Control Strategy and Operation of Renewable Energy Resources based MicroGrid : A Case Study of Chisapani, Nepal

Sujan Koirala[1], **Nawraj Bhattarai**[2]

[1,2]*Dept of Mechanical Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal.*

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Abstract - *Microgrid provides reliable and secure energy supply to the areas beyond the access to grid power. Extension of grid to the areas to connect microgrid to the grid enhances performance of weak grid while the grid can cater load imbalance and improve power quality of the microgrid. To obtain these benefits proper control strategies should be employed in each distributed energy resources (DERs) of microgrid. Also, a smooth transition of control from grid connected operation to isolated control is necessary without interrupting supply to the load in the microgrid.In this paper, a case of upcoming MG project of Chisapani, Eastern Nepal consisting of solar Photovoltaic (PV) and PMSG wind turbine with Energy Storage System (ESS) connected to LV grid is modeled and a coordinated control for effective operation of the MG is studied. Coordinated control of DERs in grid supporting control is demonstrated in grid connected operation of MG. In islanded mode of operation, grid forming control of at least one DER is demonstrated for normal operation of the microgrid. Similarly, smooth transition from grid connected to isolated mode of operation is shown resulting from planned or forced isolation of microgrid. Simulation is carried for various operation based on the parameters and site survey data collected for proposed Chisapani microgrid project. The simulation results show smooth operation during grid connected mode and islanded mode with coordinated control strategy of various DERs.*

Key Words**: Microgrid, Distributed Generation, Renewable Energy Resources, Power Sharing, Islanded Operation, Inverter Control, Coordinated Control.**

1. INTRODUCTION

Nepal is mountainous country with huge potential of hydropower. Mountainous topography a boon for running water hydropower has also been a hurdle for its development. Due to mountainous topography and sparse population grid connection not easily available and if connected the grid will be a weak grid.

As per the policy of grid connection to all parts of country, expansion of electricity to grid is not limited to urban areas only but reached the rural areas well. Therefore, the rural remote areas are expected to be connected by weak sub-transmission or distributed line to the grid. In such case, the existing MG can be connected to the grid with slight modifications. A MG with robust control can enhance performance of weak grid while grid can cater load imbalance and improve power quality of the MG. To obtain these benefits proper control strategies should be employed in each DERs and supervisory control in the MG as well. Here, smooth transition of control from grid connected operation to isolated control is necessary without interrupting supply to the load in the MG.

Various literatures have presented control of microgrid resources and supervisory control for smooth operation microgrid in various modes. [1] carried a comparative case studies on standalone solar and hybrid systems consisting of solar wind hybrid, solar wind diesel hybrid, solar wind diesel hydro biogas hybrid has been discussed. [2] proposed control strategy to support coordinated control operation between PV units and battery storage, equal power sharing among the DG sources. [3] Presented the study of techno-economic analysis of PV/wind/diesel hybrid system suggesting hybrid system would be reliable but is not economic. [4] has conducted an overview of different aspects related to the control of ac MG. The control techniques of the power converters forming the MG have been presented according to the power converter role, thereby the low-level control loops for grid-feeding, grid-forming, and grid-supporting have been described for both grid-connected and islanded operation modes. [5] studied the cooperative control strategy of MG components and evaluated management performance. [6] described and evaluated the feasibility of control strategies for the operation of a MG when it becomes isolated where no directly grid-connected synchronous generators are used. [7] studied PV-wind-battery hybrid and PV-wind-diesel- battery hybrid with aim of rural electrification in Malaysia. This study suggested PV-wind-battery hybrid as cost-effective HRES for villages in Malaysia. [8] presented the dynamic models and a control strategy on grid side converter in island mode of PQ inverter Control and VSI control. Single master operation was chosen as control strategy in island mode, where battery inverter provides a reference for voltage and frequency. [9] discussed power quality control of grid connected wind and solar hybrid system in the common DC bus.

In a country like Nepal, for the rural electrification, installation of the DERs such as wind, solar etc. are feasible to operate in the microgrid network. Earlier, isolated grid powered with microhydro were very common in Nepal [11]. But, with the advancement in the inverted based DER and sharp fall in price of Solar PV and wind turbine technology. Microgrid with solar and wind, is gaining popularity and replacing micro hydro in newer microgrids. Analysis of the microgrids operating in islanded mode and grid connected mode in Nepalese context with its unique load demand, solar and wind source availability is very important. This paper has presented the analysis of a microgrid with data from upcoming microgrid in Eastern Nepal using the appropriate control strategy mentioned above.

