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Simulation and Analysis of Virtual Impedance-based Droop Control in a PV based Microgrid in Grid Support-Grid Forming Control Mode.

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ABSTRACT: The high dependence on energy for socio-economic development is propelling the power system research in a fast pace. This is further accelerated by the depletion of fossil fuels, the climate changes and environmental problems. To tackle this situation reliable and quality power has to be harnessed from green sources. This paper focusses on the voltage and frequency regulation of a low voltage PV-BESS microgrid system during mode transition. The reverse droop control with virtual output impedance control strategy is implemented for the power sharing and control of PV and BESS converters. The PV and BESS converters operates in grid supporting and grid forming mode during on grid and off grid conditions. This prevents the toggling of control between current and voltage controls during mode transitions. The system is modelled in MATLAB/SIMULINK platform to perform the transient stability issues during islanding events. From the simulation studies, the system frequency and voltage deviations were found to be within the grid code stipulations during mode transition

KEYWORDS: Droop control, virtual impedance, mode transition, grid support-grid forming mode, frequency regulation.

I. INTRODUCTION

The technology for control and coordination of traditional power system based on synchronous machines has reached a matured state by the end of nineteenth century. Throughout the world, slowly and gradually the traditional centralised power generation is giving way to distributed generation by renewable sources. The broad classification of micro grid research includes appropriate choice of microgrid components, the microgrid system, its integration and design and finally the economic analysis tools. The selection of microgrid components is based on the appropriate switching technologies, control and protection schemes and the converter topologies employed. The standards and protocols for microgrid protection, communication, control, and co-ordination is yet another area of research. The research works using economic analysis tools investigate the social implications of the developed technical designs.

Research works in Microgrid Sytem integration and stability are extremely important in the modern world due to the increase in penetration of renewable energy sources or inertia less sources into the grid. Reduction of system inertia leads to stability issues. Moreover, the advancement in power electronics has revolutionised the load nature too. With the presence of such unpredictable and fluctuating loads and sources it's a great challenge for the power system engineer to control the stability of the modern grid.

The major challenge faced by a microgrid system is the proper power sharing between multiple renewable sources in a microgrid. In the earlier days, the technology for the control of power sharing among multiple converters followed the concepts of power sharing among parallel ups systems. Even though the ups inverters are of reduced ratings, the current sharing strategies adopted in the parallel ups systems has been implemented in an appropriate way for the power sharing among multiple inverters in the earlier days of microgrid research. Later droop control scheme for power

sharing among multiple inverters has been implemented in microgrids. Better performance was guaranteed by this control since no communication channels were needed.

The droop controller mimics the self-regulation characteristics of synchronous machines in its operation. In grid supporting power converters the droop control technique helps to regulate the active and reactive power flow between the microgrid and the utility grid thus regulating its frequency and voltage profile. In this work, a grid supporting droop control is used for the battery management system.

RELATED WORK

The conventional droop control addresses the proper power sharing among multiple inverters is achieved by increasing the droop coefficient value, but fails to regulate the voltage properly. [2][3]. The major advantage of droop control lies in the absence of communication framework making it modular and reliable. The other short comings of this control include the load dependence of the control, improper P and Q sharing due to impedance mismatch of inverters and poor transient performance. To address these issues the droop control strategy had undergone several modifications like reverse droop control [4], incorporation of supplementary transient droop [5] and angle droop for ensuring transient stability [6][7] and robust droop control [8].

II. METHODOLOGY

a. Theory of droop control

The figure depicts the mathematical representation of power flow from point A to B. The voltage vectors are represented as V_A and V_B . R and X denotes the line resistance and inductance respectively. I denote the current vector.

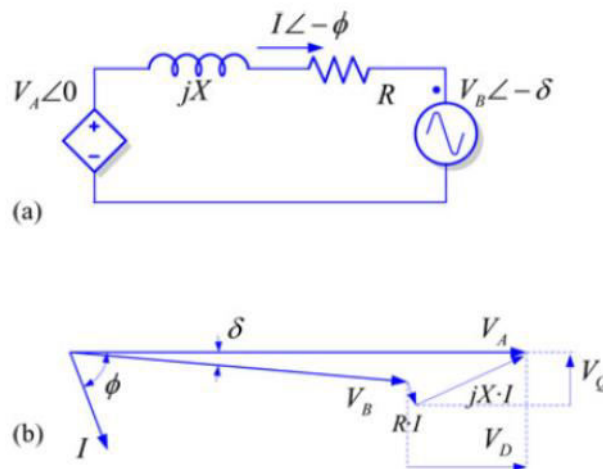


Fig1.a) Mathematical representation of power flow in a line, b) phasor representation of voltage and current.

