RESEARCH ARTICLE OPEN ACCESS

Fuzzy based control of Transformer less Coupled inductor based DC-DC converter

V. Viswanath[1], G.Shiny Vikram[2], Satyanarayana.V[3]

[1]Research Scholar ,Department of Electrical and Electronics Engineering, Ramachandra College of Engineering, Vatluru(V), Pedapadu (M), W.G.Dist, Andhra Pradesh, India.

[2]Assistant Professor, Department of Electrical and Electronics Engineering, Ramachandra College of Engineering, Vatluru(V), Pedapadu (M), W.G.Dist, Andhra Pradesh, India.

[3]Associate Professor, Department of Electrical and Electronics Engineering, Ramachandra College of Engineering, Vatluru(V), Pedapadu (M), W.G.Dist, Andhra Pradesh, India.

ABSTRACT

Most of the industrial applications use any one of the basic DC-DC converter configurations namely buck, boost, buck–boost, and Cuk converters. These converters are non-isolating converters. Buck-boost converters use inductors for storing energy from the source and release the same to load or output. This results in high stress across magnetic components. This drawback restricts usage of buck-boost converters to low power applications. Flyback converters popularly have known as buck-boost converters uses transformers for achieving wide range of step down and step up voltages. Coupled inductor based converters or tapped inductor based converters are used for achieving wide input – wide output conversion ratios. Coherent transition between step-down and step-up modes is achieved by a proper control scheme. This paper proposes fuzzy logic based closed loop control scheme for control of converter switches. Theoretical derivations of control parameters with their membership values, mamdani based rules for development of fuzzy rules and simulation results of a coupled inductor based DC-DC converter using MATLAB / SIMULINK are concluded.

Keywords - Boost, buck, coupled inductors, energy recovering snubber, wide step-down, wide step-up, wide input–wide output (WIWO) DC–DC converter, Fuzzy Logic Controller (FLC), Pulse width modulation (PWM).

I. Introduction

Application such as the front-end stage for clean-energy sources, the dc back-up energy system for an uninterruptible power supply (UPS), high-intensity discharge lamps for automobile head-lamps, telecommunications industry [2]–[4] require DC-DC converters with steep voltage ratio. The conventional boost converters cannot provide such a high dc voltage gain, even for an extreme duty cycle. High step-up DC–DC converters for above mentioned applications have the following common features. 1) High step-up voltage gain. Generally, about a tenfold step-up gain is required. 2) High efficiency. 3) No isolation is required. High step up gain from constant power low voltage gives either large input current with high output voltage or the large input current from low input voltage. It also results in serious reverse-recovery problems and increases the rating of all devices. Manipulated voltage clamped techniques are used in designing of converters to overcome the severe reverse recovery problem of the switches in high-level voltage applications, there still exists overlarge switch voltage stresses and the voltage gain is limited by the turn-on time of the auxiliary switches [6], [7]. When input power is a low-voltage source such as a battery and the required output is a high dc voltage, there is a need to develop a high power density boost DC–DC converter which features less complexity, compact size, and low cost. The major problem in developing such a converter is that the converter suffers from high current stress and, thus, it is difficult to improve the overall power efficiency. In such cases energy storage reactor is large measure in determining the performance of these converters. No other component has such dramatic effect on the distribution of component losses. As a result, the conversion efficiency is degraded and the electromagnetic interference (EMI) problem is severe under this situation [5]. In order to increase the voltage gain, boost converter topologies are to be modified.

Switching mode power supplies based on the flyback converter were widely used in industrial products for low-power applications. In the flyback converter, the transformer is adopted to achieve circuit isolation and energy storage.

Introducing a transformer in flyback converter helps attaining large step-up or step-down voltage conversion ratio. Transformers' turn ratio should be chosen as to provide the desired voltage gain while keeping the duty cycle within a reasonable range for higher efficiency. The transformer, however, brings in a whole new set of problems associated with the magnetizing and leakage inductances, which cause voltage spikes and ringing, increased core and copper losses as well as increased volume and cost.