To obtain coordinated control of DERs for stable operation during grid connected mode and islanded mode, MG of upcoming Chisapani MG is modelled and analysed. A robust control algorithm of DERs is implemented for stable operation during grid connected and islanded mode of operation and for smooth transition of the mode of operations.

2. Control Techniques of DERs

Most of the DERs used in modern microgrid are inverter-based DER. The inverter provides flexibility in operation and better control of the DERs. Inverter controls can be categorized into the four basic types viz. a) grid-forming, b) grid feeding c) grid supporting-grid forming, and d) grid supporting-grid feeding as shown in Fig-1. [4].

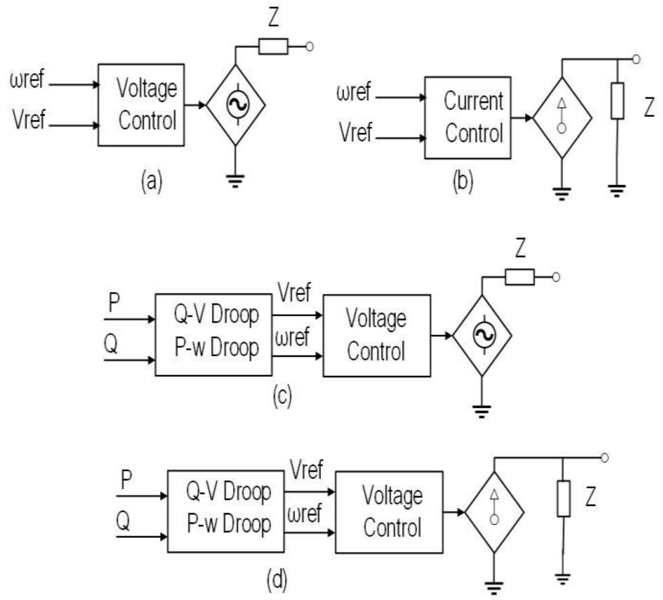

Fig -1: Four basic types of inverter control (a) grid-forming, (b) grid-feeding, (c) grid supporting-grid-forming, (d) grid-supporting-grid-feeding.

Grid-forming control represents inverter as an ideal ac voltage source which sets the voltage and frequency of the local grid using a proper control loop. Grid feeding control operates inverters to deliver power to an energized grid. Grid-supporting control supports the grid by adjusting its set points based on the grid conditions. Grid-supporting control can be realized by modification of grid-feeding or grid-forming control. Grid-supporting-grid-feeding control also typically uses a PLL driven current control, and thus does not work reliably without another source to regulate voltage and frequency. If another voltage source is not always available, then an inverter with this control must switch to grid-forming or grid supporting-grid-forming control upon transition to islanding. Grid-supporting- grid forming control is modification of grid-forming control that acts as a droop-controlled voltage source, where the voltage and frequency references are adjusted based on measured real and reactive power.

3. METHODOLOGY

3.1 Project Layout

The proposed MG system consists of a PV system, a wind energy system and a battery bank as an energy storage system (ESS) to supply the load. The solar PV system consists of a PV array and a boost DC-DC converter with a MPPT algorithm and a controlled inverter. The wind energy system is configured by a wind turbine with a PMSG, a boost DC-DC converter with MPPT algorithm and a controlled inverter. The ESS consists of battery, bidirectional buck boost DC-DC Converter and controlled inverter. 2 shows the complete block diagram of the PV-Wind with ESS system in the grid connected mode. The PV-Wind system is connected to low voltage (LV) side of grid through a coupling bus of 380 V. The system connected to the grid by upgrading the voltage 380 V to distribution voltage of 11 kV by 50 kVA transformer

