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Modelling and design of PID controller for voltage control of AC hybrid micro-grid

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ABSTRACT

The growing demand for power that needs to be remotely transported creates a fast and effective solution of Distributed Energy Resources (DERs) integration. Distributed Energy Resources (DERs) can lessen the electrical and physical distance between load loss and generator, transmission and distribution, and the level of carbon emissions. Such challenges can be overcome by using micrograds, which combine various types of DERs without interrupting the grid operation, allowing the power system to detect and control the errors more efficiently, allowing the shedding load and automatic switching through control algorithms so that blackouts and power restoration times are shortened, enabling either a relevant grid or islanded mode operation, and improving system reliability and flexibility via DERs. This work includes modelling of hybrid AC micro-grid as well as presenting an efficient control technique for micro-grid. In the present work the performance of hybrid AC microgrid system is analyzed in the islanded mode. Photovoltaic system and fuel cell stack are used for the development of microgrid. It also includes microgrid control objectives and the most common problems encountered and their solutions. The employed control technique is able to control the output voltage at a desired and standard value. The control strategies of the hybrid AC microgrid are simulated in MATLAB/SIMULINK.

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1. INTRODUCTION

Facing the needs of electricity supply with higher stability and quality, gradually decrease in fossil energy, the power network aging, increase in environmental pollution and global warming, and require the development of the microgrid. This microgrid serves a wide range of customers, for example, housing area, commercial entities, and industrial areas and give advantage to both of the grid and the consumer [1]. The distributed energy resources (DERs) some of which are fuel cells, wind generator, wind turbines, photovoltaic system (PV) and distribution storage storage (DS) unit are used in a microgrid. While, both of the distribution generations (DGs) and storage units (DSs) are include in the distributed energy resources (DER) and have a dissimilar capabilities and characters. The microgrid electrical connection point to the utility system in low-voltage bus transformer substation, consist of microgrid point of common coupling (PCC). The distributed energy resources (DERs) that run in the local grid mode have two mode of operation. It can either be in grid connected mode where the distributed energy resources (DERs) is connected to the grid or in islanded mode where the distributed energy resources (DERs) is disconnected at the point of common coupling (PCC) from the main utility grid. However, if the microgrid is operating under the islanded mode, microgrid will independently operates and provide power to the end user by its own generation. In both cases, parts that have been separated should supply a continuous energy to the connected load. Microgrid is expected to provide capacity, control and operation strategy that enough to provide at least some of the loads after disconnected from the main utility grid at the point of common coupling and operate autonomously or is called islanded mode. [1]-[4]. The main challenges in controlling and modelling the AC Microgrid is to provide the most efficient voltage control to match the dynamic demand, environment sustainability and cost-effectiveness. Type of power source the capability of the source to supply power to the load and parameters setting of the power sources also need to be considered. Unstable voltage control system leads to power system instability on its operation and control as microgrid contains variety of sources which need different control approaches.

The aim of this research is to design and model a suitable AC microgrid model and voltage control method for microgird system on an islanded mode in order to ensure the stability of the power quality, reliable and efficient operation of a microgrid.This paper also focus on designing a stable voltage control method for hybrid AC microgrid system on an islanded mode application by using MATLAB/SIMULINK.Selected results were obtained on order to investigate the voltage control issues in microgrid system.

2. STRUCTURE AND CHARACTERISTICS OF MICROGRID

Microgrid includes the part of electricity distribution system that positioned at the downstream of the distribution substation, plus contains assorted of distributed energy resources (DERs) units and various kinds of end user. Both of the distribution units (DGs) and storage units (DSs) are include in the distributed energy resources (DERs) and have a dissimilar capacities and characters. Microgrid electrical connection point to the utility system, in the low-voltage bus transformer substation, consists of microgrid point of common coupling (PCC). This microgrid attends a wide range of customers, for example, housing area, commercial entities, and industrial areas [1]. As shown in Figure 1, microgrid usually runs its operation in a grid-connected mode throughout a substation transformer. In addition, microgrid also require to provide adequate capacity, control, and working plans to supply at least part of the load after being detached from distribution system at point of common coupling (PCC) and continue to operate in islanded mode.

