An improved droop control for simultaneous voltage and frequency regulation in an AC microgrid using fuzzy logic

Ahmadi, S., Shokoohi S. , Bevrani, H., E. Hasani

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Saleh Ahmadi
Department of Electrical and Computer Engineering
University of Kurdistan (UOK)
Sanandaj, Iran
salehahmadi66@yahoo.com

Shoresh Shokoohi
Department of Electrical and Computer Engineering
University of Kurdistan (UOK)
Sananadaj, Iran
shokoohi@ieee.org

Hassan Bevrani
Department of Electrical and Computer Engineering
University of Kurdistan (UOK)
Sananadaj, Iran
bevrani@ieee.org

Elham Hasanii
Department of Electrical and Computer Engineering
University of Kurdistan (UOK)
Sananadaj, Iran
elham.hasanii@gmail.com

***Abstract*— Voltage and frequency of microgrids (MGs) are strongly impressionable from the active and reactive load fluctuations. There are several voltage source inverters (VSIs) interfaced distributed generations (DGs) by specific local droop characteristics in a MG. Change in load of a MG may lead to imbalance between generation and consumption and it will change the output voltage and frequency of the VSIs according to the droop characteristics. If the load change is adequately large, the DGs may be unable to stabilize the MG. In the present paper, fuzzy logic is used to optimally tune the coefficients of droop control based frequency and voltage regulation in an AC microgrids.**

Keywords—distributed generation (DG), droop control, fuzzy logic, microgrid (MG).

I. Introduction

The application of distributed generation (DG) has been increased rapidly in the past decades. In comparison with the conventional centralized power generation, DG units have advantages such as less pollution, higher efficiency of energy utilization, flexible installation location and decreasing power transmission losses. Most of the DG units are connected to the grid with power electronic converters, which introduces such as system resonance, and protection interference. To overcome these problems a MG concept was first proposed in the US by the consortium for electrical reliability technology solutions (CERTs) [1]. In comparison with a single DG unit, MG could offer superior power management with in the distribution networks. Moreover, the MG can operate both in tied-connected mode and islanded mode and benefit both the utility and customers in economy [2]-[8].

In islanding mode, the load power in the MG should be properly supplied by multiple DG units. Usually, the droop control method which mimics the behavior of a synchronous generator in traditional power system is adopted, which does not need the use of critical communications [9]-[17]. Typical DGs are diesel engine generators (DEGs), single shaft micro turbines (SSMTs), photovoltaic (PV) panels, wind turbines (WTs), MG main storage, solid oxide fuel cells (SOFCs), and reciprocating engines [18].

In this case, the voltage and frequency of the MG are controlled through local control loops. Usually, in order to avoid circulating currents between parallel inverters connected to MG, control strategies based on droop characteristics are applied. The present paper addresses the simultaneous impacts of active and reactive power deviations on the MGs' voltage and frequency. Then, based on the well-known droop control relationship, an improved droop control is developed to decuple the active and reactive power impacts on the voltage and frequency fluctuations.

First, the proposed droop control is tested on a simple MG and also, it is applied under several critical load changes up to 10% nominal over load. Then, a fuzzy logic structure is performed on droop control dynamic mechanism. Finally, the mentioned structure is used to an improved droop control method on 11-bus MG test case. The voltage and frequency deviations are studied under violent load changes in different buses. Simulation results are performed to illustrate the effectiveness of the proposed intelligent control scheme.

II. Analysis of the Conventional Droop Control

A. Conventional Droop Control

Consider a simple MG as shown in Fig. 1. The DG is connected to the load at point L through line impedance Z=R+jX. The power flow into a line, as represented in Fig. 1, is discussed as [17]:

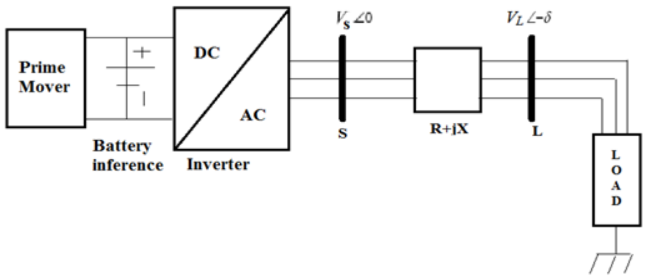

Figure 1. A simple MG with an interfaced inverter system.

