Dynamic Stability of Microgrid; A comparative study by PI & Fuzzy Controller.

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ABSTRACT

A microgrid is a small-scale power grid that can operate independently or in combination with other small power grids. Microgrid concept is based on a distributed , dispersed , decentralized , district or embedded energy production .It is a combination of distributed generators (DG's) and energy storage system with power electronic interface such as diesel generators , wind turbine generator set and power electronic devices. The control and management of microgrid operating independently is more complex due to it's poor system inertia. To study dynamic stability of microgrid , a small signal model of microgrid containing synchronous generator , asynchronous generator , power electronic based energy storage and power network along with controllers is proposed in this paper. The model is developed in microgrid dq0 reference frame. Eigen value analysis is generally carried out to study the dynamic stability of microgrid. Eigen value distribution of microgrid are considered under certain steady operating states and identified to indicate damping of oscillatory terms and it's effect on stability margin. In this paper control strategies for ESS are evaluated using PI and Fuzzy logic controllers.

IndexTerms– Distributed Generation, small signal model, system inertia, dynamic stability ,energy storage systems, microgrid.

I.INTRODUCTION

Microgrid and thereby Distributed generation concept is considered as an alternative solution for addressing technical, economical and environmental problems of conventional power grid.The most important technical advantage of microgrid is the improved power quality. Microgrid can operate in Autonomous mode or Grid connected mode. Power electronic converters are generally used to connect DG's into a microgrid. The physical system inertia is very low while operating microgrid autonomously . The term system inertia corresponds to the system power balance[4].Microgrid promotes the use of renewable energy specially solar and wind.

As the output of wind generator is not constant , it will affect the performance of overall grid. Power quality issues mainly occurs due to output power fluctuations of PV or wind and cut off or sudden application of load on a grid.This leads to the deterioration of power system stability.Energy storage system with power electronic interface can flexibly absorb or release active and reactive power in a grid, Inorder to improve the system inertia.This power absorption and release can be controlled with the help of proper control strategy/system. Various energy storage technologies are employed for microgrid. It includes vanadium redox battery (VRB), Flywheel energy storage (FES), Super capacitors, Li-ion batteries etc.[6],[9]. Dynamic stability of a microgrid analyzed based on the location of eigen values of the system. There are two methods for determining dynamic stability those are sensitivity analysis and eigen analysis. Eigen values can be calculated from small signal model of a system. This paper gives small signal model for synchronous generator , asynchronous generator , Power network and ESS. By combining all these models the complete system model can be obtained.

Based on Reference frame theory the values of current, voltage, reactances , power and load angle are transformed from local to global reference frames. PI & Fuzzy controllers are used in this paper to regulate active and reactive power flow in the network. This can be achieved by controlling switching of IGBT's used in VSC.

II. MATHEMATIC MODEL OF MICROGRID

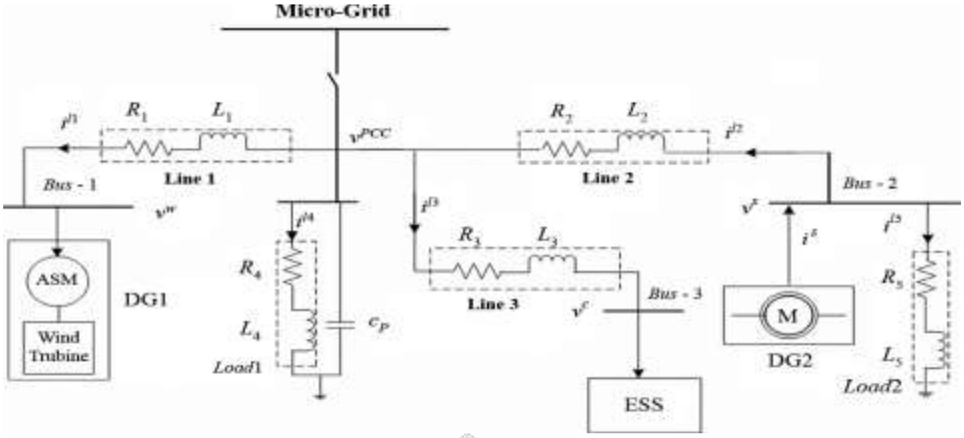


Fig. 1 shows the single-line diagram of a typical microgrid.

