

# Operation and Control of a DC Micro-grid with Wind Power Generation and Energy Storage



Dhanshri B. Bhadke, Manoj D. Patil

**Abstract:** This article researched controlling and operating a dc micro grid that can be operated in connected grid and island modes. Dc micro grid comprises of a wind turbine, dc loads, grid-connected converter arrangement and a battery energy storage scheme. When the scheme is linked to the grid, the active energy is balanced during standard operation to guarantee a continuous dc voltage. In grid ac failure, automatic power balancing is attained by combining the battery energy storage scheme as well as the grid converter. To demonstrate that the system can function under island circumstances, a synchronized battery scheme approach, wind turbine and load managing, including load shedding, is suggested. MATLAB simulations are provided to demonstrate the powerful operational presentation and confirm the predicted control system under different working situations, such as varying in load, grid ac fault, variable generation and islanding.

**Index Terms:** Energy storage, islanding, dc micro-grid, distributed generation, load shedding.

## I. INTRODUCTION

Due to growing energy response, reduction of fossil energies and with environmentally friendly conditions the electrical energy market has attention in huge deployment, research and use of Renewable Energy (RE). The technologies of producing power from unpolluted energy sources and native power production has been transformed. In spite of generation from conventional central, big generation-based power systems now days they are collected of minimal distributed energy resources (DGE) such as fuel cells, wind turbine, photovoltaic, battery, etc. this can be grid linked and stand-alone system. The outputs of these generation sources are both dc and flexible voltage/frequency ac productions and the, power-electronics tool is used in many distributed generation systems (DEG). The Power Electronic (PE) limit is used to integrate into the micro grid any number of Distributed Generation (DG), energy storage scheme, ac and dc loads. The voltage source converters depending on Pulse

Width (PWM) through Insulated Gate Bipolar Transistors (IGBT) checks are used to produce efficient voltage controller, power flow control, power matching, fault safety, and maximum power point tracing. Micro grid is a minor power supply system that is design to deliver power to minor community it includes of several minor power generating sources that creates it extremely flexible and dissimilar and it can be linked mutually to the native generating units and utility network thus for avoiding power outages. The micro grids are of three different types they are ac, dc and hybrid micro grids. Now day's research Is going on dc systems on its generation, Distribution and its uses so we are moving towards dc micro grid due their advantages over ac micro grid they are as follow: 1) Higher efficiency 2) Reduced losses due to the reduction of distinct converters for dc systems 3) Easy combination of numerous dc DERs 4) higher reliability and uninterruptible supply. Through the fast growth of power-electronics equipment and huge use of renewable energy sources, cost decrease and improvement in technologies of energy storing schemes, multi terminal low-voltage dc grid and high-voltage dc micro grid have been recommended for large-scale wind power incorporation. The protection of low-voltage dc micro grids was researched in [11] where separate safety systems were investigated and distinct fault detection and grounding techniques were analyzed.

Different operation methods of dc distribution systems for ac link fault and islanding have been studied [12]. Though, in these studies, the power generations and energy storing is huge adequate to offer full load demand and assurance smooth and transient free operation throughout control method changing and islanding. But however due to variable RES (wind turbine) and loads this cannot be possible and thus during transient condition requires close co-ordination between sources and load. The purposes of this paper are to improve operation and control techniques for the suggested dc micro grid to offer safe and reliable supply to the associated loads. Nearby corresponding strategies are created depending on the measurement of dc voltage between generators, loads, and energy storage.

## II. SYSTEM CONFIGURATION AND MODELING

The dc micro grid consider in this paper shown Fig. 1. Micro grid, it contains key components shown below:

**Revised Manuscript Received on 30 July 2019.**

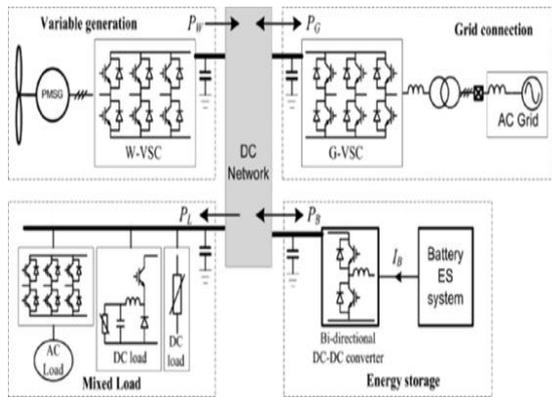
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**Fig .1 .Design of a dc micro grid**