$$P = \frac{V_s^2}{Z}cos\theta - \frac{V_sV_L}{Z}\cos(\theta+\delta) \tag{1}$$

$$Q = \frac{V_s^2}{Z}sin\theta - \frac{V_sV_L}{Z}\sin(\theta+\delta) \tag{2}$$

These conclusions form the basis for the well-known frequency and voltage droop regulation through active and reactive power, respectively:

$$f - f_0 = -k_p(P - P_0) \tag{3}$$

$$V_A - V_{A0} = -k_q(Q - Q_0) \tag{4}$$

Where f_0 and V_{A0} are the rated the frequency and voltage of MG, respectively. Hence, K_p and K_q are droop control coefficients of DG's reactive and active powers. According to equation (3) and (4), if a change occurred in the DG's reactive and active powers, the effect will be observed on the voltage and frequency of inverter.

B. Improved Droop Control

Generally, both R and X must be considered [17]. Therefore, reformed active (P') and reactive (Q') powers are as follows:

$$\mathrm{P}' = \frac{\mathrm{X}}{\mathrm{Z}}\mathrm{P} - \frac{\mathrm{R}}{\mathrm{Z}}\mathrm{Q} \tag{5}$$

$$Q' = \frac{R}{Z}P + \frac{X}{Z}Q \tag{6}$$

Now, by definition of K_R=R/X, and applying equations (3) and (4) to (5) and (6), results in [19]:

$$P' = \frac{X}{Z}\left[K_f\Delta f + P_0 - K_RK_V\Delta V_s - K_RQ_0\right] \tag{7}$$

$$Q' = \frac{X}{Z}\left[K_RK_f\Delta f + K_RP_0 + K_V\Delta V_s + Q_0\right] \tag{8}$$

Where K_f = -1/k_p and K_v= -1/k_q. The Δf and ΔV are inverter frequency and voltage deviations, respectively. The index K_R is defined to depict the percentage of the line resistivity. Finally, the equations (7) and (8) can be rewritten as follows [19]:

$$\Delta f = \frac{1}{K_f}\left(\frac{Z}{X}P' - P_0\right) + K_RK_V\Delta V_s + K_RQ_0 \tag{9}$$

$$\Delta V_s = \frac{1}{K_v}\left(\frac{Z}{X}Q' - Q_0\right) - K_RK_f\Delta f - K_RQ_0 \tag{10}$$

C. Droop control method-based Voltage and Frequency Control

Fig. 2 shows a general block diagram for the droop control. R and X are multiplied to frequency and voltage deviations, respectively. Then these values through negative feedback are linked to the pulse width modulation (PWM). First, to illustrate the effectiveness of the proposed droop control the simple case study is considered in the Fig. 1. In this test case, one DG unit through a line supplies local load.

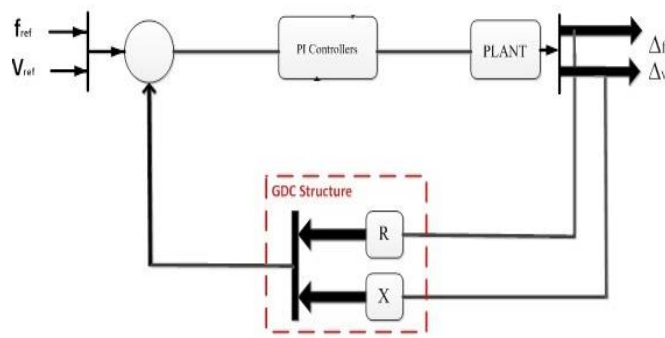

Figure 2. Block diagram of the droop control.

Then to ensure that the developed droop control approach is able to obtain a favorable result in inductive, resistive and all types of MGs, some simulations have been done in states of K_R= 0.1 (inductive line: X=10R), K_R =1 (R=X), and K_R =10 (resistive line: R=10X). The rated voltage is 400V (rms). An intense scenario for load deviations is shown in Fig. 3 and Fig. 4. It depicts that the primary active load is fixed about 1.5 pu and primary reactive load is o.5 pu before 1s. The simulation results for different values of Z are depicted in Figs. 5 and 6 (K_R=0.1, K_R=1, K_R=10). These figures depict that the proposed droop control approach stabilizes the MG's voltage and frequency following the step load changes.

