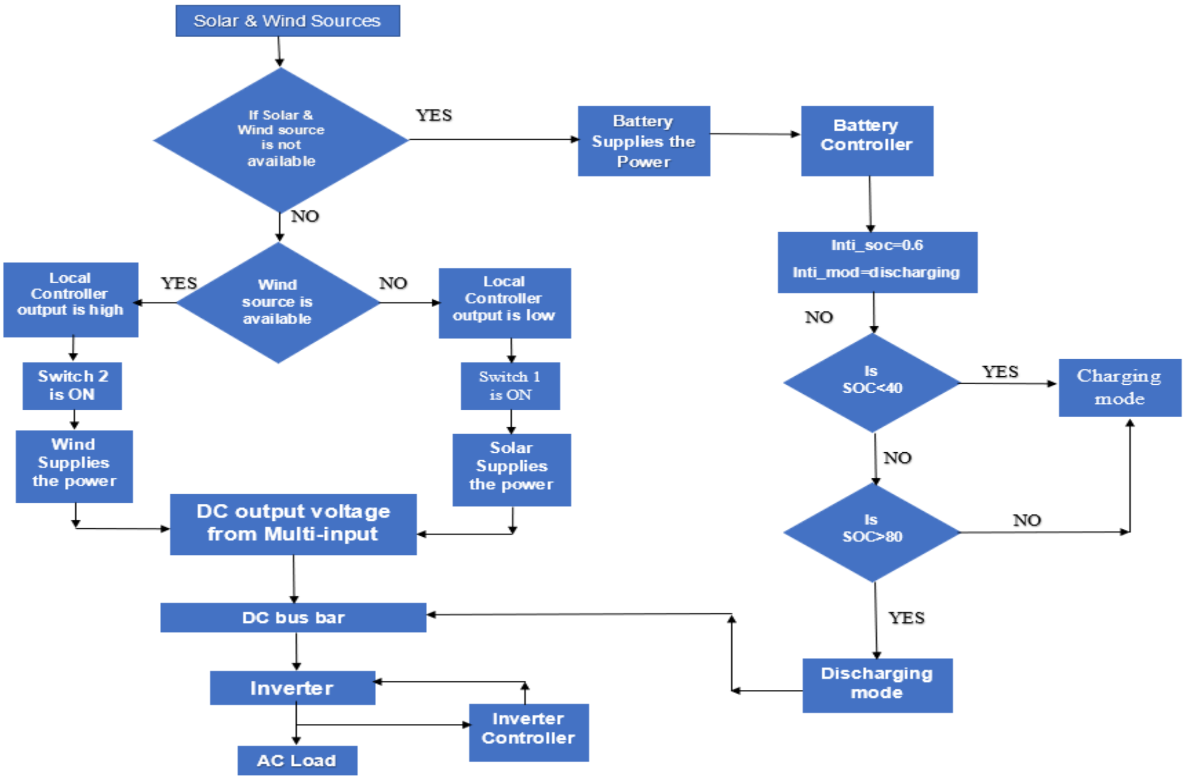


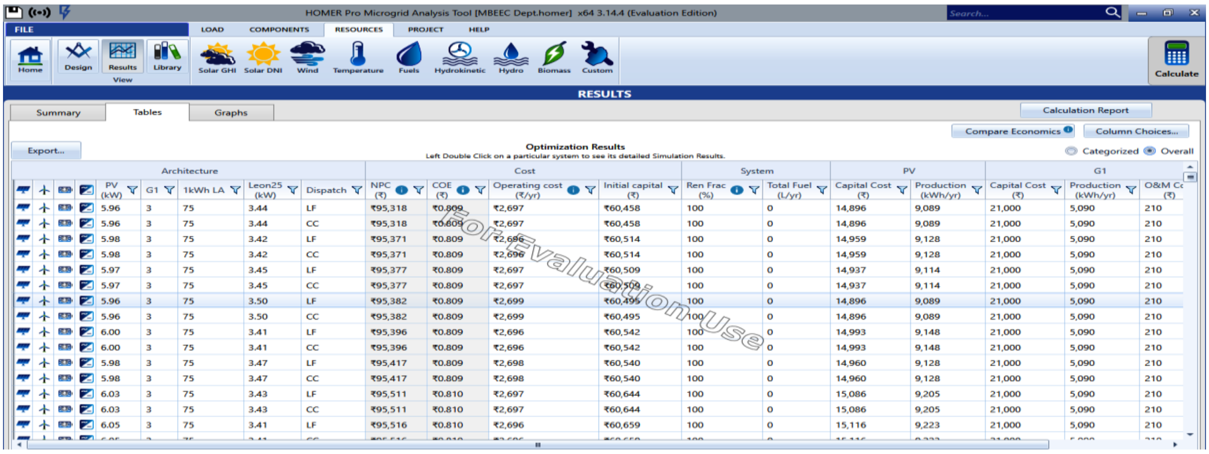
Figure-8: Complete Microgrid Flowchart

III. Simulation Circuits and Results

Sizing results from HOMER, simulation circuit of solar model, wind model, dual-input single output converter, bi-directional DC-DC converter, inverter, DISO converter for different case studies and controllers are shown below.