**WIND TURBINE or W-VSC:** Wind turbine has variable power generations and wind turbine used permanent-magnet synchronous generator (PMSG) for maximum power production. The PMSG is connected to dc network by using three phase voltage source converter (VSC) i.e. W-VSC. The maximum power point tracing (MPPT) is used with wind turbine so that usually operate at maximum power point tracing method to remove extreme power from the wind though wind power is essential to decrease below certain circumstances(e.g., strong wind fixed with a light load for the dc micro grid). Wind curtailment can be attained by using the turbine’s pitch and power control systems.

**LOAD:** Different variable loads are used in the system they may be number of dc and ac loads. The ac loads are linked to network by inverter (dc to ac) and dc loads are linked by dc-dc converters or some are directly connected to network. During standard condition the loads function on their individual benefits. But load managing is required which involves load shedding depend on pre-defined load importance levels, this may be essential throughout unusual or island circumstances.

**GRID:** In this arrangement ac network is externally associated to dc micro grid and ac grid has controlled generation. Ac network is externally linked to dc network by dc-ac converter which offers bidirectional power-flow ability. The aim to connect G-VSC is to sustain a continuous dc voltage by adjusting its power interchange among the dc and ac systems to guarantee power balance inside the dc micro grid.

**ENERGY STORAGE SCHEME:** The energy storage is used in this system to maintain stability of the system or to sustain continuous dc voltage in the system if grid failed to maintain dc voltage. In regular conditions, the battery ES scheme works at stand-in or charging /discharging mode, where a charging or discharging current can be set by the system  $I_b^*$  ensure effective performance. But under unusual circumstances (e.g., islanding or grid falut), the capability of the G-VSC for dc voltage controller is to be severely affected or totally lost. Subsequently, the battery ES scheme is essential to offer essential dc voltage regulation under these circumstances.

### III. SYSTEM OPERATING METHODS:

There are a number of distinct operating techniques that are essential to consider in order offering a safe and consistent power supply for the proper functioning of the dc micro grid

system through the variants of wind power production, load and grid connection circumstances. The methods of operation are as follows:

**METHOD 1:** In this method operation is related to the ac grid linking via the G-VSC. The G-VSC is used to automatically balance the power (i.e. if power is increased or decreased) inside the dc micro grid through the linked ac grid. Now by avoiding power losses

$$P^*_G = P_L - P_W - P_B \dots\dots (1)$$

Where

$P^*_G$  = Power contribution to the dc grid from the G-VSC

$P_W$  = Power contribution to the dc grid from the wind turbine

$P_B$  = Power contribution to the dc grid from the battery ES scheme.

$P_L$  = Power consumed by a load.

Symbol \* = signifies the necessary (reference) value.

In this technique, wind turbine attains its highest power through MPPT tracking, and subsequently the battery energy storage scheme can be charged or discharged. As the power is balanced and constant dc voltage is regulated there is no need of load shedding necessary.

**METHOD 2:** This method discusses the operation through which the G-VSC cannot meet the required power interchange as defined in (1). Because of two likely circumstances, it is possible to measure 1) the essential  $P_G$  is higher than the maximum power limit of G-VSC, 2) due to a small duration ac system failure affecting the ac voltage drop and a significant decrease in the peak power that can be transferred by the G-VSC. In this method, the G-VSC cannot control the dc voltage and, in order to sustain system stability, the battery ES arrangement necessary to control the dc voltage and provide the required power balance as

$$P^*_B = P_L - P_W - P_G \dots\dots (2)$$

$P^*_B$  should provide the full maximum range of the ES scheme so that the dc voltage can be completely controlled. If a short duration ac fault causes the error, system function can return to the pre-fault situation after clearance of the fault. If  $P^*_B$  exceeds the power limit of the ES scheme, the dc voltage cannot be regulated and the load shedding will be essential. This will be discussed in Method 3.

