Stability Enhancement in Micro-Grid Using Fuzzy Logic Controller

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Abstract- **A Fuzzy Logic-based framework is proposed for control of Micro-Grid Systems to achieve better stability when compared to conventional controller. Typically, a Micro-Grid system operates synchronously with the main grid and also has the ability to operate independently from the main power grid in an islanded mode. This paper focuses on the stability of MG operation and discusses the control techniques. The control strategy examines the FLC controller to expand the MG system stability for solving power quality issue of frequency fluctuation and voltage. It is presented that the Proposed FLC controller can be considered as a means of power quality control to improve the frequency fluctuation caused by a voltage deviation on source side with the reference of Real (P) and Reactive (Q) power of MG. The renewable sources and the storage system are connected on DC-bus which is interconnected with a MG through a Voltage Source Inverter (VSI). The attention focuses on the control technique of the VSI during grid connected operation of the MG. The MG stability and reliability can be improved by controlling the voltage and frequency. To validate the proposed modified fuzzy-logic-based controller is compared with the conventional PI controller, simulation and experimentation results are provided using a MATLAB/Simulink model.**

Keywords: **MG (MG), Fuzzy Logic Controller (FLC), Voltage Source Inverter (VSI).**

I. INTRODUCTION

The MG is a small-scale distributed electricity network, which is designed to provide power for local communities. A MG is an aggregation of multiple distributed generators (DGs) such as renewable energy sources, conventional generators, in association with energy storage units which work together as a power supply network in order to provide both electric power and thermal energy for small communities which may vary from one common building to a smart house or loads. Typically, a MG operates synchronously in parallel with the main grid. However, there MG operates in islanded mode, or in a disconnected mode. In this paper assume that when the MG is connected to the main grid and is working synchronously with it, the flow of electric power can be either from the main grid to the MG or vice-versa. In this case the flow of power is from the Micro-Grid towards the main grid, Micro-Grid is delivering power to the main grid. In other words, the excess power generated currently by the renewable electricity generators or stored previously in the batteries.

According to International Energy Agency (IEA), more people do not have access to electricity in India. Therefore the major challenges in electricity sector are two factors:

- Expanding access to electricity for sections of populations not reached by the grid
- Meeting increased demands from sections of populations within the reach of the grid
- By increasing power generation reduce around 26 % losses in transmission and distribution.

The above factors could be done by the use of Renewable Energy Sources (RES) such as solar, wind, bio and hydro etc. Using RES to meet the energy demand, it can be particularly used in remote areas. In order to achieve electricity in remote area and decrease the transmission losses we proposes the MG technique.

MG is a part of the power distribution system which uses renewable energy based of power generation connected to the grid system. The renewable energy systems like photovoltaic, wind turbine, energy storage and local loads. The MG system is the technique to ensure stable operation during faults and various network disturbances in grid and islanding connected mode.

During the operation the several Renewable Energy Sources (RES) must be equipped with the power electronics devices and controls to provide the stability and ensure to increase the power quality of the grid [1]. Renewable energy sources are commonly used as distributed generation sources in MG systems, because they are environmentally friendly, a sustainable source of energy, and constructed on either the consumer or utility side.

In the MG the major problem is arise due to the voltage and frequency instability [2]. Because of this problem the MG stability and reliability can be decreased. So there is a need of controller to control the inverter firing signals. Based on this signals the grid voltage and frequency can be maintained to their desired level. By means of power electronics devices the control and flexibility of the MG is achieved. The power converters are employed as interface with the main grid because MGs can be considered as inverter dominated electrical networks. When the MG is connected to the main grid, inverters use the signal of main grid as reference to obtain an AC signal with the correct frequency and voltage [3]. But, in islanding, the reference of the main grid is lost, so inverters must find new references to continue the generation of good power quality. So in MG, control techniques are necessary to allow the good operation of inverters.

The aim of this paper is the process of FLC control strategies allowing grid connected MG stability improvement is compared to the conventional PI controller. The paper is organized as follows: Section II describes the architecture of the investigated MG, Section III the control techniques for the VSI used as power electronic interface in the MG, while Section IV presents simulation results. Finally, Section V summarizes the conclusion of this paper.

