ISBN 978-602-53531-8-5

Development Control System Of Microgrid During Islanding Condition Using Fuzzy Logic

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Abstract

In the microgrid each of micro generation (inverter) is connected in parallel with the network or with other micro generation. During on grid conditions, connection with network can be easily done because each generation refers to the parameters of the grid and it will generate energy as much as possible from the potential energy owned, if there is excess power, it will be supplied to the grid. But during off grid conditions, not all micro generation can be connected in parallel directly. Especially on micro generation that are not equipped with power sharing capability.

In this research the control system will be developed to improve the performance of the microgrid. The on-off grid tie inverter (on-off GTI) that cannot be connected in parallel with another inverter during islanding condition will be able to connect in parallel, so that the whole system can improve performance of microgrid. The control system was developed using fuzzy logic to reconfiguration PV circuit, which intended to regulate inter-inverter parallel mechanism by taking into account the amount of radiation and the power state of each inverter. The test results showed an increase in energy absorption from PV up to 26% and increased operation of the battery up to 26.38%.

Keywords: *On-off GTI, microgrid, parallel inverter, fuzzy logic*

1. Introduction

Electrical power problems in the application of renewable energy sources connected to grid can be solved using a distributed generation approach. In this system each power generation is seen as a subsystem of a grid, called microgrids (Lasseter, R.H., 2002; Nikkhajoei, H. and Lasseter, R.H, 2009) (Kroposki B., et al, 2008). Implementation of the free market of electricity and attention to environmental issues related to pollution due to gas emissions as well as efforts to conduct energy efficiency and diversification, encourage the implementation of distributed energy source systems, especially renewable energy sources and small-scale Combined Heat and Power (CHP) plants (European Commission, 2003). In recent years, rapid developments in power electronics and semiconductor technology are driving increased application of power generation uses renewable energy sources using power converter technology. The technology development has improved the transient response faster and neither is the processing time and execution of complex control algorithms can be completed with a faster time (Xiongfei W., et al, 2012). In the solar power plant configuration, solar cells are connected in series and parallel to achieve the desired power and output voltage, according to the DC input voltage required by the power converter. Inverter as power converter will convert DC power to AC to supply load. To obtain optimal power from solar cells, the inverters are equipped with MPPT technology, which will make solar cells operate at maximum power point. Inverter technology also allows the solar power can be connected to the network, so that the electrical energy generated can be supplied to grid, and vice versa grid power will subtitute power to load when power shortage in solar generation due to the sun dim (W. Kramer, et al, 2008).

In the microgrid, each micro generation (inverter) is connected in parallel with the network or with other micro generation. During on grid conditions, connection with network can be done easily because each generation refers to the parameters of the grid and each generation will generate energy as much as possible from the potential energy owned, because if there is excess power, it will be supplied to the grid. But during off grid conditions, not all micro generation can be directly connected in parallel. Especially on micro generation that are not equipped with power sharing capability. In previous research, the on-off grid tie inverter (on-off GTI) that doesn't have the ability to share power with other inverter, can connected in parallel with other inverters when islanding condition and forming microgrid using master slave network topology and reconfiguration on PV circuit (Hartono BS., et al, 2015).

In this research the control system will be developed to improve the performance of the microgrid. The on-off grid tie inverter (on-off GTI) that can not be connected in parallel with another inverter during islanding condition will be able to connect in parallel, so that the whole system can improve performance of microgrid. The control system was developed using fuzzy logic to reconfiguration PV circuit, which intended to regulate inter-inverter parallel mechanism by taking into account the amount of radiation and the power state of each inverter.

2. Literature Review

2.1 Parallel Inverter

Each energy source in microgrid, either from wind, solar cells and other energy sources, is all converted into electrical energy using suitable power converter circuit and form a distributed power generator network. The inverter circuits operated stand alone or connected in parallel to supply the load at the same time (Chien-Liang, et al, 2010). In grid tie inverter, when tied to grid each inverter can operating in parallel and synchronized by grid power source. In islanding conditions or off grid, where there is no power from grid, it will need a control system that can manage the work of each inverter to be connected, especially in relation to distribution of power that must be supplied by each inverter. Thus each inverters can supply power to other inverter loads that shortage of power to supply the load. Control mechanism that can be use in microgrid during islanding condition can be classified into two types, using communication media and without communication media to coordinate between inverter. Load sharing method with communication media including, centralized control, master slave, average load sharing (ALS), circular chain control (3C) (Josep M. Guerrero, et al, 2008). Equivalent circuit of distributed generator using master-slave control configuration during islanding condition can be seen in Fig. 1. In the circuit below, an inverter works as voltage source that serves as temporary master while other inverters work as a current source that serve as slave.