The active and reactive power flow in the line can be represented as:

$$P_A = \frac{V_A}{R^2 + X^2} [R(V_A - V_B \cos \delta) + X V_B \sin \delta] \tag{1}$$

$$Q_A = \frac{V_A}{R^2 + X^2} [-R V_B \sin \delta + X (V_A - V_B \cos \delta)]. \tag{2}$$

In an HV grid, when the line resistance $R \ll X$, the equation (1) (2) becomes,

$$P_A \approx \frac{V_A}{X} (V_B \sin \delta) \Rightarrow \delta \approx \frac{X P_A}{V_A V_B} \tag{3}$$

$$Q_A \approx \frac{V_A}{X} (V_A - V_B \cos \delta) \Rightarrow V_A - V_B \approx \frac{X Q_A}{V_A}. \tag{4}$$



In an LV grid, when the line resistance $R \gg X$, the equation (1)& (2) becomes,

$$P_A \approx \frac{V_A}{R} (V_A - V_B \cos \delta) \Rightarrow V_A - V_B \approx \frac{R P_A}{V_A} \tag{5}$$

$$Q_A = -\frac{V_A \cdot V_B}{R} \sin \delta \Rightarrow \delta \approx -\frac{R Q_A}{V_A V_B} \tag{6}$$

According to Eq. (5), the delivery of active power mainly depends on the voltage magnitude and that of reactive power mainly depends on the phase angle amplitude of the inverter. Voltage magnitude and phase angle can be controlled, by adjusting the output voltage magnitude and frequency of the inverter, as expressed in Eq. (7) and (8) respectively:

$$\omega_i^* = \omega_n + K_q (Q_{n,i}^* - Q_i) \tag{7}$$

$$E_i^{**} = V_n - K_p (P_{n,i}^* - P_i) \tag{8}$$

Here ω_i^* and E_i^{**} are the reference frequency and voltage and $P_{n,i}$ & P_i and $Q_{n,i}$ & Q_i are the nominal and calculated active power and reactive power of the of the i th inverter respectively. K_q and K_p are the frequency droop coefficient and voltage droop coefficient respectively.

b. System description

The one line diagram of the low voltage microgrid system taken for study consisting of two solar photovoltaic source with a battery storage system connected to the utility grid is represented in fig(2).. The ac bus voltage in the microgrid is having a rating of 260V,60Hz.The parametric details of the photovoltaic module is given in table[1] and the details of the load distribution in the microgrid is tabulated in the table [2].

