Analysis of Interleaved DC-DC Converter using ANFIS Control for EV Charging Applications

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Abstract—**Robust and intelligent control algorithm design is very essential in the development of power electronics converter in order to maintain constant output voltage regardless of the variations in input voltage and load. In this paper, simulation and analysis of interleaved DC-DC converter for electric vehicle charging applications using adaptive neuro-fuzzy inference system (ANFIS) is presented. The ANFIS based control algorithm for DC-DC converter is designed to stabilize output voltage and enhance the performance of system during transient operations. To verify the proposed design, dual phase interleaved synchronous buck converter is simulated in MATLAB-Simulink based environment and simulation results on resistive load are presented.**

Keywords— ANFIS, buck converter, interleaved DC-DC converter, electric vehicles charging.

I. Introduction

Globally, the Electric Vehicles (EVs) infrastructure are considered as most environmental friendly for modern transportation system. Introduction of EVs in modern transport infrastructure is mainly due to the ever-increasing environmental degradation and greenhouse gas generation. Demand for EVs are becoming more mainstream day by day with increase in battery capacity and decrease in the battery cost. Just as the traditional internal combustion engine based automobiles spawned the need for more gas stations, in the similar way, the EVs will demand more charging systems. Power electronics plays crucial role in the EV charging systems and it is responsible for converting as well as controlling the electric power in charging systems. The major power electronics based systems used in EV charging applications are AC-DC, DC-DC converters and its associated digital control.

To deliver electric current for charging/recharging the EV's batteries, DC-DC converters along with digital control are widely used. DC-DC converters consist semiconductor based power switching devices and they are used for power conversion from one level to another level. Switching operation of semiconductor devices produces non-linearity in the system. Stability of output voltage and overall improvement in the system's performance can be achieved by variety of control methodologies [1]. Due to simplicity in design and ease of implementation, conventional control like Proportional-Integral-Deferential (PID) based approach is commonly being used in controlling DC-DC converter. With predetermined and tuned constants, conventional PID controllers are based on mathematical models. Basically, the stability of PID controllers is based on constant values. In many industrial applications, the PID controllers are commonly used to improve the overall performance of the systems. The most common type of control structure along with DC-DC converter is shown in Fig. 1. It consists of DC-DC converter, signal conditioning unit, digital control and gate driver.

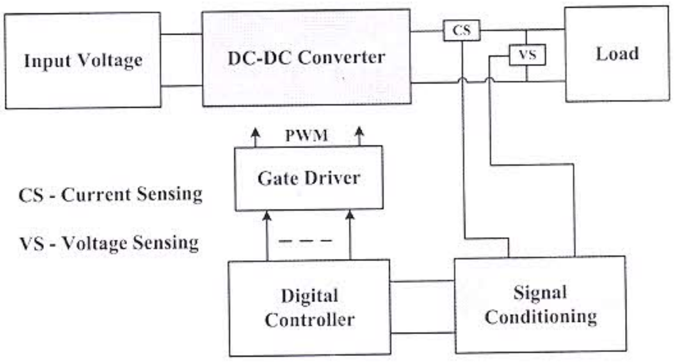

Fig. 1. Conventional control approach of DC-DC converter

The major shortcoming of conventional control approach includes their variable performance with nonlinear systems. In recent years, the design of power electronics converters with optimal control based approach has become highly desirable and finds numerous applications. The optimal control approach includes: Artificial Intelligence (AI), Fuzzy Logic Systems (FLS), Artificial Neural Networks (ANNs), Genetic Algorithms (GAs), Model Predictive Control (MPC), Sliding Mode Control (SMC) etc. Review of linear and nonlinear control approach for DC-DC interleaved boost converter is presented in [1]. To stabilize the output voltage and improve the performance of buck-boost converter in transient operation using neural network based control scheme is presented [2]. The modelling of interleaved boost converter using state space averaging techniques and its predictive current control implementation is presented in [3]. Various research on control design of DC-DC converter to improve its performance are presented [4-12].

The paper is organized as follows: Section II presents the circuit configuration and operational details of two phase synchronous interleaved DC-DC buck converter for EV charging applications. The control algorithm design using ANFIS approach and its architecture for two phase interleaved DC-DC converter is presented in Section III. This section also explains about the generation of neural net of ANFIS controller. Simulation model along with its results and discussion on resistive load is presented in Section IV. Finally, Section V addresses conclusion of the presented work.