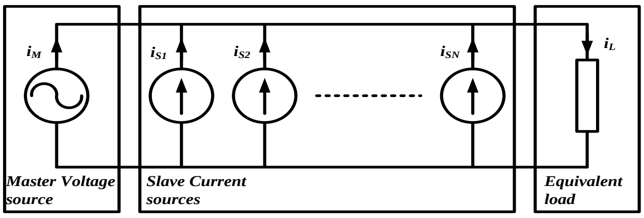


Fig. 1: Equivalent circuit of parallel inverters in distributed generator

The equivalent circuit of two paralleling inverters is shown in Fig. 2. (Hongliang Wang, et al, 2010)

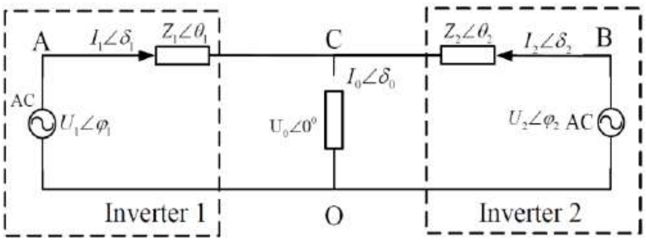


Fig. 2: Equivalent circuits of two paralleling inverters

$$S_1 = \dot{U}_1 \dot{I}_1^* = \frac{U_1^2}{Z_1} e^{j\theta_1} - \frac{U_1 U_0}{Z_1} e^{(\varphi_1+\varphi_1)} = P_1 + Q_1 \tag{1}$$

$$P_1 = \frac{U_1 R_1}{R_1^2+X_1^2}(U_1 - U_0 cos\varphi_1) + \frac{U_1 U_0 X_1}{R_1^2+X_1^2} sin\varphi_1 \tag{2}$$

$$Q_1 = \frac{U_1 X_1}{R_1^2+X_1^2}(U_1 - U_0 cos\varphi_1) + \frac{U_1 U_0 R_1}{R_1^2+X_1^2} sin\varphi_1 \tag{3}$$

Where :

- U1 and U2 are output voltages root mean square (RMS) of two inverters.
- φ1 and φ2 are the phase angles.
- U0 is RMS of the load voltage.
- Z and θ are the magnitude and the phase of the output impedance.
- R = Zcosθ, X = Zsinθ

Another thing to be concern when connecting inverters in parallel on a microgrid is the reverse current of the inverter into another inverter. This can be caused by one inverter gives a greater power, while the other inverter has a low load. A reverse current can cause damage to the DC link.

2.2 Fuzzy Logic Control

Fuzzy logic is based on fuzzy relations and fuzzy propositions, the latter being defined on the basis of fuzzy sets (Nikola K. Kasabov, 1998). The fuzzy logic is able to covering the complex system with their uncertainties and inaccuracies that can't solved using classic control theory (Bevrani, H., et al, 2012). Fuzzy Logic is set of multivalued logic that allows intermediate values to be defined between digital logic like true/false or 1/0. Fuzzy logic deal with the concept of partial truth, where the truth value may range between completely true and completely false. Classical logic only permits propositions having a value of truth or falsity.

In the application development of 7-level power inverter, FL controller is used to reduce the rise time and setling time so that the delay time can be reduced. The fuzzy logic controller control the switches present in the boost converter and H-bridge inverter. The six power electronic switches are used only one switch will operate at high frequency at any time (K. S. Gobisha, et al, 2015). Fuzzy logic controller used to control constant load voltage under varying rotor speeds or loads by vary the duty-cycle of the DC-DC converter (Pooja Patel and Jyoti Shrivastava, 2016). An algorithm to determine the optimal scheduling of microgrids is proposed (Juan P. Fossati, et al, 2015). The storage system is controlled by a fuzzy expert system. A genetic algorithm is used to determine the knowledge base of the expert system. The scheduling problem and the building of the knowledge base are jointly tackled. Simulations are performed both for a grid-connected and an islanded microgrid.

2.3 Solar Power Equation

The simplified equivalent circuit of a photovoltaic cell consists of a diode connected in parallel with a current source known as one diode model. In this model current source I_{ph} generated directly proportional to solar radiation (Dorin Petreus, et al, 2008).