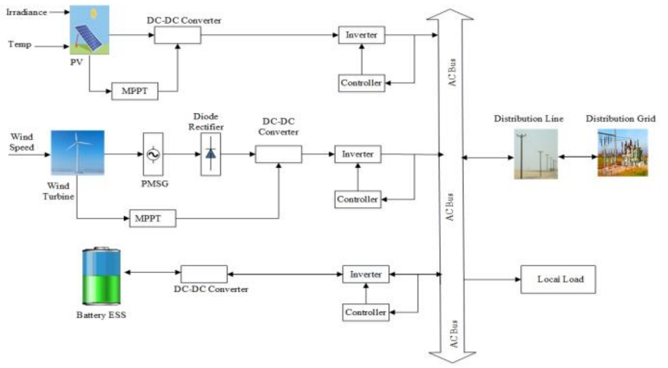

Fig -2: Block Diagram of Proposed System

3.2 Control Strategy and Power Management

The power flow at the point of common coupling (PCC), is controlled by central supervisory controller shown as Microgrid Central Controller (MGCC) in Fig-3. MGCC has communication link to obtain the information about the availability of resources of each DERs and information about grid parameters. Based, on the grid parameters and resources available, MGCC provides the set point for local controllers of each DERs. Further, MGCC detects MG islanded mode or grid connected mode and instructs the local controller accordingly.

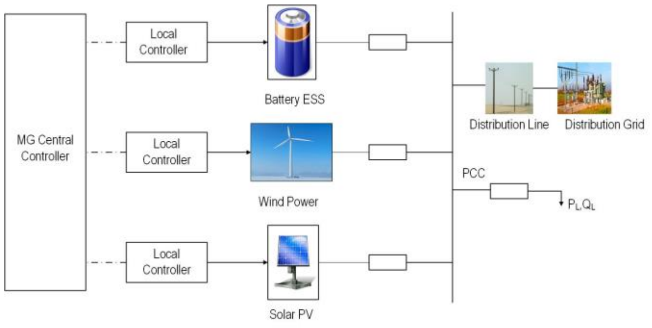

Fig -3: Overview of Control Strategy

3.3 Grid Connected Mode

In grid-connected mode, the DERs of MG operate in grid feeding control. The MG delivers excess power to the grid and during power deficit in the MG receives power from the grid to supply the local load. The grid connected microgrid with central controller contributes in the peak shaving and congestion minimization of distribution grid. For grid feeding control of DERs, the MGCC provides reference power as input to the local controller of DERs. The schematic of control of microgrid during grid connected operation is shown in Fig-4.

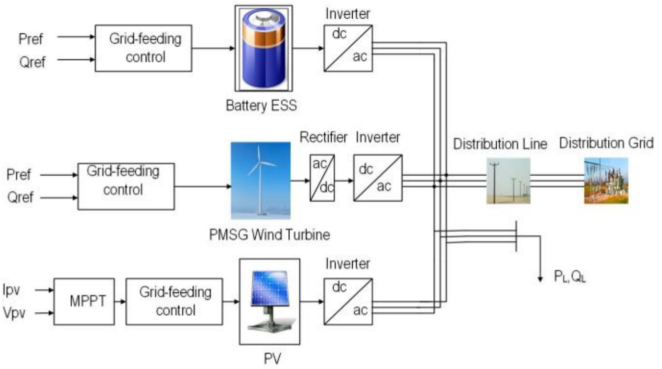

Fig -4: Control During Grid Connected Mode

3.4 Isolated Mode

In the isolated mode of operation of MG, a DER or number of DERs should operate in grid forming control to regulate standard voltage and frequency. Here, battery ESS is chosen as the grid forming control due to its fast controlling ability and ability to provide both active and reactive power. The battery ESS will operate in grid forming control within the safe zone of SoC. To operate in grid control mode operation SoC level of battery should be between 10% and 90%. The islanded mode of operation with grid forming control of battery ESS is shown in Fig-5.

