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Modeling And Analysis Of Fuzzy Logic Based Fuel Cell Power Generation For Non Linear Applications

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Abstract: *This paper proposes Fuzzy logic controller (FLC) for generating the proper pulses for fuel cell power generation system. In this paper single fuzzy logic controller is preferred for damping the oscillations in the fuel cell voltage and fuel cell current. The alternating phase shift control (APS) is utilized to compensate the voltage unbalanced on the switches and also maintained effective reliability when over loaded conditions. The middle level approachment among the APS and interleaving technology which is utilized better performance. The implemented algorithm which can compensate the harmonics and voltage stress problems effectively by the APS controller. Finally the simulated models are tested and verifies within the MATLAB/SIMULINK with breakdown conditions*

Keywords: *wave power generation system (WPGS), linear permanent magnet generator (LPMG), Archimedes wave swing (AWS), Super-Capacitor (SC).*

I.INTRODUCTION

The grid connected power system based on fuel cell is shown in Fig. 1. For a typical 10-kW proton exchange membrane fuel cell, the output voltage is from 65 to 107 V. However, the input voltage of the three phase dc/ac converter needs to be around 700 V, the voltage gain of the dc/dc converter between fuel cell and the dc/ac converter will be from 6 to 11 V. A high step-up dc/dc converter is needed for the system as shown in Fig.1. The dc/dc converter will generate a high frequency input current ripple, which will reduce the life time of the fuel cell stack [1]–[4]. High step-up ratio can be achieved by combining classical boost converter with switched inductors [6], coupled inductors [5]–[9], high-frequency transformer [10], or switched capacitor [11]–[14], [19]. They can obtain high step-up ratio with high efficiency, low-voltage stress, and low electromagnetic interference. In order to reduce output fuel cell stack output current ripple or the dc/dc converter input current ripple, either a passive filter [15] or active filter [5] can be used, however, this will increase the complexity of the system. In fact, interleaving the dc/dc converter can reduce the input current ripple of the dc/dc converter [16]. An interleaved boost converter with voltage multiplier was proposed in [13], [14]. Its voltage gain was increased up to (M +1) times (M is the number of the voltage multiplier) of the classical boost converter with the same duty cycle D and lower voltage stress. Besides, it has lower input current ripples and output voltage ripples in comparison to the classical boost converter. The interleaving boost converter with voltage multipliers is shown in Fig. 2. The converter shown in Fig. 2 can achieve low-voltage stress in the power devices, which increases the conversion efficiency. However, this is only true in heavy load when the voltage stress of the power devices might increase when it works in discontinuous conduction mode (DCM) [17], which occurs when fuel cell only supplies a light local load as shown in Fig. 1. In this case, higher voltage power devices need to be used, and therefore its cost and power loss will be increased. These authors proposed a new pulse width modulation (PWM) control method, named as alternating phase shift(APS), to overcome the problem when the converter operates in light load [17], [18].

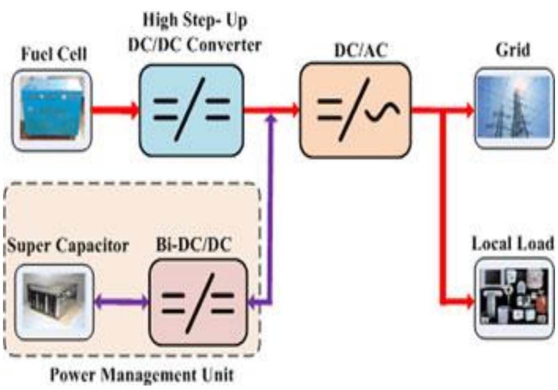

Fig.1 Grid connected fuel cell

II. MODELING OF SYSTEM

It is expected that all segments in the converter are perfect, both capacitor C1 and C2 are sufficiently expansive, and obligation cycle is under 0.5. The operation of an exchanging cycle of the converter can be separated into six stages at limit condition which the voltage weight on switch will be bigger than half of the yield voltage with conventional interleaving control, as appeared in Fig. 2.