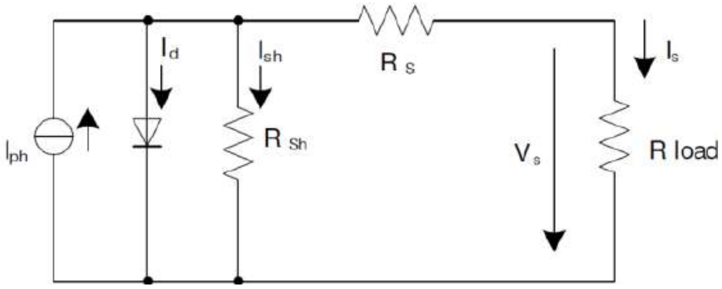


Fig. 3: Equivalent circuit of a photovoltaic cell

With:

- I_{ph} – photo current;
- I_d – diode current;
- I_{sh} – diode reverse saturation current;
- I_S – load current.

The photocurrent I_{ph} is given by the equation:

$$I_{ph} = P_1.F_s[1 + P_2.(F_s - F_o) + P_3.(T_j - T_o)] \quad (4)$$

$$I_d = I_{sat}\left[exp\left(\frac{e_o}{a_f.N_s.k}.\frac{V_s+R_s.I_s}{T_j}\right) - 1\right] \quad (5)$$

$$I_{sh} = \frac{V_s+R_s.I_s}{R_{sh}} \quad (6)$$

$$I_{sat} = P_4.T_j^3.\exp(-\frac{E_g}{k.T_j}) \quad (7)$$

Where

- F_0 = 1000W/m2
- T_0 = 298.15K,
- Tj = junction temperature.

- e_o = 1,60217733.10[19][C] is charge of electron
- a_f = "ideally factor", usualy is 1
- Ns = number of cells in series
- k = 1,380658 10 [J/K]$^{-23}$ is Boltzmann's constant
- Rs [Ω] = models the series resistance
- Eg [eV] = The band gap
- P_4 [$\frac{A}{K^3}$] = a correction factor.
- P_1 [Am2 /W], P_2 [m2/W] and P_3 [1/K] are constants, usually given by the producers
- The parameters P_4 [A/K3], R_s [Ω], R_{sh} [Ω] can be obtained from the solar panel's datasheet.

3. Propose Design

Microgrid control system design is based on the results of previous research, that can estimate the amount of power input from solar radiation by looking at the value of the PV voltage and current. While the measurement of the output power of each inverter to the load can determine opportunities for both parallel inverters. By using fuzzy logic rules and conducting a second regulatory mechanism, the inverter can work parallel in a master slave configuration. The control system consists of a controller device that will do the reading input parameters and output actuation devices that will regulate the amount of power input and local load on each inverter. Diagram of development control system as shown in Fig. 4.

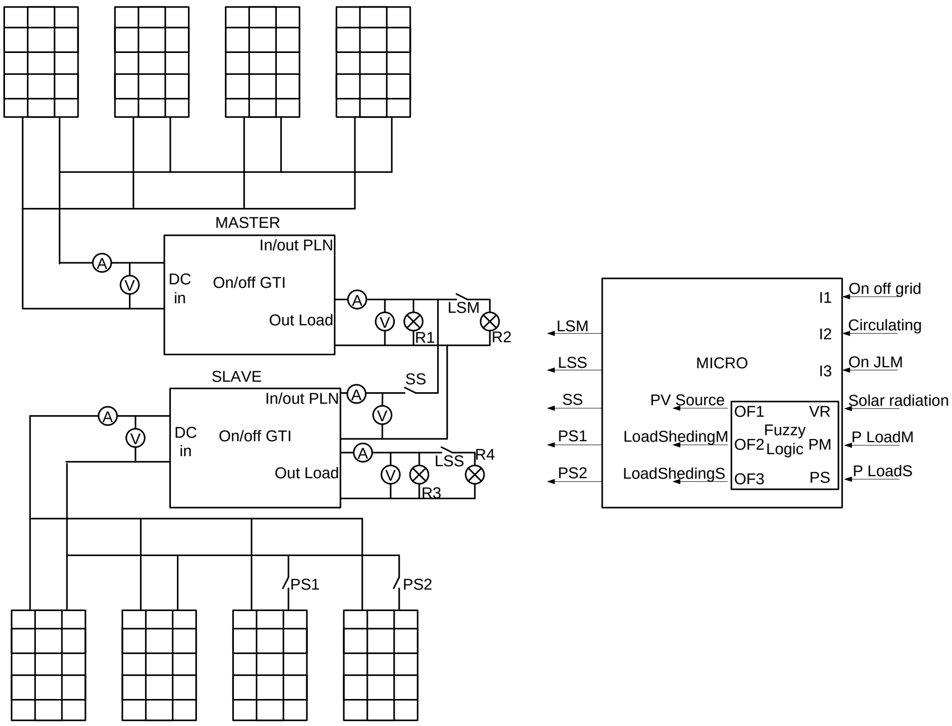


Fig. 4: Control system diagram

Control system design using matlab starts with the setting the parameters control, both for inputs and outputs, to be processed using fuzzy logic. Based on the problems identified,

fuzzy input parameters are:

- Sources of radiation
- Load on inverter master and slave.