II. Circuit Configuration

Multiphase interleaved converter has received a lot of attention due to its easy structure and simple control configuration [13-14]. It is used in applications where non-isolation, step-down conversion ratio and high output current with low ripple are required [15-17]. When selecting the output inductors, a multiphase design allows considerable flexibility, which is extremely important in applications with small form factor. A multiphase operation of converter provides a specific set of benefits to ensure that the converter performs in an optimum state, such as versatile phase configurations and phase shedding.

Two phase interleaved synchronous buck (2PISB) converter is shown in Fig. 2. Basically, two phase interleaved synchronous buck converter is a parallel set of synchronous buck converter. Each set has its own components like inductor and semiconductor switching devices. Such components are collectively called a phase. The phases are configured in parallel connections and share input and output capacitor. The individual phases of interleaved converter are active at spaced intervals equal to 360°/n over the entire switching time during steady state operation, where n is the total number of phases.

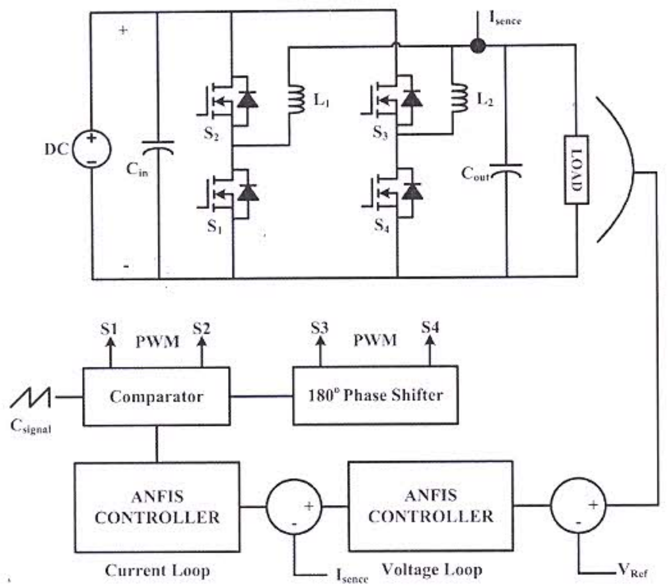

Fig. 2. Configuration of two phase interleaved converter

As the neural network based control approach is gaining popularity in power electronics converters due to its capabilities of handling variable load condition. It is based on fuzzy logic concept linked to artificial neural network. The controller of interleaved DC-DC buck converter is designed using adaptive neuro-fuzzy inference system (ANFIS) based approach. Based on knowledge base of Artificial Intelligence (AI), the ANFIS based controller can adjust their operating parameters and tune the control values in real time. The detailed analysis of ANFIS controller will be explained in the subsequent section. Two ANFIS block are used here; one for voltage loop control and another for current loop control. Both the loops are tuned separately to achieve better controlled output for given input and loading conditions. The error signal generated from ANFIS control block is compared in comparator to generate PWM signals. MOSFET S2 and S3 are spaced at 180° each. The circuit waveforms of dual phase interleaved synchronous buck converter is shown in Fig. 3. As it can be seen in Fig. 3, the switching waveforms are spaced at an interval of 180°. Hence, it is clear from the circuit waveforms that the two phases are interleaved in nature.