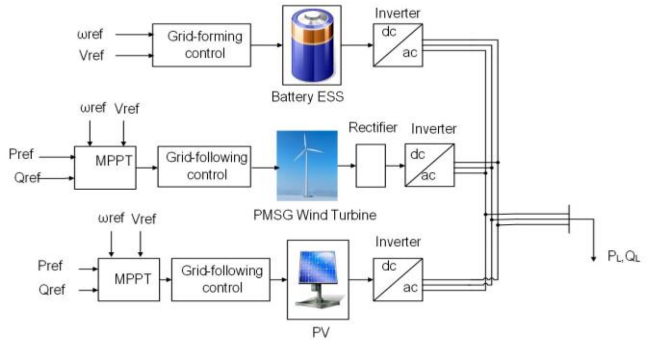

Fig -5: Control During Isolated Mode

3.5 Simulated Project Layout

Although the proposed MG system consists of a PV system, a wind energy system and a battery bank as an energy storage system (ESS) to supply the load, here in this paper the modelling and simulation is done for the solar PV system with ESS only. Accordingly, the control strategy is developed and the system response is studied. The generation capacity of the solar PV is increased to the field data to compensate the wind generation. The generation capacity of PV is modelled to be of 25 kWp which is calculated in such a way that the output power at the time of maximum measured solar irradiance is equal to the proposed installed capacity.

4. SITE SELECTION

The project site is located at Chisapani Village, Hariharpur Gadi Rural Municipality Ward No: 8, of Sindhuli district in the eastern part Nepal. The geographical coordinate of the site is 27°21'8.34"N, 85°27'44.28"E. The village resides on ridges south of the Bagmati River at elevation 355 m above sea level.

The 83 number of households are to be connected in the solar-wind – battery system in Chisapani village. In addition to the household power demand, the local enterprise power demand of 15% is estimated for an agro mill and other small businesses enterprises such as communication center, photo studio and small grinder unit. The maximum daily energy generation required to be 100 kWh and daily average energy demand required to be 85 kWh to meet the entire village demand, including all the technical losses within the generation and distribution network.

4.1 Wind Energy Resources

The measured meteorological data was obtained from Alternative Energy Promotion Centre (AEPC), Nepal. These RES data are extracted at Latitude N 27.359, and Longitude E 85.466 and presented in the Fig-6 as below.

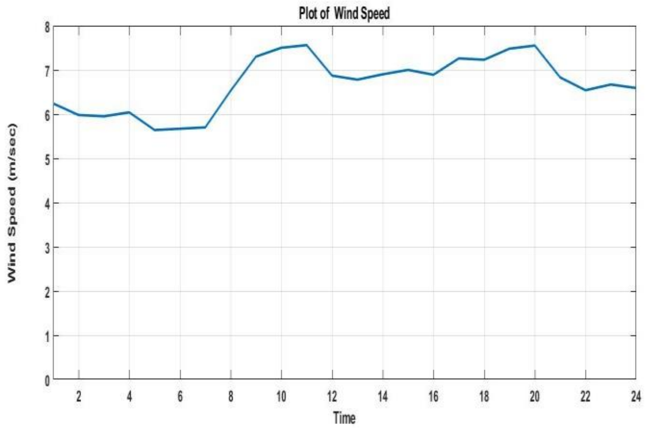

Fig-6: Wind Speed Curve

4.2 Solar Energy Resources

Chisapani area has high solar irradiance and hence is a good candidate for solar project. Fig-7 presents the daily average irradiance incident on a horizontal surface, using the data obtained from the AEPC. The average irradiance on the tilted surface at the project site ranges from a minimum of 0 W/m2 to a maximum of 584 W/m2.

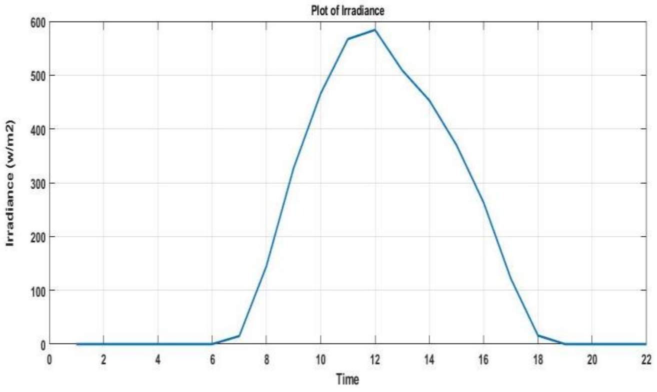

Fig-7: Wind Speed Curve

4.3 Energy Demand

The electricity demand analysis is based on the demand assessment survey conducted on each household by AEPC. The electricity demand in the village is presented in **Error! Reference source not found.**. The load pattern was calculated, based on the demand pattern of a similar village electrified with wind solar system in Nepal. The maximum estimated daily electricity demand is around 10.84 kW.

