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Stability and reliability of low voltage hybrid AC-DC microgrids power flow model in islanding operation

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Article Info	ABSTRACT
	The problem of decreasing and increasing power flow in hybrid AC-DC microgrids in islanding operations is the concern of this study. This condition arises if one sub-microgrid cannot supply load power requirements, either because of a decrease in power at the source or an increase in load on the sub-microgrid network. The result, in this study using a bidirectional converter as an interlinking converter, the converter can change the power flow from ac sub microgrid to dc sub microgrid and vice versa. With this converter, load requirements can be met despite a lack of power in one of the sub microgrids. The simulations in this study are supported by Simulink / Matlab software. This model is built in a low voltage system, and power flow analysis is in steady state with two different cases. Simulation results show the stability and reliability of power flow in both sub microgrids with stable frequency and voltage when power and load changes occur.

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1. INTRODUCTION

Technological advances in the use of Renewable Energy Sources (RES) have increased [1-2]. The application is flexible, especially in remote areas where there is no electricity grid, but renewable energy sources are abundant [3-4]. The one which popular is PV systems, which naturally produce DC power. Meanwhile, at present, many devices use DC sources, for example, Light Emitting Diode (LED) for lights, computers, and others. So it will be more efficient if the equipment that requires DC power is connected to the DC source directly without going through the converter. Furthermore, the construction of DC microgrids, which connect DC sources and DC loads directly, will reduce the use of converters [5-6]. Recently DC distribution systems or DC microgrids are also developing [7]. In addition to the use of RES which naturally produces DC power, there are several RES that produces AC power such as wind, micro-hydro, etc. And equipment that requires AC power is certainly more varied. so that currently the construction of an AC microgrid is also still being done.

The combination of AC and DC microgrids is an effective way of using RES in remote are as because the natural resources generated can be either AC or DC power. Hybrid AC-DC microgrid is a microgrid that combines DC and AC sub microgrid, both sub microgrids are connected by an interlinking converter [6, 8-9]. The advantages of hybrid AC-DC microgrids, in general, can be summarized as follows[5-6, 8-13]: Increase installed power capacity; reducing the use of power electronic equipments: converter, Power Factor Correction (PFC); improve power quality on microgrid AC, because DC load will be directly connected to DC source so that it doesn't cause harmonic pollution. Not only the advantages but also there are weaknesses of this system, one of which is power condition. Uncertain power conditions from

RES can affect system conditions, especially on islanding conditions. With the various types of sources connected to the system, a good connecting device is certainly needed, in this case, the interlinking converter is expected to be able to regulate the power according to the source conditions and needs of the existing load. A simple converter with ac voltage as the input control has not been able to flow power in both directions properly when there is a change in power and load, but can drain power when a three-phase disturbance occurs [12].

In this paper, a strategy on keeping stability and reliability of the power flow in low voltage hybrid AC-DC microgrid in islanding operations is proposed. Bidirectional converter as interlinking converter is used to connect AC sub microgrid and DC sub microgrid using input control from two sides of AC and DC sub microgrid, voltage and current from AC sub microgrid and voltage from DC sub microgrid. Simulations have been carried out in two different cases:

1. Power flow from DC to AC sub microgrids
2. Power flow from AC to DC sub microgrids.

The two cases above are also accompanied by a case of load changing on the AC sub microgrid. Power flow analysis is carried out on two sides, AC and DC sub microgrid.

2. HYBRID AC-DC MICROGRID

Combining the DC system and the AC system or better known as the hybrid AC-DC microgrid system is a good solution in addressing the current electrical energy needs. In hybrid AC-DC microgrid there are 3 main parts: 1) AC sub microgrids, 2) DC sub microgrids, and 3) interlinking converter that connects AC and DC sub microgrids. Simple power flow in a hybrid AC-DC microgrid is shown in Figure 1. Based on these three components, in the hybrid AC-DC microgrids under islanding conditions there are four operating conditions as explain in Table 1.
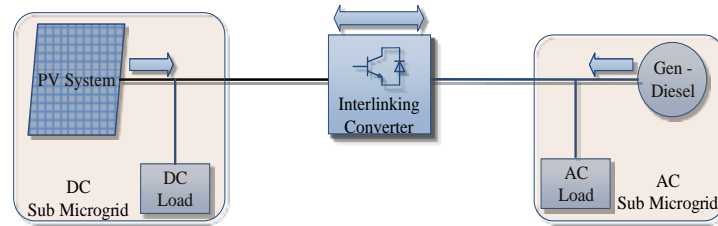

