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Research paper

Design and Analysis of Fractional PID Controller for Isolated Bidirectional DC-DC Converter

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Abstract

The switching frequency of the bidirectional DC-DC converter is increased to make the size of the converter compact. This in turn results in higher switching losses. In order to overcome this drawback, a novel isolated bidirectional dc-dc converter (IBDC) is proposed. This work discuss about the performance of proposed IBDC. The performance of the proposed converter is evaluated using MATLAB /SIMULINK and the simulation results is verified with experimental results.

***Keywords**: BDC, FPID controller, ZVS, Transient response*

1. Introduction

A DC-DC converter plays a major role in many applications such as fuel cell, hybrid electric vehicle, renewable energy system etc.,. A bidirectional DC-DC converter used in these applications should be smaller in size and lighter in weight. If the size of conventional bidirectional DC-DC converter is reduced, the switching frequency will be increased which in turn results in high switching losses[2]. Hence due to the switching loss, the efficiency of this system is reduced. In order to reduce switching losses that occur during the switching operation, a design of isolated converters is proposed to improve the efficiency of the converter [5]. The structure of an IBDC topology is also referred as Dual Active Bridge (DAB) converter and is instigated in high power transfer systems for isolation purpose. It is also appropriate for achieving high power density and galvanic isolation between the sources. Along with these, it also achieves ZVS operation with higher bidirectional power transfer capability. Thus, in order to achieve higher efficiency, a controller for a DC-DC DAB converter is structured using a single-phase DC–AC inverter (Hengsi et al. 2014). In this scheme, two different control methods were adopted to diminish ripples present in the output of the converter in the DAB converter.
Several soft computing methods were adapted for controlling DAB. A fuzzy based DAB converter system is introduced by Sowmya et al. (2015) has low stress on the switching derives and better transient response. The application of DAB for medium and high power application is suggested by Preethi et al. (2014) has the ability to perform DC to DC conversion at higher efficiency and attains ZVS condition for all switches. A three stage solid state transformer arrangement which includes AC-DC rectifier, isolated DC-DC DAB converter and DC-AC inverter has been studied by Digvijay et al. (2015).
This projected arrangement contributes better transient response and obtains reduced ripple at the output side of inverter.
From the above, it is observed that only PI and fuzzy controller has been implemented for DAB converter so far [6,12]. Hence, this work proposes an analysis of fractional PID controller for DAB bidirectional DC-DC converter system. Hence, to approve the efficiency of the proposed module, the simulation is carried out using MATLAB Simulink and the results are verified experimentally.
The main objective of this research is to design and develop a suitable control strategy for a converter. However, all these schemes indicate one or more drawbacks such as poor system efficiency and complexity of control methods and difficulty in hardware implementation. Keeping in view the above considerations, a new IBDC is proposed in this chapter.

2. Design of the Proposed Converter

The block diagram shown in Fig.1 illustrates the methodology of the proposed work. The output of the high performance DC-DC converter is connected to filter unit. The filter unit reduces the ripples present in the output of the converter. However, these converters are subjected to various disturbances either from input or output side. Hence in order to maintain the output voltage constant, controllers are implemented. Thus the controller controls PWM signals applied to the switch of the converter unit[13].

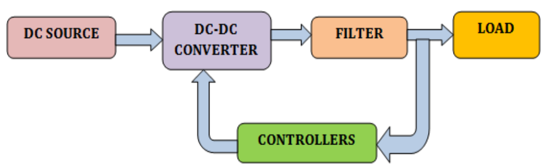

Fig. 1: Block diagram of the proposed work

3. Description of the Proposed Converter

The proposed converter represented in Fig.2 offers a galvanic isolation between two electrical circuits in order to effect of eliminate stray currents. Because of imbalances of electrical supply, the stray currents may occurred. In order to prevent this, A galvanic isolator is introduced. Thus, a transformer is utilized to obtain the voltage matching and galvanic isolation. Hence, an AC link is required for the transfer of energy. Thus the first stage of a DAB converter is associated with a single-phase rectifier[7,8]. It converts the AC voltage into a fixed DC voltage. The second stage of the DAB converter consists of an inverter. This inverter is connected with the load. As the output of the first stage of DAB converter is associated to an inverter, a large capacitor band is required at its output. So that this capacitor bank, absorbs the harmonic current present in the system and hence, the ripple present in the output gets reduced[9].