Homer Optimization Results

Once the design is complete and the necessary parameters are determined, then the system is simulated and optimized. The overall optimization results are obtained for the sizing of the microgrid components using HOMER software is shown in Fig 9.

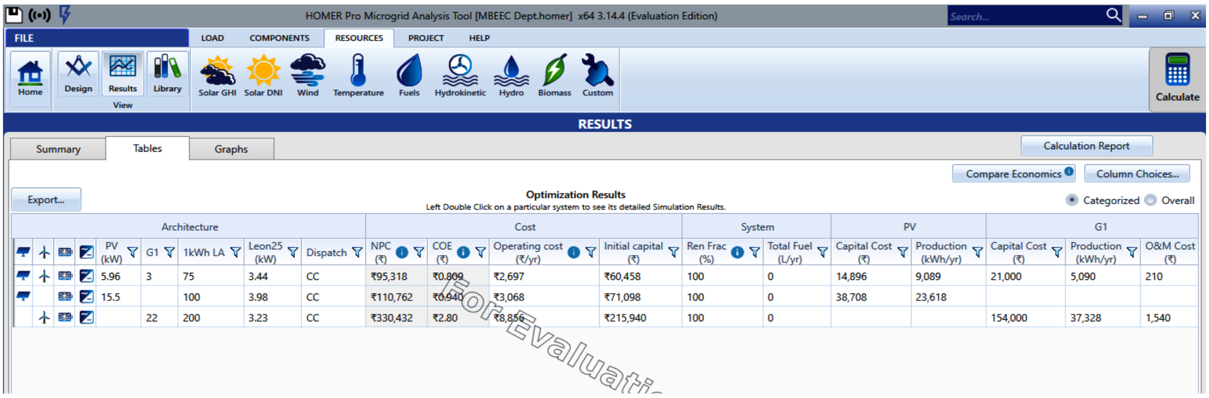


Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture					Cost				System		PV		G1		
PV (kW)	G1	1kWh LA	Leon25 (kW)	Dispatch	NPC (₹)	COE (₹)	Operating cost (₹/yr)	Initial capital (₹)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost (₹)	Production (kWh/yr)	Capital Cost (₹)	Production (kWh/yr)	O&M C (₹)
5.96	3	75	3.44	LF	₹95,318	₹0.809	₹2,697	₹60,458	100	0	14,896	9,089	21,000	5,090	210
5.96	3	75	3.44	CC	₹95,318	₹0.809	₹2,697	₹60,458	100	0	14,896	9,089	21,000	5,090	210
5.98	3	75	3.42	LF	₹95,371	₹0.809	₹2,696	₹60,514	100	0	14,959	9,128	21,000	5,090	210
5.98	3	75	3.42	CC	₹95,371	₹0.809	₹2,696	₹60,514	100	0	14,959	9,128	21,000	5,090	210
5.97	3	75	3.45	LF	₹95,377	₹0.809	₹2,697	₹60,509	100	0	14,937	9,114	21,000	5,090	210
5.97	3	75	3.45	CC	₹95,377	₹0.809	₹2,697	₹60,509	100	0	14,937	9,114	21,000	5,090	210
5.96	3	75	3.50	LF	₹95,382	₹0.809	₹2,699	₹60,495	100	0	14,896	9,089	21,000	5,090	210
5.96	3	75	3.50	CC	₹95,382	₹0.809	₹2,699	₹60,495	100	0	14,896	9,089	21,000	5,090	210
6.00	3	75	3.41	LF	₹95,396	₹0.809	₹2,696	₹60,542	100	0	14,993	9,148	21,000	5,090	210
6.00	3	75	3.41	CC	₹95,396	₹0.809	₹2,696	₹60,542	100	0	14,993	9,148	21,000	5,090	210
5.98	3	75	3.47	LF	₹95,417	₹0.809	₹2,698	₹60,540	100	0	14,960	9,128	21,000	5,090	210
5.98	3	75	3.47	CC	₹95,417	₹0.809	₹2,698	₹60,540	100	0	14,960	9,128	21,000	5,090	210
6.03	3	75	3.43	LF	₹95,511	₹0.810	₹2,697	₹60,644	100	0	15,086	9,205	21,000	5,090	210
6.03	3	75	3.43	CC	₹95,511	₹0.810	₹2,697	₹60,644	100	0	15,086	9,205	21,000	5,090	210
6.05	3	75	3.41	LF	₹95,516	₹0.810	₹2,696	₹60,659	100	0	15,116	9,223	21,000	5,090	210

Figure-9: Overall Optimization Results in HOMER

HOMER simulations are performed for several hybrid system configurations with the combination of PV/wind/Battery system for different capacities. HOMER calculates the total net present cost of all feasible systems and the optimization results are displayed by ranking them in ascending order. The categorized optimization results obtained for the proposed microgrid by the HOMER software is shown in the Fig 10. The categorized optimization result produces three different combinations. In the first category, the optimization uses combination of solar PV rating of 5.96kW, wind rating of (3kW) and battery.