II. INVESTIGATED MG

The MG have many different architectures were presented in the literature. A first example is the MG response of the Dead Beat controller in the case of grid fault [4]. The DB controller has the highest robustness in a grid fault condition. MG is a localized grouping of electricity sources and loads that usually interconnected or synchronous with the traditional power system distribution grid. MG is connected to the primary distribution network and usually operates in normal connecting mode. When a severe fault occurs in the primary distribution network, then the MG will transfer to islanding mode.[4]

The voltage level of the MG at the load is about 400V or less. It often provides both electricity and heat to the local area. It can be operated in both grid-connected mode and islanded mode. From the customer point of view, the MG can provide both heat and electricity and also can enhance the local reliability, reduce emissions, improve power quality (by supporting voltage and reducing voltage dip), and can potentially lower the costs of energy supply. From the utility point of view, application of distributed energy sources can potentially reduce the demand for distribution and transmission facilities. Clearly, distributed generations located close to loads can reduce the flows in transmission and distribution circuits with two important effects: loss reduction and substitute for network assets. Further, the presence of generations close to demand could increase the service quality for the end customers.

A MG containing parallel connected inverters where each inverter is controlled by decentralized active power/voltage frequency and reactive power/voltage magnitude droop control laws results in flexible and expandable systems . These systems have been known to have stability problems for large values of active power/voltage frequency droop control gain. However, so far the stability analysis of multi-inverter systems has always been performed in a computationally intensive manner by considering the entire MG. In a practical MG where the number of inverters may be large or the capacity of the units may differ, it becomes essential to develop a method by which stability can be examined without much computational burden. A master-less control of inverters is desirable where every inverter is a grid forming unit defining the voltage, frequency and magnitude of the MG [5]. Under such circumstances, the failure of a given inverter does not cause a collapse of the MG. Communication links between the inverters or a supervisory controller are not essential for the stable operation of the MG but can be used to enhance the transient performance of the MG. For the proper analysis and evaluation of the behavior of the MG a complete model of the investigated system have been developed.

III. CONTROL TECHNIQUES

A. Inverter Control Scheme

The inverter controls is basically classified into two types: current control and voltage control. When the inverter is connected to the utility, the grid controls the amplitude and frequency of the inverter output voltage and the inverter itself operates in the current control mode. The inverter operates in voltage control mode for such scenario providing the reference voltage and frequency.

B. Voltage Controller

In this mode, the inverter output voltage follows the reference voltage. An external voltage signal is first fed into a discrete single-phase Phase-Locked-Loop (PLL). The gain at the input of PLL is used to normalize the actual voltage signal. The output of the PLL block generates a phase angle (θ). The phase angle together with the AC voltage set point is used to generate the reference voltage, V_{ref}.

The PLL is necessary, although inverter is operating in islanded mode; the inverter voltage is synchronized with the utility voltage.[6] Then compare the actual voltage to the reference signal and the error was then fed to a FLC controller. The output of the controller was then scaled and added to a feed forward loop. The voltage controller block diagram was shown in Fig.1.

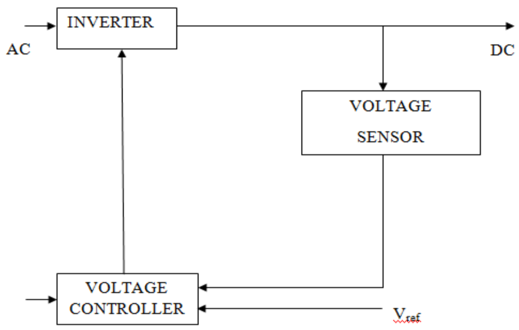

Fig.1 Voltage Controller

C. Frequency Controller

The output frequency of the Inverter is depends on the frequency of the reference signal. Here use 50Hz reference signal. So the output frequency of the inverter is 50Hz. A frequency control block diagram is shown in Fig.2..

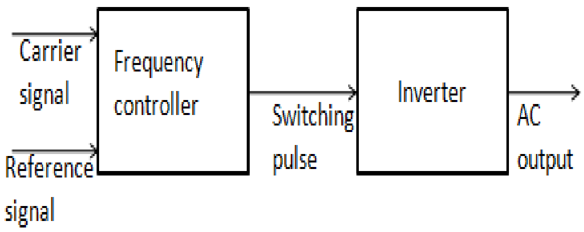

Fig.2 Frequency Controller

During the grid connected operation, the VSI uses the main grid electrical signals as reference. The control of the VSI is usually obtained in the rotating dq-reference frame synchronous to the grid voltage, However, in islanding, the inverters lose that reference and new references must be found. Consequently, the VSI must be able to operate in both configurations as grid connected inverter and stand-alone inverter.