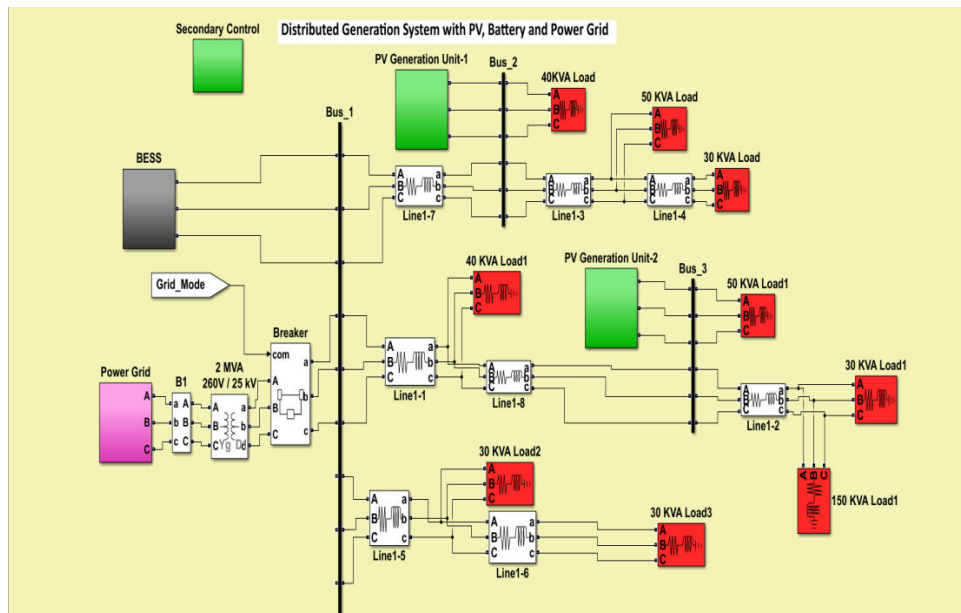


Fig.2.One line diagram of the microgrid system.



Table [1]. Microgrid system parameters.

System component	Parameter	Value/Specifications
PV system	Number of series and parallel modules	5,140
	Number of cells per module	96
	Temperature coefficient of Voc(V)	-0.177
	Short circuit current of each module(A)	5.96
	Open circuit voltage of each module(V)	64.2
	Temperature coefficient of Ioc (V/deg.C)	-0.003516
Parameters of BESS system	Type	Lead acid
	Rated capacity (Ah)	340
	Battery response time (s)	30
	Nominal voltage (V)	300
	Initial state of charge (%)	70
Micro grid parameters	System frequency (Hz)	60
	Line resistance(ohms)	0.002
	Line inductance(H)	0.0003768
	Bus voltage (V)	380

Table [2]. Details of the load distribution

Load	Active power rating (kW)	Reactive power rating (kVAR)
L1	40	4
L2	50	5
L3	30	3
L4	40	4
L5	50	5
L6	30	3
L7	30	3
L8	30	3
L9	150	15

The photovoltaic units are of 200kW under standard test conditions consist of two stage power conversion. It consists of a dc-dc boost converter and a dc to ac Voltage source inverter. The BESS unit plays a major role in frequency and voltage regulation in the microgrid system. It provides uninterrupted power to critical loads during islanded conditions. A lead acid battery having a rated power of 150kW with 340Ah has been selected for the microgrid model under study. It consists of a bidirectional dc buck boost converter and a VSI. It boosts the 300V dc voltage level to 500V. The charging and discharging of the BESS unit is controlled by a secondary control unit which generates the P and Q references for the inverters. The safe SoC operating region of the battery is maintained between 30% to 70% by the secondary control unit. The reactive power reference is kept constant 0.2pu. The active power reference is generated by the secondary control checking the grid mode.



The algorithm for power management is formulated as shown below:

ON GRID MODE:

- Step1: Measure the active power of PV1, PV2, PGRID and BESS; SoC level of the battery
- Step2: Set $PPV1=PPV2=PNOM$.
- Step3: check whether $SoC \geq 30\%$?
- Step4: If NO, charging mode $PBAT=-0.2pu$
- Step5: If YES, check $PGRID \geq 30KW$.
- Step6: If NO, discharging mode $PBAT=90\%*PNOMBAT$ (pu)
- Step7: If YES, charging mode $PBAT=-0.2pu$

OFF GRID MODE:

- Step1: Measure the active power of PV1, PV2, PGRID and BESS; SoC level of the battery.
- Step2: Set $PPV1=PPV2=PNOM$.
- Step 3: check whether $SoC \geq 30\%$?
- Step4: If NO, charging mode $PBAT=-0.2pu$
- Step5: If YES, check $(PmPV1+PmPV2) \leq (2* PNOM - PBAT)/1000$.
- Step6: If YES, Charging mode $PBAT=-0.2 pu$
- Step7: If NO, discharging mode $PBAT=90\%*PNOMBAT$ (pu).

c. Control block diagram

The grid tied inverter control strategies are broadly classified as **grid forming, grid feeding and grid supporting modes**. Here in this work a grid supporting grid forming mode is implemented for the control of BESS and PV inverters. The Droop control is implemented for the proper power sharing among the converters. Since the selected system is an LV microgrid modified reverse droop control is used. The detailed implementation of droop control with virtual impedance is as shown in fig(4).