Compared with an isolation transformer, a coupled inductor has a simpler winding structure, lower conduction loss, and continuous conduction current at the primary winding, resulting in a smaller primary winding current ripple and lower input filtering capacitance. Thus, a coupled-inductor-based converter is relatively attractive because the converter presents low current stress and low component count. However, for applications with low input voltage but high output voltage, it needs a high turn ratio, and its leakage inductor still traps significant energy, which will not only increase the voltage stress of the switch but also induce significant loss. [8] Introduces large voltage step-up using cascaded boost converters that implement the output voltage increasing in geometric progression. Voltage transfer ratio of these converters is effectively enhanced but the circuits of these converters are quite complex. [9] and [10] proposes tapped inductor based boost converters these converter circuits attain high conversion ratio with simple circuits. In [11] a new configuration is proposed by connecting the boost converter output terminal and fly-back converter output terminals in series to increase the output voltage gain with the help of coupled inductor. The boost converter functions as an active clamp circuit to recycle the snubber energy. This eliminates reverse recovery problems associated with flyback converters. This makes possible to achieve higher voltage conversion ratios. In [1] a new wide-input–wide-output (WIWO) DC–DC converter is proposed. This converter is an integration of buck and boost converters via a tapped inductor. By applying proper control to the two active switches, buck and boost actions are possible. Configuration proposed in [11] use modified pulse width modulation for control of switches.

This paper proposes new control scheme based on Fuzzy Logic Control (FLC) for the buck mode operation of tapped inductor based buck derived converters with three switches S_1, S_2 and S_3.Topology of the proposed DC–DC converter principles discussed in section II along with the operating principle in detail providing the steady-state (dc) and dynamic (ac) models as well. Fuzzy Logic Control based switching scheme is presented in section III. Section IV presents the theoretical derivations and results verified with the help of MATLAB simulation. Conclusions are given in Section V.

II. Coupled Inductor Based DC-DC Converters

Coupled inductor type DC-DC converter circuits make use of coupled inductors for energy transfer during conduction period. In most of the configurations these inductors are charged by connecting in parallel during charging mode and discharged by connecting in series.

Good literature is available for such applications, it has been prove that this kind of converters offer wide range of conversion ratios.

Bi-directional DC-DC converter topology given in [11] is considered for analysis purposes.

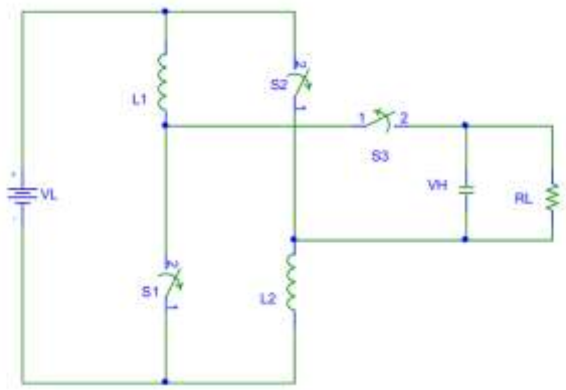

Fig.1: Model Proposed in [11]

During mode 1 operation of the converter Inductors and capacitor are allowed to charge and discharge that means inductors will get charged and capacitor gets discharged.

Amount energy stored by the inductor during charging period is

$$W = \int p(t).dt \qquad \text{...... (1)}$$

During mode 1 of operation current flowing through the inductor is given by

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{V_s}{(1+k)L}$$

$$i_{L1} = \int_0^{t_1} \frac{V_s}{(1+k)L} dt$$

$$i_{L1} = \frac{V_s}{(1+k)L} t_1 \qquad \text{...... (2)}$$

Where

Instantaneous power is $p(t)$

Applied voltage is V_s

Inductance of the coils $L_1 = L_2 = L$

Coefficient of coupling is k

Energy stored by inductor is W

Instantaneous power is given by $p(t) = v_{L1} i_{L1}$

Substitute values of v_{L1} and i_{L1} in equation (1)

$$W = \int v_{L1} i_{L1}.dt$$

From equation (2) substitute value of i_{L1}

$$W = \int v_{L1} \frac{V_s}{(1+k)L} t_1.dt$$

Energy stored by inductor by the end of mode1 is

$$W = \int_0^{t_1} V_s \frac{V_s}{(1+k)L} t_1.dt$$

$$= \frac{V_s^2 t_1^2}{2(1+k)L}$$

Total energy stored by the inductors is

$$W_L = \frac{V_s^2 t_1^2}{(1+k)L_1} \text{ J} \quad \text{...... (3)}$$

During Mode 2 load connected to the source as a result the inductors are connected in series and will get discharged, the energy thus stored by these inductors will be transferred to the capacitor, there by the capacitor starts charging.

