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Multiagent Control of DGs in Distribution Network for Active and Reactive Power Management

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Abstract — The need for reduction of burning fossil fuels and CO₂ emission has led to a change in how electrical power is being generated, transmitted and distributed. This has brought about the introduction of distributed generation units (DGs) mainly renewable energy resources as sources of power generation within the distribution network. With the growing use of distributed generations and energy storage devices across the distribution network, the architecture of the traditional grid faces challenges that threaten its safe and reliable operation. In this paper, the integration of PV and battery storage system is studied. Base models for a PV system and battery storage system were developed. The models were designed to ensure the generation of active and reactive power from the models and a multiagent control which includes a PV management system, battery management system and grid management system was developed to control the interaction between multiple DGs in the distribution network for efficient and reliable operation. Results from this study conducted via simulation show that battery storage systems are playing a big role in power management in the distribution network as they can absorb and produce both active and reactive power.

Keywords — Distributed generation, Multiagent control, Distribution network, Active and reactive power management, PV system, Battery energy storage system

I. INTRODUCTION

With the growing use of distributed generations (DGs) and energy storage devices across the distribution network, the architecture of the traditional grid faces challenges that threaten its safe and reliable operation. Conventionally, the traditional grid operation was designed for power transfer from one point, generation, to another point, distribution/consumption. However, with more DGs and energy storage devices introduced at the distribution side of the grid, the grid operation becomes more complex. This has introduced the concept of microgrids in recent times. The interaction of DGs, energy storage devices and load which can be controlled independently as a unit or centrally by the grid, to produce and manage power in an area is the basic definition of a microgrid [1].

Most of the DGs found in the distribution network are renewable energy-based (wind turbines and solar PVs). These types of power generation units have become more prominent in the network as a result of the growing concerns due to the impact of burning fossil fuels and CO₂ emissions on the environment [2], [3]. The advantages of these types of DGs are their minimal environmental impact as power is generated from natural resources and their ability to be set up on a small scale for remote areas where the power grid connection is not reliable and economical [2]. However, the intermittence of the

sun and wind pose a big challenge as to how efficiently and effectively manage the power grid with these DGs from renewable sources. To solve the challenges related to intermittence, most researchers have introduced energy storage devices into the design of a microgrid. Energy storage devices can store power generated during peak generation of PV and wind turbines and also output the power stored at times when PV and wind turbine generation is at low or no generation. All these benefits of energy storage devices' flexibility make them very important in modern power systems and especially microgrids as they can be used in many applications ranging from power management to power quality [4].

For microgrids, active and reactive power management is needed for safe and reliable operation. With injection and absorption of active power, frequency variations can be managed and with absorption and injection of reactive power, voltage variations can be managed [5]. For the safe operation and stability of the microgrid, frequency and voltage ancillary services are important. To achieve frequency and voltage regulations, various researchers have employed different techniques.

In [6], frequency regulation using PV was studied. However, the study did not include voltage regulation. In [1, 7–9], V-F and PQ control for PV and energy storage devices were studied. However, considerations and impact due to load change and interaction between different PVs, and management of power was not included in the study. In [10], similar to the PV system designed for this study, a grid-connected abc-dq0 based PV system was developed to control both the active and reactive power of the PV system. A load frequency control was implemented in [11] for an islanded microgrid structure which included a PV and storage system.

However, voltage regulation was not considered for the islanded microgrid. From the previous studies mentioned, though energy storage was considered, the interaction between more than one PV, battery and load was not considered for power management in the microgrid. In [12], a central hierarchical control which includes a primary, secondary and tertiary control was implemented to manage the power operation of DGs in the microgrid. The study did not include an energy storage device as a DG with the capability to absorb and generate active power.

This study addresses these gaps. This paper proposes a multiagent control through which the maximum capability of a microgrid with various PVs and battery systems can be harnessed. Detailed architecture of the battery and PV models are discussed in this study.