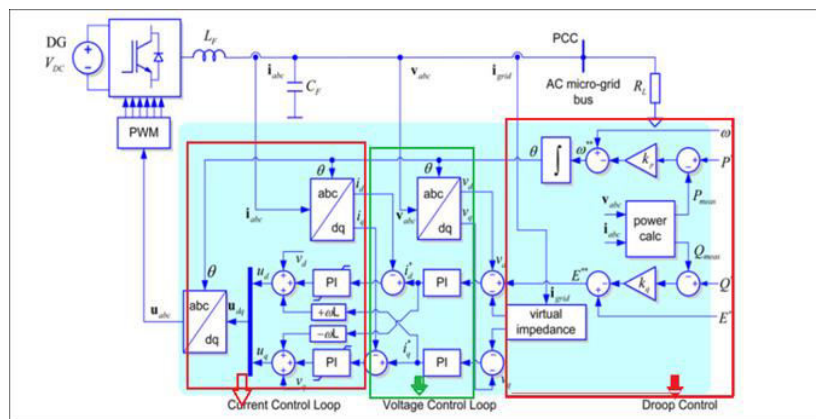


Fig (4). Droop control for grid tied inverters

It consists of a power calculation block, voltage and frequency droop control blocks, virtual impedance block and the voltage and current control blocks. The power calculation block takes the current and voltage values as input from the CT and PT kept at the inverter output and converts them to the dq frame of reference to generate Id, Iq, Vd and Vq. The instantaneous active and reactive power generated by the inverter is calculated from these parameters in the dq frame. The droop control block consists of the voltage droop control block and the frequency droop control



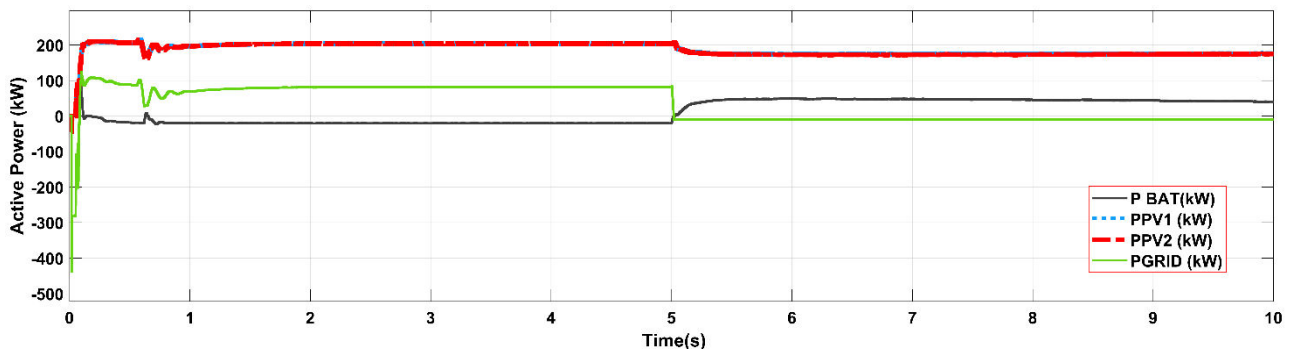
block which generate the voltage magnitude and the phase angle for the reference voltage of the inverter. The actual and reference values of the active power are compared and the error passes through a PI controller which is then compared with the measured voltage magnitude to generate the reference voltage magnitude. The actual and reference values of reactive power is compared to generate the error. This error is processed by a PI controller. The processed error is compared with the phase angle value generated by a PLL to produce the reference phase angle value. This loop is implemented to improve the power sharing and it enables decoupling of active and reactive power components. The virtual impedance adjusts the output voltage reference according to the inverter output current. In other words, it ensures proper current sharing among multiple inverters. The voltage control block generates the current references in the dq frame of reference. It takes four inputs – the voltage parameters V_d and V_q , the reference voltage magnitude and phase angle value for inverter control. This block could be further considered to have two sub blocks V_d control loop and V_q control loop. The current control block generates the input for reference voltage generator and the PWM block. A cross coupling and feed forward block is used to improve the performance of the PI controller. The droop control parameters for the modelled system is as given in the table [3].

Table [3]. Control parameters for the Inverter.