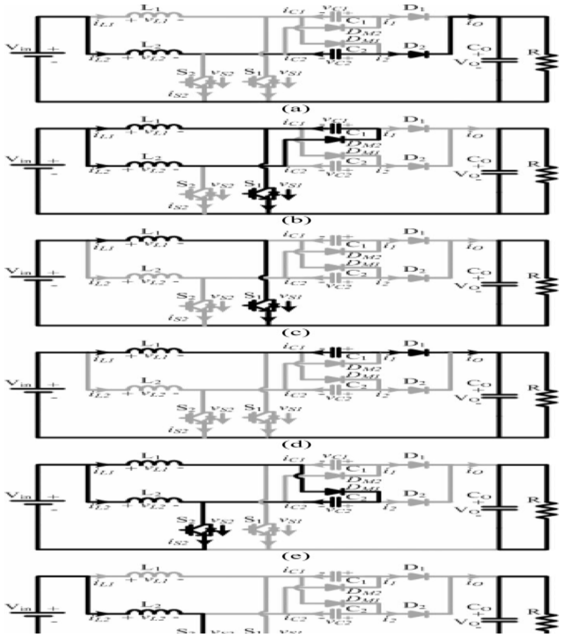

Fig. 2. Stages at boundary condition. (a) First stage (*t*0 , *t*1), (b) second stage (*t*1 , *t*2), (c) third stage (*t*2 , *t*3), (d) fourth stage (*t*3 , *t*4), (e) fifth stage (*t*4 , *t*5), (f) sixth stage (*t*5 , *t*6).

1) ***First Stage*****(*t*0, *t*1):** right now of t0 , both switch S1 and S2 are off, the vitality put away in the inductor L2 and capacitor C2 in past stage are exchanged to the yield capacitor CO through D2 as appeared in Fig. 2(a). The voltage weight on switch S1 is the info voltage Vin , and the voltage weight on switch S2 is (VO −VC2), where VO is the yield voltage and VC2 is the voltage of capacitor C2 .

2) ***Second Stage*****(*t*1, *t*2):** right now of t1 , the switch S1 is turned ON, the inductor L1 begins to store vitality from zero as appeared in Fig. 2(b). Meanwhile, if (VC1 + VC2) < VO , where VC1 is the capacitor C1 voltage, the diode D2 will be killed and the diode DM2 will be turned ON; in this way, the vitality in the inductor L2 will be exchanged to the capacitor C1 .

In the event that there is sufficient vitality in the inductor L2, VC1 will be charged to the accompanying state: VC1 + VC2 ≥ VO . At that point, the diode D2 will be turned ON once more, which is appeared in Fig. 4. On the off chance that there is insufficient vitality to charge VC1 to (VO − VC2), then it will go to the Third Stage as appeared in Fig. 3(c).

On the off chance that the vitality in the inductor L2 is simply released to zero and VC1 + VC2 = VO toward the end of the stage, then we say that the circuit works in the limit condition state. Amid the stage, the voltage weight on switch S2 is VC1 .

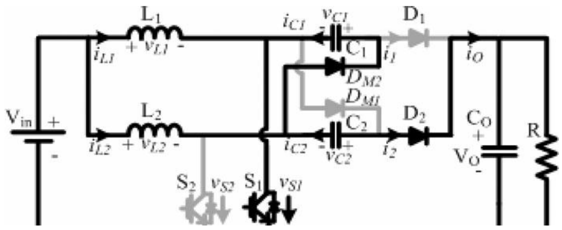

Fig.3 One stage above boundary condition.

3) ***Third Stage*****(*t*2, *t*3):** right now of t2 , the current in the inductor L2 just tumbles to zero, every one of the diodes are in off state and the inductor L1 is in charging state until the switch S1 is killed right now of t3 . The voltage weight on switch S2 is Vin . Toward the end of this stage, the current in the inductor L1 goes to the crest esteem IL1P , and

$$I_{L1P} = \frac{V_{\text{in}} D_m T_S}{L} \quad (1)$$

Where Vin is the information voltage, L is the inductance of L1 and L2,Dm is the obligation cycle at limit condition, and TS is the exchanging period.