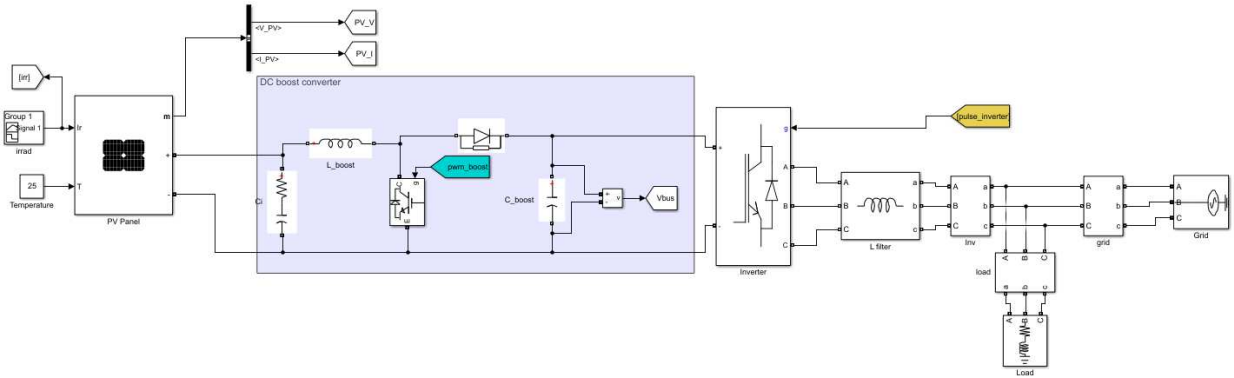


Figure 1: Grid connected PV model

Each PV system boasts of a Perturb and Observe based MPPT algorithm to always output the maximum power per irradiance level. The battery storage houses a PQ control to manage the active and reactive power. The local controls within the PV and battery system are developed in the dq0 reference frames using the d-frame to control active power and the q-frame to control reactive power. Most researchers have used this approach but did not go further to implement a working reactive power control for the PV system. The reference of the reactive power is always set to zero. This study implements a reference based on reactive power load demand. The main contribution of this paper which is the multiagent control includes; a PV control system to aggregate the total PV power, a battery management system to control the active and reactive power contribution of the battery energy storage system and supervisory control to manage the overall active and reactive power within the microgrid to ensure no or minimal grid contributions.

This paper is sectioned into six parts. Section I introduces DGs; PV and energy storage and a brief review of some control strategies for DGs. Section II presents the control design to generate active and reactive power in the PV system. Section III discusses the control of the battery system for producing active and reactive power. Section IV describes the multiagent control used for power management in the microgrid. Section V presents results and discussion from the simulation study carried out. Section VI highlights the contributions and gives a summary of the findings of this paper.

II. CONTROL OF PV SYSTEM FOR ACTIVE AND REACTIVE POWER COMPENSATION

The topology of the PV grid-connected system considered in this study includes a PV panel system, a boost converter to implement the MPPT algorithm, a three-phase inverter, an L filter, local load and an inverter control unit.

The reference power (P_{ref}) is calculated by estimating the power at the maximum point using the MPPT algorithm. This power depends on the amount of PV and irradiance levels. Knowing the load active and reactive power demand, the controller is designed such that for this scenario, when PV power (P_{pv}) is greater than load power (P_L), the excess power is exported to the grid (P_g). For reactive power compensation, if the reactive power demand is within the apparent rating of the inverter, the inverter supplies the system with the reactive power demanded. The independent control of active and reactive power for this local control is made possible through

the use of the dq0 reference frames which make possible independent control of active and reactive power.

A. PV panel

The simulation has been performed using MATLAB/SIMULINK. The PV panel used for this study is a SunPower SPR-315E-WHT-D with 315 W per panel. The arrangement consists of 17 modules in series and 10 parallel strings to output 50 kW (**Error! Reference source not found.**) at the maximum irradiance point.