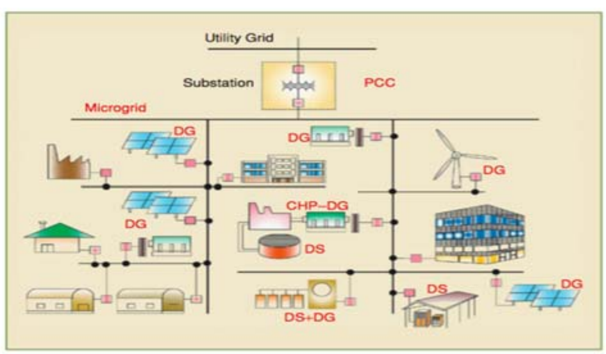

Figure 1. Microgrid structure layout with loads and distributed energy resources (DER) units

2.1. Microgrid modeling

Nowadays green energy resources become a choice that can never be questioned among the engineers and researches as an electrical generation that is free from carbon emission. The global enegy demand is predicted to be increasing in the future together with the rapid urbanization and industrialization. This increment in energy demand also will affect environment if the world is depending on conventional energy sources. Thus, Hybrid microgrid becomes a very important research recently to overcome this issue. The architecture of AC/DC Hybrid microgrid itself turn out to be an interesting topic for a further research as its design combining two types of power supply which are between AC (alternating current) and DC (direct current). The purpose of microgrid modeling is to get the understanding and study about the outcome from several designs of microgrid before its being implemented in real. The model can be further analyzed to improve the power quality and reliability of the system in the future.

2.2. Control of microgrid

A dissimilar control purposes for microgrid need to be considered as microgrid have various variation, conditions and situations [5]. The main motives of microgrid control are:

a. An economic operation of microgrid and its micro sources.
b. Coordination of the distributed energy resource (DER) and appropriate load sharing.
c. A stable process on either islanded or grid-reconnecting mode.
d. Control of power flow in microgrid and from microgrid to main grid.
e. Improvement and increasing microgrid efficiency.
f. To ensure the demands of the heat and the electricity are fulfilled by the microsources.
g. To ensure an adequate operation bonds of the microgrid with bulk power provider.
h. Support of the Energy Storage System (ESS) towards the microgrid and improve the efficiency and reliability of the system

2.3. Hierarchical structure of microgrid control system

The different importance, time scales and needs for microgrids require a hierarchical structure of microgrid control system to tackle every need at every levels of the hierarchy structure. The hierarchical structure of microgrid control system can be separate into three levels which are the primary, secondary, and tertiary controls [6]. The primary control is aimed to make stable the voltage and frequency. Following the islanded events, microgrids might lose its stability of voltage and frequency due to the inconsistency between power generated and consumed. Also, to provide the capabilities of plug and play for the $A = \pi r^2 e$ distributed energy sources (DERs) and to share the active and reactive power between them, without having any communication links. [6]-[8]. The secondary control in the hierarchy structure in the centralized controller will stabilize back the voltage and frequency of the microgrid and correct back the deviations that caused from the primary control. This secondary control is developed to produce a slow dynamic reaction over the primary control, which validates the decoupled dynamics of the primary and secondary loop and expedites each of their designs itself [9]-[11]. The last and slowest control under the hierarchy control is called as the tertiary control. The tertiary control is responsible in considering the economic anxieties in microgrid optimal operation, and control the power flow between the micro-grid and the main grid. The power between the micro-grid and the main grid can be controlled by adjusting the frequency and the amplitude of the distributed energy sources (DERs) voltages in a grid-tied mode [4], [6]-[8]. Hierarchical structure of microgrid control system as shown in Figure 2.

