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DC Microgrid for Solar and Wind Power Integration

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Abstract- Micro-grid systems are presently considered a reliable solution for the expected deficiency in the power required from future power systems. Renewable power sources such as wind, solar offer high potential of benign power for future micro-grid systems. Micro-Grid (MG) is basically a low voltage (LV) or medium voltage (MV) distribution network which consists of a number of called distributed generators (DG's); micro-sources such as photovoltaic array, wind turbine etc. energy storage systems and loads; operating as a single controllable system, that could be operated in both grid-connected and islanded mode. The capacity of the DG's is sufficient to support all; or most, of the load connected to the micro-grid. This paper presents a micro-grid system based on wind and solar power sources and addresses issues related to operation, control, and stability of the system. Using Matlab/Simulink, the system is modeled and simulated to identify the relevant technical issues involved in the operation ofwa micro-grid system based on renewable power generation units.

Keywords- Micro-grid system, photovoltaic, wind turbine, energy storage, distributed generation, Modeling and Simulation.

I. INTRODUCTION

The increasing need for energy generated with clean technologies has driven researchers to develop distributed power generation systems using renewable energy sources. On the other hand, the integration of a large number of distributed generations into distribution networks is restricted due to the limitation of the networks capacity and unidirectional power flow behavior.

Such barriers have motivated the search for an alternative conceptual solution to enhance the distributed generation integration into the distribution networks."Micro-grid" approach was proposed as a means of integrating more distributed generations into the distribution networks.
Distributed Generation (DG) in micro-grid operation provides multi benefits to the utility operators, DG owners and consumers in terms of reliable power supply, reduction in transmission system expansion and enhancement of renewable power penetration.

R. H. Lasseter proposed the first microgrid architecture that was called Clean Energy Resources Teams (CERTS). CERTS microgrid generally assumes converter-interfaced distributed generation units based on both renewable and non-renewable power sources. A microgrid system was also proposed by Barnes et al under the umbrella of the "Microgrids" European project.

The characteristics of a micro-grid system depend on the type and size of the micro-generation units, as well as the site, and the availability of the primary energy resources on the site, especially renewable power sources. Advancement in Distributed Generations (DGs) and micro-grids is accompanied by the development of various essential power conditioning interfaces and their associated control to connect multiple micro sources to the micro-grid, and tie the micro-grids to the traditional network. Micro-grid operation becomes highly flexible, with such interconnection and can be operated freely in the grid connected or islanded mode of operation. The islanded mode of operation with more balancing requirements of supply-demand may be started when the main grid disconnected due to any fault.

All the above mentioned literature presented single renewable source micro-grids. The current work presents the simulation of a micro grid model that includes two renewable energy sources; Photovoltaic (PV) and a wind turbine (WT) in addition two operational modes of operation (island and Grid connected) are investigated.

II. MODELING MICRO-GRID (MG) COMPONENTS

As mentioned above the components of the identified system are modeled using MATLAB/SIMULINK software tool.

1. PV Module:
A generalized PV model is built using Matlab/Simulink to illustrate and verify the nonlinear I-V and P-V output characteristics of PV modules. The behavior ofwphotovoltaic (PV) cells can be modeled with an equivalent circuit that includes a photocurrent source, a single diode junction and a series resistance and a shunt resistance. The Simulink model of PV module is shown in Fig.1.

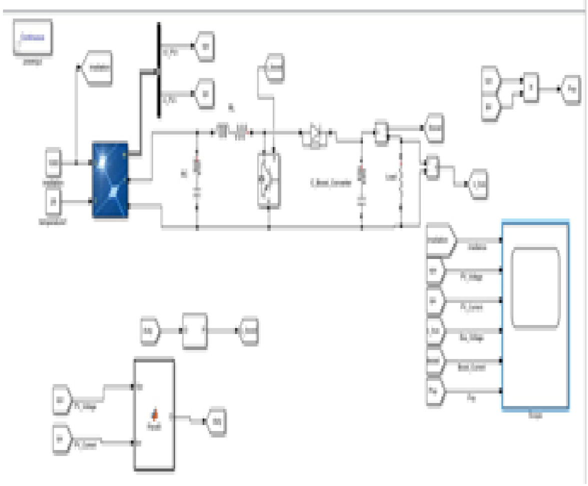

Fig 1. Matlab/Simulink model of the PV array.

