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Design of an Intelligent Bi-Directional DC-DC Converter with Half Bridge Topology

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Abstract

This paper introduces a novel Bi-directional DC-DC converter with artificial neural network controller (ANN).Bidirectional 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 and charges the battery. When the DC main fails, the converter operates as boost converter and the battery feeds the load. In both the modes the power switches are controlled by PWM technique and the PWM pulses are generated by application of ANN controller. The proposed converter with controller is simulated using MATLAB and the design is validated.

Keywords: Neural controller, DC/DC converter, half bridge topology, intelligent technique, bidirectional converter

1. Introduction

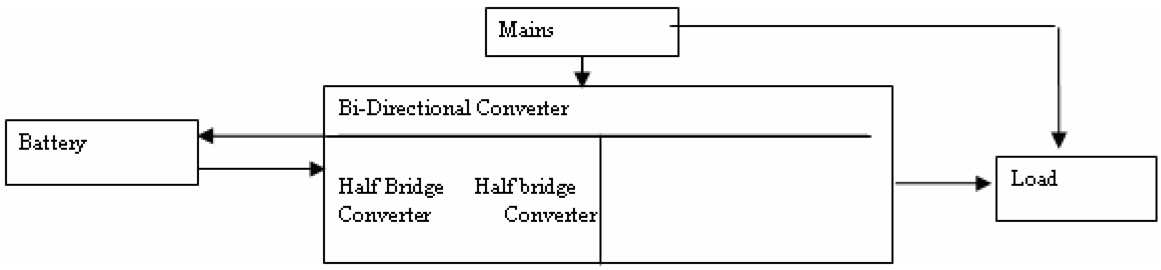
Bidirectional converters are the combined configuration of battery charging circuit and DC/DC converter circuit. They allow power flow in either direction, i.e. towards battery or away from battery. They find great application in DC UPS, battery charging circuits, Stand by DC power supplies and also in aerospace applications. Possible implementation of bidirectional converters with full bridge topology [1] using resonant [2], soft switching [3] and hard switching PWM [4] has been reported in literature. These topologies often lead to an increase in component ratings, circuit complexity and conduction losses in resonant mode implementations, high output current ripple and loss of switching signals at light loads for soft switched circuits, and lack of galvanic isolation in integrated topologies. The converter also found less user-friendly.

In the past few decades the intelligent controlling techniques show a great development. Neural network are effectively implemented in many control applications. A NN is an interconnection of a number of artificial neurons that simulates a biological brain system. It has the ability to approximate an arbitrary function mapping and can achieve a higher degree of fault tolerance [5]. This reduces the complicated algorithms and the heavy computational demands which make the implementations difficult.

The converter proposed in this paper, allows the bidirectional power flow using two half bridge topology converters. [6] The converter switches are controlled by PWM signals. These switching signals are generated by neural network control. In the above configuration the converter claims the following advantages. .(i)Low stress on switches.(ii)Galvanic isolation (iii)Reduced components count. The dynamic behavior of this converter can be improved by application of neural network control.

2. Proposed Converter

Figure 1: Blockdiagram of proposed converter.

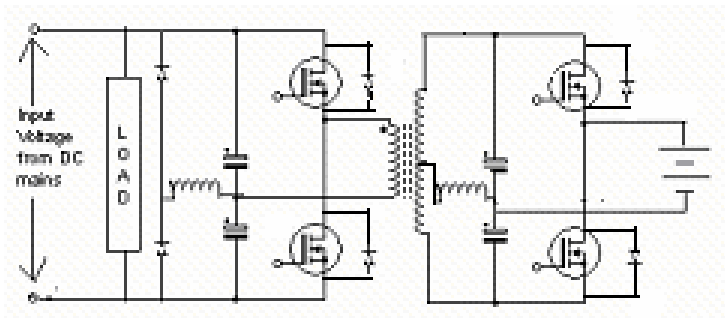


The proposed converter block diagram is shown in fig 1.It is a merge of two half bridge converters. It shows improvement in the difficulties found in literature review. The switching device used is MOSFET[7] which allows the power flow in either direction. The converter is designed to provide clean and continuous power to the load and to charge battery under essentially any normal or abnormal utility power condition.