It comprises, instead of local loads, DG1 representing an AWT with stall regulation, DG2 representing a synchronous generator equipped with excitation and governor control systems, and an ESS based on a voltage-sourced converter (VSC) with active/reactive power controller. It is connected to a distribution network at the point of common coupling (PCC), and operates autonomously when the main grid is fault. The state-space model of DG1, DG2, ESS and power network are represented on their individual local reference frame, respectively. A common reference frame is chosen as the global reference frame of the microgrid system, and all of the subsystems are shift to the global reference frame using the transformation method shown in Fig. 2.

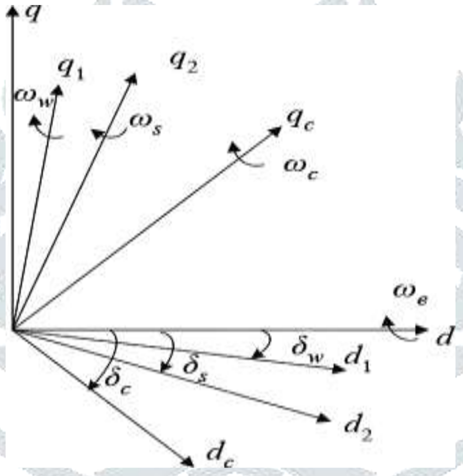


Fig.2.Global and local rotating reference frame of the microgrid.

As shown in Fig. 2, the d -axis and q-axis is taken as the global reference frame which is defined on the microgrid network rotating at angular frequency of ω_e. d1-axis and q1-axis, d2 –axis and q2-axis, dc -axis and qc-axis are the local reference frames of DG1, DG2 and ESS rotating at ω_ω ,ω_s and ω_c, respectively. Global reference frame rotates at an angular velocity of ω.

Global reference frame is transformed into local reference frame using transformation matrix given in equation (1)[5].

$$T = \begin{bmatrix} \cos\delta_n & -\sin\delta_n \\ \sin\delta_n & \cos\delta_n \end{bmatrix} \qquad (1)$$

Small signal model that is state space representation is in the form as given in equation (2),

$$\dot{x} = Ax + Bu \qquad (2)$$

In his paper small signal model of each and every part of microgrid is obtained separately then after whole system model is derived.

MATHEMATIC MODEL OF DG1

DG1 mainly consists of wind turbine , asynchronous generator and pitch control system. The electrical system of three phase symmetrical asynchronous generator in its arbitrary reference frame of $d_1 - q_1$ axis is given below,

$$V^{\omega} = EI^{\omega} + F\frac{d}{dt}(I^{\omega}) \qquad (3)$$

Where,

$$V^{\omega} = \begin{bmatrix} V_{sq1} & V_{sd1} & V_{rq1} & V_{rd1} \end{bmatrix}$$

$I^{\omega} = \left[I_{sq1} \quad I_{sd1} \quad I_{rq1} \quad I_{rd1} \right]$

V^{ω}, I^{ω} are the voltage and current vectors of stator and rotor windings.

E and F Matrices are derived in [1]

The rotor mechanical model of DG1 given as

$$\frac{d\omega_r}{\omega_b dt} = \frac{1}{2H}(\mathrm{Te}-\mathrm{T}) \qquad (4)$$

In (4) ω_b & ω_r are the base and rotor electrical angular velocity.

H represents inertia constant of load and rotor.

T_e & T are the electromagnetic and mechanical torque. T_e is given as(5)

$$T_e = X_m \left(i_{sq1} i_{rd1} - i_{sd1} i_{rq1} \right) \qquad (5)$$

Where X_m indicates mutual inductance between stator and rotor.

$$\frac{dT}{dt} = \frac{1}{T_H}(T\omega - T) \qquad (6)$$

Where T_H is the inertia time constant.

Slip in synchronous rotating reference frame

$$S = \frac{\omega_e - \omega_r}{\omega_e} \qquad (7)$$

The complete small signal model of DG1 can be obtained from (2)-(7).