2. Evaluation of MPPT algorithm:

It is very important to operate PV energy conversion system to maximum power point to obtain maximum poweroutput from the PV system. In this paper , incremental conductance method. Is used to obtain Maximum power point when.

dp / dv=0

where p= v*i

d (v*i)/dv = i + v*di/dv = 0 = =di/dv = -i/v.

The integral regulator minimizes the error (di/dv + i/v) Regulator output = duty cycle correction.

Algorithm of incremental conductance is as follows

- **Step 1:** sensing the voltage and current from solar panel and given to MPPT controller
- **Step 2:** MPPT controller compares the present with past values of the voltage and current which gives the difference

V and I

V = Vnew – Vold; I = Inew – Iold

- **Step 3:** The maximum power point is tracked by considering I/ V slope
- **Step 4:** Adding the instantaneous conductance i/v to incremental conductance which gives the error signal
- e = i / v + di/dv
- **Step 5:** This error is given to PI controller to minimize the error or drive e to zero.
- **Step 6:** The PI controller generates the duty ratio which is given to the comparator to generate PWM pulses, the
- Generated PWM pulses given to the switching device of the boost converter.
- Step7: The above steps will be repeated till the maximum power reached.

3. Experimental details:

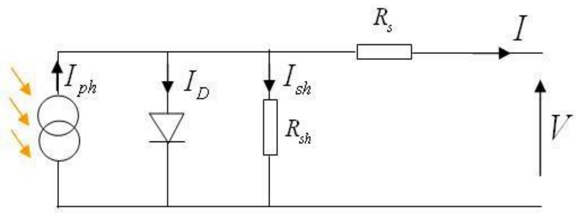

Fig 2. Circuit diagram.

I_d = Diode Current (A) = 2.9273 * 10^{-10} A
I_L = Light generated current = 7.8654 A
R_{SH} = Shunt resistor () = 313.0553
R_{SS} = Series resistor () = 0.39381

$I_d = I_o$

[/) − 1]
I_d = 7.867*10^{-10}[(36. 3/1. 5 * 103) − 1]
I_d = 2.927*10^{-10} A
V_T = (KT/q)*nI*N_{cell}
V_T = (1.3809*10^{-23} * 298.15 / 1.0022 *10^{-19})* 1 *60
V_T = 1.541477*10^{-38}
Maximum Power= 213.15(from 1 module) V_{oc} = 36.3V
Voltage at M_{pp} ($V_{mp)}$ = 29

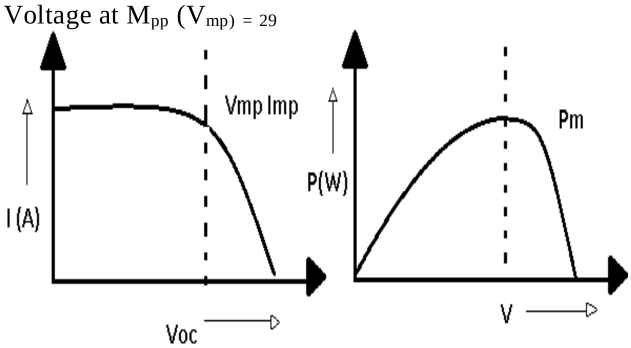

Fig 3. Characteristics of solar cell rated output and maximum power.