When the MG is in islanding, it is necessary to start the pertinent control mechanisms. The objective is to obtain a frequency deviation equal to zero and to maintain the amplitude voltage value in the islanded MG [8]. To assure this, the inverters must find new voltage and frequency references, maintaining a good power quality. The basic control structure of MG is shown in Fig.3.

In this case, the MG can be considered as an inverter dominated system, because its frequency is controlled by the power electronics. To control the active power through the inverter, the voltage DC-bus VSI side is measured and compared to bus reference. The DC voltage error feeds a FLC controller having a current reference as a output. Its control is performed in dq synchronous reference frame rotating at the fundamental frequency based on current loop controller.

The current controller is processing of signals in two coordinate systems. There are stationary and synchronously rotating coordinate systems [9]. By using the Clarke and Park transformations, the quantities in a three phase balanced sinusoidal system in steady state are transformed into dc-Park components, which is an advantage for control issues. However, in three-phase asymmetrical systems or in systems with voltage harmonics, the Park transformation does not result in dc-quantities.

Those values are the inputs of a Phase-Locked Loop (PLL) for transformation to the dq-reference frame and this ensures a fast and low distorted operation of the PLL [10]. The control is performed in the time domain without transformation of reference frame and by using controllers. The voltage of the grid is controlled by an inner current control loop and an outer voltage control loop.

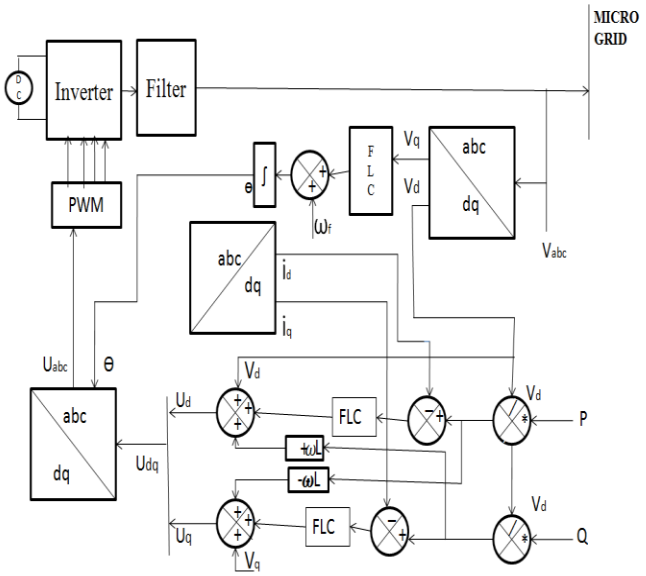

Fig.3 Basic Control Structure of MG

To constrain the inverter current within its safety limits, a fast current controller is used in the inner loop, having a reference current obtained by the outer-loop voltage regulation. An advantage of the inner current control loop is its easy current limit function. This transformation combined with FLC controller allows the steady state error to be eliminated.

D. Design Of Fuzzy Logic Control

In traditional power systems, the frequency control is mostly done by conventional PI controllers that are usually tuned based on prespecified operating loads. In case of any change in the loads, the PI controllers cannot provide the assigned desirable performance[11]. While, if the PI controller can be continuously able to track the changes occurred in the MG. So in this paper proposes the FLC control technique. In the FLC control technique can gets two inputs, one is error in voltage which is the difference between the actual voltage amplitude and another one is change in error, which is the difference between present error and previous error depends their power quality problem or sudden changes in load. Based on the two inputs the FLC controller gives the output to trigger the inverter switch as shown in Figure 1. Here choose triangular membership function corresponding to the three variables.

In order to apply the fuzzy logic to the MG system a set of fuzzy rules consisting of 18 rules. Based on this desired behavior, the corresponding fuzzy rule is: *if* the power set point is changed in MG *n*, *then* change the power set points in the other MGs *and* apply the fuzzy local control rules. The two input variables are Error (e) and Change in error (Δe). The performed fuzzy rules are given in Table I.

e / Δe	H	M	L
H	H	M	L
M	H	M	L
L	M	M	L

TABLE I
FUZZY RULES

The membership functions corresponding to the input and output variables are arranged as H, M, and L. Where H-High, M-Medium, L-Low. According to the fuzzy rules the output voltage signal can trigger the inverter.