**METHOD 3:** This technique refers to islanding and island activity as a consequence. The dc micro grid becomes an island device due to the cutting off to the external ac grid and the grid is no longer in service. The dc voltage that the battery ES scheme now needs to control and the essential energy from the ES scheme is

$$P^*_B = P_L - P_W \dots\dots (3)$$

However, the required  $P^*_B$  (battery discharge) may beat the power rating of the battery ES scheme in low wind (and, i.e., low  $P_W$ ) and high load situations. Appropriate load shedding is therefore essential in this situation in attempt to sustain dc system service. An another situation is that while  $P^*_B$  is inside the ES system's power rating, extended operation in island method effects in low battery energy storage, and appropriate load shedding is also essential to assurance power supply to the most critical loads.

On the other side, the necessary  $P^*_B$  (battery storage) could also be higher than its rating under the circumstances of heavy wind (and, large PW) and small load. Though, this condition is less serious and can be solved by primarily using the W-VSC and then the wind turbine system's stability control mechanism. In the research, this scenario is not regarded.

IV. CONTROL SYSTEM

1] Method 1 control system:

The simple control block diagrams of the wind turbine, grid, and energy storage scheme under Method 1 control are shown in Figs.2(a)–(c), correspondingly. The collect power depends on the power constant for the PMSG-based wind turbine, now for each wind speed there is a particular turbine speed corresponding with the peak active power removal from wind and the total power obtained is represented by the corresponding equation.

$$P_{max} = \frac{1}{2} \rho \pi R^3 \left( \frac{\omega m R}{\lambda_{opt}} \right)^3 C_{P\_opt} \dots \dots (4)$$

Where is the  $\rho$  air density, R is the radius of blade, and  $\omega m$  is the wind turbine speed.  $\lambda_{opt}$  and  $C_{P\_opt}$  are the optimal values of the tip speed ratio and power constant, correspondingly. As we understand, wind turbine works in MPPT method where its yield power is measured according to (4). The generator current is controlled by the W-VSC that is straight attached to PMSG to guarantee that the output current reaches the reference value. The converter control system is generally focused on the synchronous reference frame, where the axis is matched with the rotor flux generated by the permanent magnet and the axis is 90 ahead of the axis in the position of rotor revolution. Therefore, the axis current is equal to the active power. The axial current is generally fixed to zero to reduce stator copper loss but becomes negative at high rotor speed to deliver field weakness activity.

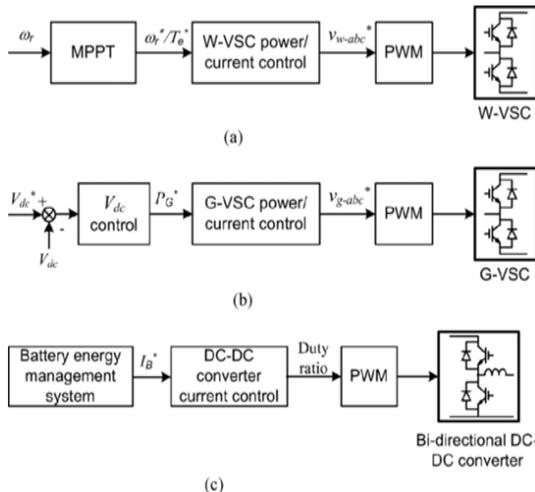


Fig.2. Block Diagram of Method 1 Control System.

The G-VSC control common dc voltage. The DC voltage regulation system is dependent on a closed-loop PI regulator whose input is the distinction among the desired and real dc voltages. The current regulation of the G-VSC is also established on the dq synchronous reference frame in which the d axis is associated with the grid ac voltage. The current of

the d axis denotes the active power where the current of the q axis denotes the reactive power[3].

The battery energy-management scheme is used to monitor the dc voltage and charging level of the battery ES system. The aim of theses system is to sustain a specific quantity of energy storage by providing proper levels of charging/discharging current  $I_B$  to the battery. By modifying the duty ratio of the bidirectional dc-dc converter the controller of  $I_B$  is attained and various methods, such as the predictive method which can be used .