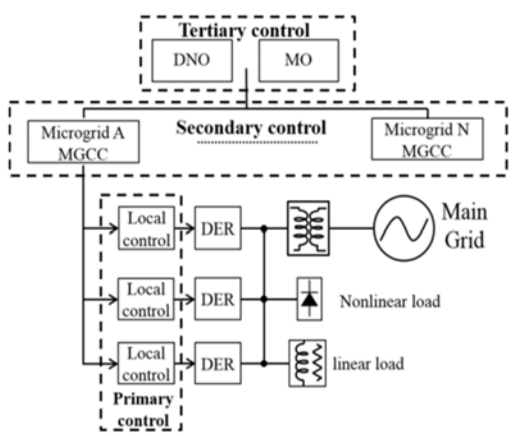

Figure 2. Hierarchical structure of microgrid control system

3. PROPOSED CONTROL

Considering the above mentioned advantages of controlling the micro-grid, this section provides an overview of the control technique employed in this work.

3.1. Basic parameters
Controlling the micro-grid and keeping the voltage and power at standard values is a tedious work comparing to conventional power system. That's because of the complex structure of micro-grid and the nature of the allocated DERs along the grid, the main parameters to focus on are as follows:

3.1.1. Voltage stability
The voltage regulation, voltage distortion, voltage profile and voltage quality are including in terms related with voltage stability. The voltage stability is to retain a stable voltage amplitude at required level in the microgrid. Voltage controllers located at each of the distributed energy source (DER) unit is to provide a local stability. Without the voltage controller, the systems could experience an oscillations of voltage and/or reactive power.

3.1.2. Frequency, f
Under the islanded mode, distributed energy sources (DERs) need to control the frequency of microgrids cooperatively and simultaneously. Since there is no dominant source under the islanded mode, it is a challenge for the frequency control and synchronization process. The line frequency range must not go beyond the pre-set value. The minimum and maximum frequency range for 50Hz grids is 48Hz to 51Hz while for 60Hz grids is 59.3Hz to 60.5Hz [12]-[15].

3.1.3. Load-sharing active and reactive power, LS P & Q
Considering the sharing of loads between the distributed energy sources (DERs) is an important principle in power management systems (PMS) to reduce the losses of the system power. The distributed energy source (DER) load sharing is to ensure that each of it supplies its preset proportion in steady state.

3.2. Mathematical analysis
3.2.1. Power equations

$$p(t) = v((t)i(t) = VmImcos(wt + \theta)cos(wt + \theta) \quad (1)$$

Where: Vm = maximum values of voltage
Im = maximum values of current

3.2.2. Active power, P

$$Q = |I||V| \ \sin(\theta) \quad (2)$$

3.2.3. Reactive power, Q

$$\mathbf{Q = |I||V| \ \sin(\theta)} \quad (3)$$

3.2.4. Apparent power, S

$$S = P + jQ = |I||V| \ \cos(\theta) + j|I||V| \ \sin(\theta) \quad (4)$$

$$S = |I||V| \cos(\theta) + j|I||V| \sin(\theta)$$

3.2.5. Capacitor, C

$$Xc = \frac{1}{\omega C} \quad (5)$$

3.2.6. Inductor, L

$$XL = \omega L \quad (6)$$

3.2.7. Per unit value, PU

$$PU = \frac{\text{Actual value in any unit}}{\text{Base or reference value in the same unit}} \quad (7)$$

3.3. Research components
These components that have been used in the simulation to construct a local controller (LC) which this control method is located at the primary control of the microgrid control hierarchy. The components are:

3.3.1. Energy sources

Energy sources are the sources of the energy that can be produce by several generation methods. Renewable energy is one of the common choices to be used in microgrid. The most common renewable energy sources are including of photovoltaic system (PV), fuel cells, wind generator and wind turbines. As for this research, photovoltaic and fuel cells will be used on the simulation [16]-[18].

3.3.2. Capacitor, C

The capacitor often connects between the energy source and inverter. The function of the capacitor is to lessen the voltage ripples, stabilize the voltage and provide or absorb energy for a short period of interruption. The capacitor also will balance the dissimilar power difference between the energy source and the input of the inverter. Capacitor also can charge and discharge energy in a circuit to balance up and to improve the the power quality of the circuit.