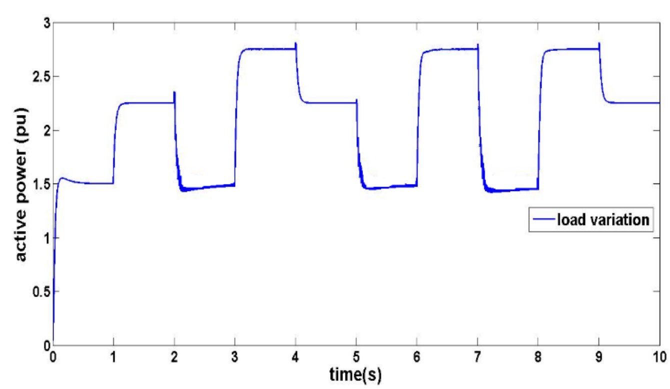

Figure 3. Load variations scenario (active power).

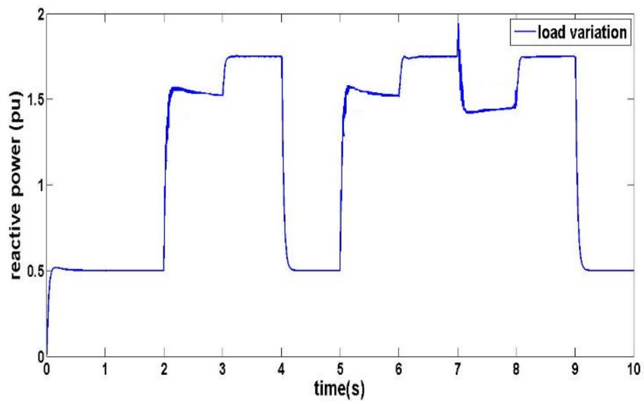

Figure 4. Load variations scenario (reactive power).

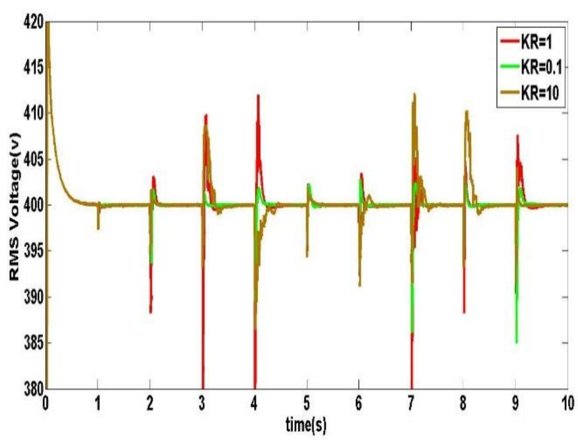

Figure 5. System response for load disturbance with different values K_R.

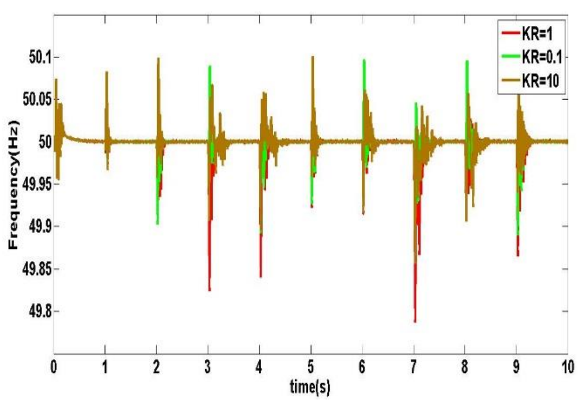

Figure 6. System response for load disturbance with different values of K_R.