Figure 1. Hybrid AC-DC microgrids

Table 1. Power condition in hybrid AC/DC microgrids [9]

	DC Sub Microgrid	AC Sub Microgrid	Interlinking Converter
Condition 1	The total dc load power is smaller than the total dc power source $$\sum_i P_{dc,i}^{load} \leq \sum_i P_{dc,i}$$	The total ac load power is smaller than the total ac power source $$\sum_i P_{ac,i}^{load} \leq \sum_i P_{ac,i}$$	the power on the IC is zero $$P_{IC}^* = 0$$
Condition 2	The total dc load power is smaller than the total dc power source $$\sum_i P_{dc,i}^{load} < \sum_i P_{dc,i}$$	The total ac load power is biger than the total ac power source $$\sum_i P_{ac,i}^{load} > \sum_i P_{ac,i}$$	$$P_{IC}^* = \sum_i P_{ac,i} - \sum_i P_{ac,i}^{load} - P_{ac}^{loss}$$
Condition 3	The total dc load power is biger than the total dc power source $$\sum_i P_{dc,i}^{load} > \sum_i P_{dc,i}$$	The total ac load power is smaller than the total ac power source $$\sum_i P_{ac,i}^{load} < \sum_i P_{ac,i}$$	$$P_{IC}^* = \sum_i P_{dc,i} - \sum_i P_{dc,i}^{load} - P_{dc}^{loss}$$
Condition 4	The total dc load power is biger than the total dc power source $$\sum_i P_{dc,i}^{load} \geq \sum_i P_{dc,i}$$	The total ac load power is biger than the total ac power source $$\sum_i P_{ac,i}^{load} \geq \sum_i P_{ac,i}$$	the power on the IC is zero $$P_{IC}^* = 0,$$

In AC or DC sub microgrid usually there are several sources, whare the notation in Table 1 are $P_{ac,i}$, $P_{dc,i}$, $P_{ac,i}^{load}$, $P_{dc,i}^{load}$, $P_{ac,i}^{loss}$, P_{IC}^{*} represent the power generated from that source in ac sub microgrid, the DC source in dc sub microgrid, the load power in ac sub microgrid, the load power in dc sub microgrid, the losses contained in the ac sub microgrid and the power flow through the interlinking converter.

2.1. Power flow in low voltage AC submicrogrids

Inductance and resistance values in the low voltage line are inversely proportional to the high voltage system, the inductance value in the low voltage line is very small and the resistance value is large. Typical line parameter in grid R', X' and typical rated current for the high, medium and low voltage line is shown in Table 2 [14-15].

Table 2. Typical line parameter

Type of Line	R' (Ω/km)	X' (Ω/km)	R'/ X'
Low Voltage	0,642	0,083	7,7
Medium Voltage	0,161	0,190	0,85
High Voltage	0,06	0,191	0,31

From Table 1 the grid with high voltage has a high inductive value while at medium and low voltage resistive value is higher. This condition indicates that the low voltage system is resistive [16]. The active and reactive power flow at two connected low voltage sources is illustrated in Figure 2, the power flow from generator to a bus is described as [17].
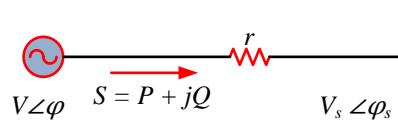