Case 1:
Parallel string = 5
Series connected string = 1 Power = 1064 W

Case 2:
Parallel string = 6
Series connected string = 1 Power = 1209 W

3. WT Module:

Wind turbine is composed of a rotor, a generator, three-blades, and a drive train. In case of high wind speed, the generator output power is controlled by adjusting the pitch angle. Power is transmitted to the grid through power electronic interface. A wind turbine extracts kinetic energy from the wind blowing through the blades. The power developed by a wind turbine is given by [10]. The Simulink model of a wind turbine equation is shown in figure 2.

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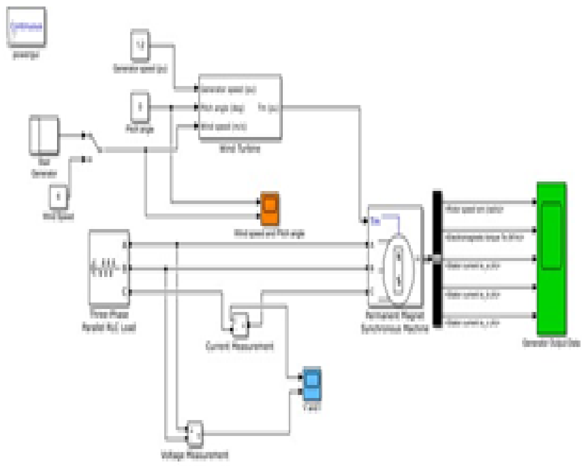

Fig 4.Matlab/Simulink model of the wind turbine block with variable speed.

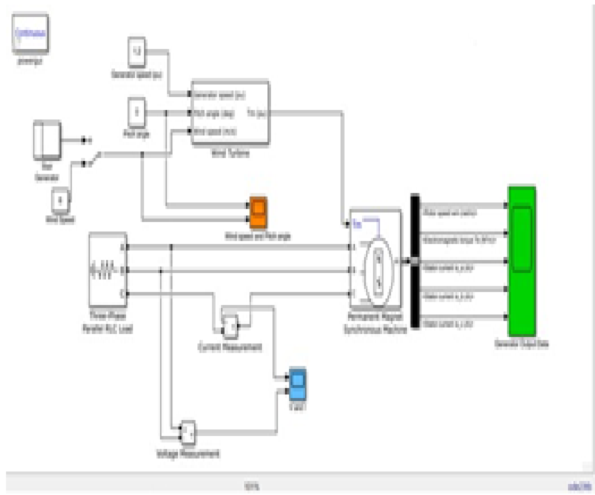

Fig 5. Matlab/Simulink model of the wind turbine block with Constant speed.

P = (½) ꞵ A v 3

P = Thermal Coefficient
ꞵ = Density of air
Temperature Coefficient (α) = -0.360 A = Swept area
v3 = Wind speed
Cp = Power Coefficient

PAvailable = (½)ꞵ A v 3Cp

Betz limit = 59.3%

Savonius - Merc air dmg (opposite air flow at fip) Darricus - Moderate to fast tip(less drag) Horizontal axis - leas drag (fast tip speed)

∴ T∝ (1/ω)

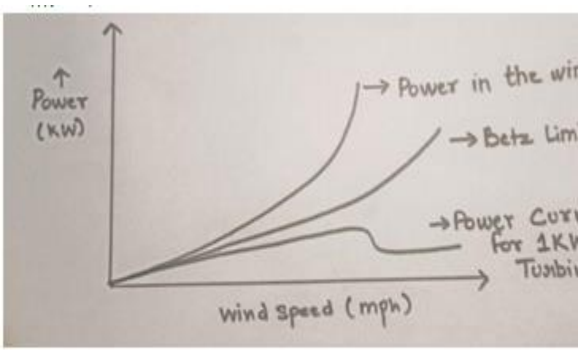

Fig 6. Characteristic of generated power vs wind
Maximum value of Cp(Cp max) = 0.48

For β (pitch angle)= 0
ƛ (Tip and speed ratio for the rotor blade) = 8.1
Pm -pu = Kp* Cp-pu * v3