As for the fuzzy output parameters are:

- Setting of PV energy sources
- Load shedding on master load
- Load shedding on slave load

Table 1: Mapping of input parameters of fuzzy logic

INPUT	H	M	L
Radiation (RAD)	> 4,5	>3,75	<3,75
Power master (PM)	> 200W	>100	<100
power slave (PS)	> 200W	>100	<100

Table 2: Mapping rules of input and output fuzzy logic

RAD		**H**	**M**	**L**
PS	**PM**	**SPV,LSM,LSS**	**SPV,LSM,LSS**	**SPV,LSM,LSS**
H	H	allon,on,on	allon,on,on	-
H	M	allon,off,on	allon,off,on	-
H	L	allon,off,off	allon,off,on	-
M	H	off1,on,off	allon,on,off	-
M	M	off1,off,off	allon,off,on	-
M	L	off1,off,off	allon,off,off	-
L	H	off1,on,off	allon,off,off	-
L	M	off1,off,off	allon,off,off	-
L	L	off2,off,off	off1,off,off	allon,off,off

Description:

RAD : radiation PM : power master PS: power slave
H : High
M : Medium
L : Low
SPV : PV source
for PV source:

- allon : Relay PS1 and PS2 on
- off1 : Relay PS1 off
- off2 : Relay PS2 and PS2 off

LSM : LoadShedingMaster
LSS : LoadShedingSlave
for LSM and LSS:

- on : perform load shedding relay means open
- off : not perform load sheding relay means close

From output mapping, it appears that the input power settings, from PV is divided into 3 levels:

- allon means, from 4 PV are used, all connected to the inverter while
- Off1 means, there is one unused PV
- Off2 means, there are two unused PV