The power circuit of converter shown in fig.2.operate in two modes called forward mode and backup mode. In forward mode mains supply feeds the load and also charges the battery. Converter operates as buck converter. The transformer provides galvanic isolation[8] between battery and mains. In the forward mode operation primary side switches are gated and body diodes of secondary side switches perform the battery side rectification.

When the mains supply fails, battery supplies the load. The converter operates in boost mode and this operation is known as back-up mode operation. Power flows in the opposite direction. In this mode the secondary side switches are gated and the primary side conduction is done through their corresponding body diodes. When both the secondary side switches are gated on transformer secondary faces an effective short circuit and the inductor stores the energy. Total battery voltage appears across the inductor. The inductor current linearly increases and energy stored in the inductor. Diodes in the primary side avoid the voltage imbalance in the circuit. Switches in the off state in half-bridge topologies are subject to a voltage stress equal to the dc input voltage and not twice that as in the push-pull and single ended forward converters. So the two switch half bridge topology is preferred over other topologies. The primary winding of the transformer in a half-bridge sustains half the supply voltage compared to the full dc voltage for the forward converter, implying half the number of turns on the primary. This allows full copper utilization of the half-bridge transformer, low number of primary winding turns, and reduction in its size and cost[9]. The gating signals applied to the switches depend on the voltage rating of load and battery condition[10]. Current mode control is employed in converter operation.

Figure 2: Power Circuit of converter.



This allows[11]

1) a pulse by pulse monitoring and limiting of current, thus avoiding flux imbalance in the transformer;
2) fast regulation to input voltage variation;
3) enhanced load regulation due to greater error amplifier bandwidth;
4) minimal external parts.

The converters are conventionally controlled by PI controllers. They produce the switching signals depending on the battery condition availability of mains supply. The design of such controllers needs deep knowledge in the operation of the converter and also the circuit model analysis of the circuit. This is simplified by employing artificial neural networks. Duty cycle range of the gating signals in conventional control technique is obtained as

Forward mode

$$d_{min} = \frac{V_{battmax}}{V_{smin}} \qquad d_{max} = \frac{V_{battmax}}{V_{smax}}$$

Back up mode

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

d_{min}-minimum value of duty cycle;