III. FUZZY-BASED DROOP CONTOL APPROACH

The weak point of the proposed droop control method is in vigorous dependency to the line parameters. A more complex MG with 3 DGs is shown in Fig. 6. The proposed technique in the previous section is depended on the line parameters. The DGs are linked to two local loads, at bus 1 and bus 2. Obviously, in the present test case, unlike the previous case study (Fig. 1), relation between consumption and generation is not done just through one line, i.e. DG 2 shared the generation between load 1 and load 2. Hence, it cannot be determinate with a peculiar resistance and inductance. According to the proposed droop control structure in the last part, a line should be existed between the DG and local load. Therefore, for new test case there are four parameters, which must be, defined ([R1 X1 R2 X2]). If the scale of MG is enough large, the number of parameters and time calculation will be considered. Hence, to solve these problems, a fuzzy logic system used to droop control method without any dependency to the line parameters.

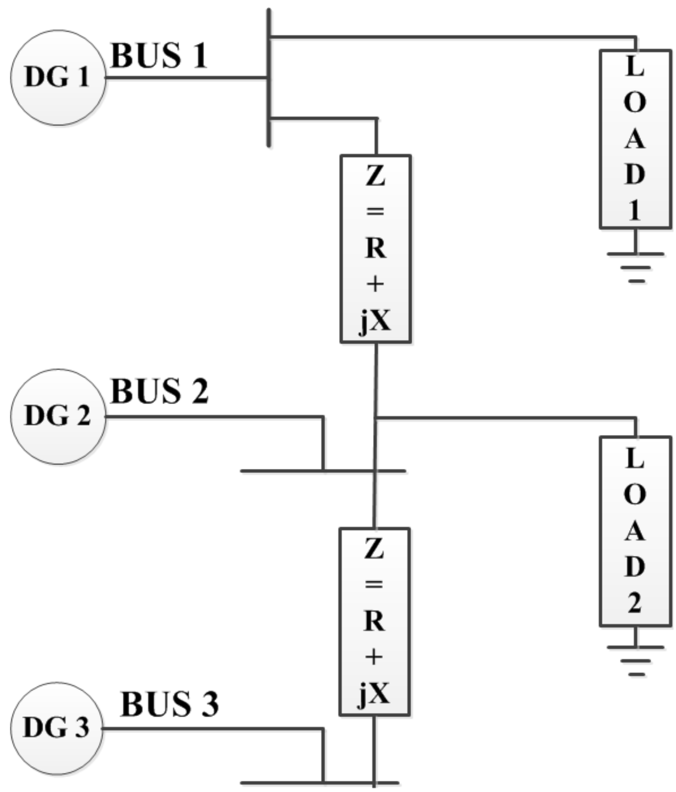

Figure 6. Complex MG with 3 DGs with connected loads.

A. *Fuzzy Logic Controller Design*

The weak point of the proposed droop control method is in vigorous dependency to the line parameters. In this section, a new approach to obtain voltage and frequency droop control is described. The purpose is determined of R and X. Fig. 7 depicts the proposed droop control based fuzzy logic system.

The process of fuzzy inference involves membership function, fuzzy logic operators, and if-then rules. This procedure is used to compute the mapping from the input values to the output values, and it consists of three sub-processes, fuzzification, aggregation, and defuzzification.

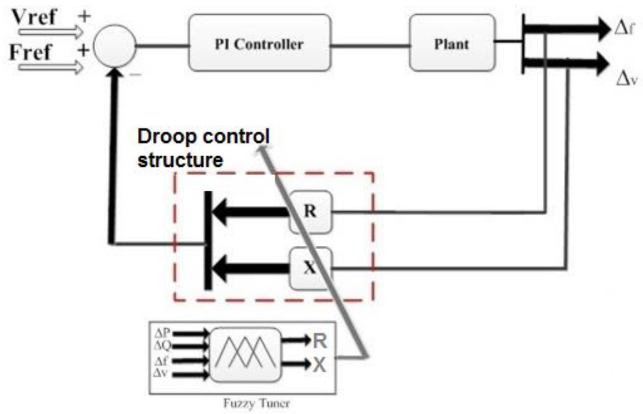

Figure 7. The droop control based fuzzy logic.