4) ***Fourth Stage*** **(*t*3, *t*4):** right now of t3 , switch S1 and S2 are in off state, the vitality in the inductor L1 and the capacitor C1 will be exchanged to the yield capacitor CO through the diode D1 , which is like First Stage. In this stage, the voltage weight on switch S1 is (VO − VC1), and the voltage weight on switch S2 is Vin . Toward the end of this stage, the current in the inductor L1 declines to be IL1M

$$I_{L1M} = I_{L1P} - \frac{V_O - V_{C1} - V_{\text{in}}}{L}(0.5 - D_m)T_S. \quad (2)$$

5) ***Fifth Stage*** **(*t*4, *t*5):** right now of t4 , the switch S2 is turned ON and the inductor L2 begins to store vitality. This stage is like the Second Stage. In this stage, the voltage weight on switch S1 is VC2 . Toward the end of this stage, the current in the inductor L1 reductions to zero from IL1M . What's more, subsequently

$$I_{L1M} - \frac{V_{C2} - V_{\text{in}}}{L}(D_2 - 0.5 + D_m)T_S = 0 \quad (3)$$

where *D*2 is the duty cycle as shown in Fig. 3.

6) ***Sixth Stage*** **(*t*5, *t*6):** right now of t5 , the current in the inductor L1 abatements to zero. Every one of the diodes are in off state and the inductor L2 is in charging state until the stage arrives at the end right now t6 . Another exchanging period will start with the following First Stage.

III. PROPOSED METHOD

The proposed controller is a fuzzy logic controller, the membership functions and rules are shown in figures 4 to7.

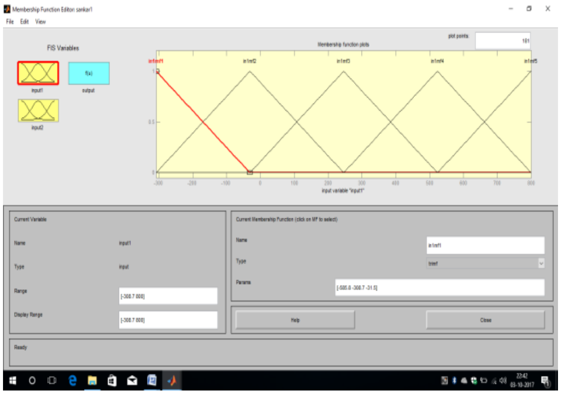

Fig.4 input 1 membership functions of FLC.

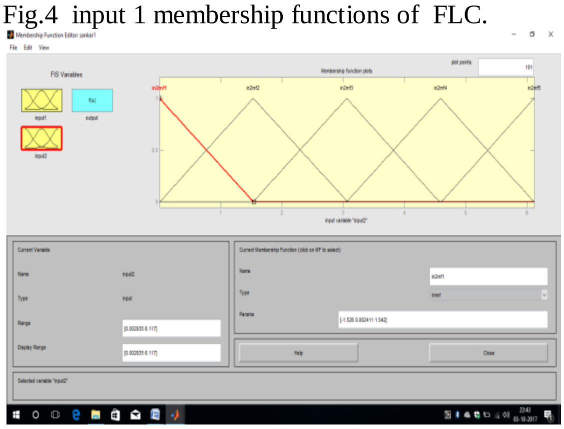

Fig.5 input 2 membership functions of FLC.

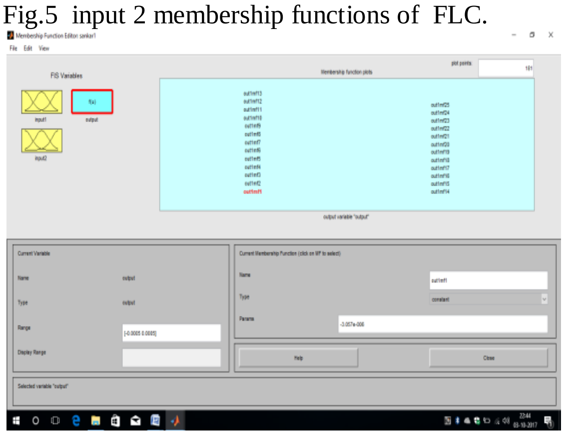

Fig.6 output membership functions of FLC.