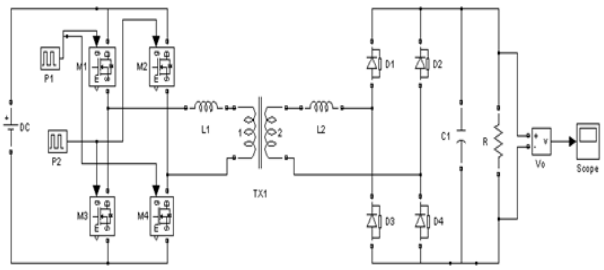

Fig. 2: Circuit arrangement of the proposed IBDC

4. Fractional order PID controller

PID controllers designed for bidirectional DC-DC converter has some limitations are as follows:

- ✓ In nonlinear applications, the performance of PID controllers is variable.
- ✓ A noise present in the process leads to large amounts of change in the output of the system.

In order to overcome this problem and to enhance the dynamic response of DC-DC converters, a Fractional Order PID controller (FOPID) or Fractional PID controller (FPID) has been implemented[10,11]. The Fractional PID controllers are widely used in industrial applications in order to enhance the system control performances. The FPID controller is the addition of the conventional PID controller which is designed on the basis of fractional calculus and is shown in Fig.3.

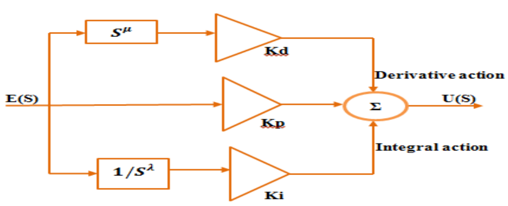

Fig. 3: Block diagram of FPID controller

The transfer function of PI $^{\lambda}$ D $^{\mu}$ is given by,

$$C(S) = \frac{U(S)}{E(S)} = Kp + Ki\ S^{-\lambda} + Kd\, S^{\mu}$$

Where,

λ and μ are positive real numbers.

Kp, Ki and Kd are the proportional, integral and derivative gain constants respectively.

From the figure, it is observed that, while choosing $\lambda = 1$ and $\mu = 1$, a classical PID controller is obtained. While applying $\lambda = 1$, $\mu = 0$ and $\lambda = 0$, $\mu = 1$ the conventional PI and PD controllers are obtained from FPID.

When compared with other conventional P, PI and PID, a fractional order offers the following advantage,

A fractional order controller is less sensitive to parameter variation than a classical PID controller. Hence it is well suited for electric vehicles application.

5. Study of Proposed IBDC in Boost Mode under Open Loop Control

Fig.4 depicts the Simulink model of the proposed IBDC in open loop control for a boost mode is performed successfully with quad-filter.

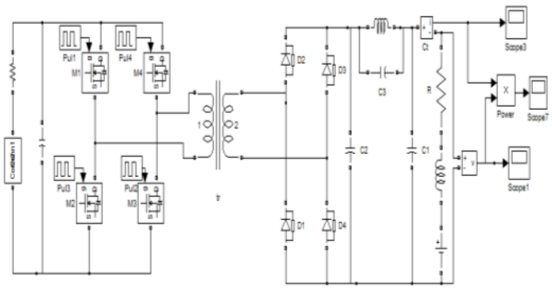

Fig. 4: Simulink model of the proposed IBDC in open loop control for boost mode

The simulated voltage waveforms of input and output and also the corresponding power obtained during forward power flow direction is depicted in Figure 5. The proposed converter response is studied by varying the input voltage from 15V to 18V at time, t=1.0secs and the corresponding results are presented. For the step input change of 4V, the corresponding output voltage changes by 8V and the load current increases by 0.01A is noted. The power also gets increased due to step change in the input voltage.

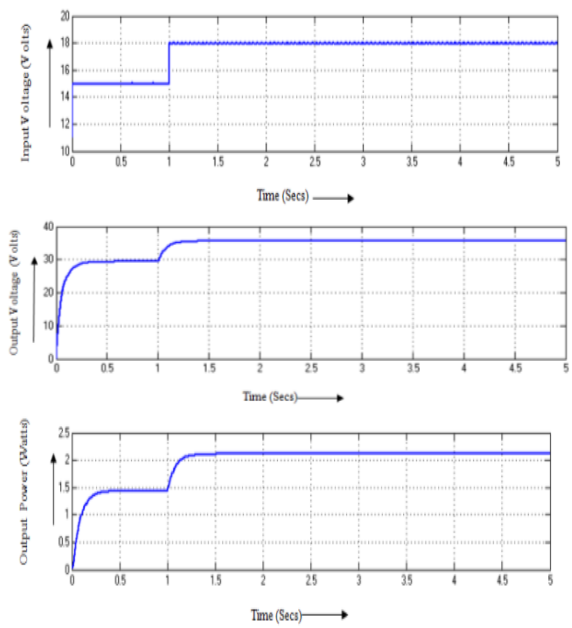

Fig. 5: Analysis of proposed IBDC in open loop control for boost mode

6. Study of Proposed IBDC in Boost Mode under Closed Loop Control

The simulation results for proposed IBDC operating in boost mode using various controllers are discussed with a input voltage of 15V. The parameter settings for controllers are obtained using Ziegler and Nichols method and are used for the simulation study.