2] Method 2 control system:

**Grid:** As the unusual dc voltage is detected, the Grid transfers from the dc voltage regulate system to the current limit procedure where the active current is dependent on predefined norms (e.g. peak current rate of the converter). This technique is illustrated by the diagram in Fig.3. As shown in this instance, when  $|\Delta V_{dc}| > 5\%$  i.e. the difference b/w desired and the real dc voltage is greater than 5 percent ,than S becomes 1/-1 and the control method is turned on. As shown, a hysteresis band is used to prevent excessive repeated shifting during execution of the control method.

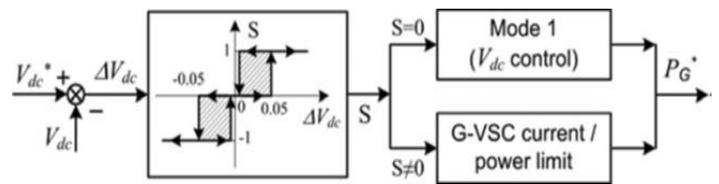


Fig.3. Block Diagram of Method 2 Control System.

**Energy Storage System:** In this method, since the G-VSC can not regulate dc voltages, the dc voltage must be measured by the battery ES system to supply equivalent to the demand. This method is represented in Fig. 4. As illustrated in Fig. 4, After the dc voltage is higher than its normal variation band (5 percent in this case), the ES battery scheme is shifted from standby mode to dc voltage regulate method which regulates the  $I_B$  (power) battery charging / discharging current to sustain a continuous dc voltage. For scheming dc voltage controller, a usual close-loop PI regulator is used as it was used for G-VSC but has distinct reference dc voltage levels (e.g., 1.05 p.u. 0.95 p.u.) respectively for dc over and under voltage circumstances. The feature of the dc voltage drop shown in Fig.4 can be used as.

$$I_B^* = \begin{cases} KB. (\Delta V_{dc} - 0.05) & \text{for } \Delta V_{dc} \geq 0.05 \\ KB. (\Delta V_{dc} + 0.05) & \text{for } \Delta V_{dc} \leq -0.05 \end{cases} \dots \dots (5)$$

Considering the specifications for the converter device, the dc droop KB must be taken into account in the control scheme and the maximum / minimum dc voltage.

Now if the cause for the initial power imbalance is related to minor period instabilities such as ac system failure, the Method 2 operation time span would be smaller. The ac grid voltage improves rapidly, for example, after ac-fault clearance, and the active power exchange among the G-VSC and the ac grid rises quickly. This results in a fast dc voltage variation (i.e.  $|\Delta V_{dc}| > 5\%$  and  $S=0$  G-VSC is shifted again to dc voltage regulate method) then hence causes the control technique to shift back from Mode 2 to Mode 1.



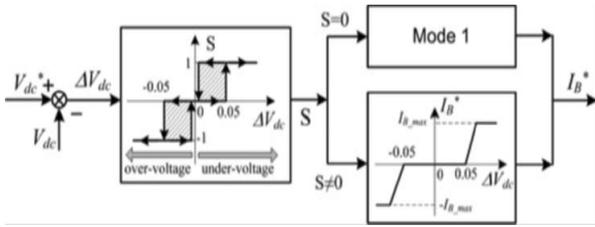


Fig. 4. Block Diagram of Method 2 Battery ES control system.

3] Method 3 Control system:

As mentioned above, this mode is called as island operation method of the dc micro grid. As we know for island operation link of the ac supply is absent for a definite range. This method can be discussed as the extension of Method 2 process ,in this method dc voltage control is done by the battery ES scheme and proper load shedding is essential.

The battery ES scheme operation is related to Method 2 operation. In the battery ES scheme, the essential power  $P_B^*$  is lower than its peak power rating  $P_{Bmax}$ , then the dc voltage can be completely regulated and there is no need for load shedding. There are several circumstances, however, where load shedding becomes mandatory.

**1) Insufficient System Power Rating causes Load shedding:** The essential power  $P_B^*$  from the battery ES scheme beats its peak power rating (i.e.  $P_B^* > P_{Bmax}$ ) as shown in figure 3 in this circumstance. As the ES scheme functions at power limit and current, dc voltage cannot be completely regulated and desired value will carry on to move away .

Now to prevent the dc micro grid's complete voltage breakdown, load shedding is used without communication depending on the dc voltage measurement.