During this mode

$$i_{L1} = i_{L2} = i_L \text{ And}$$

$$v_{L1} + v_{L2} = V_s - V_c$$

$$\frac{di_L}{dt} 2(1+M)L = V_s - V_c$$

$$\frac{di_L}{dt} = \frac{V_s}{2(1+M)L} - \frac{V_c}{2(1+M)L}$$

Voltage across capacitor is given by

$$v_C = \frac{1}{C} \int i_L dt = V_0$$

$$\frac{dv_C}{dt} = \frac{1}{C} i_L$$

Control variables for FLC are.

$$x_1 = V_{\mathrm{Re}\,f} - \beta V_0$$

Where β is feedback network ratio and V_0 is output voltage.

PWM based control signals are generated with the help of FLC Controller by taking x_1x1 and Δx_1 input variables to the fuzzy logic controller. Membership values of the input variable and the outputs of fuzzy control are explained in section III.

III. Fuzzy Logic Based Controller applied to DC – DC Converter

Through a FLC, an expert might be able to control a process based on his knowledge and observation of it, even without any mathematical model. The FLC has the following components: The fuzzification: converts the real input values to fuzzy values to be interpreted by the inference mechanism. The rule-base (*a set of if-then*: which contains the fuzzy values by means of a linguistic description of the expert to achieve good control. Inference mechanism: emulates the expert's decision making in the interpretation and application of knowledge about the best way to control the plant. Finally, the defuzzification: takes the values of the inference mechanism and converts them into actual output values. To carry out FLC design it is necessary to define the following inputs of FLC; the first input is the error (*e(k)*) given by the equation (4), where *Vo(k)* is the sampled output voltage of the boost converter and V_{Ref} is the voltage reference. The second input *(ce(k))* is given by the equation (5) where *e(k)* is the error at the *k*th sampling and *e(k-1)* is the error at the previous *k*th sampling.

$$e(k) = V_{\mathrm{Re}\,f} - V_0(k) \quad (4)$$

$$\Delta e(k) = e(k) - e(k-1) \quad (5)$$

Inputs are multiplied by gains *g0* and *g1*, respectively, and then they are evaluated in the fuzzy controller. The FLC output is the change in the duty cycle *Δd (k),* which is given by the equation (6), and it is scaled by the gain *h*.

$$d(k) = d(k-1) + h\Delta d(k) T_s \quad (6)$$

The gains in the controller inputs and output are from 0 to 1, because they are normalized, it facilitates the controller tuning. The method to calculate PMW duty cycle is through FLC output in the *k*th sampling (Δ*d* (*k*)) and adding to the duty cycle at the previous *k*th sampling (*d*(*k*-1)), this method represents discrete time integration in the FLC output. The integration at the FLC output increases the system type and reduces the steady-state error, smoothing the control signal. If the range of integrator is limited, the windup effect is avoided. So it becomes an incremental fuzzy controller. The incremental design approach provides an alternative for genetic fuzzy system in cases where the complexity of the control problem does not allow the evolutionary algorithm to adapt the entire fuzzy knowledge in one step.

3.1. Fuzzification

The fuzzification converts the numeric input into a linguistic variable by means of fuzzy sets that are defined into the universe of discourse, taking the next linguistic values: Negative Very Big (NVB), Negative Big (NB), Negative Medium (NM), Negative Small (NS), Negative Very Small (NVS), Zero Error (ZE), Positive Very Small (PVS), Positive Small (PS) ,Positive Medium(PM), Positive Big (PB), Positive Very Big (PVB) for *e* and *ce*. The fuzzy logic controller uses trapezoidal membership functions in the extremes in order to eliminate discrepancies, and it also uses triangular membership functions at the center, normalized from 0 to 1 for both cases.

The membership plots for error, change in error and duty ratio for the proposed converter are shown below.