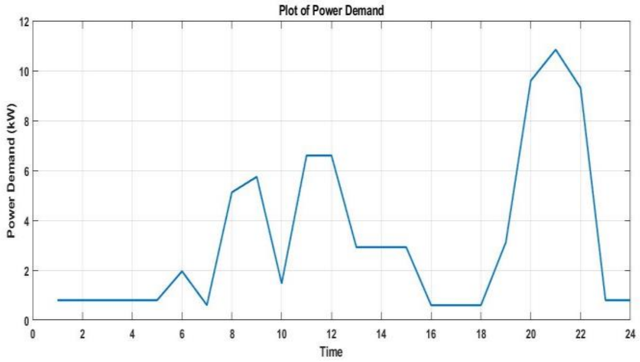

Fig-8: Daily Power Demand

4.4 System parameters at site

The micogrid system consisting of wind, solar and storage system of total capacity 35 kW is planned to meet the electricity demand of 83 households located in the clusters. The following table presents system parameters at site.

Table -1: System Parameters

S.N.	Component	Unit	Total Capacity
1	Wind Turbine (2*10 kW)	kW	20
2	Solar PV (50*300 Wp)	kW_p	15
3	Battery Bank (120* 2 V,1000 Ah)	kWh	240
4	Inverter	kVA	60

5. CONTROL STRATEGY OF DERs

The control strategy of DERs are based on the operation mode of microgrid, availability of resources and local load demand. MGCC and local controller acts together to control the DERs. Control of DER is basically control of inverter in inverter based DERs. As mentioned above, control inverter can be employed in four different methods.

5.1 Grid-Forming Control

The grid forming control is implemented in isolated mode of operation of microgrid. Here, battery ESS is controlled as grid-forming control, While, other DERs may operate as grid feeding or grid supporting. Schematic diagram of control of grid-forming control of DER is shown in Fig-9.

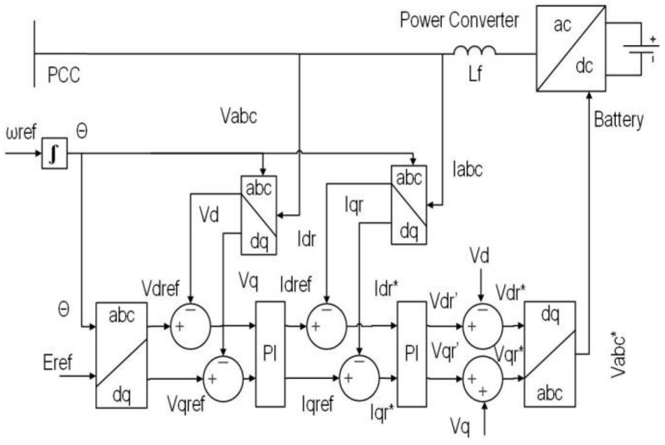

Fig-9: Control of Grid Forming DER

5.2 Grid-Feeding Control

Grid-feeding inverters are controlled as current sources, presenting high parallel output impedance. The control is used to operate DER in grid feeding mode to feed power to the grid in both isolated and grid connected mode. All DERs in grid connected mode are used in grid-feeding control. Schematic diagram of control of grid-feeding control of DER is shown in Fig-10.

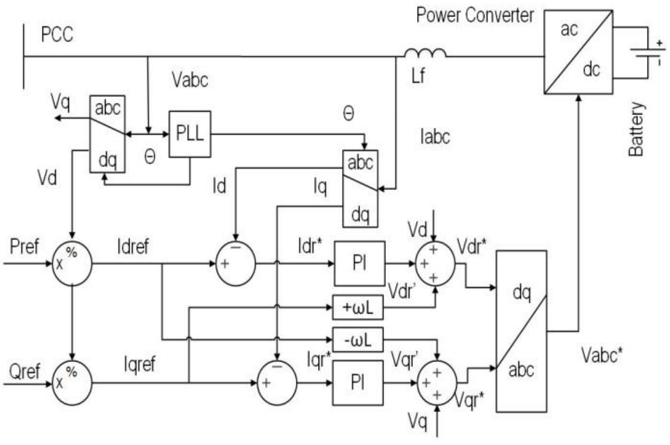

Fig-10: Control of Grid Feeding DER

5.3 Grid-Supporting Power Converter

A grid supporting control of DER may be used in parallel operation of DERs. Wind turbine can be operated as grid supporting control along with ESS control. Schematic diagram of control of grid-supporting control of DER is shown in Fig-11.