3.3.3. Inductor, L

The inductor which also sometimes called as reactor or coil is an electrical component that when the current flow through the coils, it will store the electricity in the form magnetic field. The voltage that appears across an inductor is due to its own magnetic field and Faraday's law of electromagnetic induction.

3.3.4. Local controller (LC)

The local controllers (LCs) will control the distributed ener-gy source (DER) and some of the local loads and strive to bal-ance the active and reactive power. As for this research, the proportional integral (PI) controller will be used on the local controller (LC). The proportional integral (PI) controller will control the active and reactive power of the components to achieve the accurate flows.

3.3.5. Voltage source inverter (VSI)

The voltage source inverters (VSIs) are normally used to control the network voltage and frequency and the power output while satisfy the requirements of the grid. Figure 3 is shown is MATLAB/Simulink circuit design for control of hybrid AC microgrid.

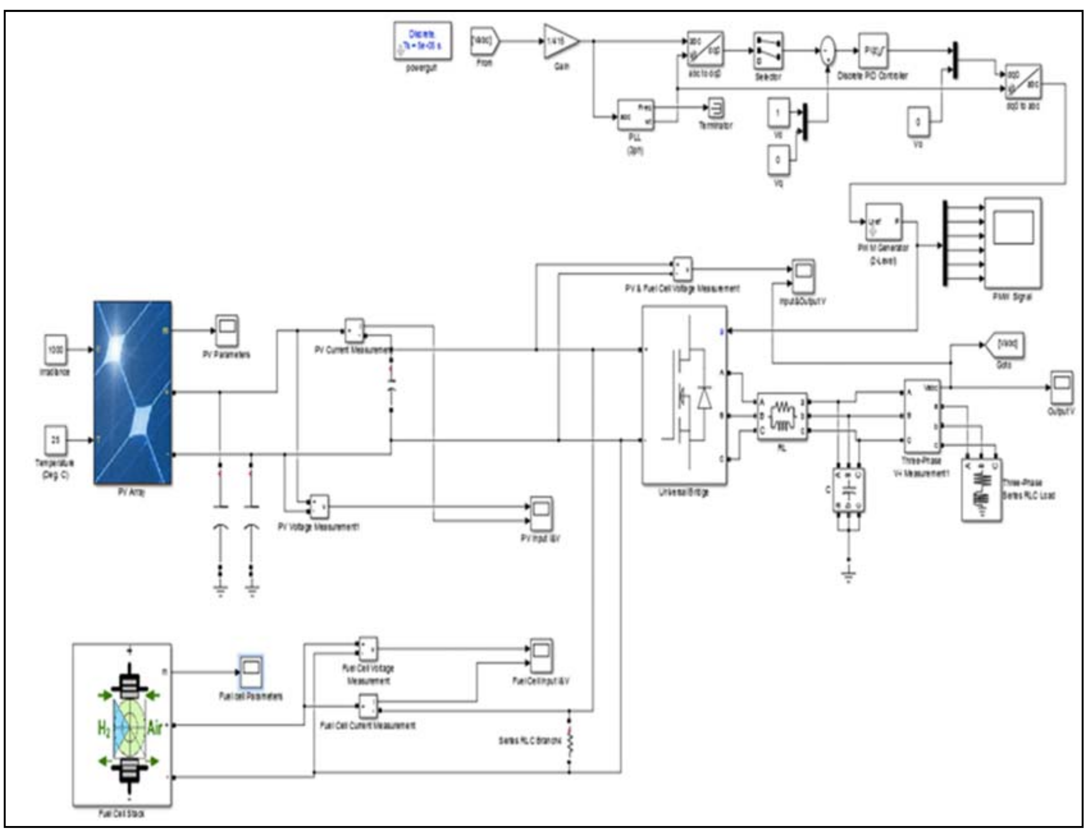

Figure 3. MATLAB/Simulink circuit design for control of hybrid AC microgrid

4. RESULTS AND DISCUSSION

The analysis will be deliberating about the voltage control strategies on a different condition for the load demand and power source from the distribution generations (DGs) of the microgrid. Others components parameter such as the gain, PI controller, universal bridge (inverter), resistor inductor (RL), capacitor (C) and three-phase RLC load were also taken into consideration and set at permissible values. The performance analysis of the voltage control is done by using the simulated results from the MATLAB/SIMULINK. From the results obtained, its shows that the microgrid has a stable voltage controller and the controller also was able to control the output voltage by following the signal from the reference value.

4.1. Control of hybrid AC micro-grid

The first block on the circuit is the gain. The gain block will be functioning as the reference value for the based voltage. The gain block is connected to the phase locked loop (PLL) and the abc to dq block. The function of the phase locked loop (PLL) is to synchronize with the grid voltage and scaled according to the input signal. The abc to dq block will convert the three axes to two axes magnitude which will make it easier to computed. The abc to dq block will be connected to the selector block. The function of the selector block is to select the input element either from the vector, matrix or multidimensional signal. Before the PI