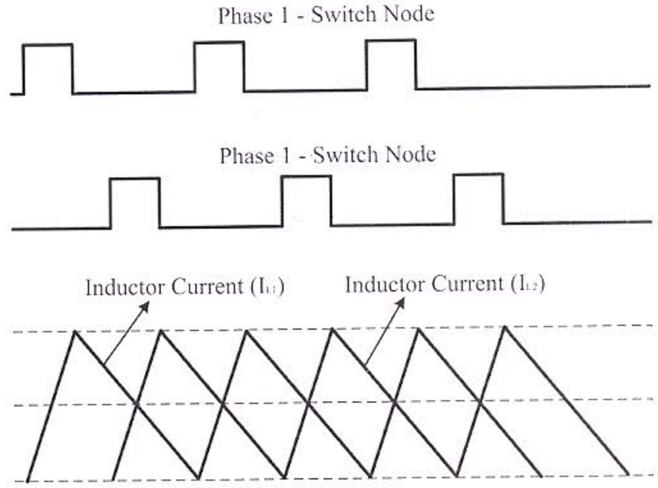

Fig. 3. Switching waveform of 2PISB converter

III. Control Design and Operation

The adaptive neuro-fuzzy inference system (ANFIS) control in DC-DC converters has received lot of attention in recent years due to its capability to improve the dynamic performance. ANFIS is a neuro-fuzzy approach in which the neural network and fuzzy inference system merge together to achieve desired results. ANFIS is also known as an artificial neural network and is based on the fuzzy inference method of Takagi-Sugeno. The ANFIS has the benefit of processing a vast volume of data and adaptability capability to various fault conditions for differences in inputs under different real-time circumstances. Mainly, the error signal and its rate of change are processed by the ANFIS controller to decide the appropriate rate of change in the output feedback of the plant.

The several research work have been done explaining the use of ANFIS based control approach for better stability and improvement in dynamic performance of DC-DC converter. The architecture of ANFIS using hybrid learning procedure in the framework of adaptive networks is presented in [18]. To improve the power quality and dynamic performance, ANFIS control scheme is presented in [19] by controlling the active and reactive power of grid tied inverter. A combination of PID and ANFIS controllers is presented in [20] to improve steady state error, efficiency in DC-DC buck converter. A comparative study of linear and nonlinear controllers for BLDC motors is presented in [21] to improve the performance. The overall schematic diagram of control architecture for two phase interleaved synchronous DC-DC buck converter using ANFIS control approach for electric vehicle charging applications is presented in the Fig. 4.

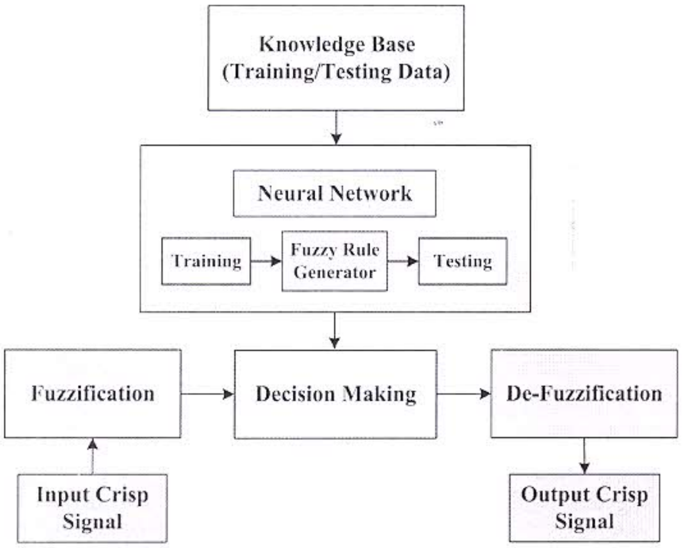

Fig. 4. Schematic of ANFIS controller for 2PISB converter

The design of ANFIS based controller utilizes Sugeno model for the fuzzy inference part and neural network for training & testing to generate rule base from the given data. As it can be seen in Fig. 4, ANFIS makes use of two different machine learning techniques i.e. fuzzy logic and neural networks for mapping the given crisp input into a crisp desired output through fuzzification, highly interconnected processing elements & information connects of neural network and de-fuzzification. The knowledge base or the training data set contains set of crisp values for input data and their corresponding crisp values for desired output data. Two different ANFIS based controllers have been utilized to control the output current and output voltage against variations in the load at output port and variations in input voltage at the input port. The training data set basically consist of complete range of values for input variable and its corresponding desired range of values for output variable. Both current and voltage loop control have been designed using 40 rules including 40 input triangular membership functions each as shown in Fig. 5. In Layer 1, all the nodes represent fuzzification of the input crisp input value. Therefore, the output of the Layer 1 is the fuzzy membership grade of the inputs. The Layer 2 basically involves fuzzy operators such as AND, OR, NOT etc. Here it applies AND operator to the fuzzified output from the Layer 1 by using simple multiplier. It further performs normalization to the firing strengths from previous layer and generates output for the next layer. In Layer 3, the output of each node is the multiplication of normalized firing strengths and the polynomials (first order polynomial for the first order Sugeno model). In the last Layer i.e. Layer 4, a simple summation of all the inputs from previous layer is performed to generate a crisp output value.