d_{max}-maximum value of duty cycle

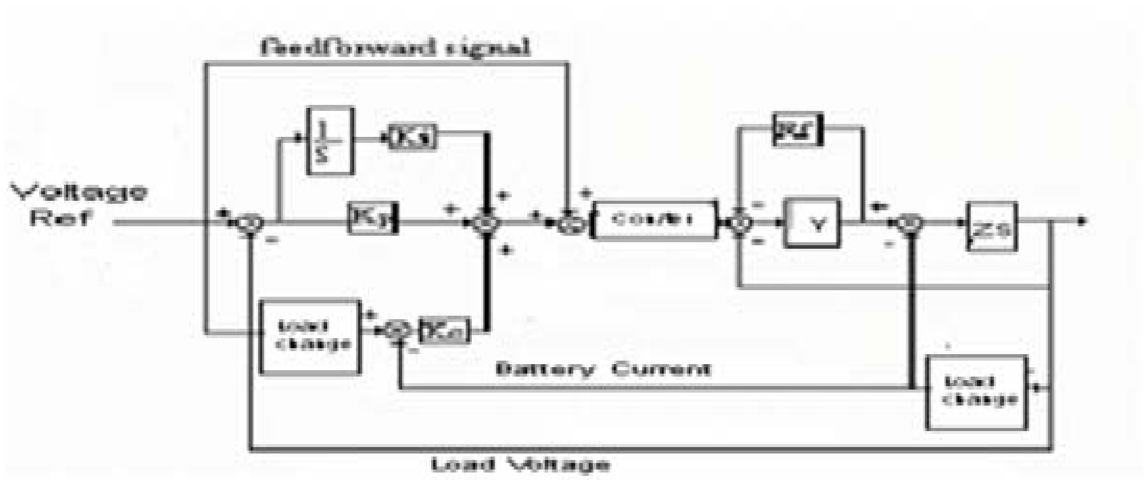
3. Controller Design

Neural networks (NNs) have been employed in many applications in recent years. An NN is an interconnection of a number of artificial neurons that simulates a biological brain system. It has the ability to approximate an arbitrary function mapping and can achieve a higher degree of fault tolerance. NNs have been successfully introduced into power electronics circuits to generate the switching signals for converters

An Artificial Neural Network (ANN) is an information-processing paradigm that is inspired by the way biological nervous system, such as brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of large number of highly interconnected processing elements (neurons) working in unison to solve problems.

Fig.3 shows the controller model with idealized load voltage reference io for obtaining example patterns. When

Figure 3: Controller Model



Neural Network is used in system control it can be trained either online or offline. In offline training weights and biases of the NN are adaptively modified during the control process. In real time control of the converter, there are no desired outputs to be presented to Neural Network since we have no prior knowledge about the loading conditions.

A Neural Network emulator can be employed to identify the converter behavior in order to determine the output error of the Neural Network controller. The disadvantage is that Neural Network emulator also needs to be pre trained with data obtained from simulations or experiments. In this paper offline training is used since it requires a large number of example patterns. These patterns may be obtained through simulations. A selected feed forward Neural Network is trained to model this controller using back propagation algorithm. After training, the Neural Network controller is used to control the converter on-line.

The converter is modeled as a proportional block with a gain K equal to V_{dc}/V_c where V_{dc} is the voltage of the dc power source and V_c is the voltage of battery as shown in Fig.1.Neural Network controller is to reduce the output voltage distortion under nonlinear loading condition. Offline training is adopted to ensure the converter will have fast transient response and low cost.

In order to obtain good example patterns for NN off-line training, we need a simulation model (as shown in Fig.3) that can perform well not only under linear loading condition, but also under nonlinear loading condition. Hence the above model is designed using a derived transfer function based upon the converter operation. The problem with the nonlinear load is that it draws distorted current so that the output voltage is distorted. If the load current can be predicted, we can design a controller to enable the output current to keep track of this predicted current. Multifeedback loop control scheme involves the inner battery current loop and a battery voltage loop as shown in Fig3. Voltage reference is fed to the load model to generate an idealized load-current-reference. The error between this current reference, and actual load current is used as the input of the controller. An outer voltage loop is employed to achieve output voltage regulation. The load model specifies for both linear and non linear conditions. For non linear loading condition a full bridge rectifier serves as the load model. This model is easy to build and to simulate. Its performance is good not only under linear loading condition but also under nonlinear loading condition. We build such a controller with an idealized load- current reference using the software tool MATLAB .

It should be noted that a fixed set of controller parameters is not good for every loading condition. Each loading condition has a set of optimal parameters, which can be determined from simulation that produces an output voltage a small enough steady state error.

The output voltage, load current, and battery current are collected as the inputs to the NN. The compensation signal, instead of the whole modulation signal, is collected as the desired output of the NN. By using this compensation signal as the desired output of the NN, more effective learning and better control performance can be achieved. In the case of bidirectional converters, the database should include the input-output patterns under all possible loading conditions and battery conditions [12]. A new example pattern is obtained each time the load model is changed. The pattern database contains hundreds of patterns, in which two-thirds are for forward operating condition, and the other one third is for backup mode operation. In the selection of an NN for the converter, we believe the NN should be as simple as possible (with fewer inputs and fewer hidden nodes) so as to speed up the control process and to reduce the controller cost. The training of the NN is automated by a computer program that presents a randomly selected example pattern from the pattern database to the NN a large number of times. During each time, the weights and biases of the NN are updated using the back propagation algorithm to make the mean square error between the desired output and the actual output of the NN less than a predefined value. The Neural Network controller shown in