In order to apply the fuzzy logic to the isolated MG system for tuning of R and X controller, a set of fuzzy rules consisting of 36 rules is used to map input variables, Δf (frequency deviation), Δv (voltage deviation), ΔP (active power variation) and ΔQ (reactive power deviation) to output variables, R and X. The membership functions for inputs and outputs are shown in Fig. 8. The performed fuzzy rules are given in Table I. The membership functions corresponding to the input and output variables are arranged as Negative Large (NL), Negative Medium (NM), Negative Small (NS), Positive Small (PS), Positive Medium (PM), Positive Large (PL), Low (L), Normal (N) and High (H). They have been arranged based on triangular membership function that is the most popular one. The antecedent parts of each rule are composed by using AND operator. Here, Mamdani fuzzy inference system is also used [20].

TABLE I
THE FUZZY RULES SET

	Δv	NL	NM	NS	PS	PM	PL
Δf	L	NL	NM	NS	PS	PM	PL
	N	NL	NM	NS	PS	PM	PL
	H	NM	NS	PS	PM	PL	PL

	ΔQ	NL	NM	NS	PS	PM	PL
ΔP	L	NL	NM	NS	PS	PM	PL
	N	NL	NM	NS	PS	PM	PL
	H	NM	NS	PS	PM	PL	PL

IV. CASE STUDY AND TEST SCENARIO

To test and check the effectiveness of the proposed droop control method based on fuzzy controller; first the 11-bus MG is used in Fig. 8. Test case contains Single Shaft Micro-Turbine (SSMT), Wind Turbine, PV, MG Main Storage and Solid Oxidation Fuel Cell (SOFC) with a same structure for all DGs. Then, by occurring violent changes in four loads at different times, the influence of dynamic load changes with fuzzy controller on the MG performance is evaluated. Tables II and III are shown load changes scenario bus load and the active and reactive, respectively. Figs. 10 to 12 depict the effectiveness of the fuzzy logic-based proposed droop control for DGs have critical situation in compared to others.

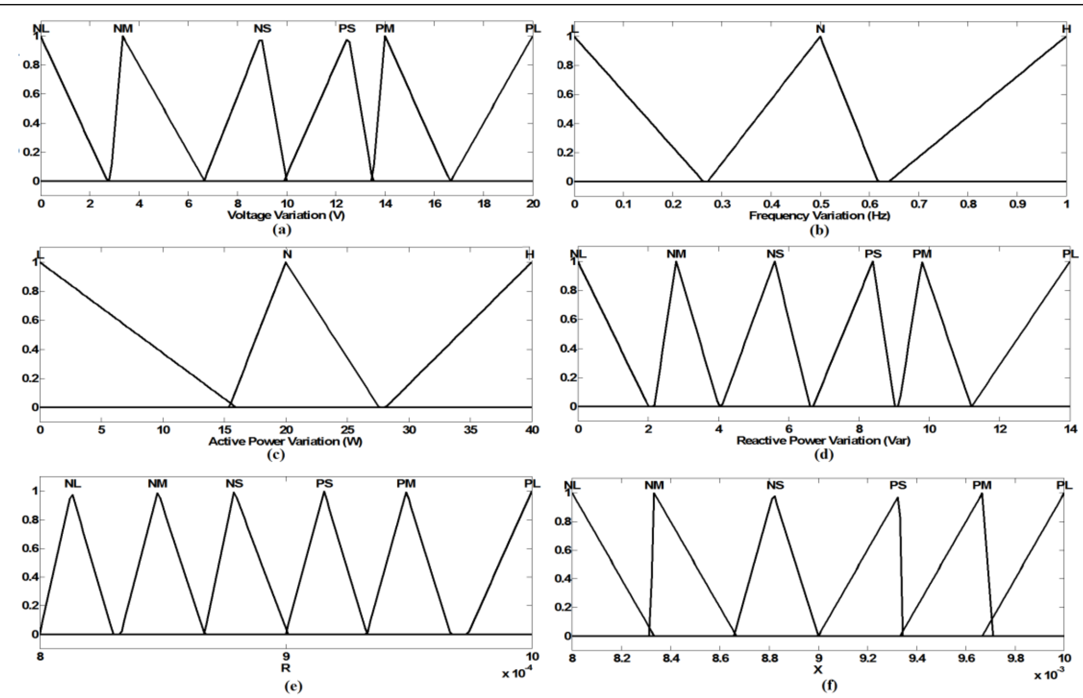

Figure 8. Membership functions for inputs a) voltage variation, b) frequency variation, c) active power variation and d) reactive power variation, also outputs e) R and f) X.