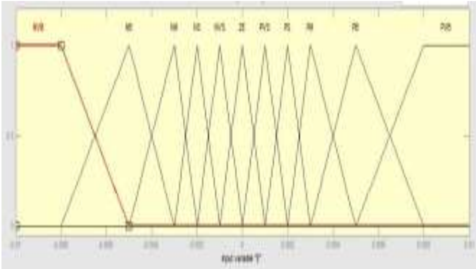

Fig.2: Membership Function for Linguistic variable 'Error'

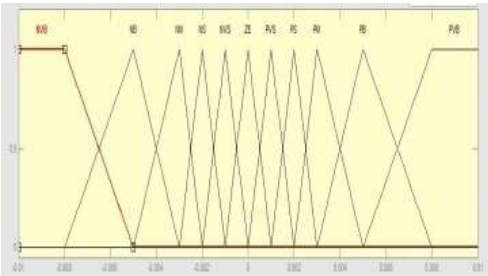

Fig.3: Membership Function for Linguistic variable 'Change in Error'

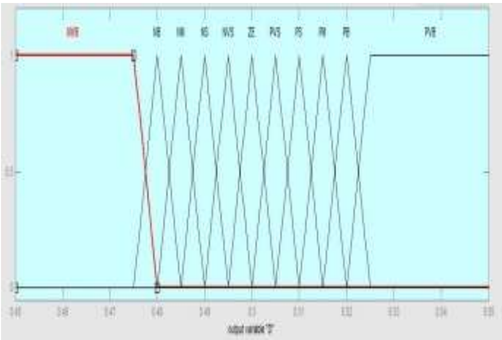

Fig.4: Membership Function for Linguistic variable 'Duty Ratio'

3.2. Rule Base

The rule base is defined by the relations between the inputs and output with rules of type *IF-THEN*. In our case, the designed controller has 11 fuzzy sets for each linguistic variable, which generates 121 rules that can be expressed as a Mamdani linguistic fuzzy model, like in the equation

IF e is Ai_1 and ce is Ai_2, THEN Δd_i is B_i (7)

Where e and ce are the input linguistic variables, Δi is the output linguistic variable, Ai_1 and Ai_2 are the values for each input linguistic variables on the universe of discourse and B_i is the value in output in the universe of discourse. The rules are based by heuristic knowledge in the behaviour of the DC-DC converter, which when the voltage is less than the reference, it is necessary increase the duty cycle, and when the voltage is higher than the reference the duty cycle is reduced. In addition, by considering the differential component, the speed at which the error is approaching to the reference can be described. The rule base is showed in the Table 1.

E CE	NVB	NB	NM	NS	NVS	ZE	PVS	PS	PM	PB	PVB
NVB	PVB	PVB	PVB	PVB	PVB	PVB	PB	PM	PS	PVS	ZE
NB	PVB	PVB	PVB	PVB	PVB	PB	PM	PS	PVS	ZE	NVS
NM	PVB	PVB	PVB	PVB	PB	PM	PS	PVS	ZE	NVS	NS
NS	PVB	PVB	PVB	PB	PM	PS	PVS	ZE	NVS	NS	NM
NVS	PVB	PVB	PB	PM	PS	PVS	ZE	NVS	NS	NM	NB
ZE	PVB	PB	PM	PS	PVS	ZE	NVS	NS	NM	NB	NVB
PVS	PB	PM	PS	PVS	ZE	NVS	NS	NM	NB	NVB	NVB
PS	PM	PS	PVS	ZE	NVS	NS	NM	NB	NVB	NVB	NVB
PM	PS	PVS	ZE	NVS	NS	NM	NB	NVB	NVB	NVB	NVB
PB	PVS	ZE	NVS	NS	NM	NB	NVB	NVB	NVB	NVB	NVB
PVB	ZE	NVS	NS	NM	NB	NVB	NVB	NVB	NVB	NVB	NVB

Table – 1: Fuzzy Rules relating Linguistic Variables

3.3. Inference Mechanism

The inference mechanism of Mamdani controller is based on generalized modus ponens through cartesian intersection of membership grades e and ce (ue and uce) and applying the Mamdani's min fuzzy implication where the result of inference mechanism is w_i, and c_i is taken from the rule base, like in the equation (8). Some controlling rules considered in this paper are shown in Table 1.

$$w_i = \min\{ue(i), uce(j)\} * c_i \tag{8}$$

3.4. Defuzzification

In the defuzzification operation a logical sum of the inference result from each of the four rules is performed. In this study means of Mamdani's method is implemented. The defuzzification converts the conclusions of the inference mechanism into actual inputs for the process. Which can be developed by the center of gravity method for Mamdani type showed in the equation (9), where bi is the center of the membership function and ∫u(i) denotes the area under the membership function u(i), and it is calculated using the equation (10), with w as the width of the base of the membership function and the height H.

$$\Delta d(k) = \frac{\Sigma bi \int u(i)}{\Sigma \int u(i)} \tag{9}$$

$$\int u(i) = w\left(H - \left(\frac{H^2}{2}\right)\right) \tag{10}$$

One can see the control surface which displays the output for each one of the possible inputs of e and ce in the FLC. For this propose, the duty cycle value is obtained using MATLAB software for different values of error and change of errors. The results are used by the converter, which sets the output value from the table values and errors and change in errors .The fuzzy levels for output signal versus different error values and change in error and for diverse types of membership functions.