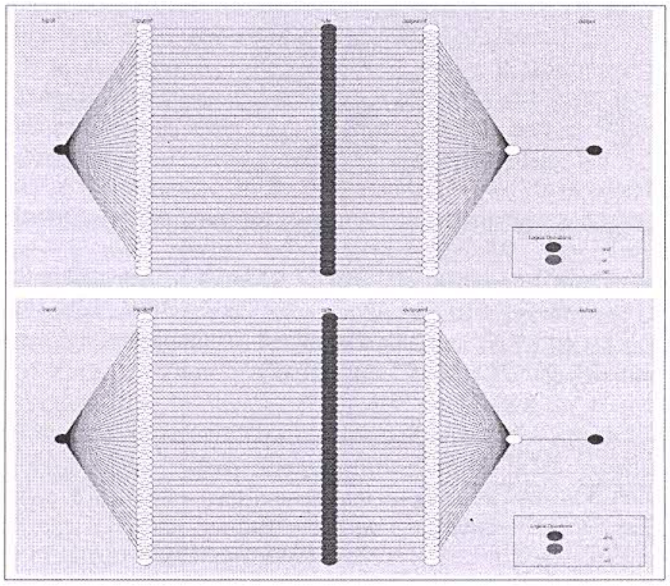

Fig. 5. Neural net of ANFIS controller

IV. SIMULATION MODEL AND RESULTS

The two phase interleaved synchronous DC-DC buck converter with ANFIS control for electric vehicle charging applications is simulated in MATLAB-Simulink-based environment. The required specifications and designed component values used for simulation on resistive load are presented in table I.

TABLE I

Specifications and Designed Parameters

Parameters	Nominal Values
Input DC voltage (VDC_{input})	110-130 VDC
Rated output power (P_{Rated})	1.5 kW
Output voltage (VDC_{output})	48 VDC
Allowable output transient	0.5V
Maximum duty cycle	0.41
Input capacitor (C_{input})	440μF
Inductors ($L_{phase-1}$ and $L_{phase-2}$)	100μH
Output capacitor (C_{output})	94μF
Switching frequency	100kHz

The MATLAB-Simulink-based simulation model of two phase interleaved synchronous DC-DC buck converter with ANFIS control approach for electric vehicle charging applications is depicted in Fig. 6. The simulation was carried out on resistive load at full power capacity of 1.5kW.

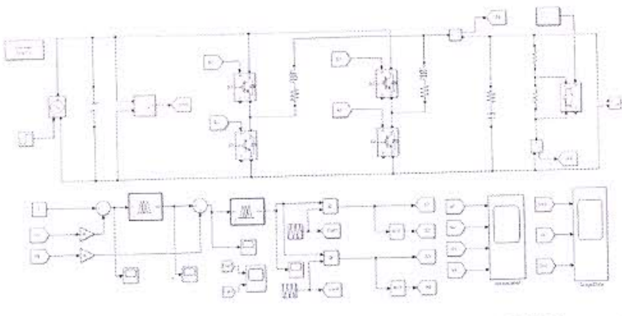

Fig. 6. Simulation model of converter using ANFIS control

Switching waveforms of MOSFET S1 to S4 is presented in Fig. 7. The MOSFET S1 and S3 are separated by 180° phase shift. The MOSFET S2 and S4 are operated in complementary mode with respect to S1 and S3 respectively.

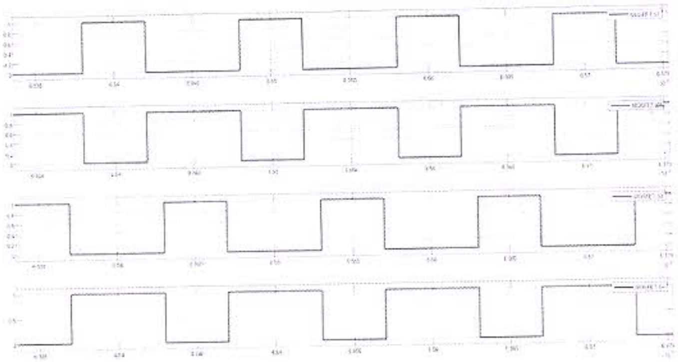

Fig. 7. Switching pattern of MOSFET S1 to S4

The output response of DC-DC converter using conventional control is given in Fig. 8. In conventional PID control, the Kp, Ki and Kd needs to be tuned to get smaller settling time but it takes large number of tuning iteration. Step change in input voltage is given and corresponding results are obtained.