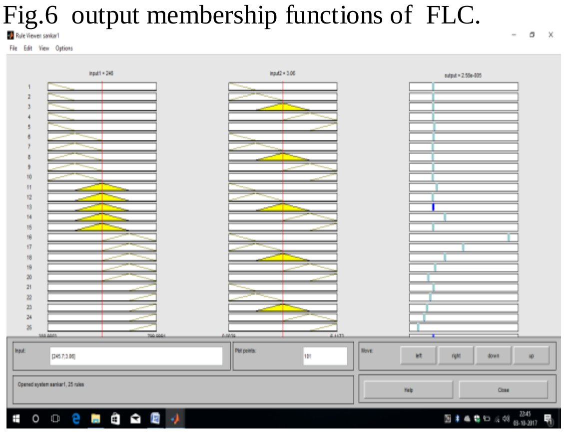

Fig.7 Rules of FLC.

IV. TEST SYSTEM & RESULTS

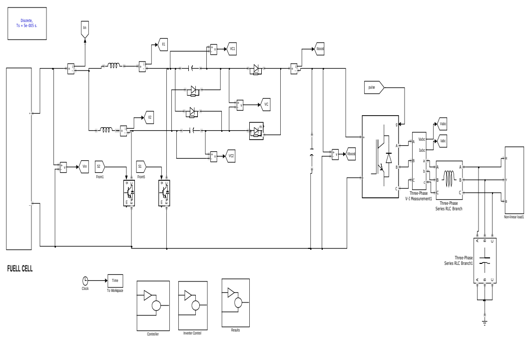

Fig.8 Simulation diagram of fuel cell with PI controller.

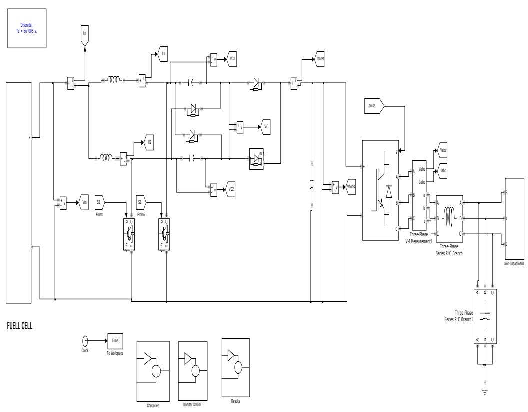

Fig.9 Simulation diagram of fuel cell with FLC controller.

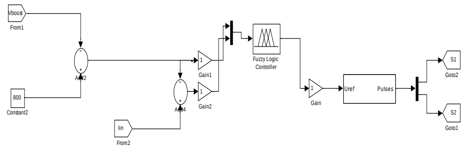

Fig.10 FLC controller internal diagram.

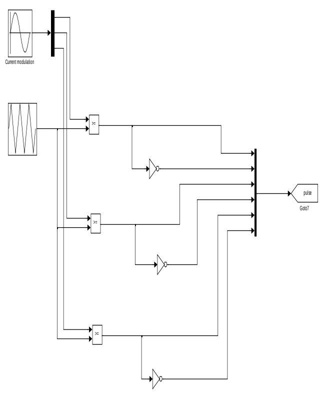

Fig.11 FLC controller inverter internal diagram.

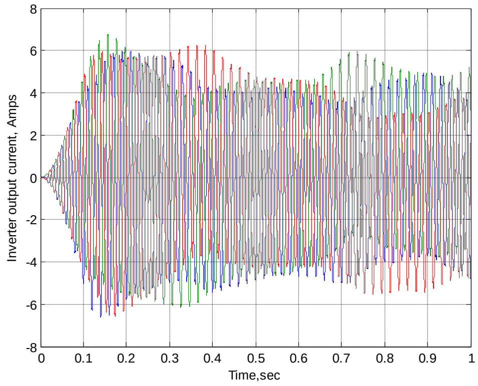

Fig.12 Inverter output current with PI controller.