controller block, V_d and Vq blocks were installed. The V_d block is set at 1 p.u as the reference value and the Vq was assuming to be zero. Then, the sensor (V_{abc}), is tapped at the output of the three-phase V-I measurement before the three-phase series RLC load. The value from the sensor will be computed and the PI controller will calculate it to get the amount of value that have been set at the gain and V_d block. The output from the PI controller will be injected to the PWM generator. It will generate the control that has been calculated by the PI control to inverter to control the output of the renewable sources. PWM generator will carry the information of the control signal to the inverter either to buck or boost the output voltage by following the reference value of the p.u that has been set earlier. The employed control technique has been tested under different scenarios as follows:

4.2. Scenario 1: Variation in load, fixed renewable energy sources and P.U voltage reference values

On the first scenario, the parameters of the photovoltaic and fuel cell stack were assumed at one fixed value as mentioned on the parameters setting above. The reference voltage for this system has been set at 415 V value. While the three-phase series RLC load was set at various load condition. Table 1 shows the summary of the simulated cases.

On the first scenario, the parameters of the photovoltaic and fuel cell stack were assuming at one fixed value. While the reference voltage was set at 415 V and the three-phase series RLC load was set at various load condition. At load value of 10kW, it shows that voltage control has been boosted from 316.269 V input voltage to 417.846 V output voltages. While at load value of 50kW, the voltage input of 356.192 V has been boosted up to 383.268 V output voltages. However, at load value if 100kW the output value started to decrease from 361.269 V input voltage to 323.269 V output voltage. Also, at load value of 150kW the output value started to decrease from 365.551 V input voltage to 276.812 V output voltages. This shows that the system is no longer able to boost up the input voltage in order to get the desired output voltage. The system has lost its control as the load is getting higher than the voltage controller can rectify. Result shown in Figures 4-7.

Table 1. Summary of the simulated cases study one

No.	Load variation (W)	Input voltage (V)	Output voltage (V)	Per unit (P.U)	Output voltage reduction (%)
1.	10K	361.269	417.846	1.00	0
2.	50K	356.192	383.268	0.92	7.65
3.	100K	361.269	323.269	0.77	22.10
4.	150K	365.551	276.812	0.66	33.30