Kp= Power gain when Cp-pu & v3 = 1pu

∴ Kp≤ 1
Average wind speed in India = 6m/s Blade length = 1000 = 1 * (½) * 1.1839 * A * 63
A = 7.8209 = πr2
r = 1.5774 m S = √3 VI
I = 110/ (400*√3) I = 0.1587 A
Vld = 400

III. RESULT OF SIMULATION COMPONENTS

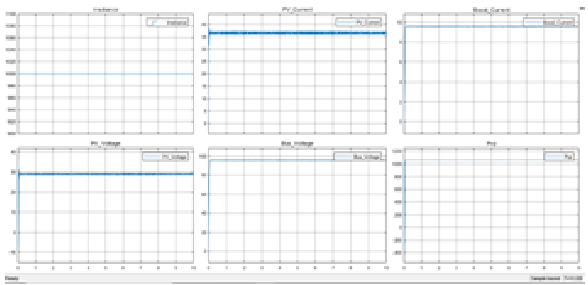

Fig 7. Simulated output of Irradiance, PV Current, Boost Current, PV Voltage, Bus Voltage, Pvp.

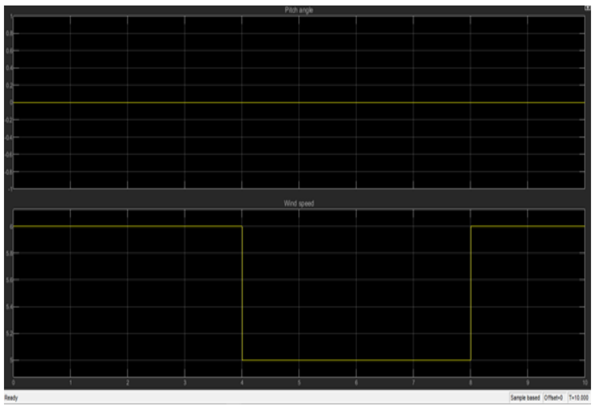

Fig 8. Wind speed and pitch angle scope

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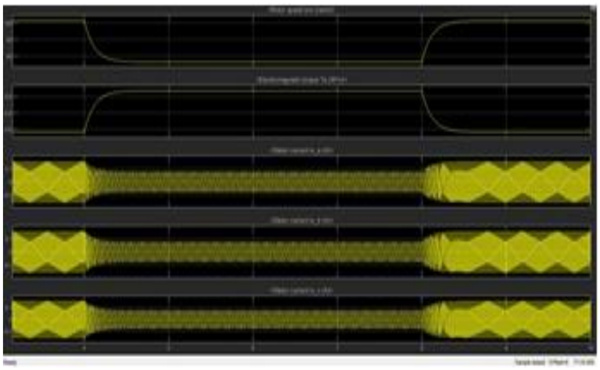

Fig 9. Generator Output Scope.

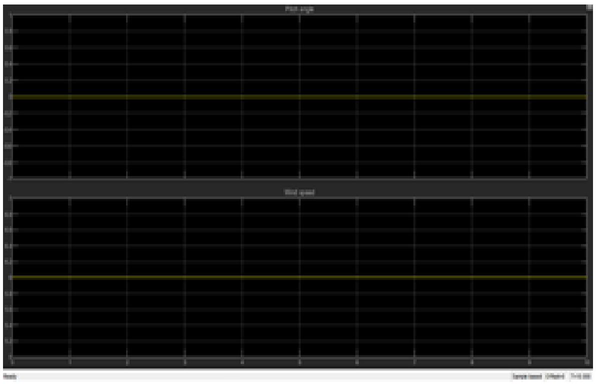

Fig 10. Wind speed and pitch angle scope (constant speed).

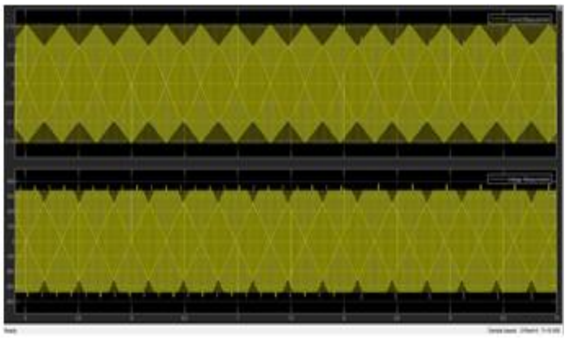

Fig 11. Voltage and Current measurement Scope (Constant Speed).