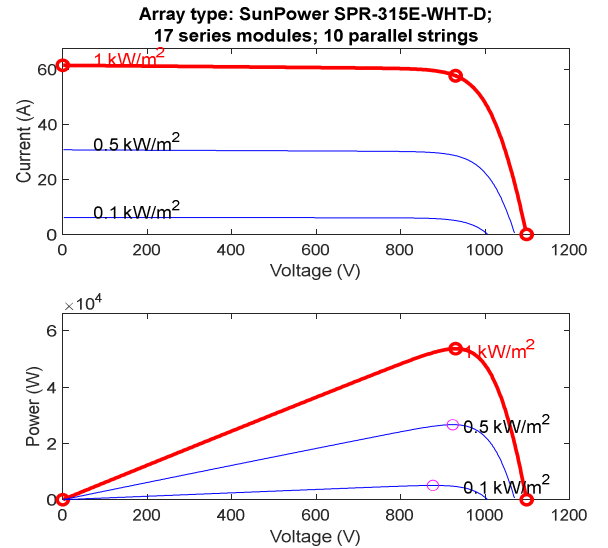


Figure 2: IV, PV curves for typical PV system

B. MPPT algorithm

The IGBT in boost converter topology is used to control the maximum power output from the PV panels. To ensure maximum power extraction from the PV to the load or grid, the MPPT algorithm is used. There are several MPPT techniques like Perturb and Observe (P & O) in [13], and Incremental Conductance (IC) which have been proposed by researchers over the years. In [14], artificial neural networks based MPPT was discussed for PV systems. These techniques have different levels of accuracy, complexity and efficiency.

For this study, the Perturb and Observe MPPT algorithm was used to track the maximum power point of the PV system. The duty cycle to trigger the IGBT of the boost converter is estimated from the MPPT algorithm and using a DC-DC signal generator, a PWM signal was generated to trigger the switch.

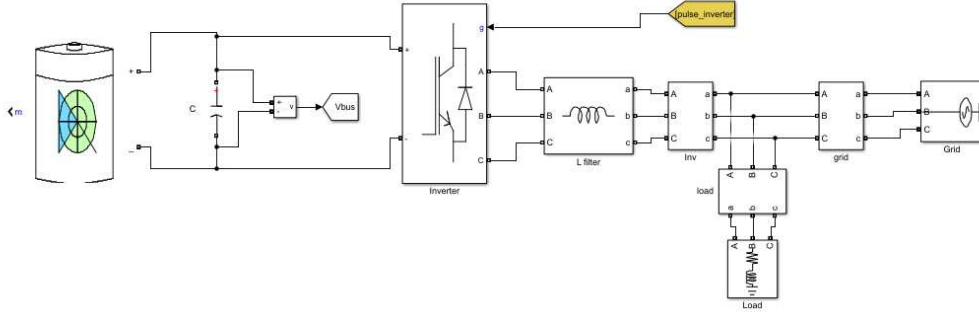


Figure 3: Grid connected Simulink Battery model

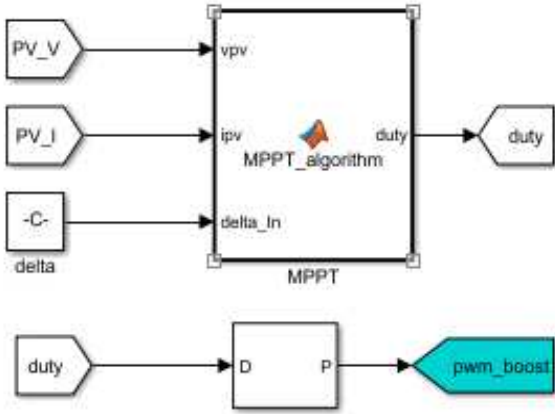


Figure 4: MPPT algorithm and PWM signal generation for boost converter

C. Inverter control

The inverter is a power electronics device that is used to convert the DC voltage generated from the PV panels to AC voltage. The inverter also makes it possible to achieve active and reactive power control.

This control was achieved as mentioned earlier using the dq0 transformation. The synchronization of the grid and the inverter voltage and current is achieved using a Phase-locked loop (PLL) to get the angle, ωt . The inverter and load current are then transformed from abc to dq0 to decouple d and q frames to extract the active and reactive current components respectively.