Figure 2. Equivalent circuit in AC sub microgrids

$$P + jQ = S = VI^{*} = V \left(\frac{V - V_s}{r}\right)^{*} \tag{1}$$

Active and reactive power that flow accros between generator and bus are described as [8]:

$$P = \frac{|V^2|}{r} - \frac{|V||V_s|}{r} \cos \delta \tag{2}$$

$$Q = -\frac{|V||V_s|}{r} \sin \delta \tag{3}$$

$$\delta = \varphi - \varphi_s = \int (\omega - \omega_s) dt \tag{4}$$

Where $V, \varphi, V_s, \varphi_s$ are generator voltage amplitude, generator phase angle, bus amplitude voltage, bus phase angle, and ω, ωₛ are angular frequency of the generator and the bus, respectively, represents the line resistance.

2.2. Power flow in low voltage DC microgrid

In DC sub microgrids, the active power is [12, 18]:

$$P_{dc} = V_{dc} I_{dc} \tag{5}$$

Where I_{dc} the amount of current coming from all DC sources going to the interlinking converter, and V_{dc} is the voltage in the gate between the DC sub microgrid and interlinking converter. The active power flowed to AC sub microgrids :

$$P_g = P_{dc} - \sum(P_{dc-ac}, P_{lc}) \tag{6}$$

Where, P_{dc-ac} is the loss power which due to the conduction and commutation of the converter IGBT, and P_{lc} is the instantaneous power absorbed by the filter. Assuming, there are no power losses in the converter and the filter.

$$P_g \approx P_{dc} \tag{7}$$

Only active power is transferred to AC sub microgrid:

$$Q_g = 0 \tag{8}$$

2.3. Interlinking converter

The interlinking converter as interface equipment between the two sub-microgrids requires controls that allow the converter to work in two directions, as an inverter and rectifier, according to the conditions of both sub-microgrids. For this reason, interlinking converters use the bidirectional converter concept.

In Figure 3, the interlinking converter uses three legs with six Insulated Gate Bipolar Transistor (IGBT)s. The input control is come from both sides, in the AC sub microgrid side using current and voltage, and the voltage in the DC sub microgrid side [19-23].

The voltage from the AC sub microgrids become input for the Phase Locked Loop (PLL) circuit before transformed to the d-q coordinate along with the current from the AC sub microgrids. Phase-Locked Loop (PLL) is to equalize the phase angle in the interlinking converter systems. Meanwhile, the Voltage from DC sub microgrids will be compared with the DC reference voltage and controlled with PI controller. The value of the $i_{d\,reff}$ depends on the results of the PI control and the constant value which is set as the maximum and minimum values as in (9).
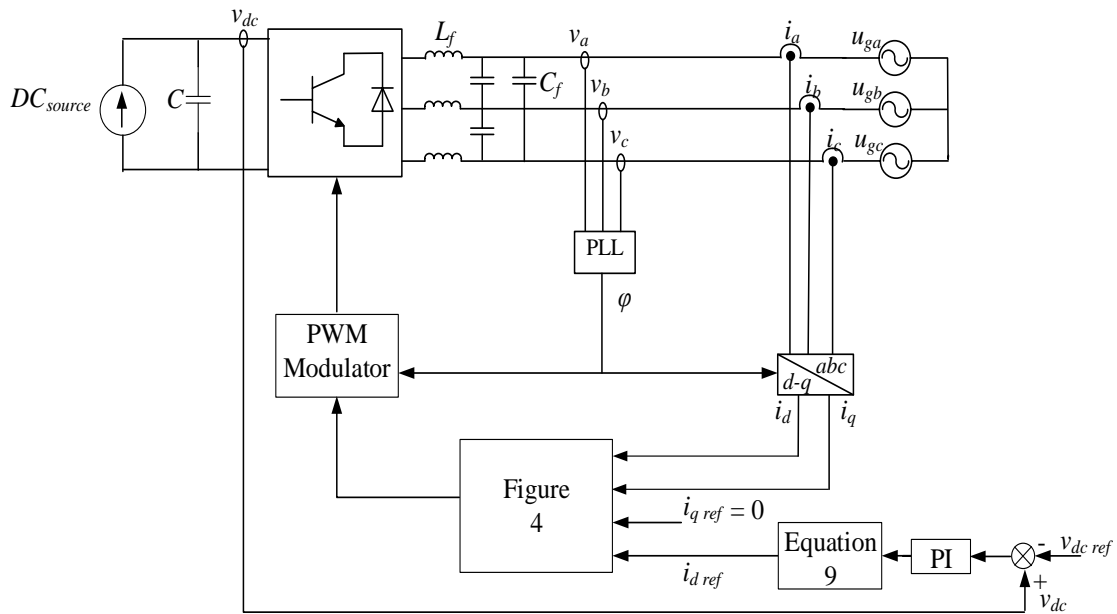