IV. Simulation & Results

To demonstrate the performance of proposed DC-DC boost converter, in MATLAB/Simulink with reference to the values given in the Table 2. A constant voltage source of 14 V is input to converter with R load. A reference voltage of 42V is assumed for closed loop operation. The complete model consists of voltage source, linear load, and a FLC based converter.

S.No	Load Power (W)	Io (Avg) Amps	Vo (Avg) Volts	δV Volts	% δV
1	50	1.1800	41.7500	0.0417	4.1
2	100	2.3200	40.900	0.0262	2.6
3	150	3.4515	40.5400	0.0248	2.4
4	200	4.6390	40.9150	0.0044	0.4
5	250	5.7610	40.6600	0.0055	0.5
6	300	6.8675	40.3750	0.0065	0.6
7	350	7.9665	40.1250	0.0077	0.7
8	400	9.0415	39.8650	0.0087	0.8
9	450	10.1150	39.6100	0.0098	0.9
10	500	11.1435	39.3600	0.0105	1.05

Table-2: Variation of Different parameters when Converter is supplying load

Variation of Different parameters when Converter is supplying different loads is shown in Table-2.

MATLAB based simulation model developed with the help of simlink and Fuzzy logic tool box for implementation of Fuzzy based control of Transformer less, Coupled inductor based DC-DC converter is shown in Fig.5. Simulation based results are presented when converter is supplying a load power equal to 200W. Fig.6 represents Fuzzy Logic controller implemented, In Fig.7. The output of Fuzzy controller (Duty Ratio) is presented. Fig.8 voltage across load and current through load are presented.