The references of the d and q frames are the input from the MPPT algorithm regulating the DC link voltage and the reactive component, q, of the load current respectively. The active and reactive power produced by the inverter is adjusted using a PI controller that tunes the error between the reference and inverter output in each reference frame. The signal gotten from the PI controller is collated to get the d and q frames and transformed back to the abc frame. Finally, a PWM signal is generated to switch the inverter.

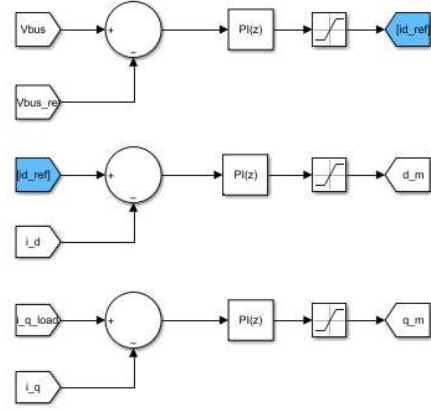


Figure 5: Inverter dq control schematic

D. L filter

The L filter in this PV system design is used to filter out or reduce harmonics that were produced by the inverter due to its PWM switching. The L filter was designed using the methodology proposed in [15]. The maximum inductance value of the filter hence is given by;

$$L_{max} = \frac{V_g^2}{2\pi f_g P} \times 10\% \quad (1)$$

Where; V_g is the grid voltage, f_g is the grid frequency and P is the inverter's rated power.

III. CONTROL OF BATTERY SYSTEM FOR ACTIVE AND REACTIVE POWER COMPENSATION

The structure of the battery system is similar to the PV system designed in section II. The topology of the battery grid-connected system considered in this work includes a battery, a three-phase inverter, an L filter, local load and an inverter control unit. The major difference in the structure of the PV and battery system is the inverter control.

For this study, the PQ model was designed also in the dq0 reference with the inverter current transformed from abc to dq0 and the active and reactive power of the battery inverter compared to a reference to output desired power values. The resulting signal is transformed from dq0 back to the abc frame. The schematic for this model is shown in Figure 3.

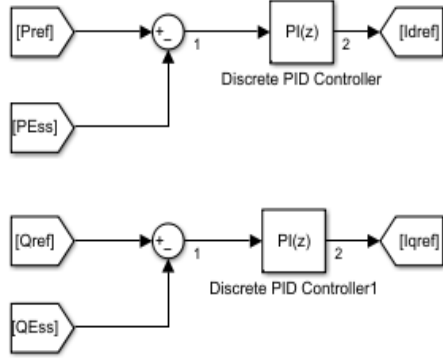


Figure 6: Reference generation for inverter dq control of the battery system.

IV. SUPERVISORY CONTROL TO MANAGE DG'S

This section details the interaction between the designed DGs. The PV and battery models designed and discussed in Sections II and III were compressed to allow easy plugin of models into a distribution network.

The task of the supervisory control is to ensure minimal interaction with the grid. This supervisory control has three agents that ensure the proper functioning of the microgrid. The function of the controller is to manage the active and reactive power demand and generation within the microgrid.

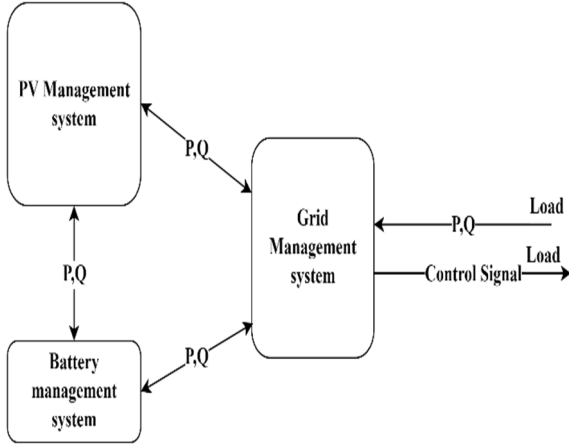


Figure 7: Multiagent supervisory control

The first agent is a PV management system that aggregates the total power and number of PV connected to the network. The second is a battery management system that manages the battery contribution to ensure charging of the battery when PV generation is in excess, and discharge when PV generation is lower than the load demand. The third agent is the grid management system. This controller is a supervisory control that monitors and acts when there is either a change in the PV generation or load demand and acts accordingly by sending control signals to the loads.