**2) Insufficient Energy Storage Causes Load Shedding:** In this event, however the power rating of the ES scheme is bulky adequate to regulate the dc voltage , but due to extended island operation the battery capability (stored energy) becomes low. To assurance power supply to those critical loads, load shedding is required.The representation of Fig. 5. Shows, if the battery capability becomes low or is under a definite level, Reference dc voltage ( $V_{dc}$ )for the battery ES system varies to a low value, eg 0.9 p. u. and remains at this value for a definite period of  $T_s$ . Simultaneously, the load terminal dc voltage becomes somewhat less than 0.9p.u., which effects Load to trip .Now if no further load shedding is necessary dc voltage reference value after certain period. For suitable load shedding scheme separate load and ES regulator is essential to be properly match with the Time Period.

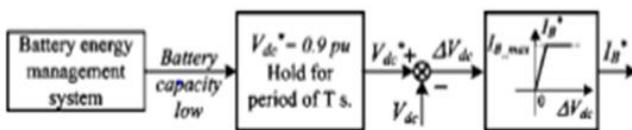


Fig.5. Configuration of Insufficient Energy Storage System for Method 3.

V. RESULT'S AND ANALYSIS

The simulations have been carried out in MATLAB Software. Table I lists the complete power evaluations of its simulation system. The wind turbine is valued at 2 MW and the full load is also 2 MW. A 1-MW G-VSC and a 0.5-MW ES scheme are used. Loads 1 and 4 are linear loads denoted by using constant resistances. The particular loads are linked to the dc bus and required power-electronic interface, and dc voltage difference causes effect on their power consumption. Therefore, Load is rated to 1.5kw.

How to value the load, generation, grid and ES arrangement is difficult to forecast. One method is to evaluate load and power generation averages and distinctions, considering irregular load shedding, and island operation probability. The minimum requirement for G-VSC should match the difference among the average load and generation. For example, if the average wind turbine generation is 0.6 MW and the average load consumption is 1.4 MW, then it would be necessary to have G-VSC with a minimum power rating of 0.8 MW. For high demand and variable generation, higher G-VSC may be required. If the dc micro system is regularly neccessary to operate at island mode, comparatively higher ES power rating is needed.The probable period of island operation chooses the storage capacity of ES system. The ES system used in this simulation is 300v/10Ah lead acid type battery and the shared dc-link voltage is fixed at 400 V.

Table I: Simulation System Component's Ratings

DC grid voltage	400 V
Wind turbine	2MW,permanent magnet synchronous generator.
G-VSC	1MW
Battery ES system	0.5MW Battery 300V/100Ah Lead Acid
Load	Load 1&2:constant resistance type Load 3&4:constant resistance type Each rated at 1.5KW

Simulation is carried out in three different cases they are as below:

- Case 1) The dc micro grid is linked to an exterior ac grid with natural wind and load variants;
- Case 2) The dc voltage can not be controlled by the Grid and , therefore, the dc voltage is regulated by the battery ES scheme;
- Case 3) Island operation with the load shedding necessity.

Case 1

Figure.6. Shows the outcomes of the Case 1 simulation and the primary operation events listed in Table II. Loads 1 and 2 are turned on (3 KW) when the simulation starts and the wind speed is 12 m / s. The rotor speed of the wind generator is around 0 p.u. And the wind turbine produces around 0 MW respectively, as shown in Figure. The original battery capacity is-33.396.

The G-VSC regulates the standard dc voltage at 1.0 p.u as the arrangement is linked to the system. As shown in the diagram. The following occurrences are shown in Table II:

**Event 1:** At 0.2 s, the battery current steps down to -90A and the G-VSC input power is adapted to keep a steady dc voltage of 1.0 p.u. As the outcome is presented in Fig, the storage capacity improves.

**Event 2, 3, 5, 6:** In this case wind speed is boosted at 1sec from 3 m/s to 12 m/s and at 2sec Load 3 is turned on the scheme and at 4sec Load 4 is turned on and at 5sec Load 6 is turned off. However, the G-VSC regulates the dc voltage well.

