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Bi-directional DC–DC Converter with Adaptive Fuzzy Logic Controller

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Introduction

The Bi-directional DC-DC converters are involved in power flow between two dc sources. They allow power flow in both the direction without change in polarity of voltage. They are used in DC Un-interruptible Power Supplies and Battery charging circuits. Initially Bi-directional power flow is obtained by constructing individual converters for each direction of power flow. Then they are implemented by soft switching (1) and resonant techniques (2,3).But it increases the component rating and circuit complexity also its losses. It misses the soft switching signal at light loads also. To overcome these difficulties a Bi directional converter which is a merge of a half bridge converter and push pull converter is proposed. This converter uses the bidirectional power flow property of MOSFET and provides the bi-directional power flow using only one transformer. It claims the following advantages also.(i)Low stress on switches.(ii)Galvanic isolation (iii)Reduced components count. The dynamic behavior of this converter can be improved by application of intelligent techniques such as neural networks and fuzzy logic. Intelligent technique implemented controller designing strategy started nearly a decade back. In 1994 a FLC controller (4) is proposed for simple DC-DC converters. This has been implemented by using Digital Signal Processor (TMS320C50) in 1996. In the year 1997 neural network control is designed for DC-DC converters (5). In 2006 different control strategies have been proposed to control DC-DC converters and implemented by using microcontroller and a specialized hardware (6). In recent years neurofuzzy controllers and adaptive fuzzy logic controllers simplify the process of controller design and provide efficient control (6). In recent years, more interest has been developed in the intelligent technique based controllers for most of the circuits because of i) simplicity in controller development ii) Possibility of automated control iii) Need of less skilled labour. The block diagram of FL controller is shown in Fig. 1.

Proposed converter topology

This paper proposes a bi-directional DC-DC converter controlled by Adaptive Fuzzy Logic Controller. Adoptive fuzzy logic denotes fuzzy logic with an adoption algorithm. Fuzzy Logic controller is constructed and adoption algorithm is imposed on this controller.

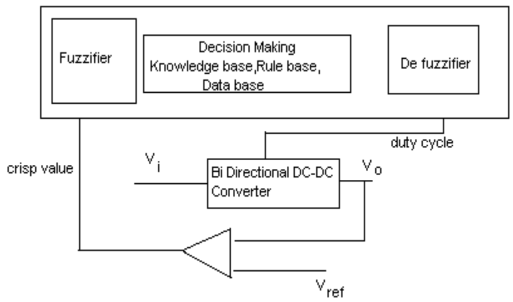

Fig. 1. Block diagram of FL Controlled Converter

The proposed Bidirectional converter shown in Fig. 2 includes two converters topologies. The primary side of the transformer is connected with a half bridge converter which includes the switches S1 and S2 and fed by power supply. The secondary of transformer is connected to the switches S3 and S4 and forms a push pull topology. The converter operates in two modes. In forward mode operation switches S1, S2 are operated and S3, S4 are switched off. The duty cycle of S1 and S2 limited to be less than 0.5 .The converter exhibits the operation as buck converter. In back up mode S3, S4 are switched and the switches S1, S2 are in off condition and the duty cycle of S3 and S4 is set to be more than 0.5. Operation of the converter in this mode is similar to boost converter Individual switching signals applied for individual switches. Following assumptions were also made for proper analysis of the converter:

i. The switches and diodes are ideal
ii. Transformer is ideal and the turns ratio is one
iii. All the voltages and currents applied are periodic

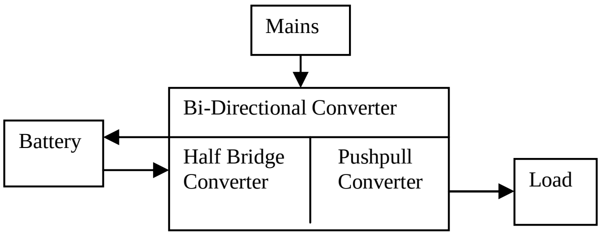

Fig. 2. Block diagram of proposed converter

The proposed half bridge and pushpull combined topology shown in Fig. 3 is advantageous in the following aspects when compared to the conventional converters: (i)The switches are subjected to voltage stress only equal to the DC input voltage. But in the conventional push pull converter the switches are subjected to voltage stress twice the input voltage. (ii)In low power conditions usage of two switch half bridge topology reduces the size of LC filter required, when compared with four switch full bridge converter topology

Duty cycle variation of the switching signal depends on the input voltage of the converter. It is given by the expressions shown below. Forward mode:

$$d_{min} = \frac{V_{battmax}}{V_{smin}} , \qquad d_{max} = \frac{V_{battmax}}{V_{smax}} ; \tag{1}$$

Back up mode:

$$d_{min} = \frac{Vs\text{-}V_{battmin}}{V_s} , \qquad d_{max} = \frac{1\text{-}2V_{smin}}{V_s} ; \tag{2}$$

where d_{min} – minimum value of duty cycle; d_{max} – maximum value of duty cycle.