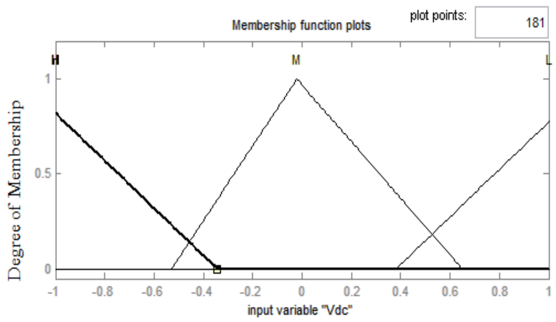

Fig. 4 Membership Function for Input Variable Error

The numerical values for these three input variables are normalized to the [0 1] interval, and then are Fuzzified using three fuzzy sets defined as Low (L), Medium (M), and High (H) as can be seen in figure 2. The input variables after fuzzification will be fed to a fuzzy inference engine where the rule-base is applied to the input-output variables and the output will be determined by human reasoning. There is only one output variable from the fuzzy controller. The input variable error V $_{dc}$ corresponding to their fuzzy rules are shown. The rules are set depends upon their Error (e) and Change in error (Δe). The numerical values for these three input variables are normalized to the [0 1] interval, and then are fuzzified using three fuzzy sets defined as Low (L), Medium (M), and High (H) as can be seen in Fig. 4.

The input variables after fuzzification will be fed to a fuzzy inference engine where the rule-base is applied to the input-output variables and the output will be determined by human reasoning. There is only one output variable from the fuzzy controller. The FLC computes variable step sizes to increment or decrement the duty cycle, therefore the tracking time is short and the system performance during steady-state conditions is much better than with conventional PI controller.

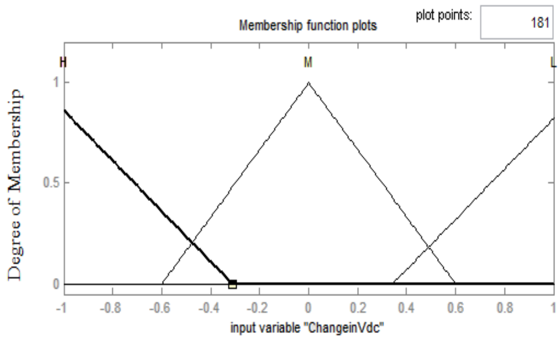

Fig. 5 Membership Function for Input Variable Change in Error

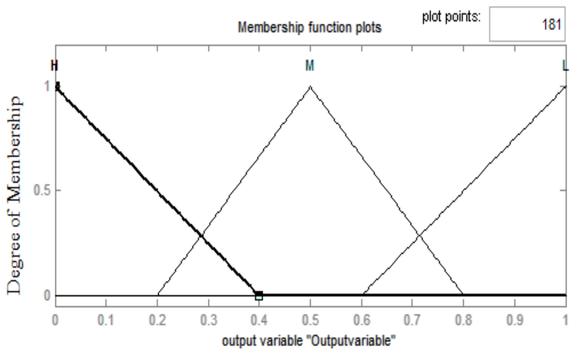

Fig. 6 Membership Function for Output Variable

IV. SIMULATION RESULTS

Simulations have been run using MATLAB/SIMULINK model based on power system tool box. SimPower Systems extends Simulink with tools for modeling and simulating the generation, transmission, distribution, and consumption of electrical power. This simulation model consists of the following three main parts:

- Voltage to Angle Converter
- PI Regulator
- Ideal VSI

The simulation of MG was designed by the FLC controller rules. The MG operation was done by the input/output voltage of its nominal values, filter component parameters were presented in Table II. Here the nominal values are specified based on the perunit values of the given parameters. Based on the input parameters the controller was performed to trigger the inverter signals.

The entire control of the inverter is performed in stationary d-q reference frame. A simulation has been conducted with the investigated MG connected to the main grid to control the inverter signals to the proposed FLC controller. In proposed FLC controller two inputs are given to the FLC. One is DC voltage (400V) and the second input is the change in DC voltage. Then the output of the FLC is given to the reference quadrature axis current I_q [12].