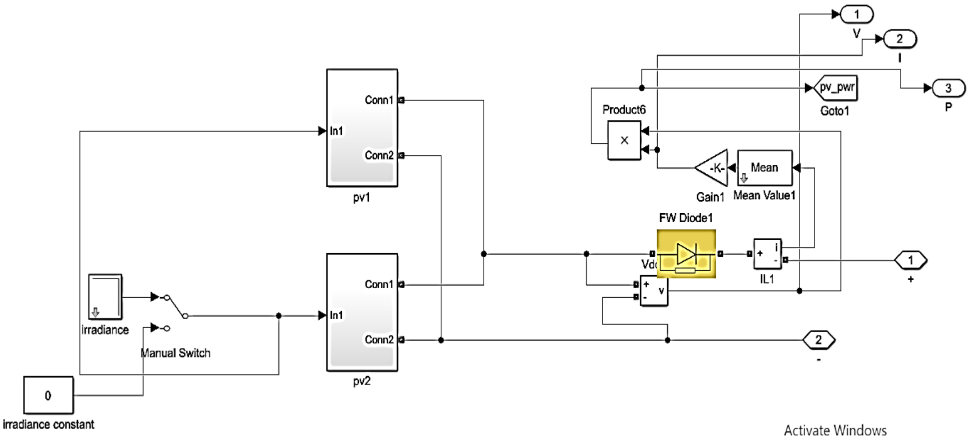
Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture									Cost				System		PV		G1		
				PV (kW)	G1	1kWh LA	Leon25 (kW)	Dispatch	NPC (₹)	COE (₹)	Operating cost (₹/yr)	Initial capital (₹)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost (₹)	Production (kWh/yr)	Capital Cost (₹)	Production (kWh/yr)	O&M Cost (₹)
✓	✓	✓	✓	5.96	3	75	3.44	CC	₹95,318	₹0.809	₹2,697	₹60,458	100	0	14,896	9,089	21,000	5,090	210
✓		✓	✓	15.5		100	3.98	CC	₹110,762	₹0.940	₹3,068	₹71,098	100	0	38,708	23,618			
	✓	✓	✓		22	200	3.23	CC	₹330,432	₹2.80	₹8,856	₹215,940	100	0			154,000	37,328	1,540

Figure 10: Categorized Optimization Results in HOMER

Solar Model

The schematic circuit of solar model as shown in Fig 11 consists of manual switch, it is used to switch ON and OFF the solar model. The solar module is said to be in ON condition, if the irradiance is set to 1000 w/m^2 and OFF condition for 0 w/m^2. The output voltage, current and power waveform of solar model is shown in Fig 12.



Activate Windows

Figure-11: Schematic Circuit of Solar model

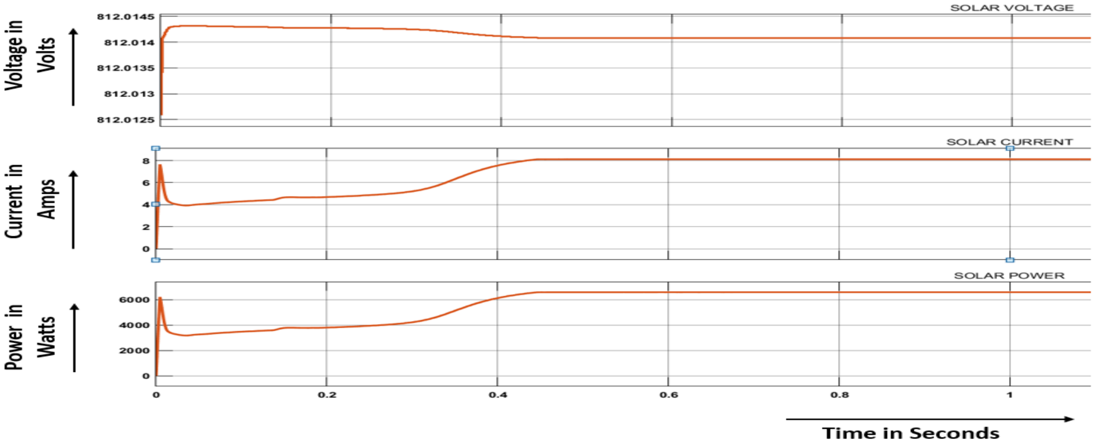


Figure-12: Output Waveform of Solar Model in ON Condition

WIND MODEL

The schematic circuit of wind model as shown in Fig 13 consists of wind speed parameter which is used to obtain a different output for different speed. The output voltage, current and power waveform of wind model is shown in Fig 14.