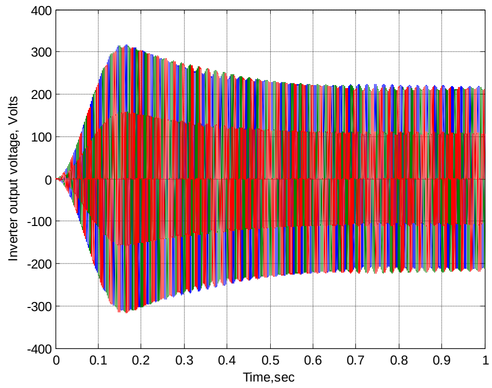

Fig.13 Inverter output current with PI controller.

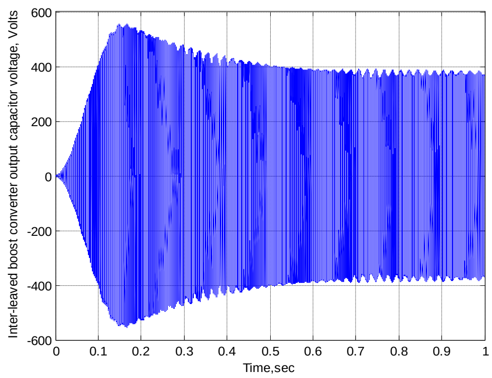

Fig.14 Output capacitor voltage with PI controller.

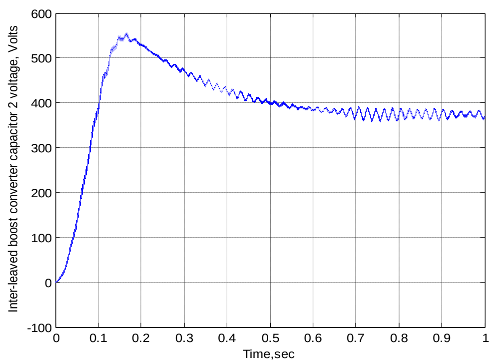

Fig.15 Output voltage of capacitor 2 with PI controller.

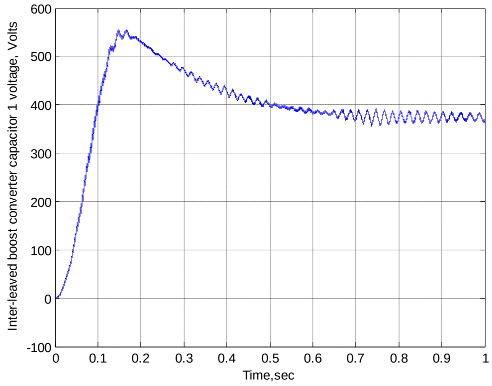

Fig.16 Output voltage of capacitor 1 with PI controller.

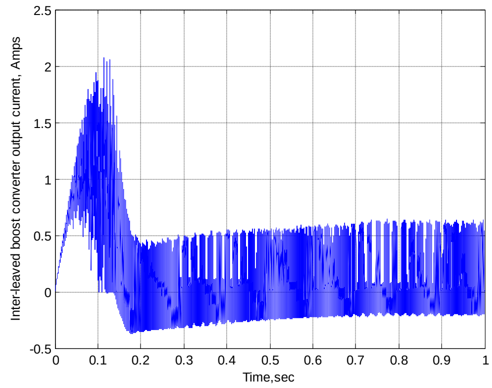

Fig.17 Boost converter output current with PI controller.

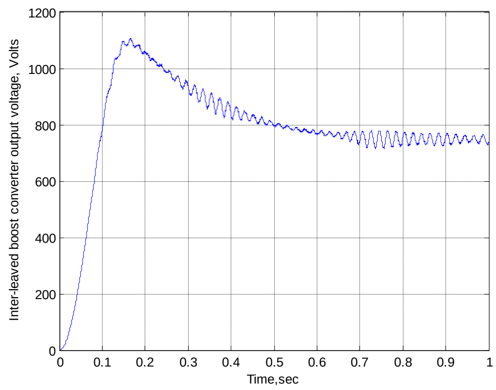

Fig.18 Boost converter output voltage with PI controller.