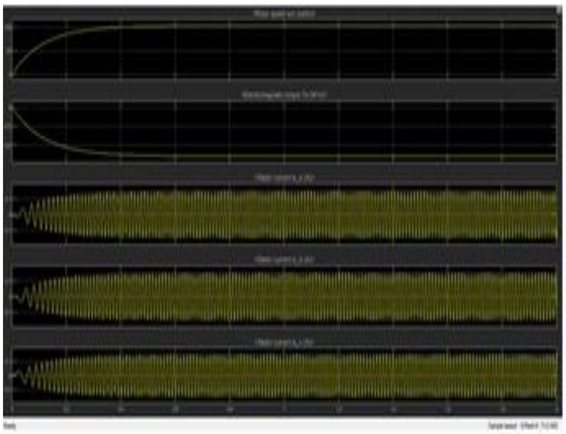

Fig 12. Generator Output Scope (Constant Speed).

IV. BATTERY ENERGY STORAGE SYSTEM

The battery energy storage system is used to store the energy from the distributed generation system so that it can be available for real time and future use. It also caters the need of supply and demand balance.

The most commonly used batteries are Lead acid batteries. Lead-acid battery storage has advantages like low cost, good technique and higher energy capacity (MW level), etc. These are mainly applied to the backup capacity and frequency control of the power system and uninterruptible power supply (UPS) function.

However, it has disadvantages like low storage energy density, less time of charge-discharge and a certain amount of pollution produced during production.

When there is adequate sunlight and favourable wind, the system not only supplies the local loads but also transports the surplus energy to the storage system or the grid.

And in a case of successive cloudy days and no wind weather, the field generation power lacks not to guarantee the normal operation of the loads, at that moment; the power storage system will release energy.

One of the important concepts in battery selection is that the amp-hour rating of a battery is discharge-rate specific. The greater the discharge rate, the less energy can be withdrawn from a specific battery.

V. ADAPTIVE DROOP CONTROL

In autonomous mode of operation, the BESS is responsible for keeping the voltage of the dc bus in a defined acceptable range for providing UPS service.

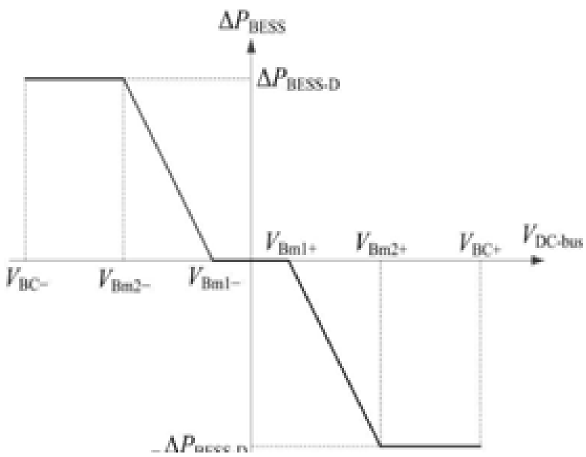

Fig 13. Droop control of BESS power electronic converter to mitigate power deviations of dc microgrid in normal SOC of the BESS.

Devised for a case where the real-time SOC of the BESS is within close range of the optimized SOC of the BESS from the scheduling calculated in Section III-C. The acceptable realtime SOC is determined through definition of upper and lower boundaries around the optimized SOC.

If the real-time SOC is within these boundaries, the droop control of the BESS power electronic converter is selected as shown in Fig. 13 to support the dc voltage. In this case, the upper boundary and the lower boundary lead to a symmetrical droop response.