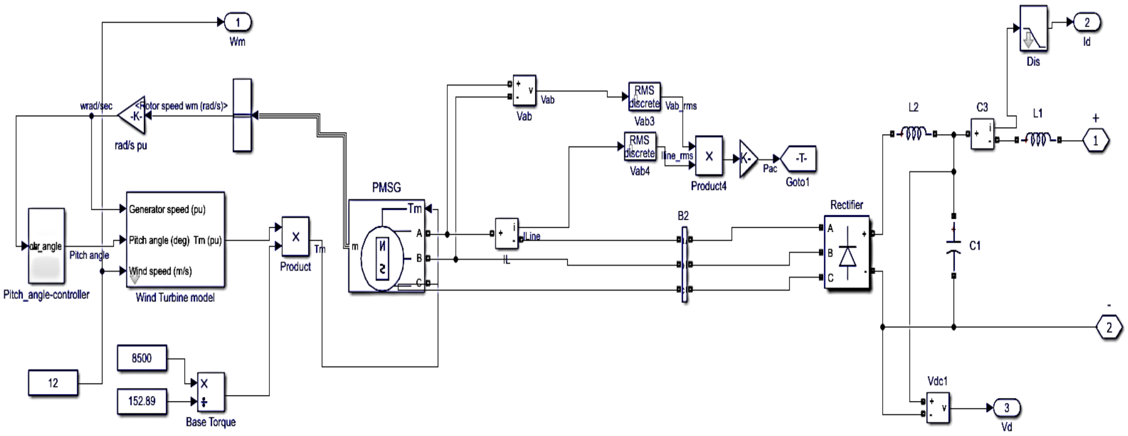


Figure-13: Schemaic Circuit of Wind Model

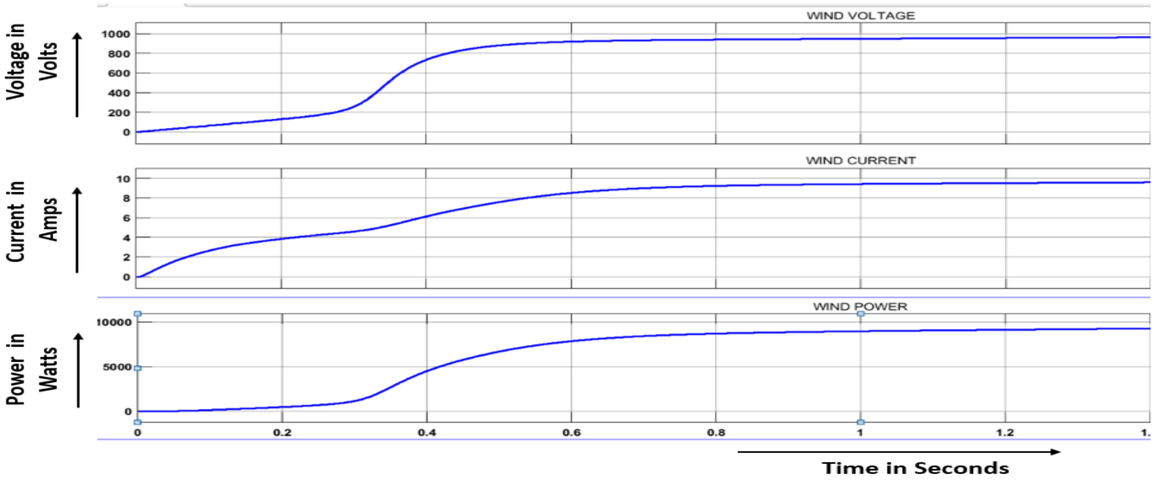


Figure-14: Output Waveforms of Wind Model

Dual Input Single Output Converter

The schematic circuit of DISO converter consisting of both solar and wind as two input sources to obtain a constant DC voltage as shown in Fig 15. The output voltage, current and power waveform of DISO converter is shown in Fig 16.