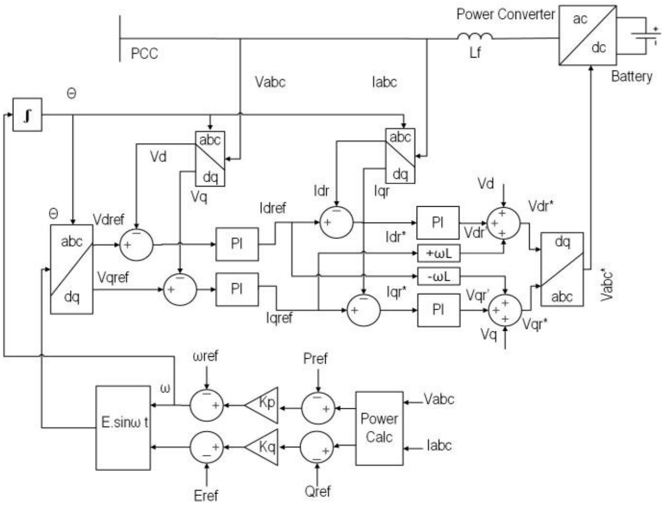

Fig-11: Control of Grid Supporting DER

6. RESULT AND DISCUSSION

The simulation model of the proposed PV solar with energy storage has been modelled using a MATLAB/Simulink environment under different weather and load conditions. MATLAB/Simulink simulation is used to verify the proposed control strategy. In this paper the Solar PV of 25 kWp with ESS of 1000 Ah with 240 V (240 kWh). The complete system is simulated, and the system response is studied for various load combinations at PCC and inverter bus.

In order to verify the effectiveness of the control strategy in the proposed microgrid model, detailed simulation analysis was carried out at different operation like grid connection mode, islanded mode and transition from grid connection to islanded mode. The simulation is carried for duration of 2.4 sec, with each tenth of second representing an hour of a day.

6.1 Grid Connected Operation Mode

During the grid connection mode, the solar PV operate in P-Q control mode and battery ESS was allowed to charge and discharge according to availability of power generation with respect to power demand, solar irradiance level, and amount of power flow to the grid network. During this analysis, voltage and frequency level in MG network, power sharing among DERs units, battery storage, and grid source were analyzed with varying solar irradiance, and load conditions.

The active (P) and reactive (Q) power contribution from PV, ESS, and grid source, observed during the varying load and varying solar irradiance of PV in the MG network is shown in **Error! Reference source not found.**12 and Fig-13.

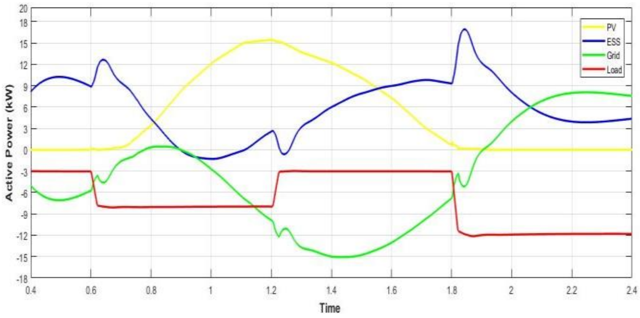

Fig-12: Plot of Active Power During Grid Connected Mode

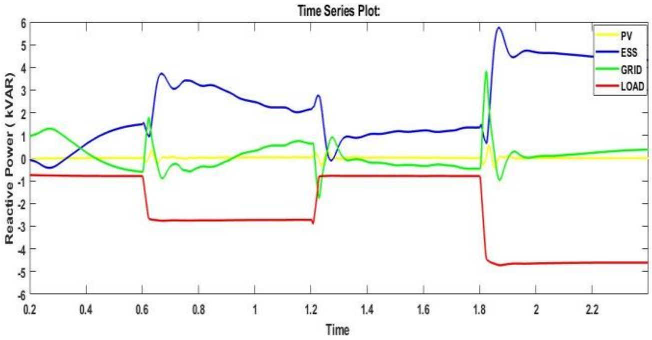

Fig-13: Reactive Power Plot During Grid Connected Mode

Initially, the solar irradiance is nil up to 0.7 sec representing morning. The load increased from active power (P) of 2 kW and reactive power (Q) of 0.78 kVAR to P= 7 kW and Q=2.73kVAR at time t= 0.6 sec. and decreased to 4 kW and 1.17 kVAR at time t=1.2 sec, which again increased to 11 kW and 4.3 kVAR at time t=1.8 sec. In this operation, both PV and ESS control operated in grid feeding control supplying reference power.