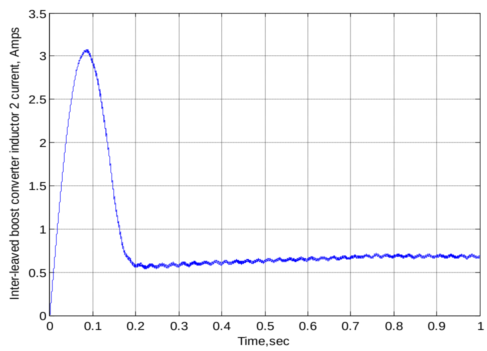

Fig.19 Boost converter inductor 2 current with PI Controller.

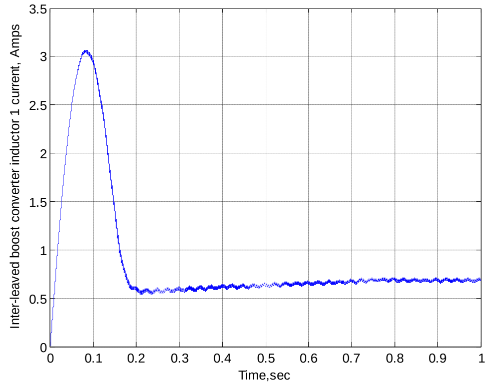

Fig.20 Boost converter inductor 1 current with PI Controller.

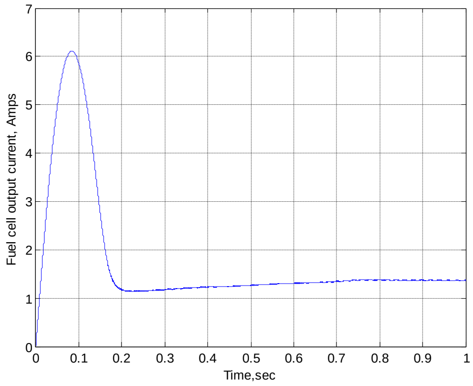

Fig.21 Fuel cell current with PI Controller.

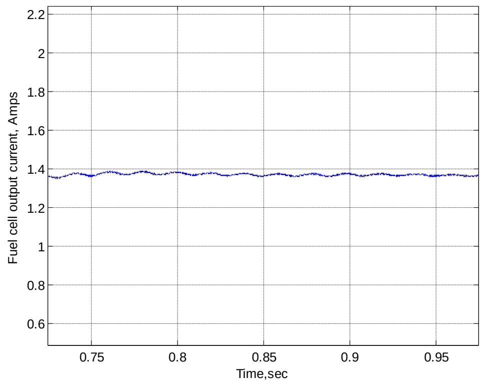

Fig.22 Fuel cell current with PI Controller.

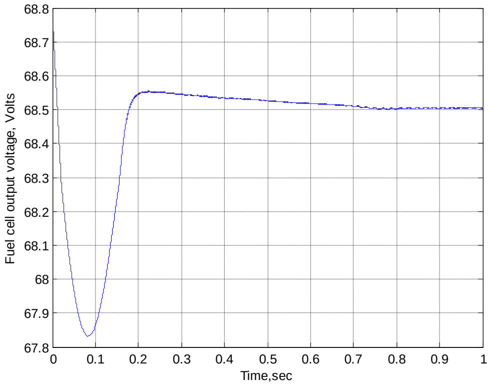

Fig.23 Fuel cell voltage with PI Controller.

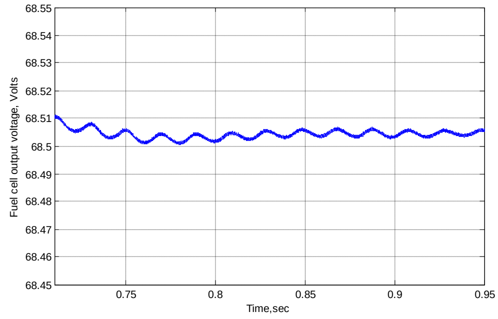

Fig.24 Fuel cell voltage with PI Controller.