The state space model of DG1 in global reference frame represented as (8)

$$\Delta\dot{x} = A\omega\, \Delta x^{\omega g} + B_v^{\omega}\, \Delta v^{\omega} + B_u^{\omega}\, \Delta u^{\omega} \qquad (8)$$

Where,

$\Delta x^{\omega g} = \left[\Delta i_{sq1}^{g} \quad \Delta i_{sd1}^{g} \quad \Delta i_{rq1} \quad \Delta i_{rd1} \quad \Delta\omega_r \quad \Delta T \right]$

$\Delta v^{\omega} = \left[\Delta V_{sq1}^{g} \quad \Delta V_{sd1}^{g} \right] T$

$\Delta u^{\omega} = \left[\Delta V_{rq1} \quad \Delta V_{rd1} \quad \Delta V_{\omega} \right] T$

$\Delta V_{\omega} = \frac{\pi V_{wind}^{O} \rho C_T R_C^3}{T_H} \Delta V_{wind}.$

MATHEMATIC MODEL OF DG2

DG2 consists of Diesel generator and a three phase generator with governor and excitation control system.

Synchronous generator in reference frame $d_2 - q_2$ is

$$V^s = GI^s + H\frac{d}{dt}(I^s) \qquad (9)$$

Where,

$V^s = \left[V_{q2} \quad V_{d2} \quad V_{k1q2} \quad V_{k2q2} \quad V_{kd2} \quad V_{fd2} \right] T$

$I^s = \left[i_{q2} \quad i_{d2} \quad i_{k1q2} \quad i_{k2q2} \quad i_{kd2} \quad i_{fd2} \right] T$

Voltage and current vectors of the stator windings, the damper windings , and the field windings.

The matrices G, H are derived in [1]

The rotor mechanical model of synchronous generator is given as

$$\frac{d\omega}{\omega_b dt} = \frac{1}{2H_s}\left(T_M - T_e \right) \qquad (10)$$

The electromagnetic torque is given as

$$Tes = X_{md}\left(-i_{d2} + i_{fd2} + i_{kd2} \right) i_{q2} - X_{mq}\left(-i_{q2} + i_{k1q2} + i_{k2q2} \right) i_{d2} \qquad (11)$$

Where X_{md} & X_{mq} are the magnetizing inductances.

Relationship of ω & δ_s given by,

$$\frac{d\delta_s}{\omega_b dt} = \frac{\omega - \omega_e}{\omega_b}$$

$$\Delta \dot{x}^{sg} = A_s \Delta x^{sg} + B_v^{s} \Delta v^{s} + B_u^{s}\, \Delta u^{s} \qquad (12)$$

Where,

$\Delta x^{sg} = \left[\Delta i_{q2}^{g} \quad \Delta i_{d2}^{g} \quad \Delta i_{k1q2} \quad \Delta i_{k2q2} \quad \Delta i_{kd2} \quad \Delta i_{fd2} \quad \Delta\delta_s \quad \Delta\dot{\delta} \right] T$

$\Delta v^{s} = \left[\Delta V_{q2}^{g} \quad \Delta V_{d2}^{g} \right] T$

$\Delta u^{s} = \left[\Delta V_{fd2} \quad \Delta T_M \right] T$

MATHEMATIC MODEL OF ESS

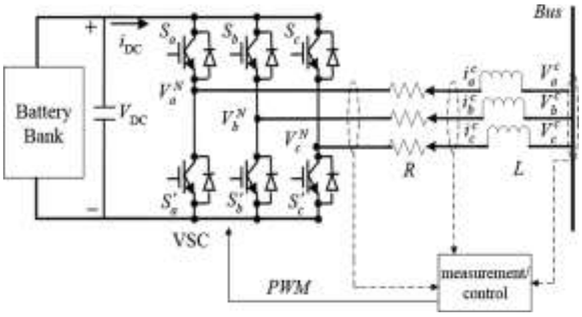


Fig.3. Schematic diagram of ESS

ESS includes battery as shown in Fig.3 and it’s corresponding power electronic interfaces with their control systems

In the local reference frame $d_c - q_c$ the power circuit equations is given by

$$\begin{bmatrix} \frac{di_{dc}}{dt} \\ \frac{di_{qc}}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & \omega_b \\ -\omega_b & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} i_{dc} \\ i_{qc} \end{bmatrix} + \frac{1}{L} \begin{bmatrix} V_{dc} & - V_{dc}^N \\ V_{qc} & - V_{qc}^N \end{bmatrix} \qquad (13)$$