Controller design

The process of fuzzy logic controller design includes the following processes. (i)Fuzzification; Process of representing the inputs as suitable linguistic variable.(ii)Decision Making; Appropriate control action to carried out. It is based on the knowledge base and rule base. Knowledge base and rule base are the details about the linguistic variables and control rules (iii) DefuzzificationProcess of converting fuzzified output into crisp value.

The inputs to the FLC are error signal and difference of error signal. The output is the duty ratio of the switching signal.

$$e=V_{ref} – V_o; \; d(t)= d(t – 1) – d(x(t)) , \tag{3}$$

where d(t – 1) – duty cycle at (t –1)th instant; V_o – output voltage; d(x(t)) – change in duty cycle; V_{ref} – reference voltage; d(t) – duty cycle at t^{th} instant; e – error signal.

All the linguistic variables are assumed to have same number of linguistic values. The shrinking span membership function algorithm proposed by Chies and Hsieh is used to construct FLC without need of expert presence. This algorithm involves the process of arranging the membership functions of a linguistic variable in orderly manner across universe of discourse.

The shrinking factor (S_f) decides the span of member ship function. By applying various values of S_f to one linguistic variable, most suitable most suitable membership function can be decided.

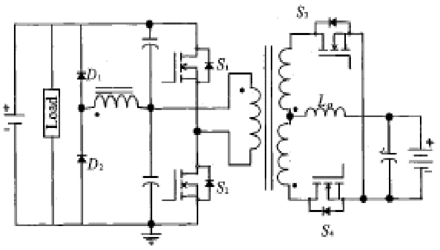

Fig. 3. Power circuit of proposed converter

Mamdani type controller is chosen for this application and the basic rule of this type of controller is:

$$\text{IF e is A and de is B THEN d(t) is C;} \tag{4}$$

where A and B – fuzzy subsets; C – fuzzy singleton.

Each universe of discourse is divided into seven subsets such as Positive Large(PB), Positive Medium(PM), Positive Small(PS), Zero(ZE), Negative Small(NS), Negative Medium (NM), Negative Large(NB).The rule base for the corresponding membership functions is decided by index representation method as shown in Table 1. Table 2 shows the linguistic label representation of rulebase.

Table 1. Rule mapping by index representation

e/de	–3	–2	–1	0	1	2	3
3	0	1	2	3	4	5	6
2	–1	0	1	2	3	4	5
1	–2	–1	0	1	2	3	4
0	–3	–2	–1	0	1	2	3
–1	–4	–3	–2	–1	0	1	2
–2	–5	–4	–3	–2	–1	0	1
–3	–6	–5	–4	–3	–2	–1	0

Table 2. Labels of linguistic variables

e/de	NB	NM	NS	ZE	PS	PM	PB
PB	ZE	PS	PM	PB	PB	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PS	NM	NS	ZE	PS	PM	PB	PB
ZE	NB	NM	NS	ZE	PS	PM	PB
NS	NB	NB	NM	NS	ZE	PS	PM
NM	NB	NB	NB	NM	NS	ZE	PS
NB	NB	NB	NB	NB	NM	NS	ZE

The center of gravity method of defuzzification is applied to obtain crisp result from the linguistic values obtaine according to rule base.

$$du = \frac{\Sigma W_i C_i}{\Sigma W_i} . \tag{5}$$

The inputs to the AFLC are the training data from model file and the outputs are the membership functions. It adopts various parameters according to the training data fed through pattern file. The algorithm calculates the overall error index (e_{io}) and updates the parameters to make e_{io} to be zero. Finally application of AFLC ensures desired operation of proposed converter.

Simulation Results

The proposed converter is simulated using MATLAB package. The rating of converter in both modes is given in Table 3.

Table 3. Rating of converter in both the modes.