**Event 4:** The capability of the battery is -33.393 at 2.4sec  
Table II: Operation Events for Case 1

Events	Operation condition	Time(s)
(1)	Battery current step --90A(charging)	0.2
(2)	Wind velocity improved	1.0
(3)	Load 3 turned on	2.0
(4)	Battery capability reaches -33.393	2.4
(5)	Load 4 turned on wind speed reduced	4.0
(6)	Load 1 turned off	5.0

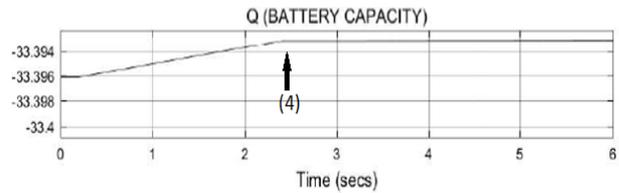
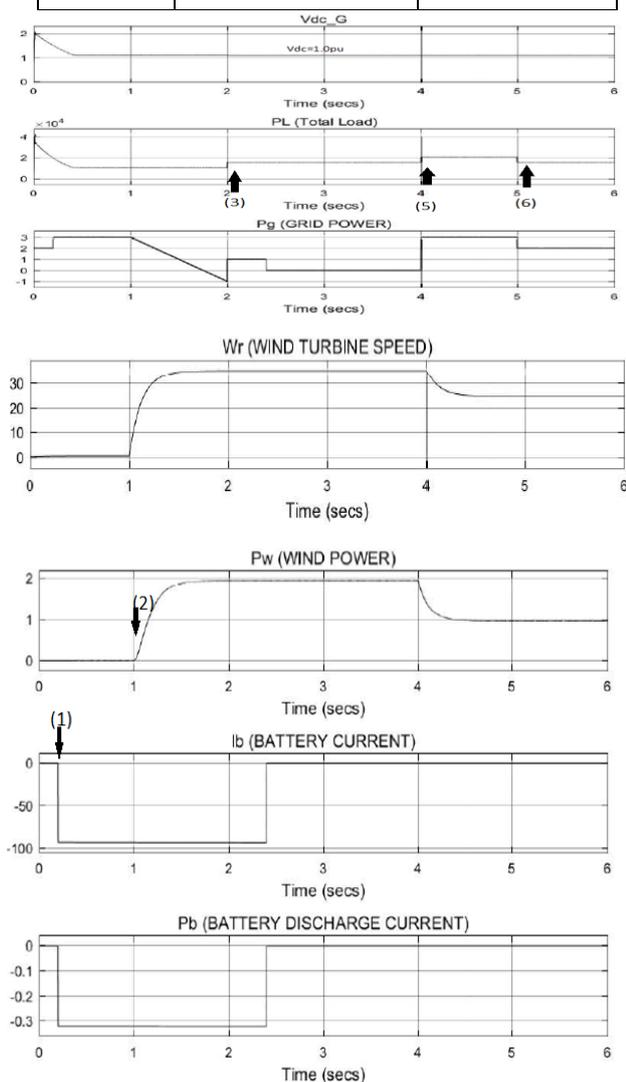


Fig.6. The simulation results for Case 1

**Case 2**

Further regulation and functioning of the scheme is analyzed in accordance with Case 2 and Figure.7. The outcomes of the simulation and the primary operation activities are shown in Table III. Loads 1 and 2 are turned on (3 KW) when the simulation begins and wind produces about 1.5 MW (PW) as presented in Figures respectively. PB 0.5MW as the figure shows. The G-VSC supplies from the ac system about 0.9MW (PG) and regulates the standard dc voltage is at 1.0 p.u. As illustrated in Figure below.

**Event 1:** The large 200ms at 1sec ac voltage drop occurs because of an ac fault near the connection point. Now this incident decreases the G-VSC's transferred power to nearly 0 and creates instant reduction in dc voltage. Now the Grid cannot retain continuous dc voltage. Once the under voltage (0.95 pu) is identified by the battery ES device module, it automatically switches from charging mode to dc voltage regulate and improves its current to overcome the G-VSC power loss. The dc voltage is kept at about 0.95 p.u.

**Event 2:** Ac fault is removed at 1.2sec in this event and ac voltage is rapidly recovering. As a result, Grid's produced power and dc voltage are increasing. Now, dc voltage can be regulated by the Grid and ES battery device moves back to charge mode. The dc voltage is at 1.0 p.u.