TABLE II
INPUT PARAMETERS

PARAMETERS	VALUES	
Input/output	Input Voltage(V_{DC})	400 (v)
	Output Voltage (Va,Vb,Vc)	230[V_{rms}], 50[Hz]
	V nominal	500 V
	F nominal	50 Hz
	V nominal (dc)	500 V
	P nominal	1000 W
	PWM frequency (grid)	5000 Hz
	Mod_index_max_grid	100
Filter Components	Filter Resistance (R_f)	1 Ω
	Filter Capacitance (C_f)	0.012 µF

Then the output of FLC is fed to the current controller. By using this method the VSI pulse signal can be varied. The simulation model of FLC Controller is shown in the Figure .Using the proposed FLC controller the response of FLC controller voltage at B 400 p.u, current B 400 p.u, real power, reactive power, V_{dc}, frequency, voltage at B 25 p.u, current B 25 p.u is shown below in Figure 5.

From the simulation of MG the line voltage and line current is taken from the B400 (400V) and B25 (25V). The simulation of proposed FLC controller is compared to the conventional PI controller. The figure shows the simulation results when compare to PI controller, the proposed FLC controller gives the better performance of the real and reactive power. So MG stability and reliability can be increased. In this simulation the main grid is tied with the MG by the B400. The MG ac voltage amplitude and frequency by adjusting, at a higher level control layer at the references of real and reactive powers, P and Q to be delivered [13].

Due to the disturbance applied to the load side the MG gives deteriorate performances than the proposed method. In MG the 400 V DC voltage is given , during the disturbance will be applied, that is 0.8 sec the breaker is off and it will be on at 0.12 sec . During this time period the Real (P) and Reactive power (Q) of the grid was changed with respect to their different load conditions. Frequency controller can also be a FLC controller which is driven by subtraction of system from 50[Hz].

The frequency controller can also be a FLC controller which is driven by subtraction of system frequency from 50 [Hz]. Frequency of the system can be measured by a PLL, and in order to get a better performance over the conventional PI controller. By increasing stability and reliability of the MG use proposed FLC controller.

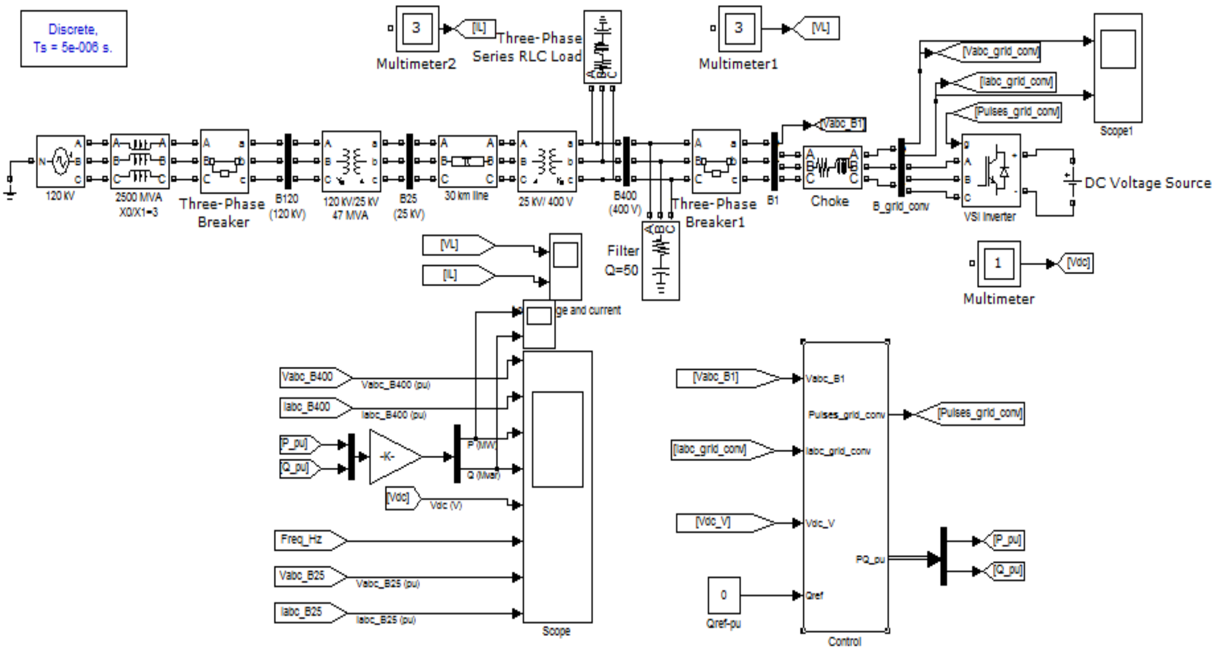

Fig. 7. Simulation Diagram of MG

For the system shown in Fig.7 which a 120kv DG is connected to the MG. A disturbance is inserted to the network at t=0.08 sec to 0.12 sec. The aim is to investigate the response of the controller and mutual effect of active and reactive power [14].