For this study, 5 PV models with a maximum capacity of 50 kW each at maximum power point, local loads of different power ratings, a battery module and a utility grid (415 V) were connected to model a distribution network.

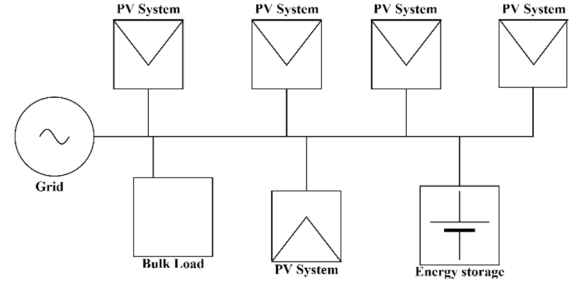


Figure 8: Network connection schematic

V. RESULTS AND DISCUSSION

A. PV active and reactive power simulation results

In section II of this paper, active and reactive power control for a PV system was proposed. For validation, this system was simulated using SIMULINK. The result showing active and reactive power contributions from the PV system is shown in Figure 9.

The nominal voltage for the simulation is 415 V and the frequency of the grid and system is 50 Hz.

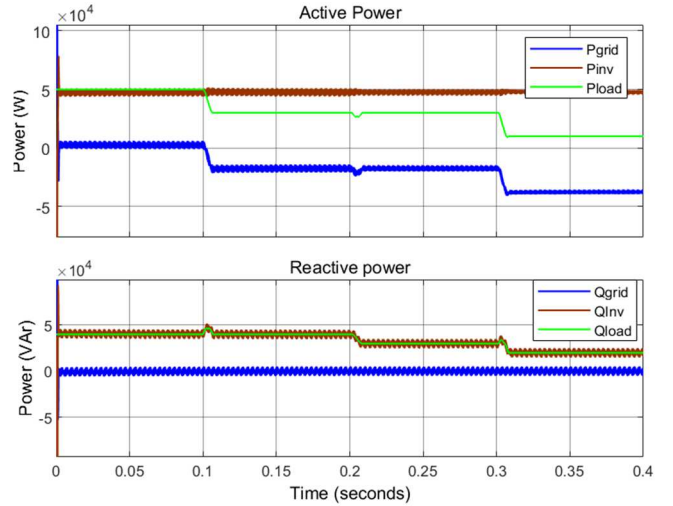


Figure 9: PV system Active and Reactive power

Figure 9 shows the active and reactive power of the load, PV and grid. The plots also show the following scenarios; drop in load demand for active power but no change to reactive power, drop in load demand for reactive power but no change to active power and drop in active and reactive power load demand.

The simulation results as presented in Figure 9 show that between 0 and 0.1 seconds, the load demand for active and reactive power was met by the PV system with zero contribution from the grid. Between 0.1 and 0.2 seconds, the load demand for active power was reduced by 20 kW. The reduction in load demand leads to the difference of 20kW exported to the grid. However, there is no change to the reactive power at this point. At 0.2 seconds, there is a drop in reactive power demand by 10 kVar but no change in active power demand. The PV system was able to provide just the amount of reactive power, while still providing active power to the load and exporting the remaining to the grid. At 3 seconds, there is a drop both in active and reactive power load demand. This drop increases the active power exported to the

grid to 40 kW and the active power load demand of 10 kW is still met by the PV system. At this point also, the reactive power demand drops to 20 kVar.

From this simulation, the PV system can contribute to both active and reactive power management in a microgrid by meeting local load demands of both active and reactive power and still export excess power to the grid.