Figure 3. Interlinking converter

$$i_{d\,reff} = \begin{cases} i_{d\,reff}\,; \ -C_{min} < i_{d\,reff} < C_{max} \\ -C_{min}\,; \ i_{d\,reff} < -C_{min} \\ C_{max}\,; \ i_{d\,reff} > C_{max} \end{cases} \tag{9}$$

As an input PWM modulator the values of v_d and v_q are the sum between i_d and i_q with $i_{d\,reff}$ and $i_{q\,reff}$ that controlled by the PI controler, as described in Figure 4. Finally, the PWM modulator produces pulses that move the switch on IGBTs in the interlinking converter.
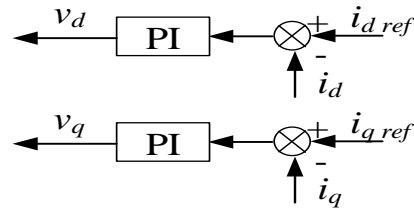
Figure 4. Current Regulator

3.   SIMULATION AND DISCUSSION

Hybrid AC-DC microgrids are modeled by SIMULINK/MATLAB simulation. DC sub microgrid have 2 DC sources, 600 voltage, each connected with permanen load of 1 KW, while the power from the DC source will be set to determine the system response. Generator with 4MW capacity, 400V voltage, 50Hz frequency, R/X ratio 7 as a source in AC sub microgrid, connected with 1 MW permanen load and 1 MW as additional load. DC sub microgrid is connected to AC sub microgrid via an interlinking converter as shown in The simulation algorithm is started by setting the power source conditions in the DC sub microgrid as explained in Figure 5. With power changes in DC sub microgrid, the power flow that occurs in the system can be separated into two different cases, they are:

1. Power flow from DC to AC sub microgrids (IC in Inverter Mode).
2. Power flow from AC to DC sub microgrids (IC in Rectifier Mode).

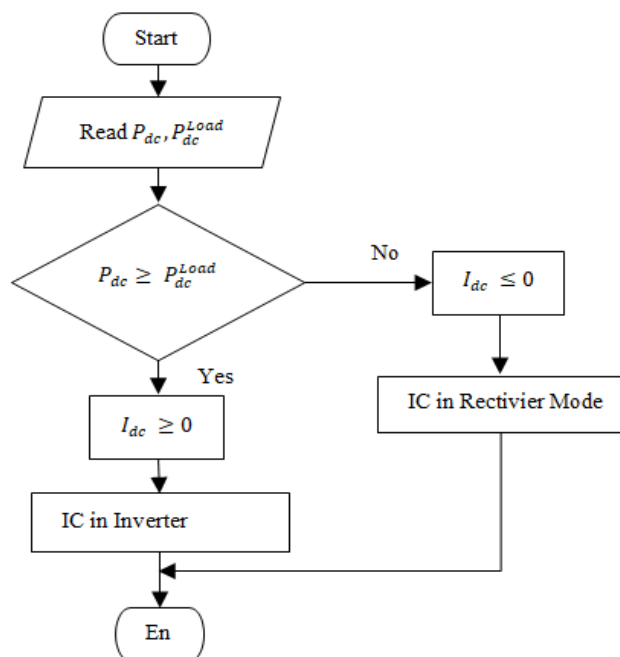Power flow analysis was carried out in two places, in the DC sub microgrid and AC sub microgrid (Figure 1).