In the voltage range between VBm1− and VBm1+, battery storage does not react to the voltage deviations of the dc bus. In the voltage range from VBm1− to VBm2− and also from VBm1+ to VBm2+, the droop control of the BESS reacts. Therefore, PBESS modifies the power output PBESS to mitigate the voltage deviation of the dc bus. Finally, in the voltage range from VBm2− to VBC− and also from VBm2+ to VBC+, the droop curve is in a saturation area, and thus the BESS contribution is at its maximum and constant.

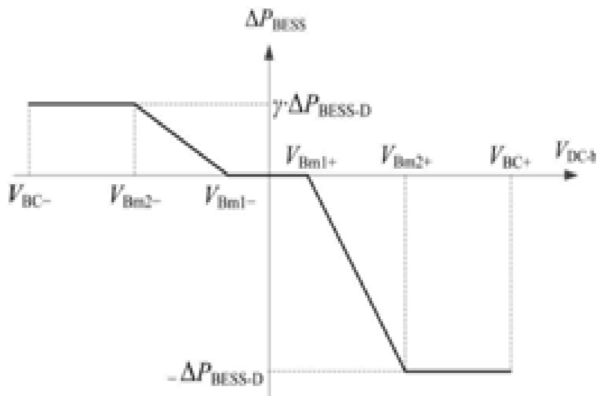

Fig 14. Droop control of BESS power electronic converter to mitigate power deviations of dc microgrid in lower than the scheduled SOC of the BESS.

The second droop curve as shown in Fig. 14 is devised for a situation where the real-time SOC of the PBESS is lower than the optimized and scheduled SOC of the BESS. Therefore, the BESS contributes to stabilizing the dc bus voltage by charging at the same power as shown in Fig. 13.

However, the upper boundary of the BESS droop response is reduced by the factor γ, and it is equal to γ •PBESS-D. This way, the SOC can come closer to the optimized and scheduled SOC.

The third droop curve as shown in Fig. 15 is devised for a situation where the real-time SOC of the BESS is higher than the optimized and scheduled SOC of the BESS. Therefore, the BESS contributes to stabilizing the dc bus voltage by discharging at the same power as shown in Fig. 13. DC Voltage Droop Control in Autonomous Mode:- In the autonomous mode, the main grid is disconnected. Then, the fast charging service has less priority compared with the supply of other loads. The control of the BESS converter is also defined by the voltage–power droop as discussed. The BESS so supports the voltage of the dc bus.

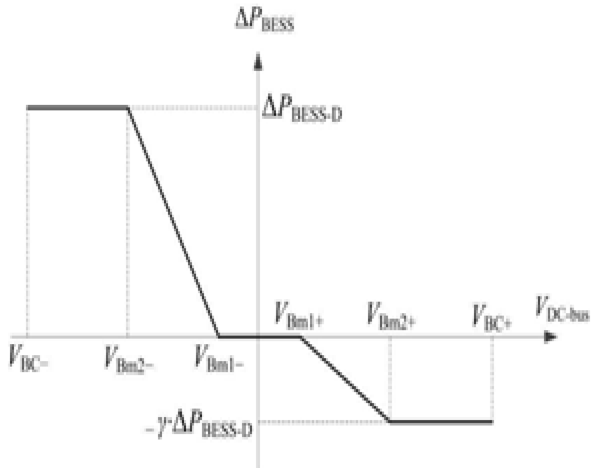

Fig 15. Droop control of BESS power electronic converter to mitigate power deviations of dc microgrid in higher than the scheduled SOC of the BESS.