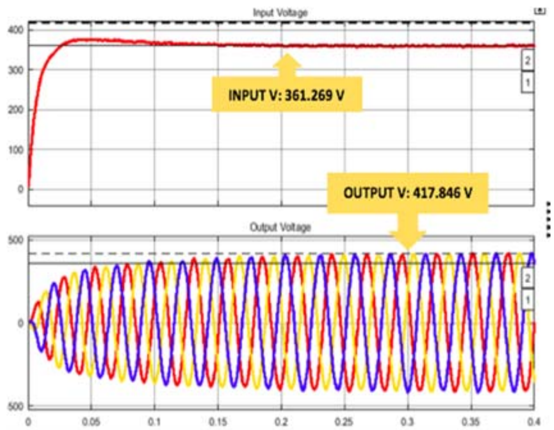

Figure 4. Input and output voltage with 10kW load

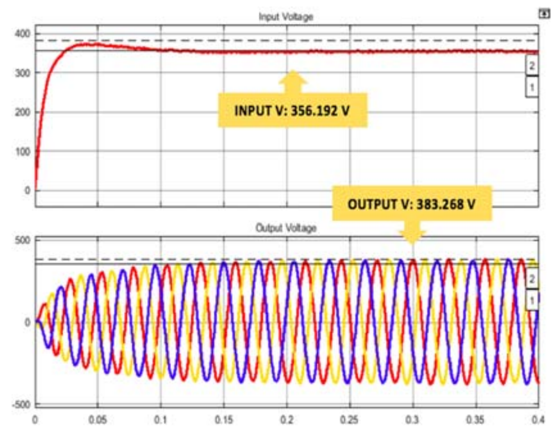

Figure 5. Input and output voltage with 50kW load

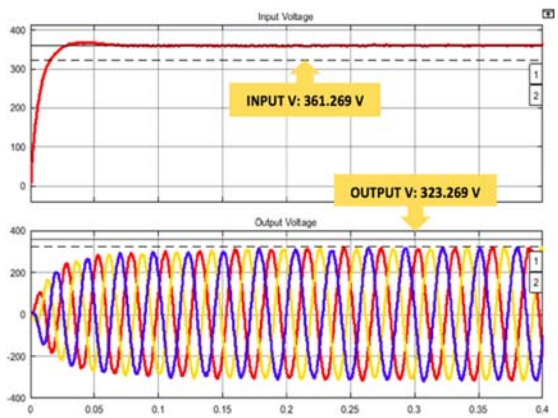

Figure 6. Input and output voltage with 100kW load

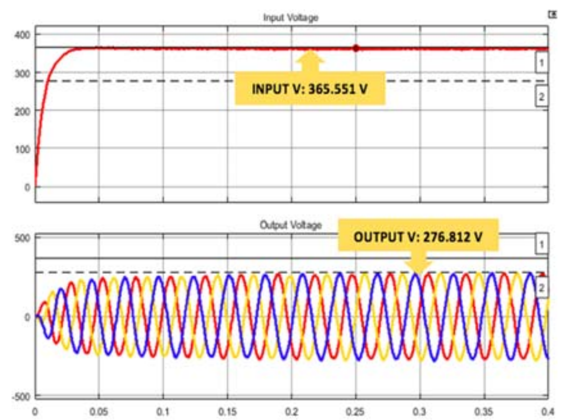

Figure 7. Input and output voltage with 150kW load

4.3. Scenario 2: Fixed renewable energy sources and load values with variable P.U voltage reference

As for second scenario, the photovoltaic, fuel cells parameters and load are assuming at fixed value. The reference voltage for this system has been set at 415 V value. While p.u reference voltage is set at a difference value. Table 2 shows the summary of the simulated cases on this case study

As on the second scenario, (Fixed Renewable Energy Sources and Load Values with Variable P.U Voltage Reference), the results obtained shows that, changing the value of p.u voltage reference causes the output voltage results from the inverter were also changing accordingly. Photovoltaic, fuel cells parameters and load are assuming at fixed value. The reference voltage for this system has been set at 415 V value. While p.u reference voltage is set at a difference value. At p.u reference voltage of 1 p.u, simulated results show that from the input voltage of 316.019 V has produced 417.846 V output voltage. While at p.u reference voltage of 0.5 p.u, from the input voltage 528.016 V input voltage has produced 205.757 V output voltage. At p.u reference voltage of 0.25 p.u, from the input voltage 555.062 V input voltage has produced 107.228 V output voltage. This proves that this voltage controller is able to control the output voltage of the microgrid according to its preset value. Result shown in Figures 8-10.