B. Supervisory control for DGs simulation results

The main aim of this supervisory control is to ensure adequate management of active and reactive power in the microgrid. Unlike the case of the PV, where excess power was absorbed by the grid, the battery energy storage can absorb and give excess power, this allows for minimal interaction of the microgrid with the main grid. For validation, this system was also simulated using SIMULINK. The result showing active power management of the multiagent control system is shown in Figure 10.

The PV system generation capacity used for this study is 50 kW at an Irradiance level of $1,000 \text{ W/m}^2$ and temperature of $25 \text{ }^\circ\text{C}$ and battery capacity is 200 kW.

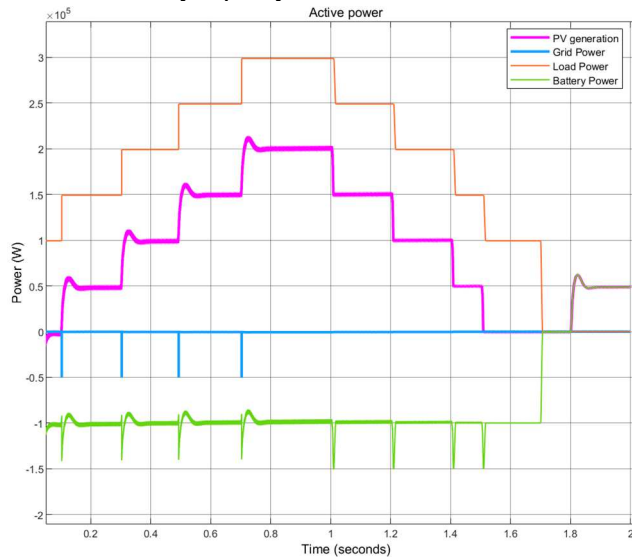


Figure 10: Active power management using the multiagent control

Figure 10 shows the power exchange curves for the PVs, battery system, loads and the grid. The plots show the following active power management scenarios; a PV connection to the network and reaction of other components, a PV disconnection from the network of other components, and contributions of the battery storage.

The simulation results as presented in Figure 10 show that between 0 and 0.1 seconds, the load demand of 100 kW was met by the battery storage. At 0.1 seconds, the first 50 kW PV was connected. Immediately after the connection was observed, the controller sent a turn-on signal to the load to consume the power generated and this was connected to the network, and the battery storage was able to take part in the transient stability to ensure proper connection. The same reaction was observed for the connection of the remaining PV systems. At 0.8 seconds, the load demand from the network is a total of 300 kW with 100 kW from the battery, 200 kW

from the PVs connected to the network and no export or import of power to and from the grid. At 1 second, the first PV is disconnected and the controller disconnects 50 kW worth of load from the network. The same case was observed upon the disconnection of the other PV systems. At 1.7 seconds, the 100 kW load was disconnected from the network. Since there is no generation at this point, the energy storage also generates or consumes no power. At 1.8 seconds, there is still no load demand and a 50 kW PV system was connected. The control system was able to detect the connection and allowed the battery system to charge by consuming the PV generation in the network still with no export or import to and from the grid and load demand.

Figure 11 shows the active power, reactive power and state of charge profile of the battery during the simulation. From this, it can be observed that since there was no reactive power demand, there was no generation of reactive power. However, the state of charge of the battery gradually declined as the battery was feeding a load of 100 kW. Upon disconnection of the load at 1.7 seconds, there is no power demand from the battery and generation within the network so the state of charge does not change. At 1.8 seconds, one PV is connected to the network and this power generated is consumed by the battery. This reflects in the state of charge as the curve gradually begins to increase till the simulation was completed.