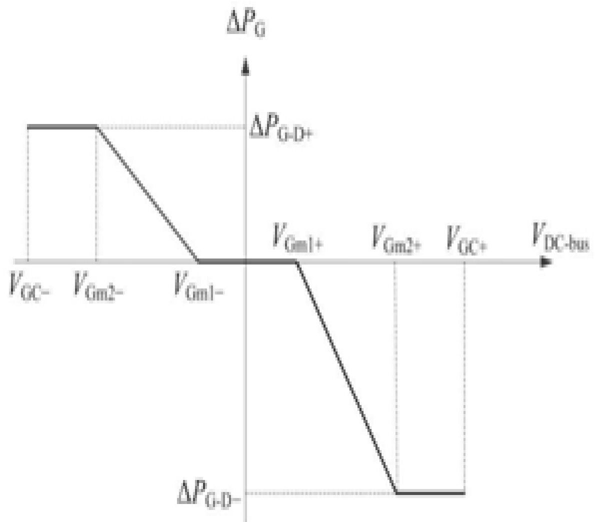

Fig 16. Droop control of the grid power electronic converter in interconnected operation mode of dc microgrid.

There are several approaches to model a battery. A commonly used battery model is the Thevenin equivalent circuit. In this case Simulink implements a set of predetermined charge behavior for four types of battery: Lead-Acid, Lithium-Ion, Nickel-Cadmium and Nickel-Metal- Hydride.

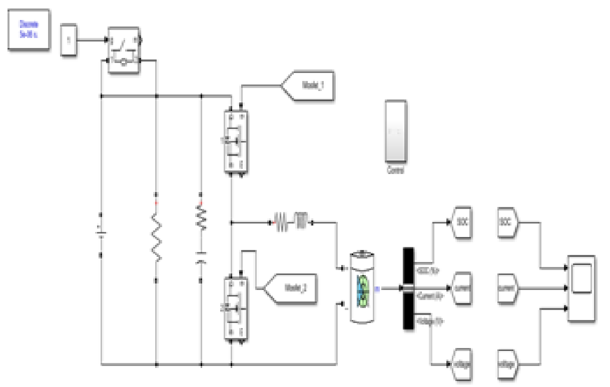

Fig 17. Matlab/Simulink model of Battery Energy Storage System.

Simulink implements a set of predetermined charge behavior for four types of battery: Lead-Acid, Lithium-Ion, Nickel-Cadmium and Nickel-Metal- Hydride. Figure 18 illustrates a detailed modeling of charge & discharge battery in Matlab/Simulink Scope.

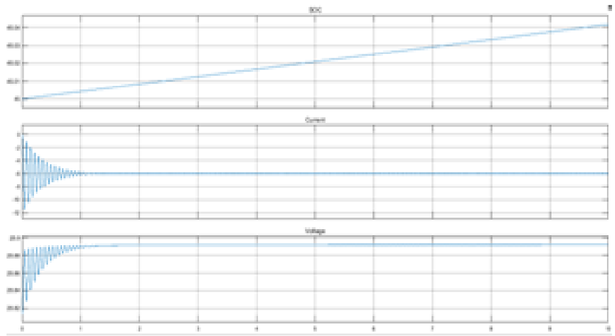

Fig 18. Scope: - Battery Energy Storage System.

VI. INTEGRATED MODEL

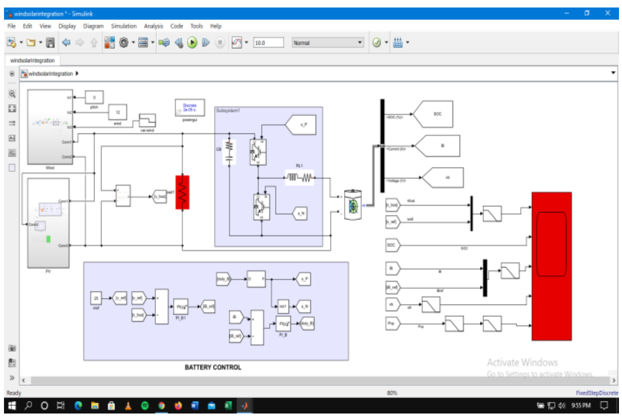

Fig 19. The simulation in MATLAB of the integrated model of PV, Wind and battery energy storage system.