Figure 5 Simulation algorithm

3.1. Power flow in DC sub microgrid

In the first case, power flow from DC to AC sub microgrids, the power on the DC sub microgrids is set in 10 KW, in t = 3s then drops to 5 KW and goes down again in t = 4,5s to just 1 KW. A decrease in power makes changes in the current direction, from DC sub microgrid to AC sub microgrid to vice versa. The change of current direction cause changes in power flow, the power flowing from positive 8 KW gradually down to negative 5 KW. In voltage, there is a little overshoot when the power change, but it is relatively stable. Greater overshoot occurs when there is a large load change in AC sub microgrid, but this does not cause changes in power flow direction.

In the second case, the power on the DC sub microgrid is set in 1 KW, then rises to 5 KW and rises again to reach 10 KW. This case is the opposite of the condition in the first case. The simulation starts with the condition of DC sub microgrid that lacks of power. Figures 6 and 7 describe the result of this simulation.
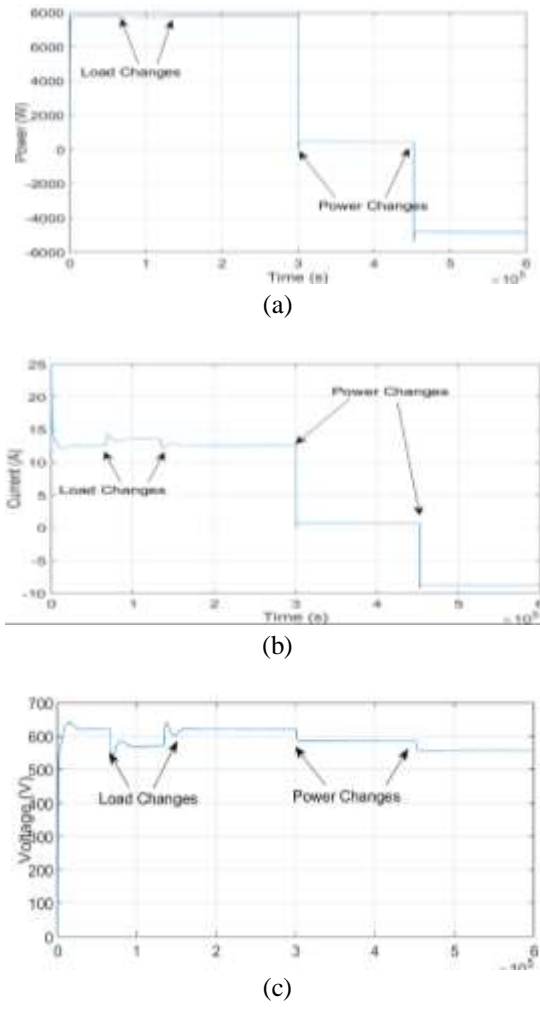

(a)

(a)

(b)

(b)

(c)

(c)