Control Parameter	Value
Frequency droop coefficient	0.006
Voltage droop coefficient	0.5
Nominal voltage(V)	380
Nominal angular frequency (rad/sec)	377
Virtual inductance (mH)	0.005
Virtual resistance (Ω)	0.4331

III. EXPERIMENTAL RESULTS

The microgrid system under study was modelled and simulated in SIMULUNK environment. Initially the microgrid was connected to the utility grid. At $t=5s$ the microgrid is isolated from the utility grid to mimic an unintentional islanding condition. At $t=8s$ it gets reconnected to the utility grid. The active power generated by the two PV systems, the battery, and the grid during this period is as shown in figure (5). The PV1 and PV2 operates at full rated capacity of 200kW.



Fig(5).Active power share of different sources in the microgrid.

The dc link voltage of the battery adjusts itself during the transients and we can see from fig(6) that the overshoot in dc link voltage is well within limits. Fig(7) shows the modulation index of the battery.

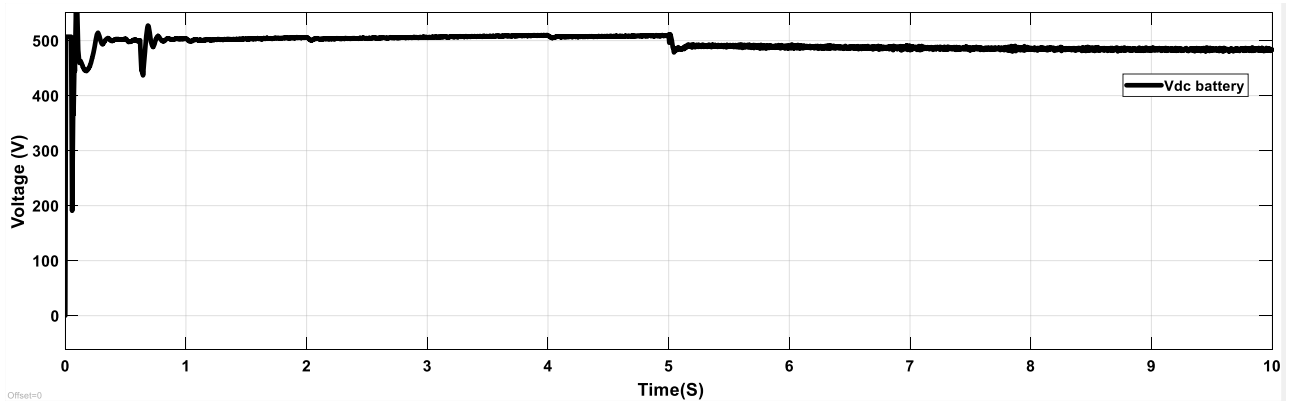
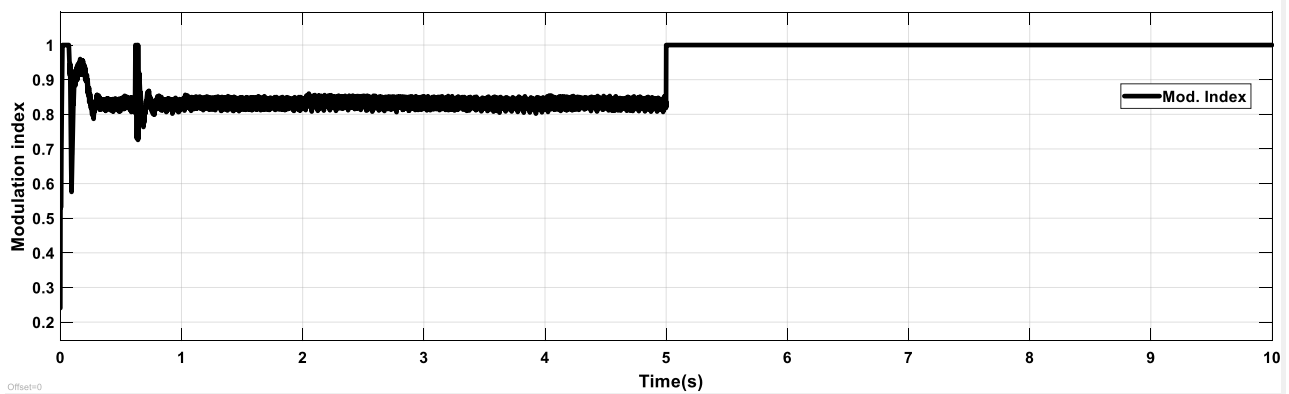


Fig (6). Dc link voltage of the battery



Fig(7).Modulation index of the Battery.