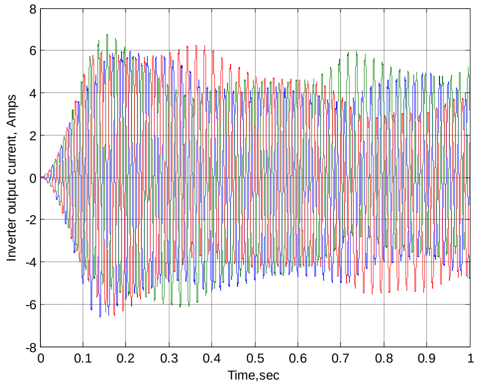

Fig.25 Inverter output current with FLC controller.

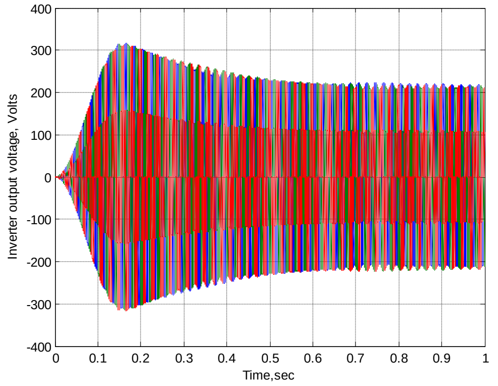

Fig.26 Inverter output voltage with FLC controller.

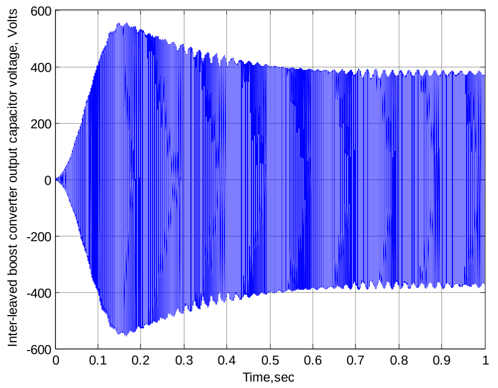

Fig.27 Output capacitor voltage with FLC controller.

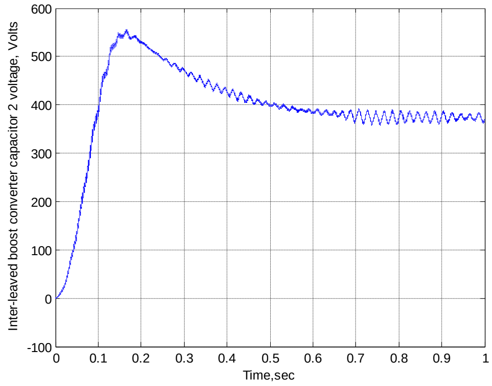

Fig.28 Output voltage of capacitor 2 with FLC controller.

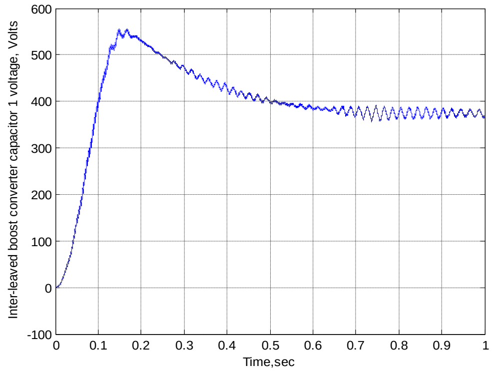

Fig.29 Output voltage of capacitor 1 with FLC controller.

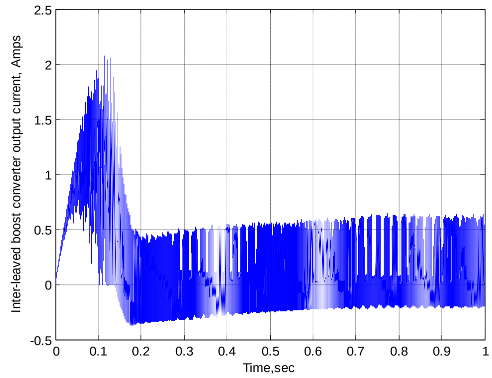

Fig.30 Boost converter output current with FLC controller.