The output of the generalised module built in MATLAB/Simulink of PV Module Wind and Battery Energy Storage System. Hee all models are connected and integrated in such a way that the power loss is less in all the forms and the extra amount of energy produced when theproduction is more and load consumption is less then the remaining energy can be stored in the energy storage system for later to use with minimum losses and vice versa.The Simulation scope of the integrated model is PV, Wind and battery system.

In this scope the energy generated is of 4KW, 1KW is from the slar and 3KW is from the wind and then this energy is stored in the battery energy storage system at the times of greater amount of generation as we know that the energy produced from renewable resources are inconsistent in nature so when the energy production is lower and consumption is higher then we can use the energy that is kept and stored in the battery.

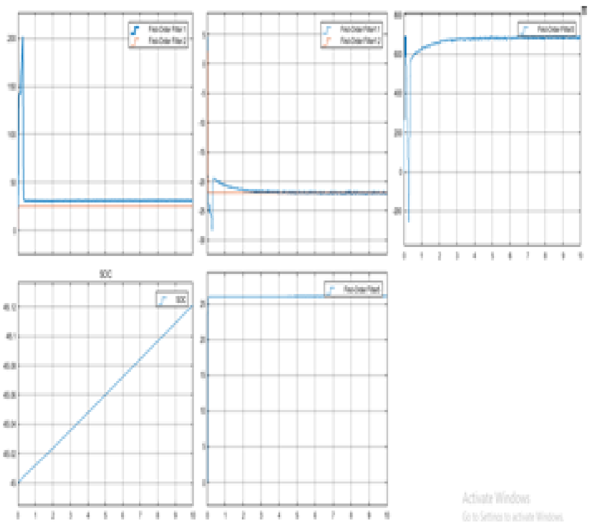

Fig 20. The simulation in MATLAB of the integrated model of PV, Wind and battery energy storage system scope.

VII. CONCLUSION

A dc microgrid for renewable power integration has been proposed. The operational optimization and power-electronics based voltage–power droop control was developed, and the functioning was demonstrated through simulation. Interaction with the main grid was controlled as a result of an operational optimization that seeks to minimize cost and emissions.

A method to quantify the uncertainty affiliated with the forecast of aggregated wind and PV-based power generation was created and used to quantify the energy reserve of the battery energy storage system. The battery is parallel-connected with a supercapacitor to form multillevel energy storage.

The latter plays a critical role in compensating renewable power fluctuations and providing the power needed when EVs stop by for fast charging. In accordance with the microgrid paradigm, operation is also supported in autonomous mode to support UPS when the connection to the main grid is unavailable. During such periods, fast charging is not supported, as the priority shifts to supplying critical local loads. Power electronics is a key enabling technology in connecting all energy resources to the dc bus. The converters support the dc voltage through a droop control scheme.

The control proposed here is adaptive in that the voltage–power droop curves are modified depending on the outcome of the operational optimization. As a novelty, asymmetric droop curves were proposed for the converters connected to the storage so as to also support the objective of bringing the actual battery SOC close to the desired one as scheduled.

This ensures, in particular for the multilevel energy storage, that the contribution toward dc voltage control does not compromise its role in providing adequate energy reserve. For the special case of an urban location, the vertical integration within a tower building offers renewable wind and solar power harvesting on the top and energy delivery at the bottom on the ground level, for example for EV charging.

The structure contributes to closely co-locating renewable power generation and delivery to local stationary and mobile EV energy resources. In sum, this paper contributes to the microgrid paradigm by a novel droop control that takes into account storage SOC when adaptively setting the slopes of the voltage–power droop curves; the proposed forecast based on contributes to quantifying energy reserve.

In an urban setting, a tower-integrated installation to co-locate harvesting of wind Energy and local delivery of clean energy is an alternative. The optimization for power exchanges and dc voltage control using adaptive control are performed through power electronic converters that serve as interfaces to all resources.

The resulting energy system serves local stationary and EV-based mobile consumers, and it is a good citizen within the main grid as it reduces emissions by local usage of wind and solar energy.

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