Parameter/Mode	Forward Mode	Backup mode
Input Voltage	300-400V	No mains supply
Output voltage	300-400V	350V
Output Power	100W	300W
Operating Frequency	100KHz	100KHz

The waveforms are repetitive for every switching cycle. The waveforms is divided into many time intervals and analyzed.

Forward mode operation is divided into four time intervals. The waveforms are shown in Fig. 4. During interval t_{1f} $V_s/2$ voltage appears across primary winding and the primary current builds up. In interval t_{2f} there is no voltage across primary and secondary winding. So there is no power transfer and the converter performs freewheeling action. Half the input voltage appears across switches. In the third interval t_{3f} the operation is similar to interval t_{1f} and the secondary side diodes offers rectification. In the interval t_{4f} the operation is similar to interval t_{2f}.There is no primary side conduction in this interval. In all these time intervals the reverse voltage appears across switches does not exceed $V_s/2$.

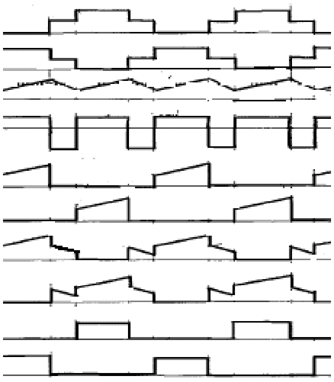

Fig. 4. Waveforms during forward mode operation: voltage across S_1,S_2; load current; load voltage; current flowing through S_1,S_2,DS_3,DS_4

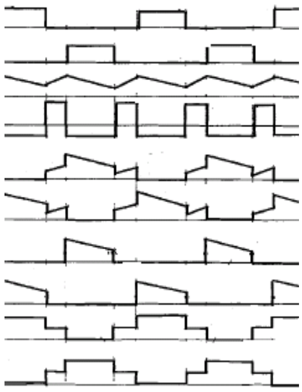

Fig. 5. Waveforms during backup mode operation: voltage across S_3,S_4; load current; load voltage; current flowing through S_3,S_4,DS_1,DS_2

Back up mode operation is also divided into four intervals. The waveforms are shown in Fig. 5. In the first interval t_{1b}, transformer secondary subjected to short circuit. The inductor stores energy and the total battery voltage appear across inductor. The bulk capacitors provide output load power. In the second interval t_{2b} the energy stored in the inductor is transferred to load. Equal voltage appears across primary and auxiliary winding. So both the capacitors get charged simultaneously. In the interval t_{3b} the operation is similar to interval t_{1b}.In the last time interval t_{4b} operation is similar to t_{2b} interval. The diodes causes equal charging of capacitors.

In the simulation of AFL controller, pattern file is generated initially. It consists of three vectors two inputs error and change of error and the output vector is change of duty cycle. Seventy two epochs were performed and the error measure is $9.3X10^{-5}$.The shrinking factor S_f value is 0.35. Fig. 6(a) and Fig. 6(b) show the waveforms of input and output vectors obtained during simulation.

The results indicate that this method provides an easy and systematic way in designing the AFLC. The generated membership functions and rule base are general and could be used for any without any modification.

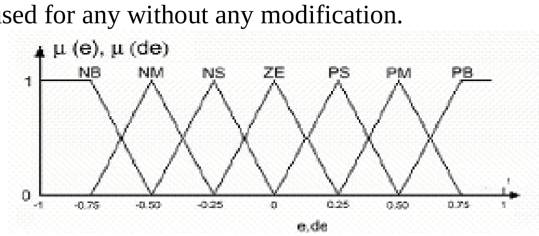

Fig. 6(a). Input vectors; error and change in error

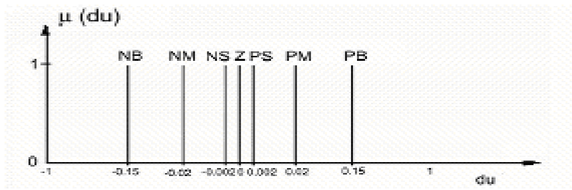

Fig. 6(b). Change in duty cycle

Hardware results

Laboratory prototype of the above proposed converter is developed with the help of microcontroller ST52T420. It is an 8 bit micro controller. It effectively performs fuzzy logic and Boolean operations. Components used in prototype construction are tabulated in Table 4.