Inductance L is used as a filter element for each phase. R denotes lump resistor of converter and power line. VDC is the DC bus voltage which usually consider constant for Voltage source converter. V_{dc}^N and V_{qc}^N are the voltage of VSC in $d_c - q_c$ axis frame. V_{dc} and V_{qc} are voltages of AC bus $d_c - q_c$ axis frame. i_{dc} and i_{qc} are the current component of VSC. The state space representation of ESS power circuit is given as (14)

$$\Delta\dot{x} = A_c \Delta x^{cg} + B_v^c \Delta v^c + B_u^c \Delta u^c + B_u^\delta \Delta\dot{\delta}c \qquad (14)$$

Where,

$\Delta x^{cg} = [\, \Delta i_{qc}^g \quad \Delta i_{dc}^g]\, T$

$\Delta v^c = [\, \Delta V_{qc}^g \quad \Delta\, V_{dc}^g]\, T$

$\Delta u^c = [\Delta V'_q \quad \Delta V'_d]\, T$

$V'_q = V_{qc} - V_{qc}^N - i_{dc}\omega_b L$

$V'_d = V_{dc} - V_{dc}^N - i_{qc}\omega_b L$

PLL i.e phase lock loop which detects the electrical phase value.

The mathematical model of PLL is represented by

$$\Delta\dot{\omega}c = -\Delta\dot{\delta}c \left(K_p + \frac{K_i}{s} \right) = K_p \Delta\omega - K_i \Delta\delta_c \qquad (15)$$

Where,

K_p, K_i are the PI coefficients of PLL Controller.

Here PI Controller is used for controlling switching of IGBT’s. PI controller reduces the disturbances and oscillations of system due to power unbalance. The small signal model in global reference frame of ESS control system is given by

$$\Delta\dot{x}cc = A_{cc}\Delta x^{cc} + B_{cc}\, \Delta x^{cg} + B_v^{cc} \Delta v^c + B_u^{cc} \Delta u^{cc} \qquad (16)$$

Where,

$\Delta x^{cc} = [\Delta v_{qc}^l \quad \Delta v_{dc}^l \quad \Delta v_{qc}^{Nl} \quad \Delta v_{dc}^{Nl} \quad \Delta i_{qc}^l \quad \Delta i_{dc}^l \quad \Delta v_c^q \quad \Delta v_c^d \quad \Delta\omega_c]\, T$

$\Delta u^{cc} = [\Delta P_{ref} \quad \Delta Q_{ref}]\, T$

v_c^d and v_c^q are the states of PI regulator of current controller in $d_c - q_c$ axis.

$\Delta v_{qc}^l, \Delta v_{dc}^l$ are the filtered value of V_{qc} and V_{dc}. $\Delta P_{ref}, \Delta Q_{ref}$ are the active and reactive power output of ESS.

MATHEMATIC MODEL OF NETWORK

The network model in abc stationary reference frame is represented as

$$R_1 i^{l1} + \frac{L_1 di^{l1}}{dt} = v^{PCC} - v^{\omega}$$

$$R_2 i^{l2} + \frac{L_2 di^{l2}}{dt} = v^s - v^{PCC}$$
$$R_3 i^{l3} + \frac{L_3 di^{l3}}{dt} = v^{PCC} - v^c$$
$$\frac{C_P dV^{PCC}}{dt} = i^{l2} - i^{l1} - i^{l3} - i^{l4} \qquad (17)$$

Where

R_n and L_n are the line resistance and inductances for n th branch, nth branch current is i^{ln}. v^{PCC} , v^{ω} , v^s and v^c are the voltage vectors of viz. PCC , Bus-1, Bus-2 , and Bus-3.

$$R_5(i^s - i^{l2}) + \frac{L_5 d(i^s - i^{l2})}{dt} = v^s \qquad (18)$$

Where

i^s = DG2 current vector.