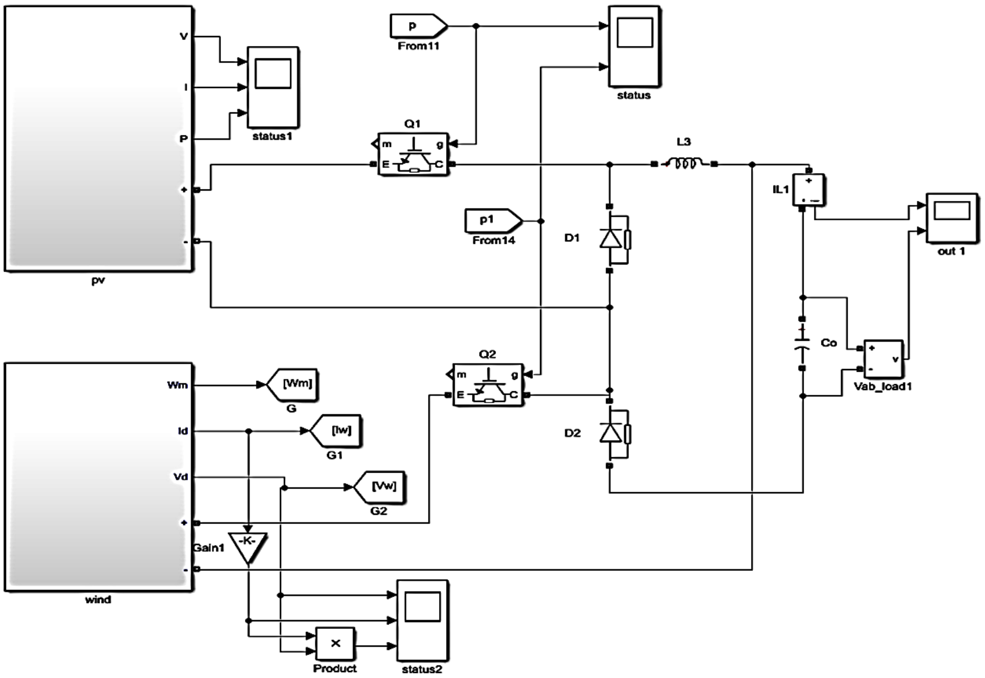


Figure-15: Simulation Circuit of Dual Input Single Output Converter

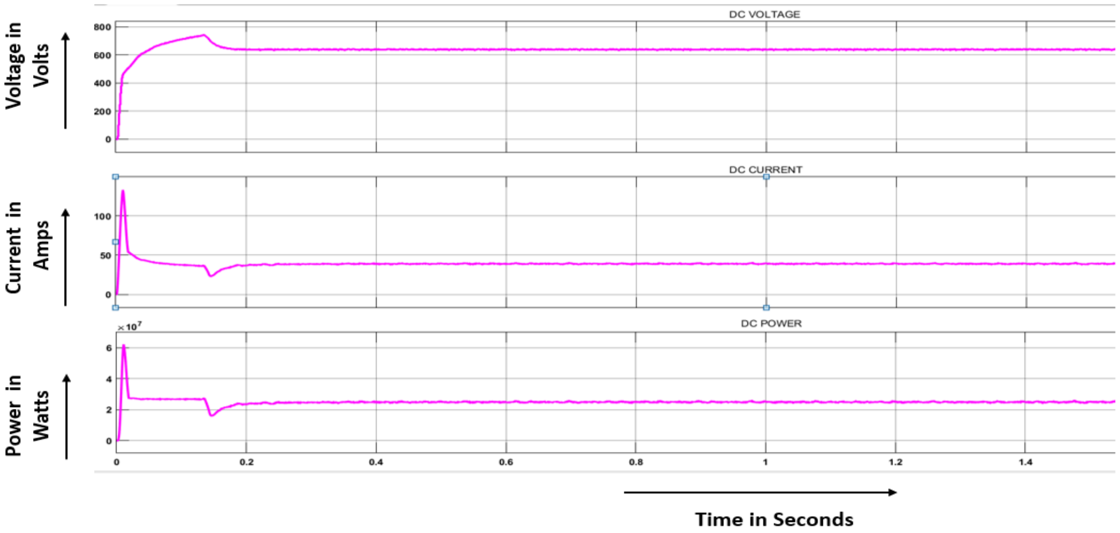


Figure-16: Output Waveforms of DISO converter

Dual Input Single Output Converter Working States

In this paper, different working states are considered to know the DISO status during uncertainties of renewable sources. The different cases and working states are shown in Table 3. All these cases are simulated and the output results are obtained. The DC output of dual input converter remains constant in all the cases discussed. The output DC voltage for all the four cases of dual input converter is shown in Table 3. The DC voltage of 640.5 V, DC current of 40A and DC power of 25 KW are obtained in one of cases.

Table-3: Output DC voltage of DISO in Each Working State

Cases	Working States		DISO Output
	Solar	Wind	DC Voltage
1	1	0	638
2	0	1	640.5
3	1	1	641.1
4	0	0	637.5

Output of DISO for Different Solar Irradiance and Wind Speed

The voltage, current and power for different solar irradiance and for different wind speed are tabulated in the Table 4. As the solar irradiance and wind speed is varied the output voltage, output current and output power varies. Hence DISO converter maintains almost constant output voltage even in source variations.

Table-4: DISO Output for Different Solar Irradiance and Wind Speed

SOLAR PANEL				**WIND TURBINE**				**DISO Converter**
SOLAR Irradiance in w/m^2	**Voltage in Volts**	**Current in Amps**	**Power in Watts**	**Wind Speed in m/sec**	**Voltage in Volts**	**Current in Amps**	**Power in Watts**	**DC Voltage**
1000	812	8.11	6592	12	986	9.82	9690	641.1
800	812	7.24	5883	8	638.5	7.24	4624	639
600	812	6.40	5203	6	471.4	6.41	3022	638.7
400	812	5.59	4546	4	308	5.59	1728	638.1
200	812	4.29	3450	2	40	4.23	169	640.8

Bidirectional DC-DC Converter

The schematic circuit of bi-directional converter for battery storage system is shown in Fig 17. The complete state of charging and discharging of battery with 60% as its initial capacity is shown in Fig 18.