Figure 6. DC sub microgrid power, current and voltage in inverter mode, (a) Power, (b) Current, (c) Voltage
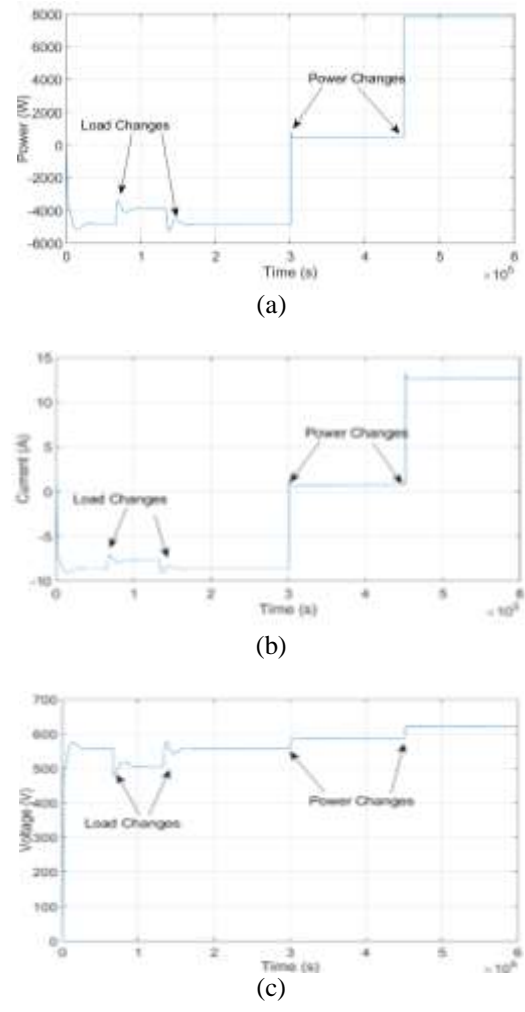
Figure 7. DC sub microgrid power, current and voltage in rectifier mode (a) Power, (b) Current, (c) Voltage

3.3. Power flow in AC sub microgrid

In the first case, the power flow on the AC sub-microgrid due to a decrease in power on the DC sub-microgrid can be seen in Figures 8, 9 and 10. In Figure 8(a), there is a voltage reaction combined with a current during the simulation. Change direction of power flow is indicated by an angular shift between current and voltage almost 90^0 [13, 24-25]. Figures 8(b) and 8(c) are excerpts from Figure 8a which show the shift. Figure 9 describes the result of active and reactive power, and Figure 10 show the frequency that occurs in the AC sub microgrid.

The results of the second case are described in Figures 11, 12, and 13. As in the first case, the phase shift in current to voltage indicates a change in the direction of the power flow shown in Figures 11 and described in Figures 11 (a) and 11 (b). An increase or decrease in power causes a little overshoot on active power, reactive power, and frequency. Greater overshoot occurs due to additional load, but this does not change the power flow direction.
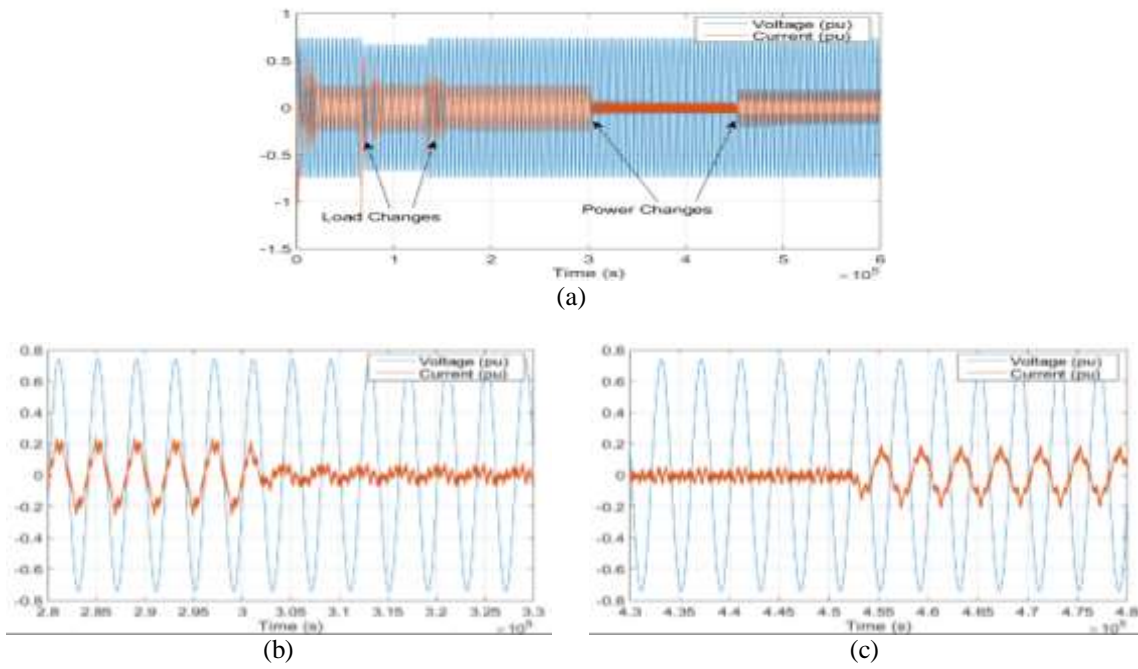
(a)