The small signal model in global reference frame of network is represented as

$$\Delta\dot{x}net = A_{net}\Delta x_{net} + B^{\omega}_{net}\Delta v^{\omega} + B^{s}_{net}\Delta v^{s} + B^{c}_{net}\Delta v^{c} \qquad (19)$$

And

$$\Delta v^s = D_{net}\Delta x_{net} + D^{n}_{net}\Delta\,\dot{x}net + D^{s}_{net}\Delta x^{sg} + D^{ns}_{net}\,\Delta\,\dot{x}sg \qquad (20)$$

SYSTEM MODEL

The complete small signal model can be obtained from each subsystem

$$D_{sys}\Delta\,\dot{x}sys = A_{sys}\Delta x_{sys} + B_{sys}\Delta v_{sys} + C_{sys}\Delta u_{sys} \qquad (21)$$

Where

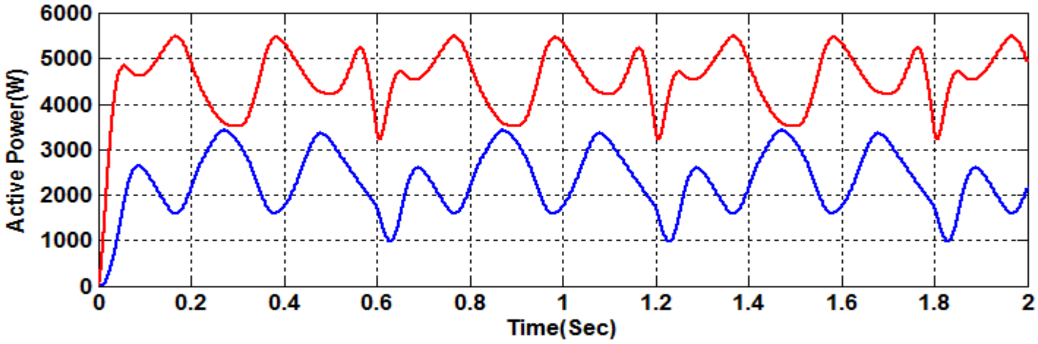
$\Delta x_{sys} = [\Delta x^{\omega g}\ \ \Delta x^{sg}\ \ \Delta x^{cg}\ \ \Delta x^{cc}\ \ \Delta x_{net}]\ T$

$\Delta v_{sys} = [\Delta v^{\omega}\ \ \Delta v^{c}]\ T$

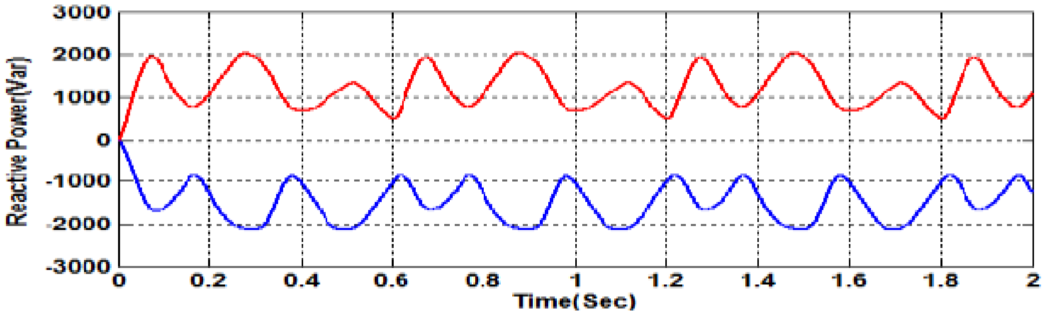
$\Delta u_{sys} = [\Delta u^{\omega}\ \ \Delta u^{s}\ \ \Delta u^{cc}]\ T$

IV.SIMULATION AND EXPERIMENT RESULTS

The microgrid model shown in fig.1 is established under MATLAB/SIMULINK environment. Simulation platform is in time domain. Here system response shown with or without ESS. From these simulation results fact reveals that ESS can flexibly and effectively release and absorbs active/reactive power. Thereby reducing power unbalance. With increase in wind turbine speed ESS absorbs active power as the output of wind is large. Similarly it absorbs reactive power and release active power when speed decreases.[4][5]