During the grid connected mode, the regulation of voltage and frequency level in microgrid was mainly supported by the grid source. As shown in Fig-14 and Fig-15, only a small variation in voltage and frequency level was observed during the variation in solar irradiance and local load.

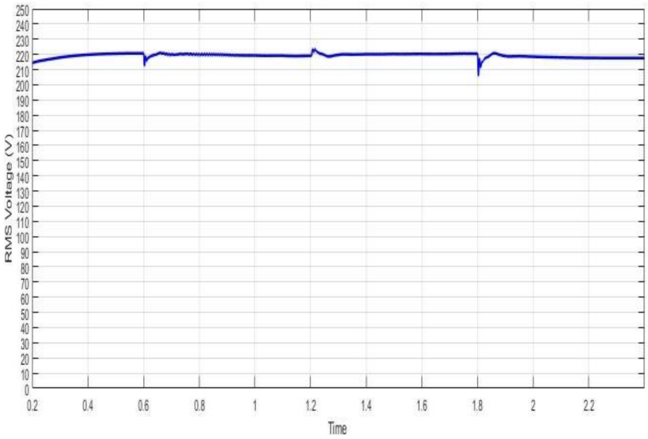

Fig-14: RMS Voltage at Load Bus During Grid Connected Mode

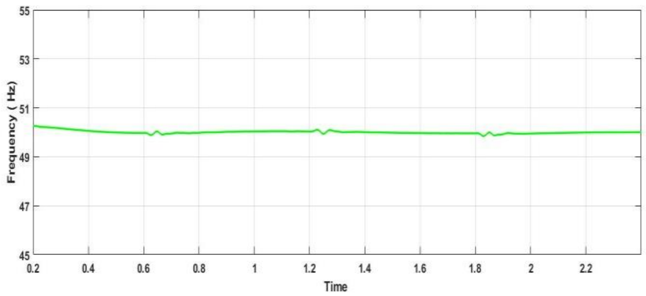

Fig-15: Frequency at Load Bus During Grid Connected Mode

6.2 Islanded Operation Mode

In islanded mode of operation, the microgrid is not connected to the grid hence, the load demand is met by the DERs of the microgrid only. PV and ESS will share power generation to meet the load demand and keep voltage and frequency level within the limit in MG network. According to availability of PV power generation and total load in microgrid network, the battery storage was allowed to charge and discharge accordingly. The active (P) and reactive (Q) power contribution from PV and ESS observed during the varying load and varying solar irradiance on PV in the MG network is shown in Fig-16. Active power generation for PV at the starting is zero as there is no solar irradiance and the power generation to increase of solar irradiance

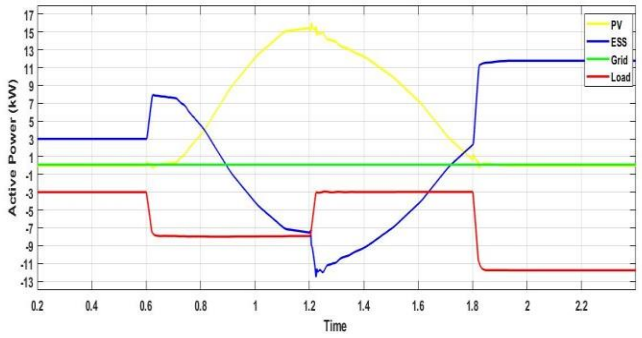

Fig-16: Active Power During Islanded Mode

Battery storage is charged when the total power demand less than the maximum power generation of PV and discharge when the total power demand exceeds maximum power generation of PV in the network. The battery will charge and discharge during PV power generation variation and maintaining the voltage and frequency constant.