(b)

(c)

Figure 8. AC sub microgrid voltage and current in first case (a) The results of the whole simulation,
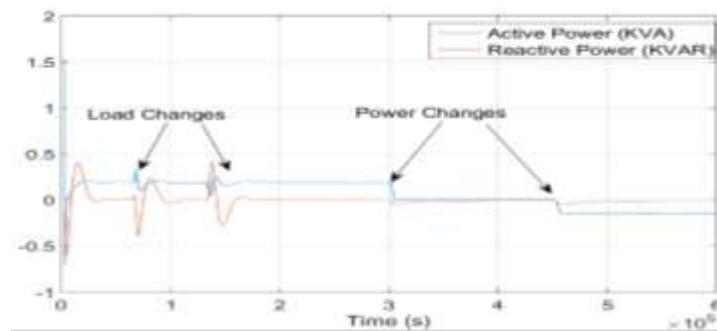(b) simulation at t = 2.8 s to t = 3.3 s (c) simulation at t = 4.3 s to 4.8 s

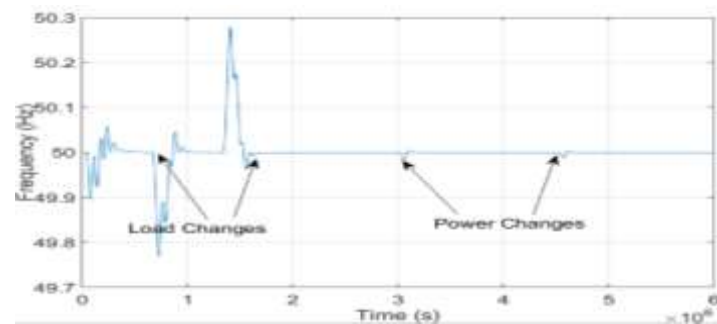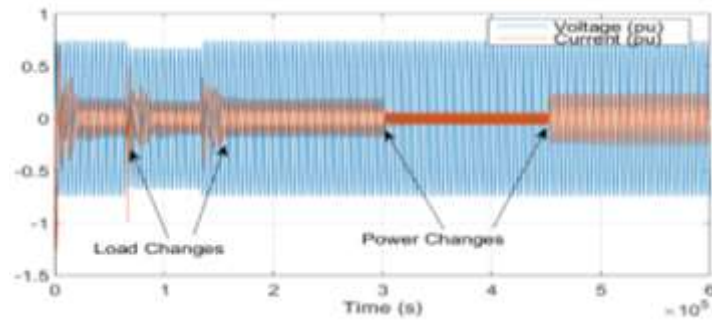
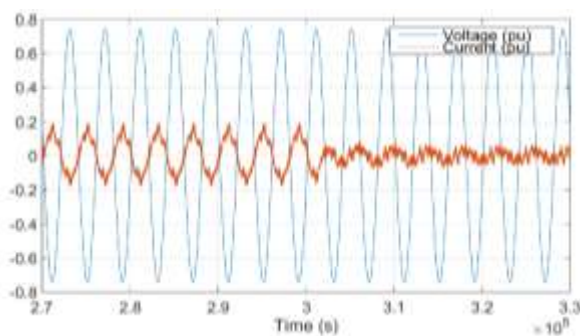Figure 9. Active and reactive power in first case
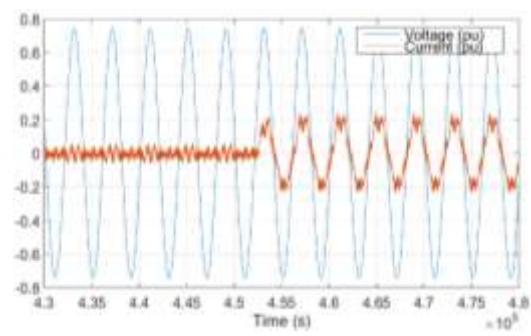