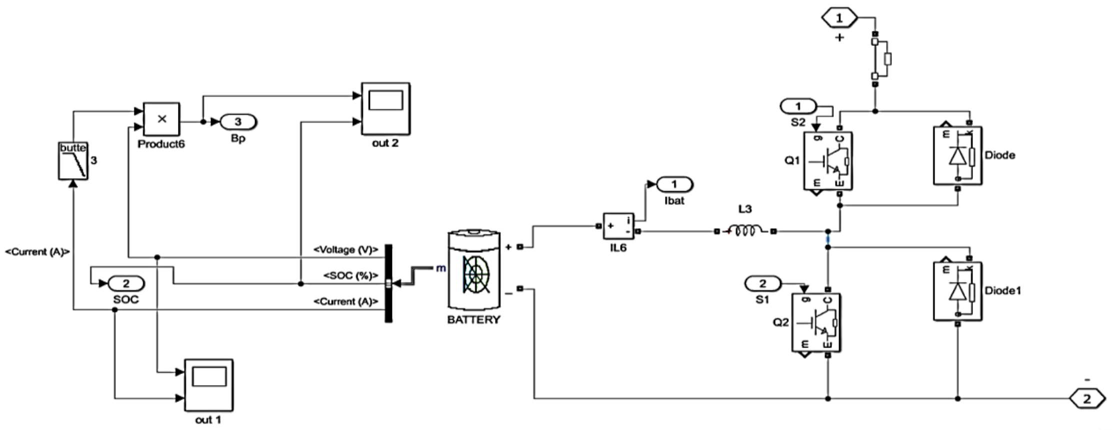


Figure-17: Schematic Circuit of Bidirectional DC-DC converter

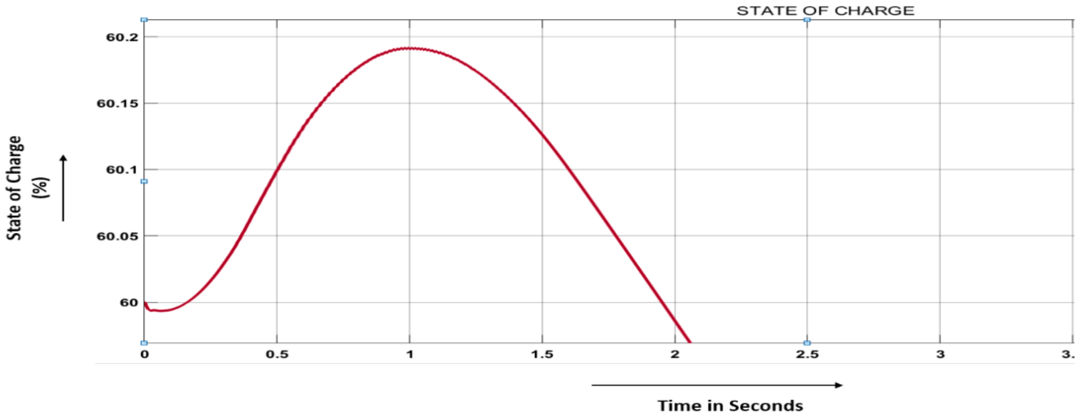


Figure-18: Output Waveforms of Charging and Discharging stage

The schematic circuit of sub-controllers like battery controller, local controller and inverter controller are shown in Fig 19.