TABLE II
LOAD CHANGE SCENARIO FOR 11-BUS MG TEST SYSTEM

Time (second)	Bus Number	Load Change(KVA)
0.1-1.2	2	17+j4
1.5-2.3	5	13+j4
2.7-3.4	9	19+j1
3.7-4.2	7	15+j5

TABLE III
LOADS IN 11-BUS MG TEST SYSTEM

BUS NUMBER	Load (KVA)
2	15+j5
5	18+j6
7	19+j5
9	20+j8

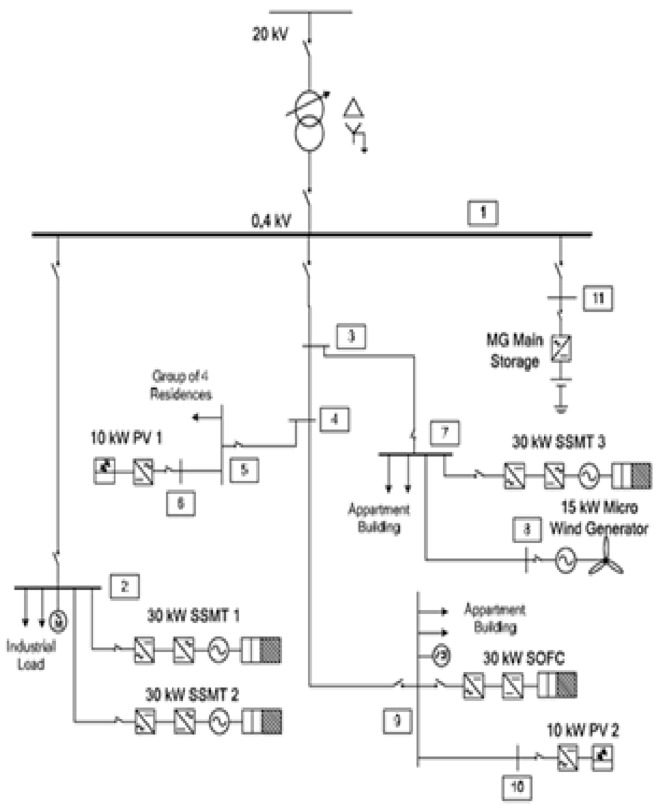

Figure 9. 11 bus system (Case Study).

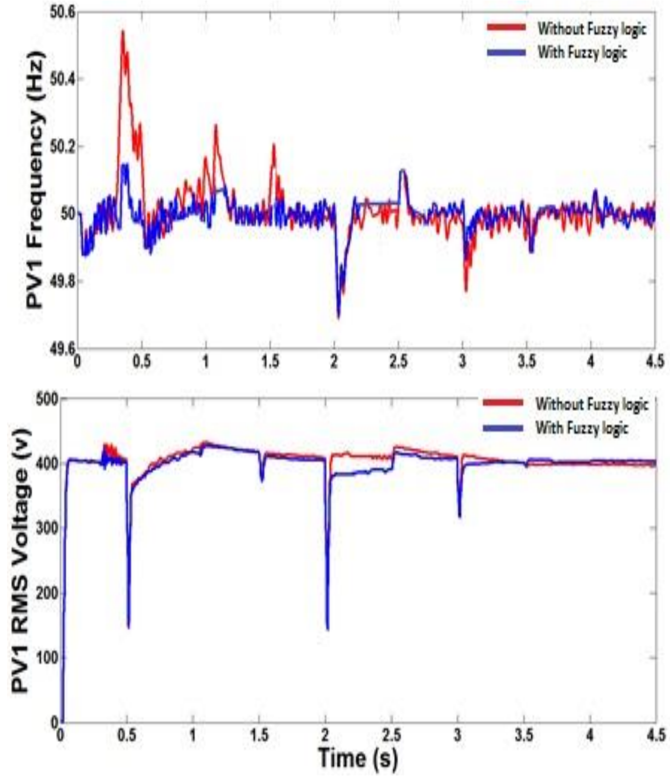

Figure 10. PV1 voltage and frequency profile under violent load changes.