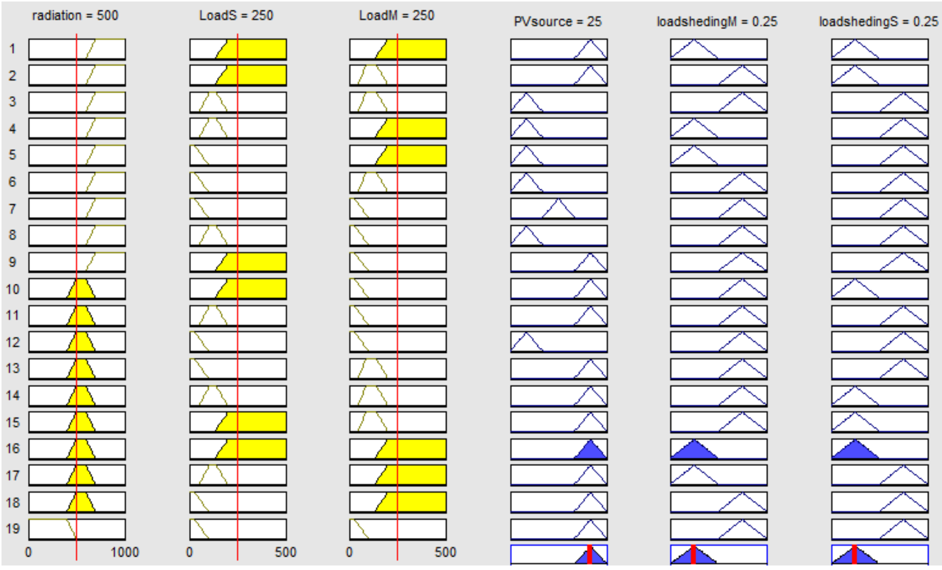


Fig. 5: Rule viewer of fuzzy logic control

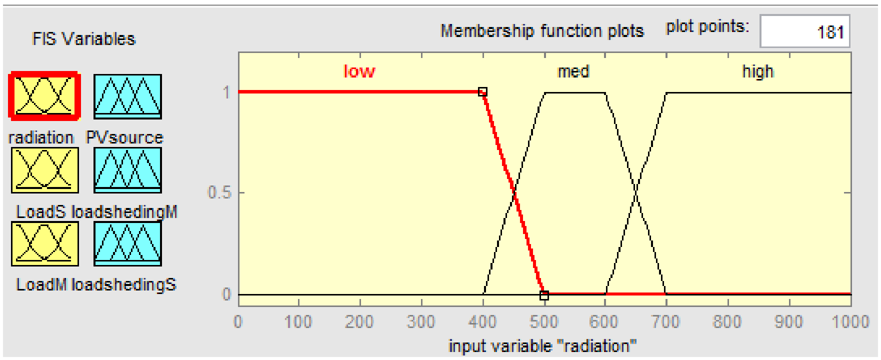


Fig. 6: Membership function plot

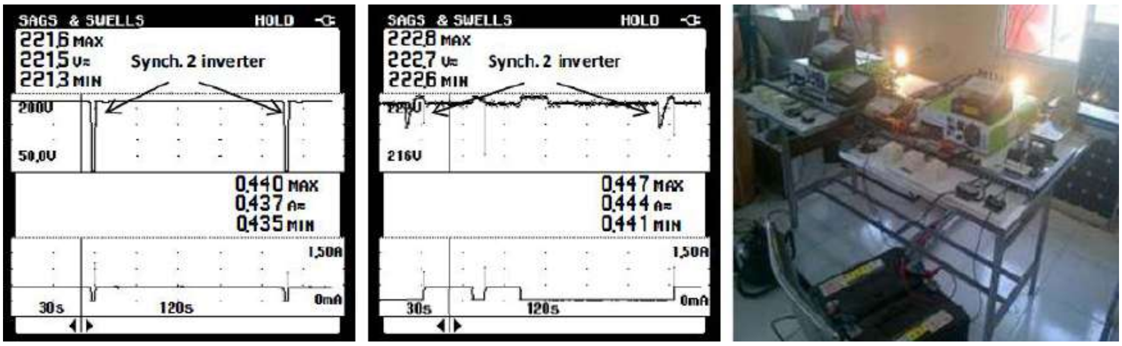
Solar radiation will be measured using a radiation measuring circuit, which will convert the amount of radiation into voltage of 0 volts to 5 volts. Based on the measurement results, the amount of radiation is classified into, above 700W/m2 (> 4.5 volts) as high radiation / high (H), above 600W/m2 medium / medium (M) and under 600W/m2 less / low (L). Similarly done to define fuzzy parameters, to power local loads of master and slave, as shown in table above.

Based on the mapping of input and output fuzzy logic, a fuzzy logic control system design using matlab is performed. Design begins with a fuzzy inference system. Starting from the fuzzification of input and output. Proceed with the design of fuzzy rule between inputs and outputs. Designed by using the rule viewer to be seen whether metlab control system works as designed.

4. Result and Discussion

Based on the analysis of the rule viewer, control system design using fuzzy logic has worked corresponds to a mapping of input and output design. In the system controller development, the main operation is having two parallel mechanisms inverter duringthe islanding condition (off grid). during on grid conditions, then microcontroller just read connection status to the grid, without control mechanisms at all. Based on inputs and outputs test on the system microcontroller, it looks that appropriate design program has been running. Program has not been implemented to microgrid system functions as a whole. This is due to limitations of available resources both human resources and testing facilities, but from the representation of the input and output of the I/O microcontroller, it can be concluded that the system has been able to work as designed.

The test results showed that when both paralleled inverters performed without prior arrangement, the instability occurs when both inverter synchronization process failed. This is caused due to excessive power supply of the slave inverter, so that reverse current occurs on master inverter. Protection of the master inverter disconnects both parallel inverters. To balance the power demand on the load, the configuration of solar panels on the slave inverter is reduced, so that power is supplied to the load is reduced and the condition can occur in both synchronous inverter operated parallel. The measurement results of two synchronous condition inverters operating in parallel as shown in Fig. 7 (Hartono BS., et al, 2015). The test results showed an increase in energy absorption from PV up to 26% and increased operation of the battery up to 26.38%.



(a) (b) (c)

Fig. 7: (a) unstable condition of parallel 2 inverter (b) Synchronous condition, 2 pieces of inverter stable and stability is achieved due to the setting of fuzzy logic (c) Parallel inverter output voltage

5. Conclusion

Control mechanisms of micro grid systems, consisting of on-off GTI, during islanding conditions, can be done by arranging the PV circuit configuration using the fuzzy control method. The test results showed an increase in energy absorption from PV up to 26% and increased operation of the battery up to 26.38%. The use of on-off GTI in microgrid applications can be performed in a master-slave configuration. In this configuration, one inverter works as reference to other inverter is connected to it.

It should be considered to controlling the operation of two on-off GTI in parallel can be perform by controlling the input energy from PV to the inverter which acts as a slave, does not exceed the power which required by the load so there is no reverse current into the master inverter. Input energy control is done by configuring the number of PV panels connected to slave inverter in order to obtain the appropriate amount of power input, so that both inverters can work as a microgrid.

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