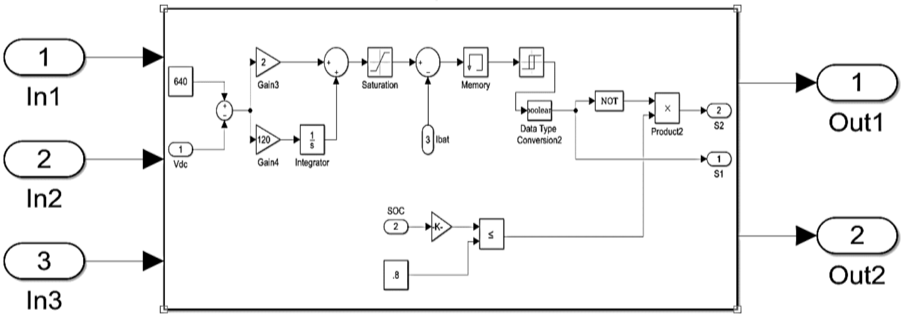


Figure-19: Schematic Circuit of Battery Controller

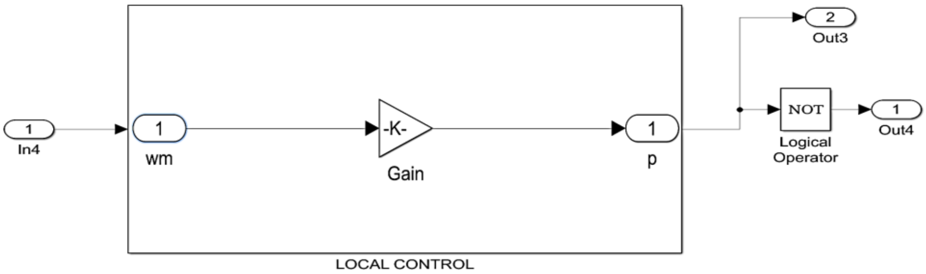


Figure-20: Schematic Circuit of Local Controller

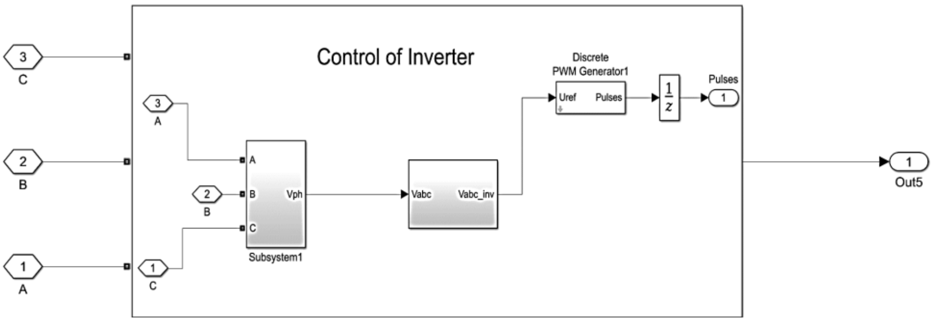


Figure-21: Schematic Circuit of Inverter Controller

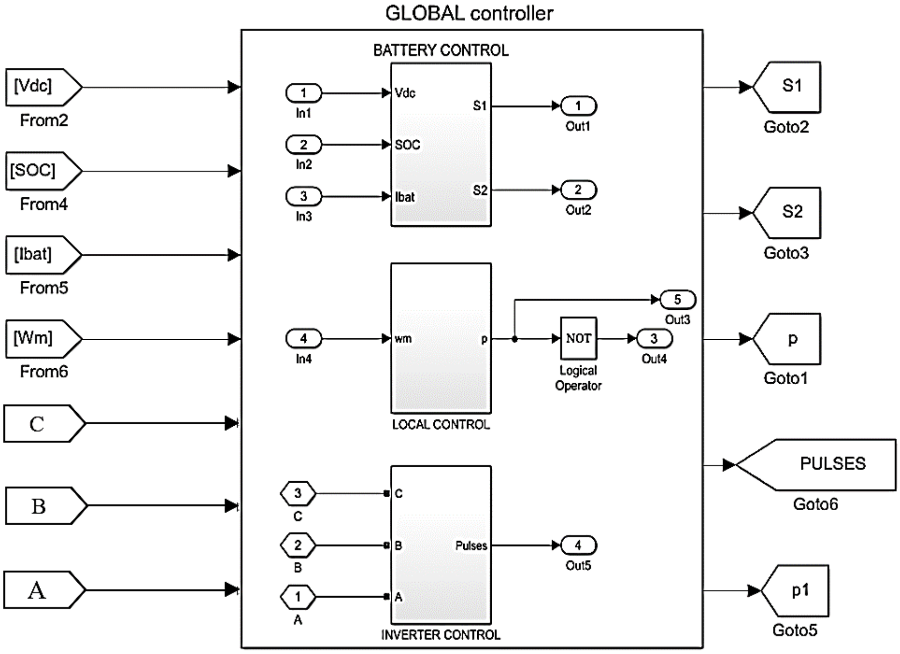


Figure-22: Schematic Circuit of Global Controller

Complete Circuit of Microgrid

The schematic circuit of proposed microgrid is shown in Fig 21. The output voltage, current and power waveform of inverter is shown in Fig 22.