**Event 3:** Load 3 is turned on at 2sec in this case to increase G-VSC's power and to match the additional power requirement. As the G-VSC (Grid) attains its 1 MW power limit, it can't regulate the dc voltage anymore.

Now ES scheme changes to dc voltage regulate mode when detecting low dc voltage and the dc voltage is set to 0.95 again.

**Event 4, 5:** Load 4 is turned on at 3.0 sec and Load 1 turned off at 4.0 sec. And the battery ES scheme controls dc voltage.

**Event 6:** Load 3 is turned off at 5.0sec, resulting in an increase in the complete power transferred in to the dc micro grid are more than complete load demand. The G-VSC and the ES battery scheme, alternatively, move away to the dc voltage regulate and charging mode.

Table III: Operation Events for Case 2

Events	Operation condition	Time(s)
(1)	AC grid fault lasting 200ms	1
(2)	AC grid fault is removed	1.2
(3)	Load 3 turned on	2
(4)	Load 4 turned on	3

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(5)	Load 1 turned off	4
(6)	Load 3 turned off	5

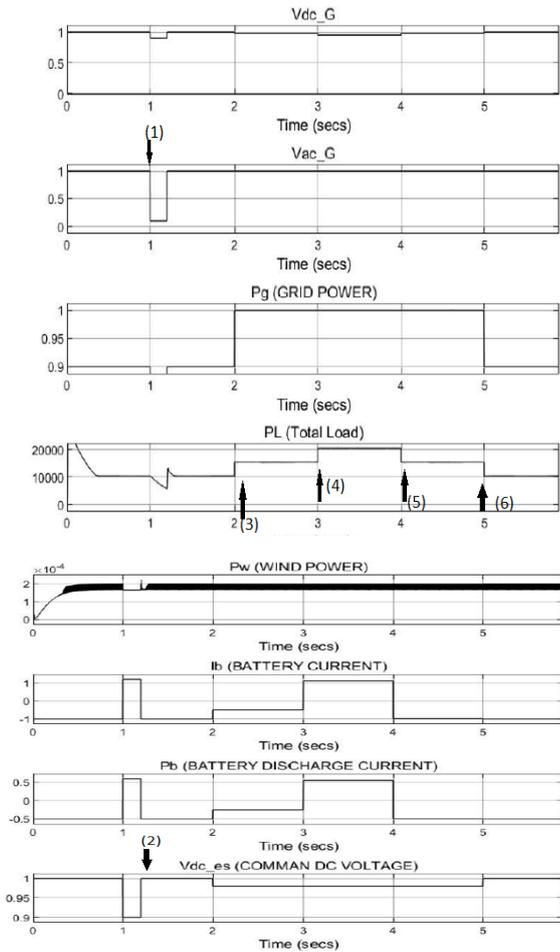


Fig.7. The simulation results for Case 2.

## Case 3

Case 3 (i.e., islanding) control system and function simulations are shown in Figure. The primary operating incidents are listed in Table IV. Load 1, 2, and 4 are switched on (4.5 KW) when the simulation starts and the wind turbine produces about 1.15 MW as shown in Figure.8. As shown in Figure, the battery current is initially fixed to 0.2 kA (charging). The G-VSC supplies approximately 0.45-MW and regulates the standard dc voltage to 1.0 p.u again. Load 2 has the lowest preference in the simulation and immediate trips. Once the voltage of the dc terminal is less than 0.85 pu. Load 4 has the highest preference and cannot be trip up. Load 1 trip when the dc terminal voltage remains under 0.9 pu. In excess of 0.5 s. Based on Figure. The previous occurrences can be noted in Table IV:

**Event 1:** Connection to the ac grid will be broken at 1sec in this incident and the dc micro grid will become an island scheme. The battery ES scheme regulates the dc voltage and the dc voltage is about 0.95.

**Event 2:** Wind velocity at 2sec is reduced so that power is not produced. As no power is produced, ES scheme power output increases to fulfill and continue the dc voltage at 0.95pu.