Table 4. Specifications of components used in prototype

S.No	Component	Rating/Model
1	Diode	IN4007A
2.	MOSFETS	IRF840
3.	Capacitors	150µF
4.	By pass capacitor	470µF
5.	Inductors	2mH&380µH

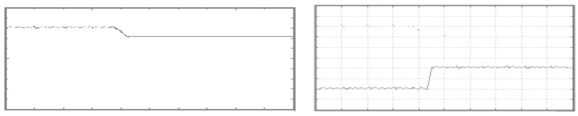

Fig. 7. Waveforms of load voltage, inductor current when switching from forward to back up mode of conduction

Wave forms of various currents and voltages are obtained for both the modes of operation. Fig**.** 7 shows the waveforms of battery voltage, inductor current and transformer charging current in the forward mode operation when there is power available in mains. Fig**.** 8 shows the waveforms in back up mode operation Fig**.** 9 shows the waveforms of converter when its switching from forward to back up mode.

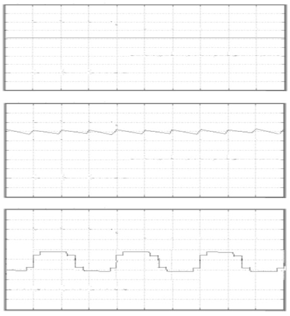

Fig. 8. Forward mode: waveforms of load voltage, inductor current and transformer primary current

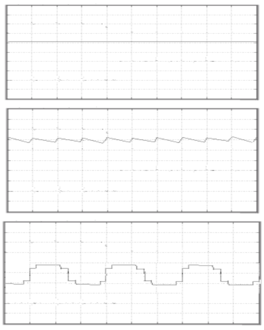

Fig. 9. Back up mode: load voltage, inductor current, transformer primary current

The waveforms imply that the proposed converter produces less amount of ripples, less voltage distortion, automatic switch over control.

Conclusion

In this paper the design methodology of a bidirectional DC-DC converter with adaptive fuzzy logic controller is discussed. The laboratory prototype constructed proves the effectiveness of the converter without existence of an expert. The AFL Controller regulates the output voltage of the converter.

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N. Rajarajeswari, Dr. K. Thanushkodi. Bi-directional DC–DC Converter with Adaptive Fuzzy Logic Controller // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 1(89). – P. 65–68.

A bi-directional DC-DC converter with adaptive fuzzy logic controller (AFLC) is introduced. Bi-directional power flow is obtained by the same power components and provides a simple, efficient, and galvanically isolated converter. In the presence of DC mains the converter operates as buck converter, powers the down stream converter and also charges the battery. When the DC mains fails, the converter operates as boost converter and the down stream converters are fed by battery. In both the modes the power switches are controlled by PWM technique and the pulses are generated by application fuzzy logic with an adoption algorithm. The proposed converter is simulated using MATLAB and laboratory prototype is developed to validate the simulation results. Ill. 9, bibl. 11 (in English; summaries in English, Russian and Lithuanian).

Н. Раяраясвари, Др. К. Танусходи. DC-DC преобразователь с адаптивным управлением // Электроника и электротехника. – Каунас: Технология, 2009. – № 1(89). – С. 65–68.

Описывается DC-DC преобразователь, который используется для управления двухсторонними потоками мощности. Преобразователь питается от батерии и значительно повышает надежность работы. Анализ преобразователя проведен применяя программу MATLAB. Результаты подтверждены зкспериментально. Ил. 9. библ. 11 (на английском языке; рефераты на английском, русском и литовском яз.).

N. Rajarajeswari, Dr. K. Thanushkodi. Dvikryptis DC–DC konverteris su adaptyviosios neraiškiosios logikos valdikliu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 1(89). – P. 65–68.

Pateiktas dvikryptis DC-DC keitiklis su adaptyviosios neraiškiosios logikos valdikliu. Dvikryptis galios srautas sukuriamas naudojant tuos pačius galios komponentus. Taip gaunamas paprastas, efektyvus ir galvaniškai atsietas keitiklis. Esant DC maitinimui, keitiklis įtampą žemina, maitina nuosekliai prijungtą srauto keitiklį ir įkrauna bateriją. Nutrūkus DC tiekimui, keitiklis įtampą didina, o nuosekliai prijungtą keitiklį maitina baterija. Abiem atvejais galios komutatoriai valdomi PWM būdu, kai impulsus generuoja neraiškioji logika su adaptyviuoju algoritmu. Keitiklis sumodeliuotas naudojant MATLAB. Modeliavimo rezultatams patvirtinti sukurtas laboratorinis keitiklio prototipas. Il. 9, bibl. 11 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).