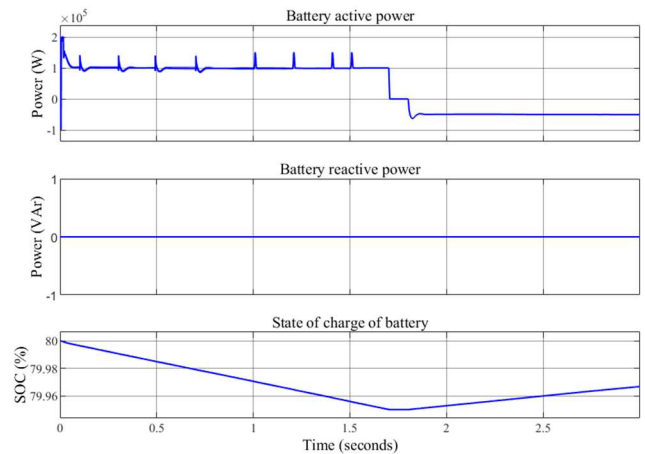


Figure 11: Battery active and reactive power contribution

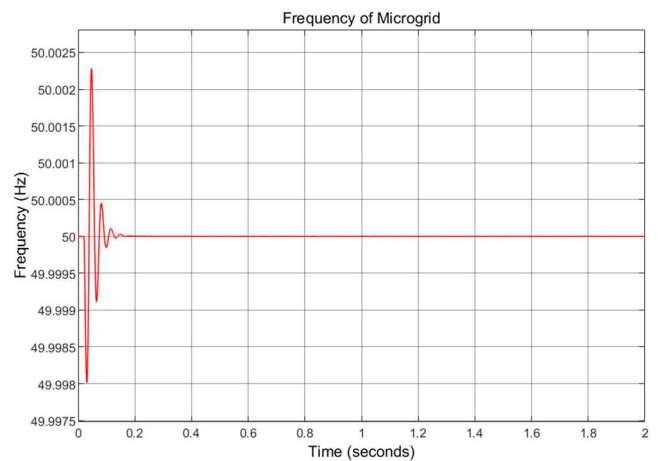


Figure 12: Frequency of the microgrid

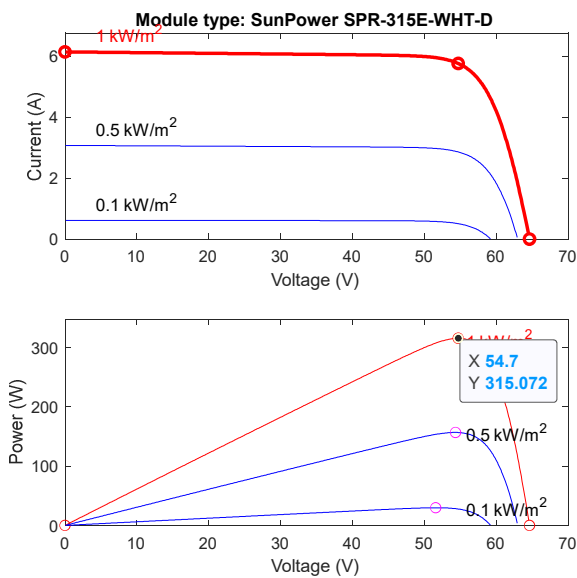
VI. CONCLUSION

Though this research is still in the preliminary stage, the PV and battery systems have been proven in this study to have very important roles to play in the stability of the distribution network through the provisioning of ancillary services in the distribution network.

From this paper, it can be concluded that PV and battery systems can take part in ancillary services as both DGs allow for independent control of active and reactive power. The use of a multiagent control also helps to manage active and reactive power within a microgrid to ensure the system is safe, stable and reliable.

VII. APPENDIX

IV, PV curve for SunPower SPR-315E-WHT-D



REFERENCES

[1] S. Adhikari and F. Li, "Coordinated V-f and P-Q control of solar photovoltaic generators with MPPT and battery storage in microgrids," *IEEE Trans. Smart Grid*, vol. 5, no. 3, pp. 1270–1281, 2014, doi: 10.1109/TSG.2014.2301157.

[2] S. Paghdar, U. Sipai, K. Ambasana, and P. J. Chauhan, "Active and reactive power control of grid connected distributed generation system,"

Proc. 2017 2nd IEEE Int. Conf. Electr. Comput. Commun. Technol. ICECCT 2017, pp. 5–11, 2017, doi: 10.1109/ICECCT.2017.8118019.