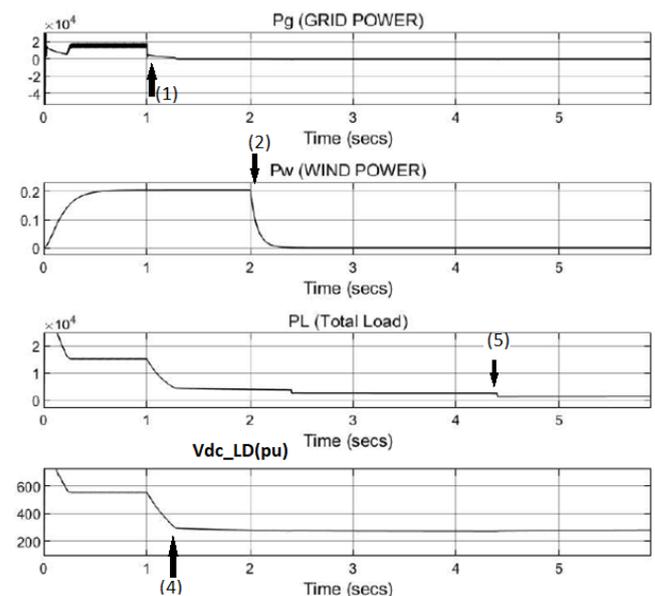
**Event 3, 4:** The extreme power limit of the battery ES scheme is reached at approximately 2.15 sec and cannot be further increased. As the power produced by the wind turbine begins to decline, the dc voltage begins to decline leading to the power imbalance. Once the voltage of the dc falls to 0.85 pu. Load 2 is instantly dropped at about 2.4 s. Load 2 trip guarantees that the overall load demand is balanced and the ES scheme gets back the dc voltage regulation as shown in Figure below.

**Event 5:** Load 1 dc terminal voltage seen in figure at about 4.4 s. 4.6 It's less than 0.9 pu. Load 1 is tripped for a duration of 0.5 s. This causes only the most significant load to remain attached to the dc micro grid(i.e. Load 4 in this instance). As the wind turbine produces extra power than the load necessity, battery can now effectively continue to be charged. The voltage of the dc continues at 0.9 pu. By the regulator of the ES scheme.

**Event 6:** At 4.9 s, the dc voltage is held at 0.9 p.u. For 1s, the dc voltage transfers by the ES device unit to 0.95 p.u.

Table IV: Operation events for case 3

Events	Operation condition	Time(s)
(1)	Grid AC disconnected i.e islanding	1
(2)	Wind speed decrease.	2
(3)	The peak power rating of the battery ES device achieved	2.15
(4)	Load 2 tripped	1.4
(5)	Load 1 tripped	4.5
(6)	Vdc back to 0.95 pu	4.9



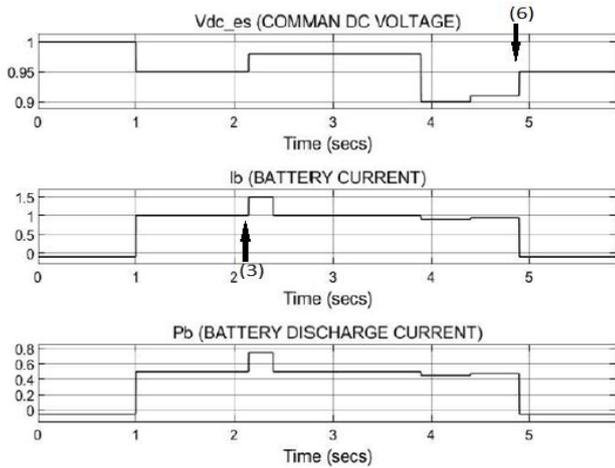


Fig.8. The simulation results for Case 3

## VI. CONCLUSION

This Paper recommends a control and operating scheme for a dc micro grid composed of Energy storage (ES), varying load, wind generation and connection to the ac network (grid). Three distinct control and operating techniques have been implemented to continue the constant dc voltage.

1. DC voltage regulation and power balancing under standard power and load fluctuations is done by using an ac grid linked converter (GVSC).
2. In the ac grid failure and G-VSC power restrict the dc voltage regulation and energy balancing is done by using Grid and ES.
3. Island operation and load shedding approach depends on two distinct dc voltage ranges to guarantee a safe energy source to the most critical loads.

During distinct working situations, dc voltages are used as the regulator input for the operation method interchanging. Scheme simulations equivalent to the three distinct operating methods verified the dc micro grid operation's satisfactory results.

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