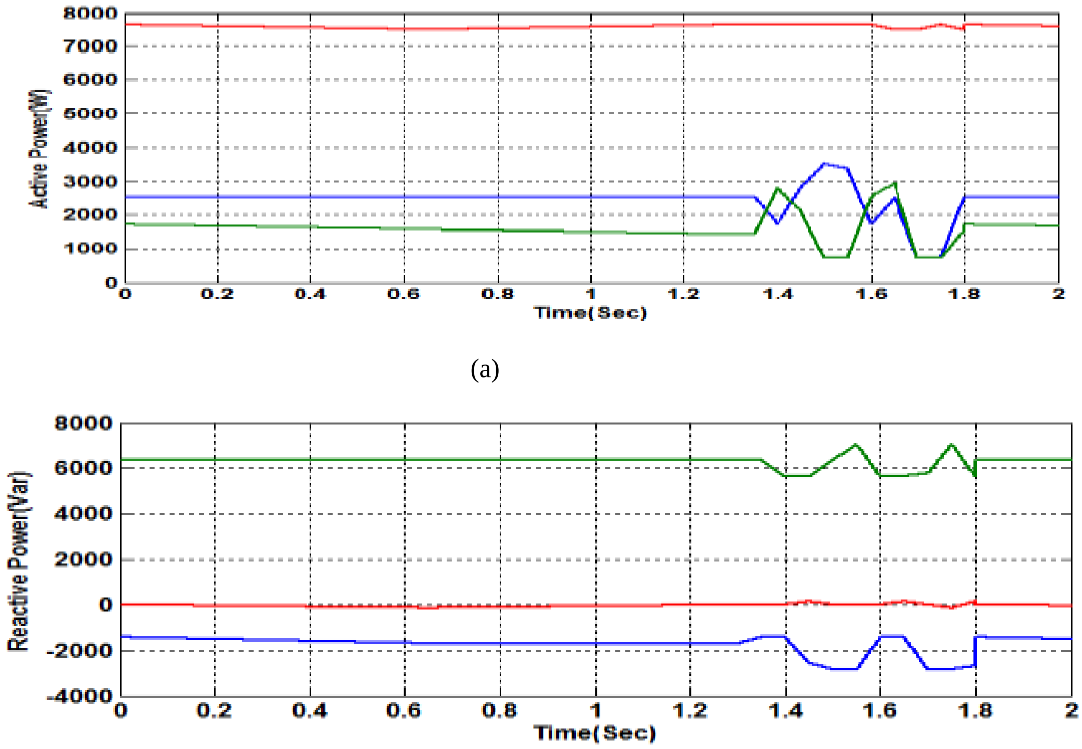


(a)



(b)

Fig.4.System response to wind disturbance without ESS (a)Active Power (b)Reactive Power.
In Fig.4.(a) & (b) Red curve shows the variation of active/reactive power of DG2 while Blue curve shows power variation of DG1.



(a)

(b)

Fig.5.System response to wind disturbance with ESS (a)Active Power (b)Reactive Power.
In Fig.5.(a) & (b) Green curve represents response of ESS to system disturbances.

As stated above ESS can track output power change of DG1(wind generator set) accurately and mitigate adverse effect of power unbalance on system.This power balancing is possible due to the control system associated with ESS. In this paper fuzzy logic controller is used to maintain power flow between ESS and grid. This results into improved system stability ,voltage quality, and frequency profile.