The ESS will supply the P and Q in as per the load demand. Here PV works for the grid feeding and ESS works as grid forming regulating voltage and frequency. As shown in Fig-17 and Fig-18, it can be concluded that only a small variation in voltage and frequency level was observed during the varying solar irradiance and load conditions in the MG network.

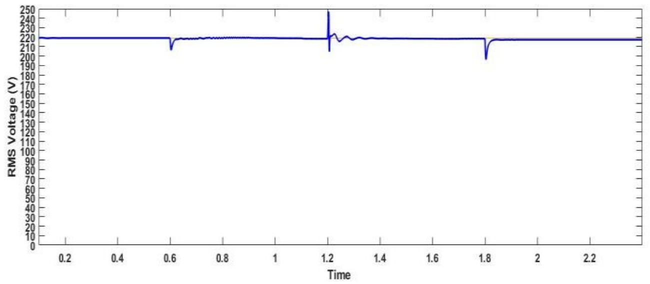

Fig-17: RMS Voltage at Load Bus During Islanded Mode

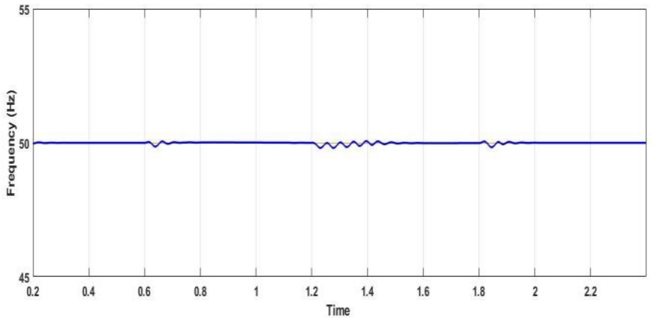

Fig-18: Frequency at Load Bus During Islanded Mode

5.3 Transition Operation Mode

In transition from grid connected to islanded mode of operation, the PV and ESS were continued to Supply the load in smooth manner. Fig-19 and Fig-20 shows the power contribution from each resources. The ESS charge and discharge and power send to grid or take from grid as per the available power of solar PV and load demand at that time.

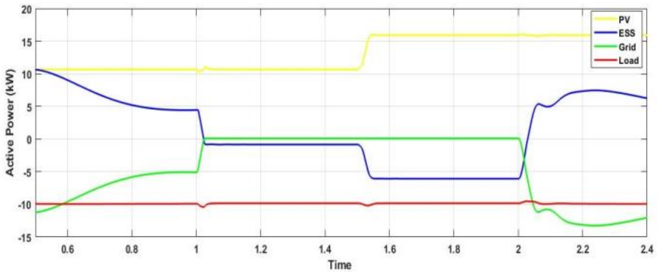

Fig-19 : Active Power During Transition

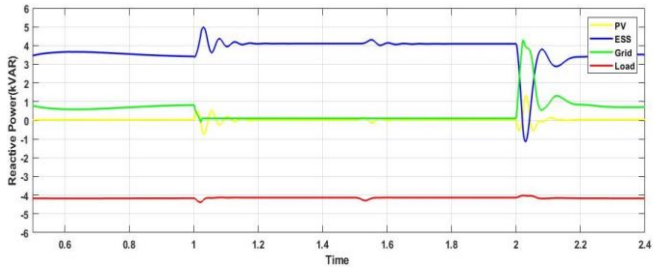

Fig-20: Reactive Power Transition

7. CONCLUSIONS

In grid connected mode of operation active and reactive power contribution from PV, ESS and grid was ensured in coordinated way by means of microgrid central controller strategies. Similarly, better regulation of voltage and frequency level in weak grid was ensured with additional support from the MG. The PV will generate the power at its maximum available capacity to feed the local load and ESS will supply the balance fixed power so that the net power will be supplied or taken from the grid up on the variation of the load. Only a small variation in voltage and frequency level was observed while varying solar and varying load conditions in MG network.

In the islanded mode of operation, factors such as power sharing, coordinated operation between PV and ESS, and variation of voltage and frequency level were analyzed while varying load in the MG network. The ESS will be charged or discharged to balance the power generation from the PV and power consumed by the load thus maintaining the variation of voltage and frequency with in the tolerable limit. The inverter of PV provide the active power only based on the irradiance and the ESS balanced the power in the network, thus the ESS operated as grid forming controller regulating frequency and voltage of local grid to the set points

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