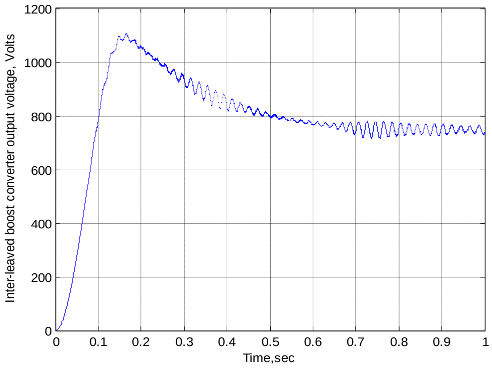

Fig.31 Boost converter output voltage with FLC controller.

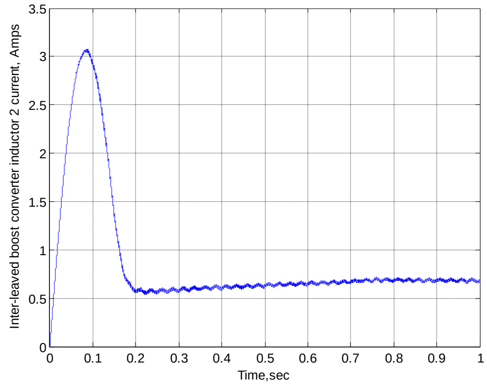

Fig.32 Boost converter inductor 2 current with FLC Controller.

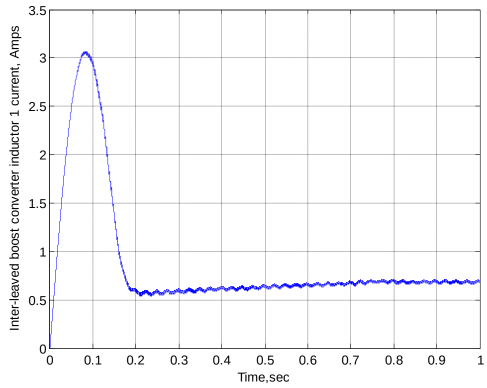

Fig.33 Boost converter inductor 1 current with FLC Controller.

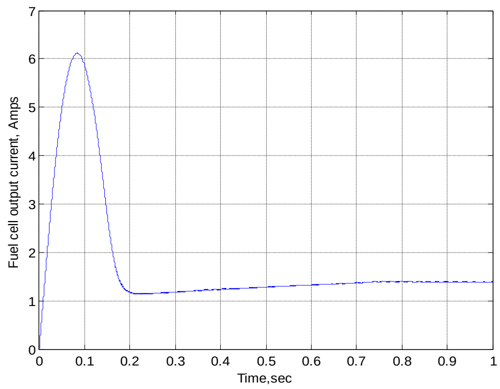

Fig.34 Fuel cell current with FLC Controller.

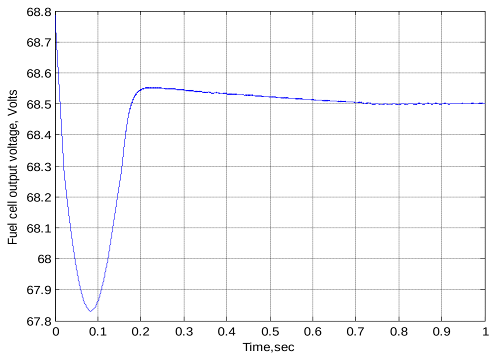

Fig.36 Fuel cell voltage with FLC Controller.

From the results it is concluded that the Fuzzy logic controller damping the oscillations of fuel cell voltage and current effectively as compared with PI controller. The fuzzy logic controller reduces the magnitude of voltage oscillations as well as current oscillations.

V. CONCLUSION

In this paper, Fuzzy logic controller is proposed for proper generation of pulses to Fuel cell power generation with non linear loads. In this paper two PI controllers are replaced with single robust Fuzzy logic controller, therefore economically the proposed controller is preferable. The proposed controlled also damping the oscillations in the fuel cell voltage and currents.

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