Figure 4: Neural Network Controller

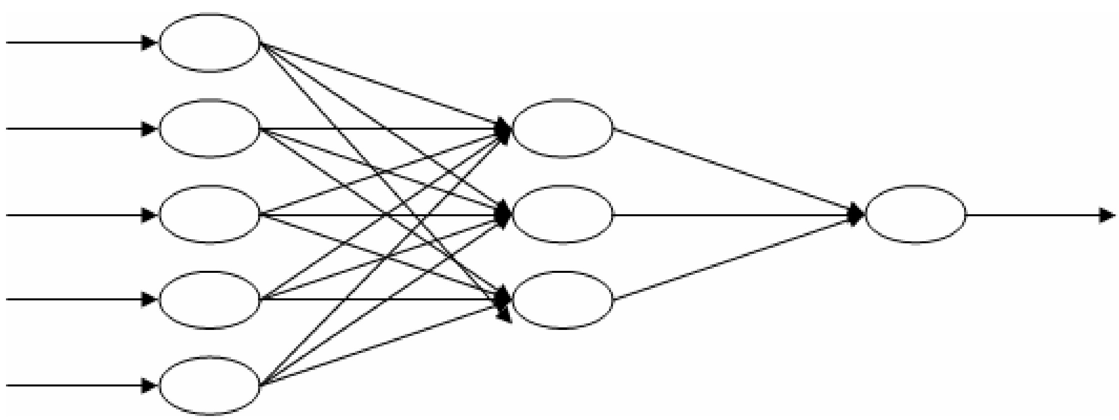


Fig. 4 has a 5-3-1 structure (five inputs, three nodes in a hidden layer and one output node). The nodes on the hidden layer have a sigmoid transfer function, and the output node has a linear transfer function[13]. This NN structure is the result of many repeated trials. The structure is found to be simple but efficient. Its inputs are input current, current through S_1, current through S_2, current through S_3, current through S_4, Battery voltage, and error voltage between the reference voltage and the output voltage.The training of the NN is done using the Neural Network toolbox of MATLAB.[14]

$e=V_{ref}-V_o$; $d(t)= d(t-1)-d(x(t))$

d(t-1)=Duty cycle at (t-1)th instant; V_o=Output Voltage;d(x(t))=Change in duty cycle; $_{ref}$=RefVoltage; d(t)=Duty cycle at t^{th} instant e=error signal;