Table 2: Summary of the simulated cases study two

No.	Per Unit Reference Voltage Variation (P.U)	Input Voltag (V)	Output Voltage (V)	Output Voltage Reduction (%)
1.	1	361.019	417.846	100
2.	0.5	528.016	205.757	49.58
3.	0.25	555.062	107.228	25

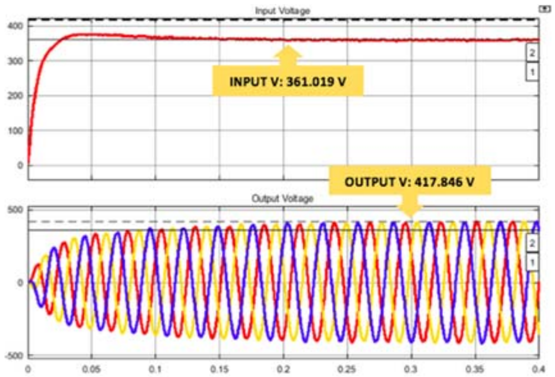

Figure 8. Input and output voltage with 1 p.u reference voltage value

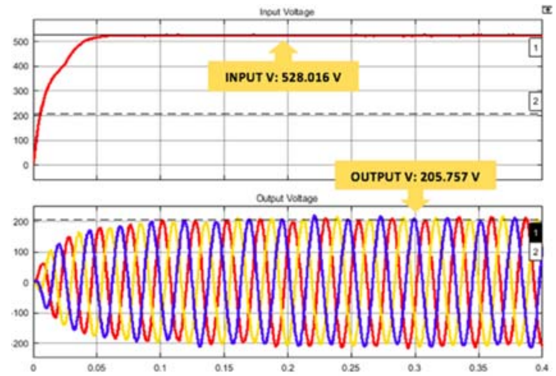

Figure 9. Input and output voltage with 0.5 p.u reference voltage value

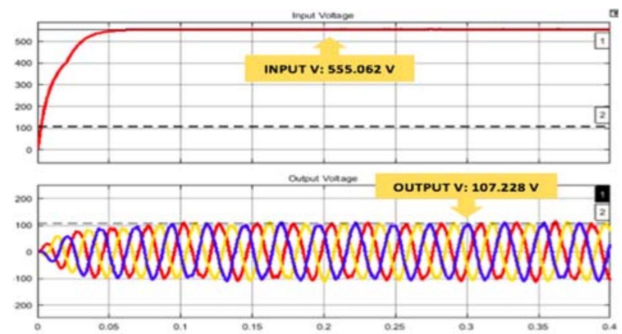

Figure 10. Input and output voltage with 0.25 p.u reference voltage value

5. CONCLUSION

In this work, a hybrid AC micro-grid has been successfully modelled and fully utilized the advantages of using the distributed energy resources DERs. The inclusion of DERs has introduced different challenges to the micro-grid which increased the need to design a controller to maintain the stability of the micro-grid. A PID controller has been designed and employed to control and keep the micro-grid parameters within the limit. The proposed control technique has the ability to boost and buck the voltage values according to the load requirements. Different scenarios have been created to test the applicability and capability of the designed controller. The obtained results show that, the proposed control technique to control the micro-grid has a good response towards the various operation conditions.

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REFERENCES

[1] Shi, Wenbo, Xiaorong Xie, Chi-Cheng Peter Chu, and Rajit Gadh. "Distributed Optimal Energy Management in Microgrids." *IEEE Trans. Smart Grid*, vol6, pp. 1137-1146, 2015.

[2] Eid, Bilal M., Nasrudin Abd Rahim, Jeyraj Selvaraj, and Ahmad H. El Khateb. "Control methods and objectives for electronically coupled distributed energy resources in microgrids: A review," *IEEE Systems Journal*, vol. 10, pp. 446-458, 2016.

[3] Yang, Nanfang, Damien Paire, Fei Gao, and Abdellatif Miraoui. " *2013 IEEE Industry Applications Society Annual Meeting*, Lake Buena Vista, FL, pp. 1-9, 2013.