6.1. IBDC with FPID Controller

Fig.6 depicts the Simulink diagram of proposed converter with FPID controller. The parameter settings considered for simulation studies are, K_p=5, K_i=7, K_d=0.92, t_s=2μsecs, λ=1.01 and μ=0.98. Fig.7 shows the proposed system output voltage and output power for the sudden variation in input voltage. From the simulated waveforms, it is concluded that there is less fluctuation in the output, when the input is suddenly incremented from 15V to 18V at time t=1.0 secs. From the results, it is evident that the response of FPID controller is more efficient and less sensitive than a classical PID controller.

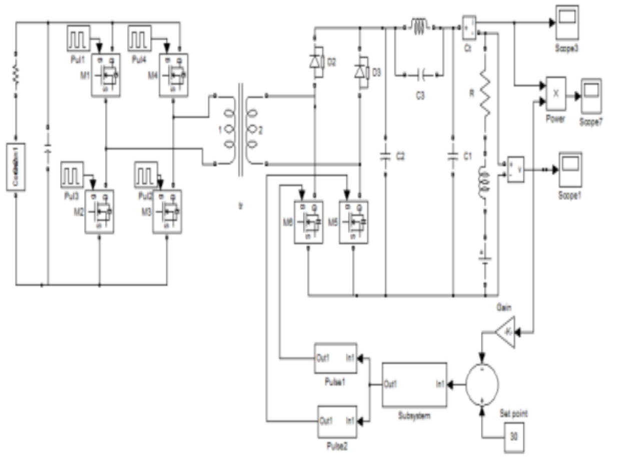

Fig. 6: Simulink model of the proposed IBDC with FPID controller in boost mode

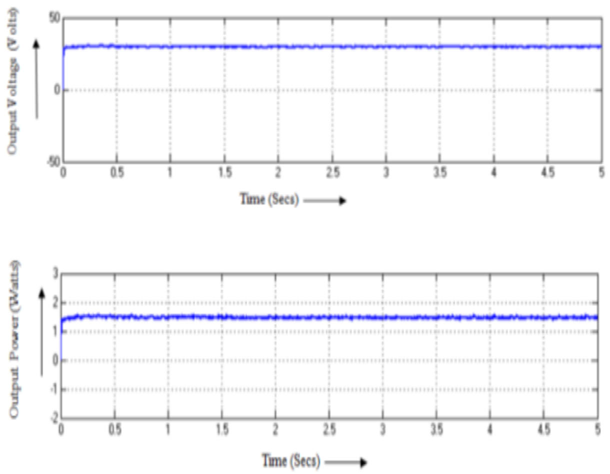

Fig. 7: Analysis of proposed IBDC with FPID controller in boost mode

The response of proposed IBDC is compared between the conventional controllers operating in boost mode and are summarized in Table 1. This is done in terms of rise time, peak time, settling time and steady state error.

Table 1: IBDC - Comparison of responses with various controllers in Boost mode

Controllers for IBDC in Boost mode	Rise time	Settling time	Peak time	Steady state error
	T_r	T_s	T_p	E_{ss}
	(secs)	(secs)	(secs)	(V)
PI	0.25	3.5	1.35	0.6
PID	0.16	2.1	1.21	0.2
FPID	0.3	0.35	0.53	0.15

From the above table, it is observed that proposed converter with FPID provides better settling time. Also the steady state error gets reduced considerably from PI controller to FPID. Thus, the choice of optimal control for the proposed converter operating in boost mode is chosen with FPID which provides faster response with virtually no overshoots when compared to other controllers.

7. Study of Proposed IBDC in Buck Mode under Open Loop Control

Fig.8 illustrates the Simulink model of the proposed IBDC in open loop control. Fig.9 represents the simulated waveform of input voltage, output power and output voltage in the reverse power flow direction.

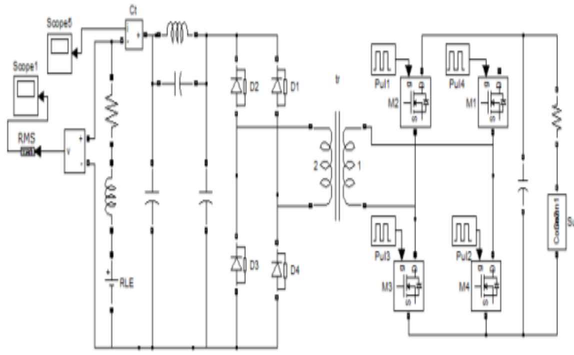

Fig. 8: Simulink model of the proposed IBDC in open loop control for buck mode

The input voltage is kept at 15V for RLE load. The output voltage possess less ripple due to the presence of quad filter. It also demonstrates the response of the proposed converter, where the input voltage is suddenly incremented at time t=0.5secs.