Figure 10. Frequency in first case

(a)

Figure 11. AC sub microgrid voltage and current in second case (a) The results of the whole simulation, (b) simulation at t = 2.7 s to t = 3.3 s, (c) simulation at t = 4.3 s to 4.8 s

(b)

(c)

Figure 11. AC sub microgrid voltage and current in second case (a) The results of the whole simulation, (b) simulation at t = 2.7 s to t = 3.3 s, (c) simulation at t = 4.3 s to 4.8 s

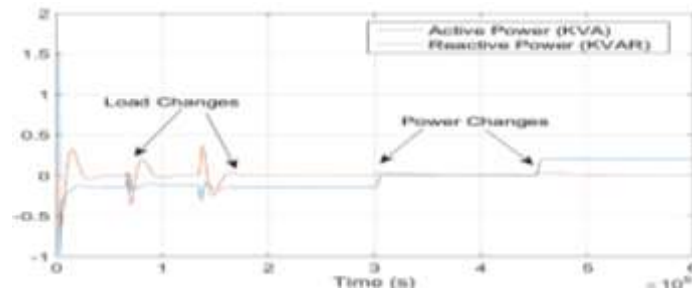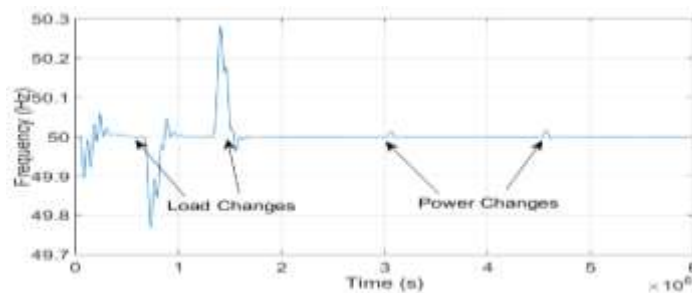
Figure 12. Active and reactive power in rectifier mode

Figure 13. Frequency in rectifier mode

4. CONCLUSION

This paper discusses the low voltage hybrid AC–DC microgrids power flow in islanding operation. The model simulation of hybrid AC-DC microgrid model have been carried out in two different cases, power flow from DC to AC sub microgrids and power flow from AC to DC sub microgrids. The result of the simulation shows that the model has a good response to power changes conditions. With the phase shift between current and voltage proves that the interlinking converter can flow the power, either active or reactive power from the dc sub microgrid to the ac sub microgrid and vice versa. In addition to power flow, interlinking converters can also keep the voltage and frequency system stable and reliable during load and power changes. Overall it can be said that the model can be simulated properly.

ACKNOWLEDGEMENTS

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Hasti Afianti was born in Surabaya East Java Indonesis, in 1974. She received bachelor and master degree in electrical engineering from ITS Surabaya, in 1998 and 2005, respectively. She also worked as a lecturer in University of Bhayangkara Surabaya. She is currently working toward the doctoral degree, in electrical engineering in Power System and Simulation Laboratory (PSSL) ITS Surabaya. Her research interest includes power system modeling and simulation, microgrid, power quality, distribution automation system and renewable energy.

Ontoseno Penangsang was born in Madiun East Java Indonesia, in 1949. He received bachelor degree in electrical engineering from ITS Surabaya, in 1974. He received M.Sc and Ph.D degree in Power System Analysis from University of Wisconsin, Madison, USA, in 1979 and 1983, respectively. He is currently a professsor at Department of Electrical Engineering and the Head of Power System and Simulation Laboratory (PSSL) ITS Surabaya. He has a long experience and main interest in power system analysis (with renewable energy sources), design of power distribution, power quality, and harmonic migitation in industry.

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