[3] Y. Chen and K. Smedley, "Three-Phase Boost-Type Grid-Connected Inverter," vol. 23, no. 5, pp. 2301–2309, 2008.

[4] R. Vatu, O. Ceaki, M. Mancasi, R. Porumb, and G. Seritan, "Analysis of ancillary services within smart grid framework," *Proc. - Int. Conf. Mod. Electr. Power Syst. MEPS 2015*, 2015, doi: 10.1109/MEPS.2015.7477164.

[5] H. Liu, Y. Zhang, and H. A. Mantooth, "Residential renewable energy distribution system with PQ control," *2015 IEEE Int. Conf. Build. Energy Effic. Sustain. Technol. ICBEST 2015*, pp. 33–38, 2016, doi: 10.1109/ICBEST.2015.7435861.

[6] L. D. Watson and J. W. Kimball, "Frequency regulation of a microgrid using solar power," *Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC*, pp. 321–326, 2011, doi: 10.1109/APEC.2011.5744615.

[7] S. Adhikari, F. Li, and H. Li, "P-Q and P-V Control of Photovoltaic Generators in Distribution Systems," *IEEE Trans. Smart Grid*, vol. 6, no. 6, pp. 2929–2941, 2015, doi: 10.1109/TSG.2015.2429597.

[8] S. Chakraborty and D. Kumar, *Closed-Loop V-f Control Strategy for PV-Battery Energy Storage System in Stand-Alone Microgrid*, vol. 693 LNEE. Springer Singapore, 2021.

[9] S. Chakraborty, P. Arvind, and D. Kumar, "Integrated Solar PV MPPT and V-f Control for Stand-alone Microgrid," *Proc. - 2019 Int. Conf. Electr. Electron. Comput. Eng. UPCON 2019*, no. 2, pp. 2–7, 2019, doi: 10.1109/UPCON47278.2019.8980045.

[10] M. G. Molina and P. E. Mercado, "Modeling and control of grid-connected photovoltaic energy conversion system used as a dispersed generator," *2008 IEEE/PES Transm. Distrib. Conf. Expo. Lat. Am. T D-LA*, no. 33407, pp. 1–8, 2008, doi: 10.1109/TDC-LA.2008.4641871.

[11] T. Ota, K. Mizuno, K. Yukita, H. Nakano, Y. Goto, and K. Ichiyanagi, "Study of load frequency control for a microgrid," *2007 Australas. Univ. Power Eng. Conf. AUPEC*, pp. 1–6, 2007, doi: 10.1109/AUPEC.2007.4548110.

[12] L. Meng, M. Savaghebi, F. Andrade, J. C. Vasquez, J. M. Guerrero, and M. Graells, "Microgrid central controller development and hierarchical control implementation in the intelligent microgrid lab of Aalborg University," *Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC*, vol. 2015-May, no. May, pp. 2585–2592, 2015, doi: 10.1109/APEC.2015.7104716.

[13] J. J. Nedumgatt, K. B. Jayakrishnan, S. Umashankar, D. Vijayakumar, and D. P. Kothari, "Perturb and observe MPPT algorithm for solar PV systems-modeling and simulation," *Proc. - 2011 Annu. IEEE India Conf. Eng. Sustain. Solut. INDICON-2011*, no. 1, 2011, doi: 10.1109/INDCON.2011.6139513.

[14] L. P. N. Jyothy and M. R. Sindhu, "An Artificial Neural Network based MPPT Algorithm for Solar PV System," *Proc. 4th Int. Conf. Electr. Energy Syst. ICEES 2018*, pp. 375–380, 2018, doi: 10.1109/ICEES.2018.8443277.

[15] S. Hasan, Suherman, D. P. Saragi, Y. Siregar, and M. Al-Akaidi, "The LCL filter design for three phase DC-AC voltage converter," *J. Phys. Conf. Ser.*, vol. 1783, no. 1, 2021, doi: 10.1088/1742-6596/1783/1/012067.