[4] Bidram, Ali, and Ali Davoudi. "Hierarchical structure of microgrids control system." *IEEE Transactions on Smart Grid*, vol. 4. pp. 1963-1976, 2012.

[5] F. Moehrke and J. Myrzik, "Control methods for microgrids," *2014 49th International Universities Power Engineering Conference (UPEC)*, Cluj-Napoca, pp. 1-6, 2014.
[6] H. Wen, H. Yu and Y. Hu, "Modeling and analysis of coordinated control strategies in AC microgrid," *2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)*, Birmingham, pp. 702-707, 2016.
[7] Guangqian, D.I.N.G., Feng, G.A.O., Zhang, S., Loh, P.C. and Blaabjerg, F, "Control of hybrid AC/DC microgrid under islanding operational conditions," *Journal of Modern Power Systems and Clean Energy*, vol. 2, pp.223-232. 2014.
[8] Dong, Bo, Yongdong Li, Zhixue Zheng, and Lie Xu. "Control strategies of microgrid with hybrid DC and AC buses." *In Proceedings of the 2011-14th European Conference on Power Electronics and Applications (EPE 2011)*, pp. 1-8, 2011
[9] Salem, Mohamed, Awang Jusoh, N. Rumzi N. Idris, Himadry Shekhar Das, and Ibrahim Alhamrouni. "Resonant power converters with respect to passive storage (LC) elements and control techniques–An overview." *Renewable and Sustainable Energy Reviews,* vol. 91, pp. 504-520. 2018.
[10] Salem, M., Jusoh, A. and Idris, N.R.N. "Implementing buck converter for battery charger using soft switching techniques," *2013 IEEE 7th International Power Engineering and Optimization Conference (PEOCO)*, Langkawi, pp. 188-192, 2013.
[11] Salem, M., Jusoh, A., Idris, N.R.N., Sutikno, T. and Abid, I. "ZVS full bridge series resonant boost converter with series-connected transformer." *International Journal of Power Electronics and Drive Systems (IJPEDS),* vol 8, pp.812-825. 2017.
[12] Salem, M., Jusoh, A., Idris, N.R.N. and Alhamrouni, I. "Extension of Zero Voltage Switching range for series resonant converter. "*2015 IEEE Conference on Energy Conversion (CENCON)*, pp. 171-175, 2015.
[13] Salem, M., Jusoh, A., Idris, N.R.N. and Alhamrouni, I. "A review of an inductive power transfer system for EV battery charger. " *European Journal of Scientific Research*, vol. 134, pp. 41-56. 2015.
[14] Salem, M., Jusoh, A., Idris, N.R.N. and Alhamrouni, I. "Comparison of LCL resonant converter with fixed frequency, and variable frequency controllers," *2017 IEEE Conference on Energy Conversion (CENCON)*, Kuala Lumpur, pp. 84-89, 2017.
[15] Alhamroun, I., Salem, M., Jusoh, A., Idris, N.R.N., Ismail, B. and Albatsh, F.M.,. "Comparison of two and four switches inverter feeding series resonant converter," *2017 IEEE Conference on Energy Conversion (CENCON)*, Kuala Lumpur, pp. 334-338, 2017.
[16] Caramia, P., G. Carpinelli, F. Mottola, and G. Russo. "An optimal control of distributed energy resources to improve the power quality and to reduce energy costs of a hybrid AC-DC microgrid," *2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)*, Florence, pp. 1-7, 2016.
[17] Yi Z, Babqi AJ, Wang Y, Shi D, Etemadi AH, Wang Z, Huang B. "Finite-Control-Set Model Predictive Control (FCS-MPC) for Islanded Hybrid Microgrids," 2018.
[18] Haifeng L., Wei X., Jialin L. & Lin B., "Research on stability control of AC/DC hybrid micro-grid based on multi agent system," *International Conference on Renewable Power Generation (RPG 2015)*, Beijing, pp. 1-6, 2015.