4. Simulation Results

Figure 5: Output Current in forward mode

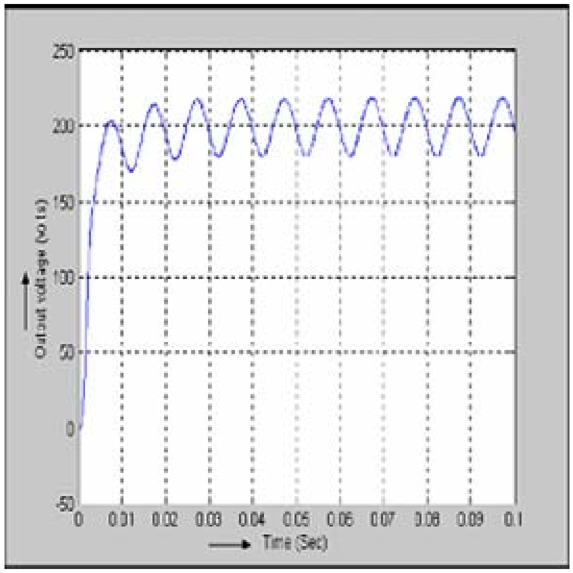


Figure 6: Output Voltage in forward mode

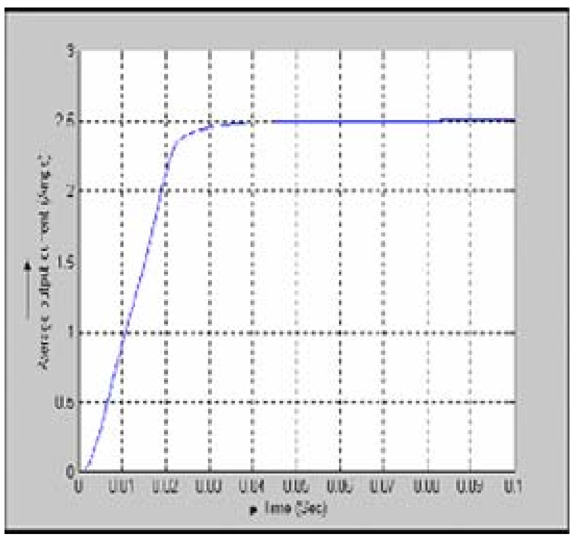


Figure 7: Waveforms of Gating Signals Generated in NN Controller

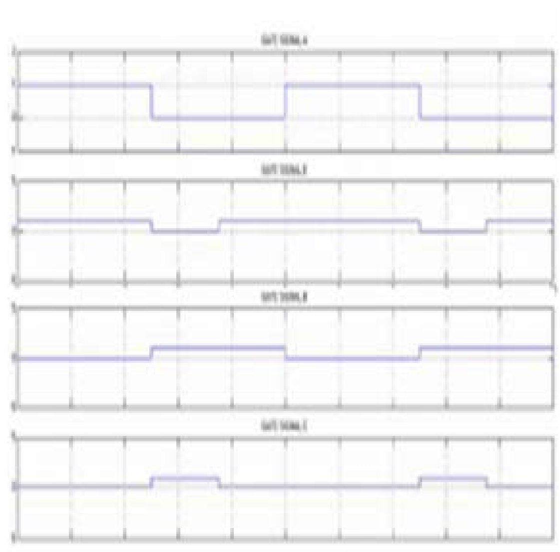
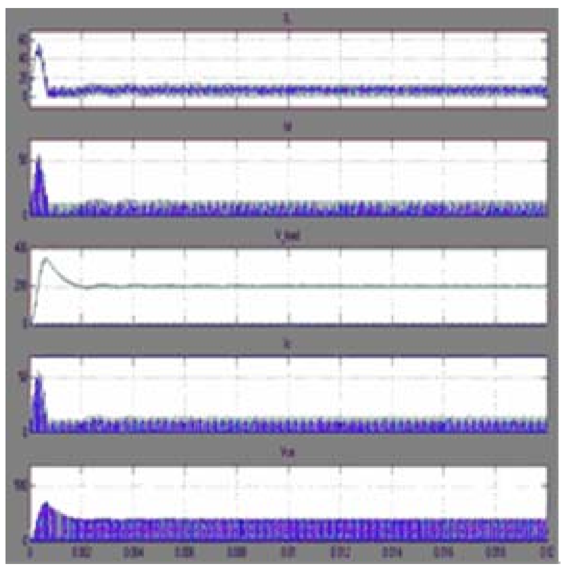


Figure 8: Waveforms in backup mode



Figures 6,7 and 8 gives various voltage and current waveforms of bidirectional converter in forward and backup mode. In the forward mode the power is supplied by the mains and in the backup mode the power is supplied by the battery.

5. Conclusion

A bidirectional DC/DC converter with integrated half bridge converter is proposed and an NN controller is implemented in that converter. The proposed converter ensures effective performance with less loss, better efficiency and good regulation. The simulation results of NN control shows that for the desired requirement, the usage of Neural Network controller is unavoidable. The disadvantages of analogue implementation such as temperature drift, electro magnetic interference are completely absent in this technique. The digital technique involves the complicated algorithms and the heavy computational demands make the implementations difficult. Hence the control of converter by neural network is highly applicable.

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