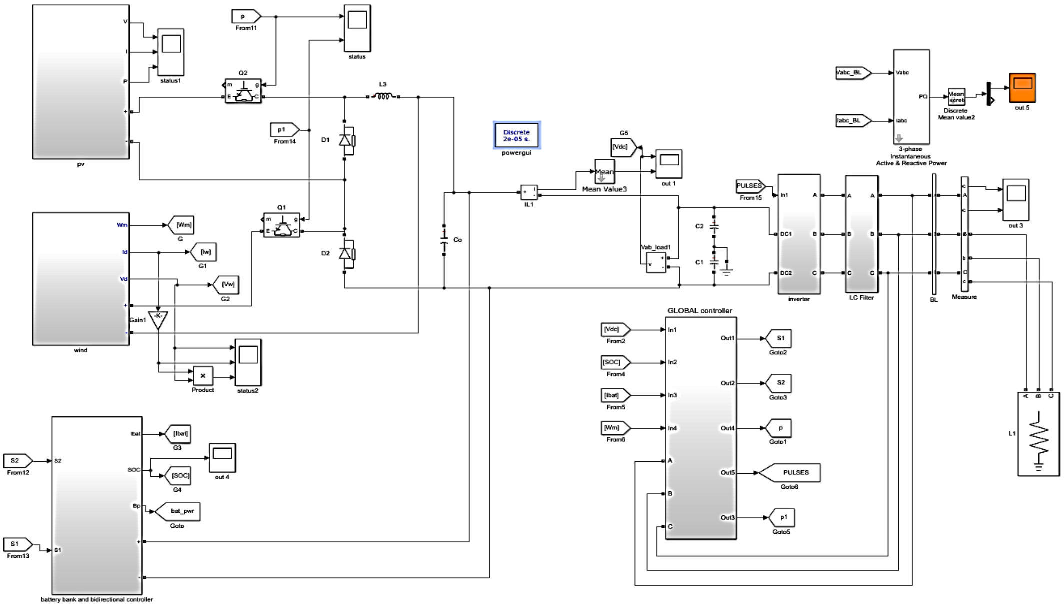


Figure-23: Complete simulation Circuit of Microgrid

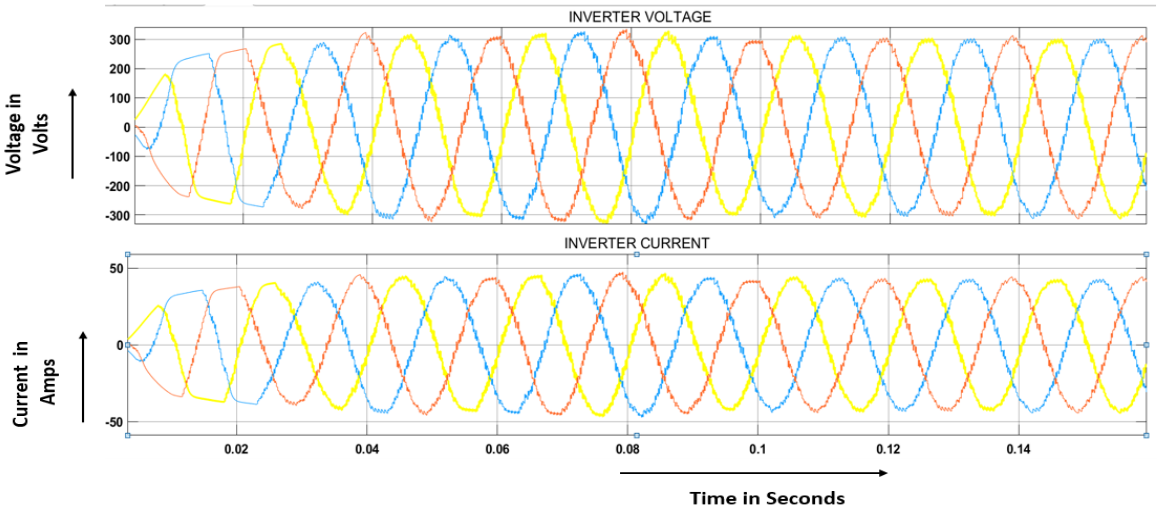


Figure-24: Output Waveforms of Inverter

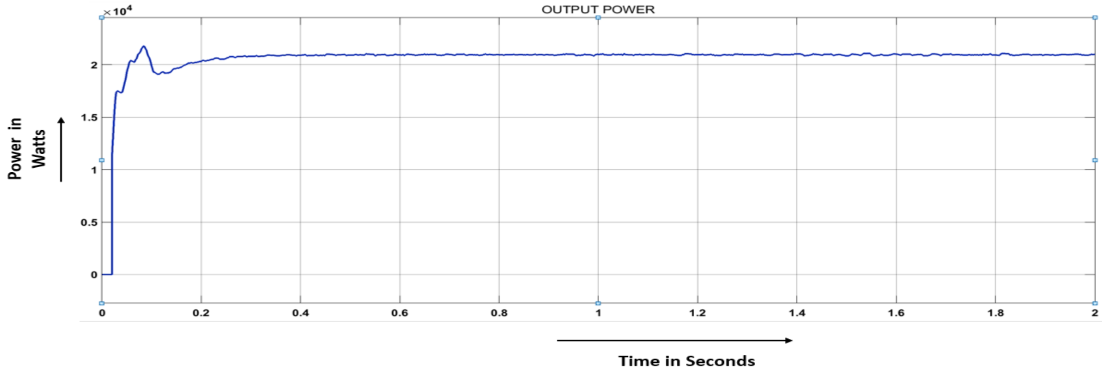


Figure-25: Output Waveforms of Inverter

IV. Conclusions

A sudden or large change in load causes instability in the power system. Controllers helps to coordinate and optimize system functions with intelligent capabilities to ensure reliable, safe, and efficient microgrid power generation and distribution. Optimal sizing of microgrid components was designed to ensure feasibility and economic viability. Hybrid power management software HOMER was used for sizing of each component of a microgrid. An optimized power management algorithm for hybrid power systems was developed and implemented. MATLAB Simulink was used for the development of complete circuit schematic of the microgrid. For the entire power management of microgrid, the PI controller based global controller is developed that consists of all sub controllers like local controller, battery controller and inverter controller.

As per the HOMER optimization results, for the peak load of 3.30 KW the solar panel of capacity 5.96 KW and wind turbine of capacity 3KW was designed. The battery with three strings of 80 Amps, nominal voltage of 12V with size of 75 number lead acid batteries were designed. The output power of 6.5KW and output voltage of 812V was obtained from solar model. The output power of 9.5KW and voltage of 986V was obtained from wind model. These outputs were used as input to the DISO converter. A constant DC voltage of 640 was obtained across DISO. Even in uncertainties of sources, the DISO maintained constant DC output voltage of 640 V. The battery with BDC was used for back up purpose. The DC voltage is then fed to inverter and inverter converts DC to an AC output voltage of 240V with a 25kW load.

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