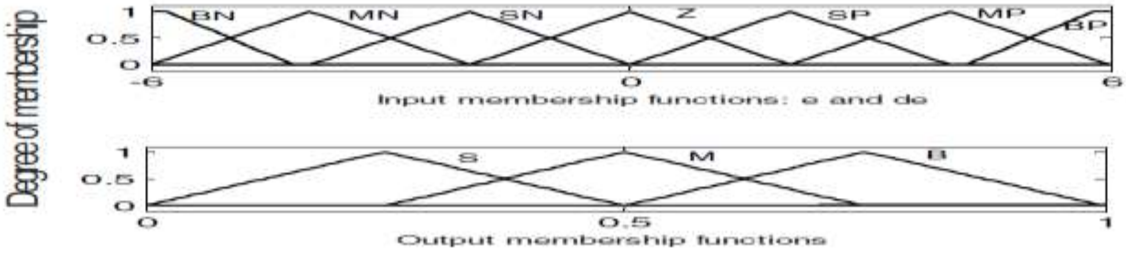
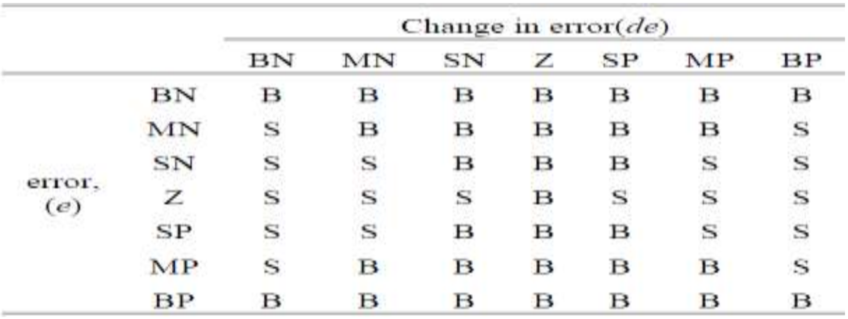


Fig.6.Membership function for voltage controller.

The membership functions representing the input and output fuzzy sets for voltage control loop is shown in Fig.6. The input variables are given as seven membership function. Similarly the output variables are represented by set of membership functions as shown in Fig. 6. the rule base is important part of the FLC, which defines the input variables to the output model properties . The designed rule base for voltage control loop is shown in Table I. [14]

Table-I Rule base for designed fuzzy controllers.



		Change in error(de)						
		BN	MN	SN	Z	SP	MP	BP
error, (e)	BN	B	B	B	B	B	B	B
	MN	S	B	B	B	B	B	S
	SN	S	S	B	B	B	S	S
	Z	S	S	S	B	S	S	S
	SP	S	S	B	B	B	S	S
	MP	S	B	B	B	B	B	S
	BP	B	B	B	B	B	B	B

Table-II Output values with corresponding FUZZY & PI Controllers.

PI				FUZZY			
P(W)		Q(Var)		P(W)		Q(Var)	
With ESS	Without ESS	With ESS	With out ESS	With ESS	Without ESS	With ESS	Without ESS
1988	1522	870.4	565.3	2545	1887	1497	1064

As paper is based on comparative study of FUZZY and PI controller performance above Table-II shows difference in the output values of PI and Fuzzy controller. Thus, adaptive nature of the FLC and robust structure of the PI controller are Synthesized . Eventually, an adaptive PI controller which can adopt changes because of different operation conditions, grid disturbances and natural effects with fast transient response is obtained. Simulation studies are validated with experimental results. Simulation results show that proposed system has fast dynamic response with a low overshoot and short settling time. PI controller commonly used in the control of power electronic converters can also be used in control of grid interactive inverters. The gains of the PI controllers are usually determined by using various methods and the mathematical model of the system such as Ziegler–Nichols methods. Performance of this PI controller get affected due to change in system parameters and external factors for example noise .Also if the controllers are used with grid interactive inverters which are operating in wide range, can get affected by environmental factors such as wind blow or solar radiations. Gain values of PI controllers mainly get affected due to these environmental factors as well as system parameter variations. But Fuzzy controllers are independent from the effect of above mentioned parameters. Hence with grid connected systems adaptive nature of controllers are generally used.

V.CONCLUSION

In this paper,a state space model of typical microgrid is represented including asynchronous generator,synchronous generator,and voltage source converter with corresponding control system. All the components of microgrid are modeled individually in local reference frame, then combined to get complete system model in global reference frame. This model is developed for autonomous microgrid. The system dynamic stability is analyzed based on the eigen values. Eigen values are calculated from obtained system model. The system stability mainly influenced by power unbalance due to intermittent generation of DG1.ESS plays important role in improving system stability by managing active/reactive power. The release and absorption of power controlled by controlled switching of IGBT's used at VSC. This control can be achieved with any of the controller. In this paper, results of both PI & Fuzzy are compared .From the Table-II it is clear that FUZZY gives more satisfactory results than PI while balancing power and hence system disturbances. With the help of Fuzzy controller we can obtain greater values of active and reactive power.

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