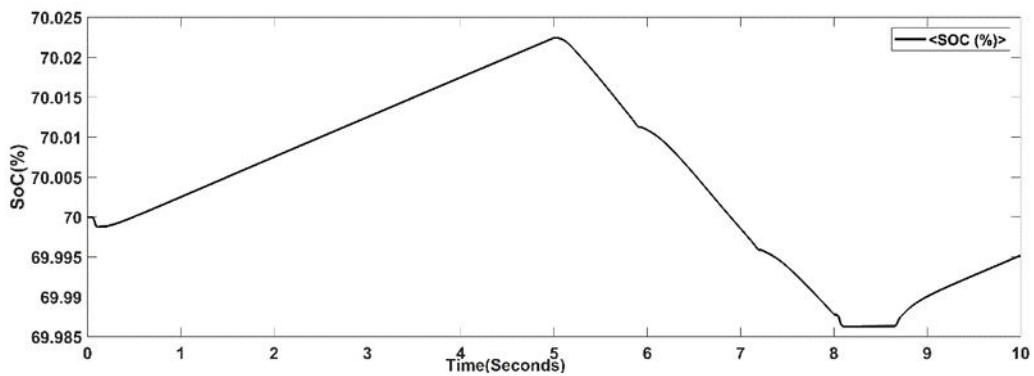


Fig (8). The state of charge of the battery during the transition.

The state of charge of the battery is kept well within limits as shown in fig (8). At the instant of islanding it starts discharging and it switch over to the charging mode as soon as it reconnects to the grid. Fig (9) shows the output parameters of the grid.

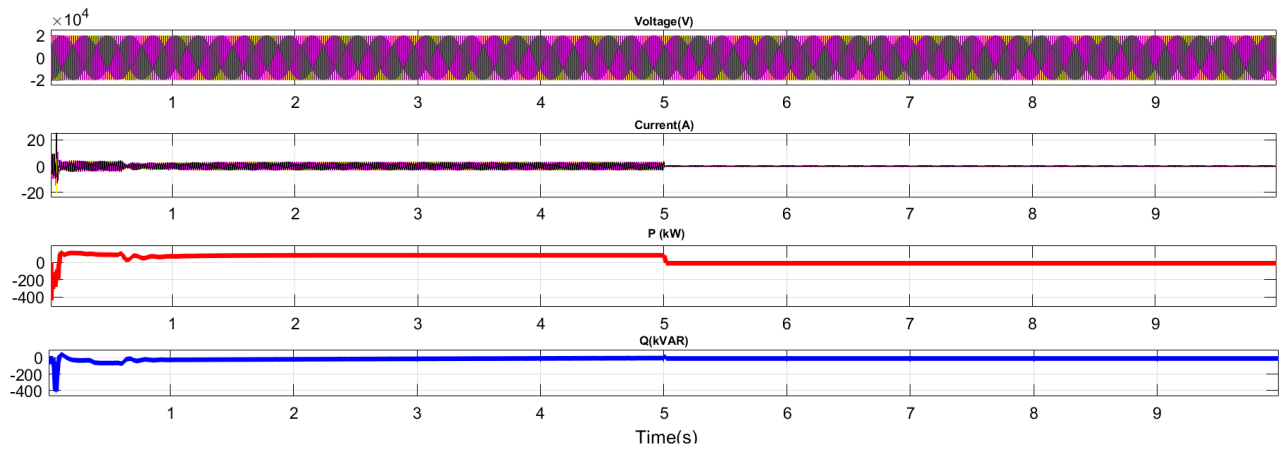


Fig (9). The output parameters of the grid.

IV. CONCLUSION

A PV based microgrid with battery energy storage system was modelled in MATLAB /SIMULINK platform. A secondary control unit based on active power management algorithm was developed. Virtual impedance-based droop control was implemented for the proper power sharing between the DG sources. It can be observed from the results that the battery management system operates within the specified SoC level and goes through it charging and discharging cycles during the islanding conditions to maintain the frequency and voltage profile of the ac bus within the microgrid. The variations in the frequency and voltage are well within the limits prescribed by the stipulated standards.

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