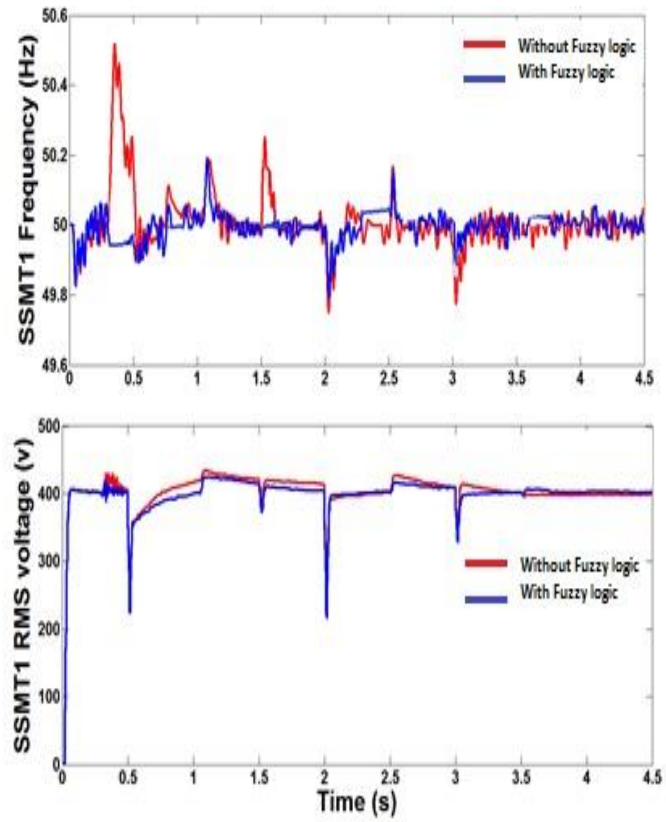

Figure 11. SSMT1 voltage and frequency profile under violent load changes.

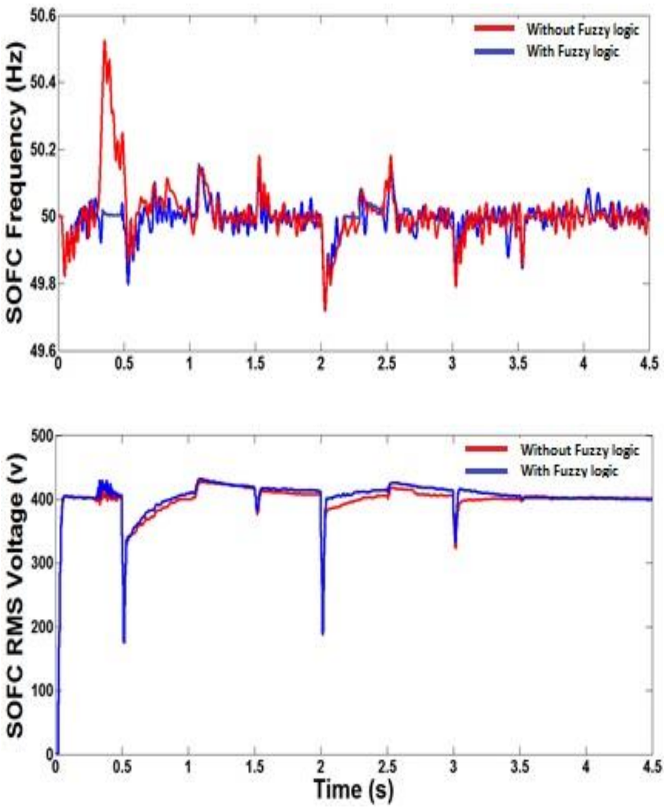

Figure 12. SOFC Voltage and frequency profile under violent load changes.

V. Conclusion

This paper presents a fuzzy approach for intelligent model based generalized droop control for simultaneous frequency and voltage regulation in an AC microgrid. The addressed droop control highly depends on MG line parameters. To remove this dependency an adaptive fuzzy inference system is considered.

An important issue raised in the ac microgrids is frequency regulation in the presence of disturbances, uncertainties, and load changes. Finally, for test and check the proposed droop control fuzzy approach is used for 11-bus test case system.

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