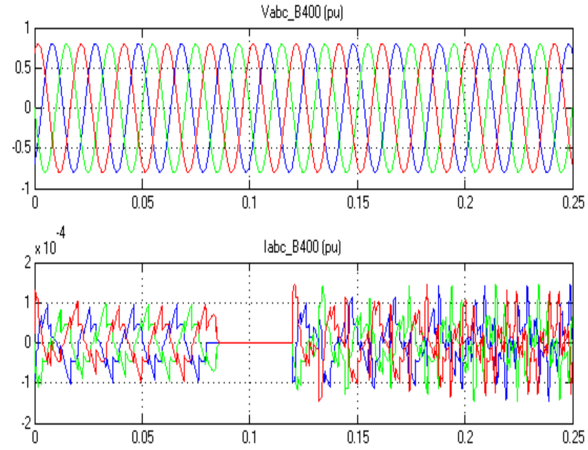

Fig. 8. Voltage and Current at B400 [pu]

First the voltage and current response of the controllers when connected to the B400V [pu] is shown in Fig.8. [15].After the disturbance lost the voltage and current is taken from theB25 [pu] is shown in Fig.9.

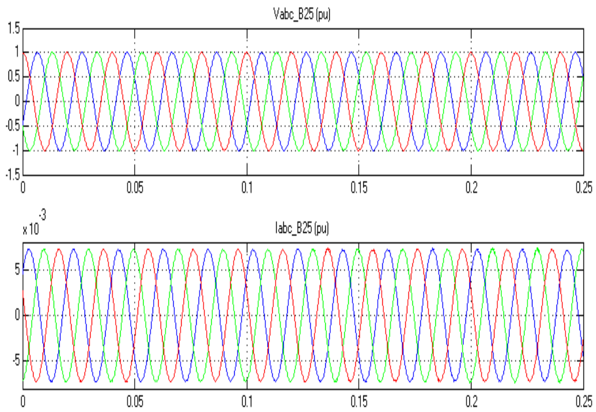

Fig. 9. Voltage and Current at B25 [pu]

From the simulation diagram during the disturbance occurs the real and reactive power is shown in Fig.8. When compare to conventional PI controller the FLC controller gives the better performance. The comparison of PI and FLC response of Real and Reactive power are shown in Fig.10 (a), (b). The performance of real and reactive power is better when the system is compared to PI controller [16].

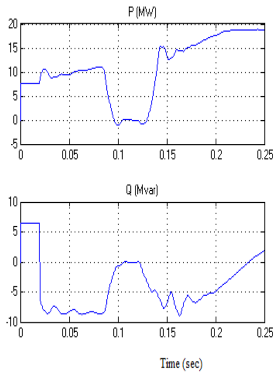

Fig. 10. (a)

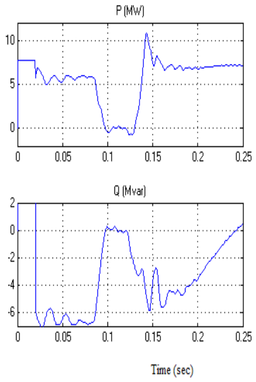

Fig.10(b)

Fig. 10. (a) Real & Reactive Power of PI Controller Fig. 10. (b) Real & Reactive Power of FLC Controller

V. CONCLUSION

In this paper the MG architecture has been modeled in order to analyze its behavior during grid connected operation. The model is based on a DC supply and a VSI used for the interconnection with the main grid. The VSI plays an important role because it acts as interface and fixes the AC voltage amplitude and frequency of the signal into the main grid. In this operation the reference given by the grid is lost and a different control technique is required by the VSI to create new references. In this particular case, simulations results show that using a VSI and control strategies, it is possible to have a good power quality on the MG during grid connected operation. The modeling of MG for power system configuration is done in MATLAB/SIMULINK environment. The inverter model was developed to maintain stable system under various loads and resource conditions and also the control mechanisms are studied. Proposed FLC controller is used to control voltage, frequency, real and reactive power in MG. The proposed FLC controller real and reactive power responses are compared with PI controller. The analysis of the response of the proposed method is better compared to conventional PI controller.

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