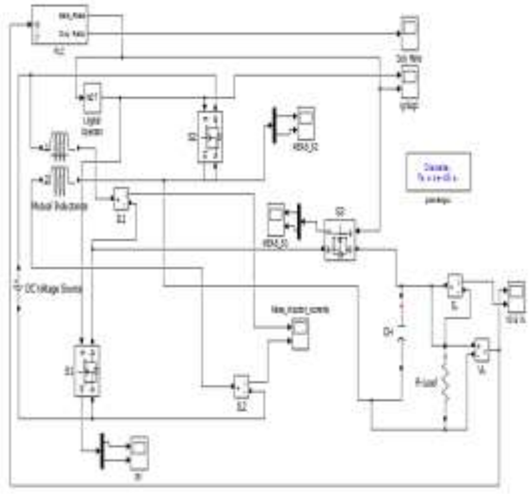

Fig.5: MATALB based schematic of Transformer less boost Converter

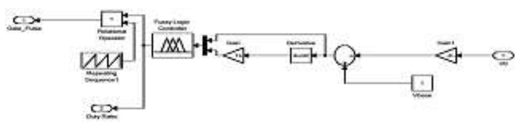

Fig.6: Schematic of Fuzzy Logic Based Controller

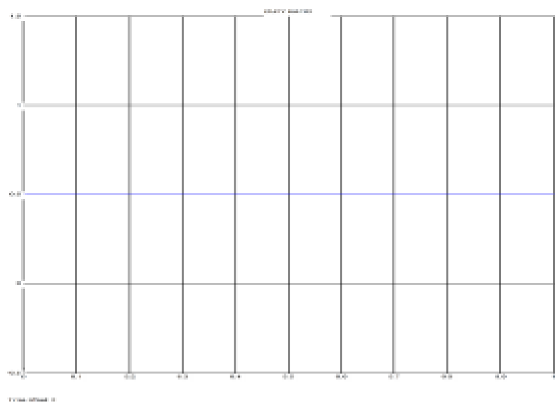

Fig.7: Output of Fuzzy based Controller

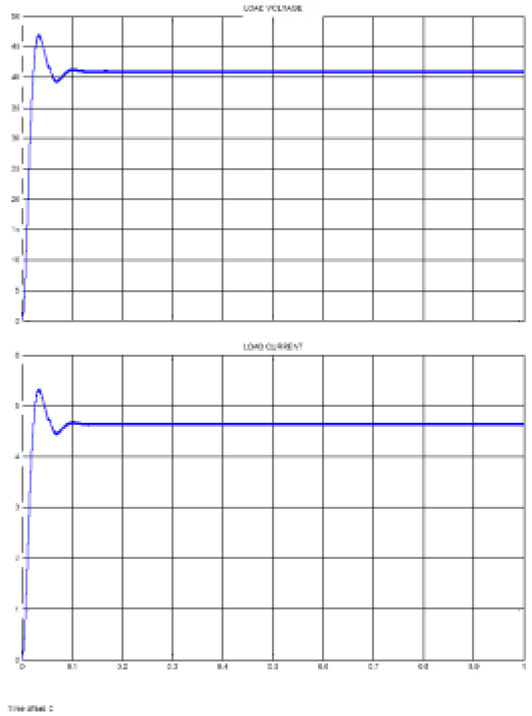

Fig.8: Voltage across load and current through load when the load connected to the converter is 200W.

V. Conclusion

Fuzzy logic Control is designed for achieving a conversion gain of 3 with a duty ratio equal to D = 0.5. The converter is simulated for different load conditions varying the load power from 50W to 500W. It is observed that FLCS based circuit gives very quick response and attains good regulation when the load subjected to vary. The converter operates in continuous conduction mode and the switches are subjected to less voltage stress. The FLC based control scheme gives a better regulation for a wide operating range of load powers.

REFERENCES

[1]. Hao Cheng, Keyue Ma Smedley , Alexander Abramovitz , "A Wide-Input–Wide-Output (WIWO) DC–DC Converter", IEEE Trans. Power Electron. , vol. 25, no. 2, pp. 280–289, Feb. 2010.

[2]. I. Barbi and R. Gules, "Isolated dc –dc converters with high-output voltage for TWTA telecommunication satellite applications," IEEE Trans. Power Electron., vol. 18, no. 4, pp. 975 –984, Jul. 2003.

[3]. O. Abutbul, A. Gherlitz, Y. Berkovich, and A. Ioinovici, "Step-up switching-mode converter with high voltage gain using a switched-ca-pacitor circuit," IEEE Trans. Circuit Syst. I, vol. 50, no. 8, pp. 1098–1102, Aug. 2003.

[4]. K. C. Tseng and T. J. Liang, "Novel high-efficiency step-up converter," Proc. Inst. Elect. Eng. , vol. 151, pp. 182 –190, 2004.

[5]. N. Mohan, T. M. Undeland, and W. P. Robbins, Power Electronics: Converters, Applications, and Design. New York: Wiley, 1995.

[6]. M. M. Jovanovic and Y. Jang, "A new soft-switched boost converter with isolated active snubber," IEEE Trans. Ind. Appl., vol. 35, no. Mar./Apr., pp. 496–502, 1999.

[7]. C. M. C. Duarte and I. Barbi,"An improved family of ZVS-PWM active-clamping DC-to-DC converters, " IEEE Trans. Power Electron. , vol. 17, no. 1, pp. 1 –7, Jan. 2002.

[8]. F. L. Luo and H. Ye, "Positive output cascade boost converters," Proc. Inst. Electr. Eng. Electr. Power Appl., vol. 151, no. 5, pp. 590–606, Sep. 2004.

[9]. Q. Zhao and F. C. Lee, "High efficiency, high step-up dc–dc converters," IEEE Trans. Power Electron. , vol. 18, no. 1, pp. 65–73, Jan. 2003.

[10]. N. Vazquez, L. Estrada, C. Hernandez, and E. Rodriguez, "The tapped-inductor boost converter," in Proc. IEEE Int. Symp. Ind. Electron. , Jun., 4–7, 2007, pp. 538–543.

[11]. Lung-Sheng Yang, Tsorng-Juu Liang Analysis and Implementation of a Novel Bidirectional DC–DC Converter, IEEE Transactions On Industrial Electronics, Vol. 59, No. 1, January 2012, pp 422 – 434.

[12]. Ion Iancu "A Mamdani Type Fuzzy Logic Controller" Fuzzy Logic - Controls, Concepts, Theories andApplications, Prof. Elmer Dadios (Ed.), ISBN: 978-953-51-0396-7, 2012.