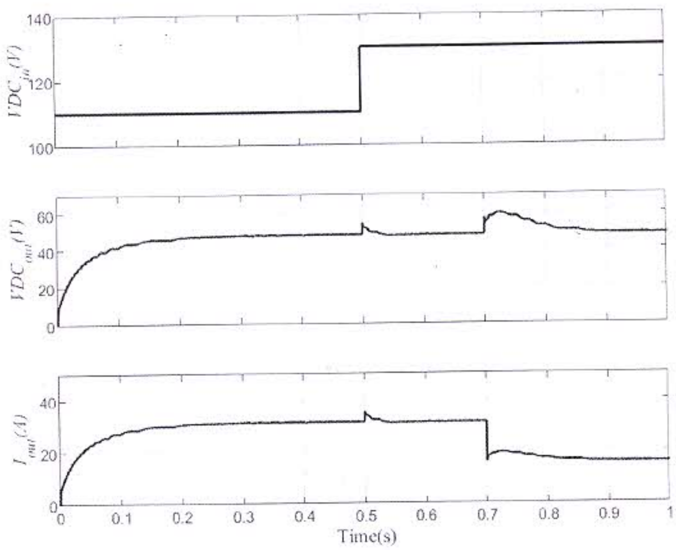

Fig. 8. Output response using conventional control approach

The simulation results on resistive load using ANFIS based controller for two phase interleaved synchronous DC-DC buck converter is presented in Fig. 9. Step change from 100% to 50% in load is given and its corresponding results are obtained. Due to ANFIS controller, the dynamic response, such as settling time is enhanced during load transients as shown in Fig. 9. With use of ANFIS based controller, as step change in input voltage is given, the overshoot in the output voltage is less as compared to conventional control approach.

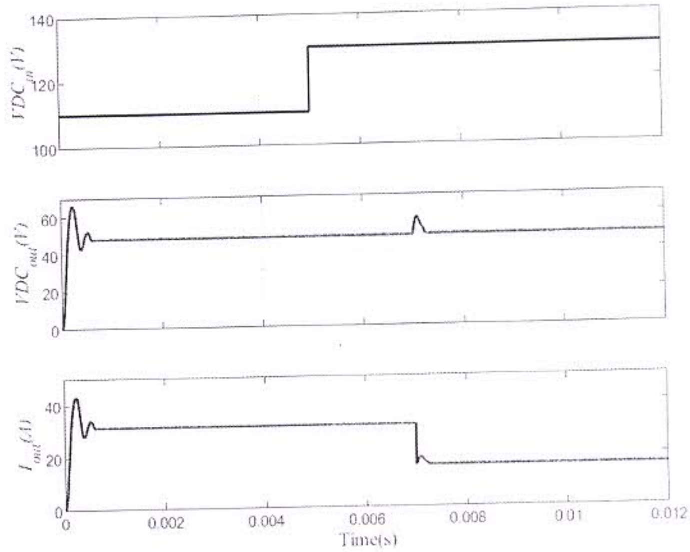

Fig. 9. Output response using ANFIS based control approach

V. Conclusion

The paper presented control of two phase interleaved synchronous DC-DC buck converter using ANFIS control approach for electric vehicle charging applications. During the input voltage transients, transient response of output voltage like overshoot and undershoot is improved. During load step change, the settling time improves when ANFIS based control is used. Interleaving of converters reduces the requirement of large input and output capacitance. The ANFIS-based controller uses the Sugeno model for the fuzzy inference portion and neural network for training and testing to generate rule base from available data. As compared to conventional control, the ANFIS controller for interleaved DC-DC converter stabilizes output voltage and enhanced the performance of system during transient operations. ANFIS controller gives smooth transition of voltage and current during load variations.

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