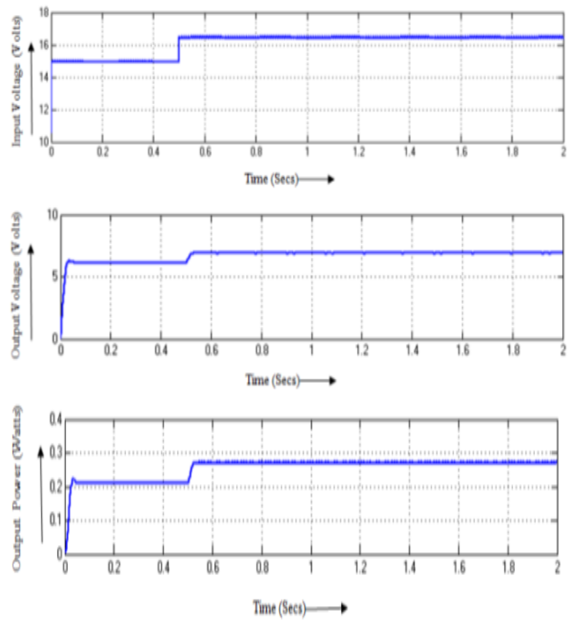

Fig. 9: Analysis of proposed IBDC in open loop control for buck mode

8. Study of Proposed IBDC in Buck Mode under Closed Loop Control

The performance of the proposed converter is improved by implementing conventional controllers such as PI, PID and FPID. Simulation results under closed loop controller using conventional controllers are discussed for buck mode with an input voltage of 15V.

8.1. IBDC with FPID Controller

The proposed converter with PID controller is replaced with FPID controller which is shown in Fig.10. The parameter settings are considered to be the same as used in boost mode of operation.

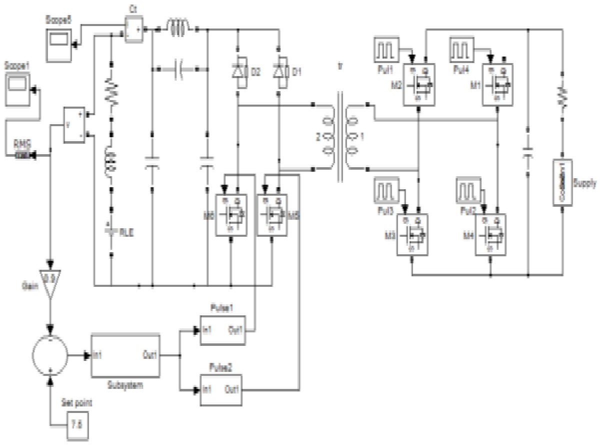

Fig. 10: Simulink model of the proposed IBDC with FPID controller in buck mode

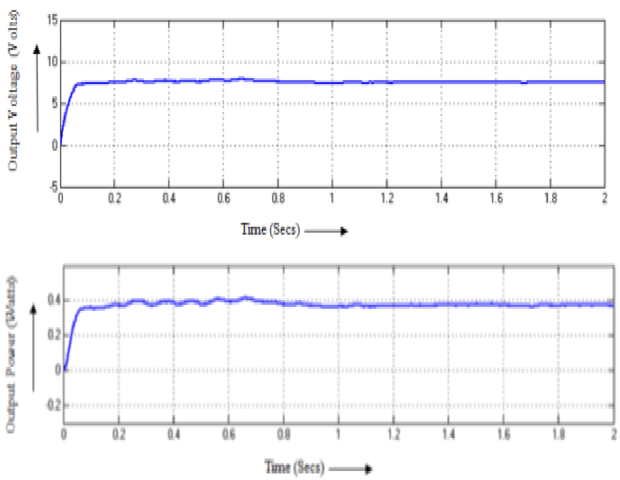

Fig. 11: Analysis of proposed IBDC with FPID controller in buck mode

Fig.11 shows the system output voltage and output power for the same step change in input from 15V to 16.5V. The settling time of the FPID controller is about 0.5secs. From the waveforms, it is inferred that the controller response is smooth even though there is sudden input variation.

9. Results and Discussion

Table 2 precise the response of IBDC operating in buck mode with the other conventional controllers. The comparison is done in terms of peak time, settling time, rise time and steady state error.

Table 2: IBDC - Comparison of Responses with Various Controllers in Buck Mode

Controllers for IBDC in Buck mode	Rise time T_r (secs)	Settling time T_s (secs)	Peak time T_p (secs)	Steady state error E_{ss} (V)
PI	0.035	1.03	0.7	0.06
PID	0.03	0.8	0.65	0.03
FPID	0.03	0.5	0.6	0.01

It is obvious that the converter designed with FPID possess less settling time and has minimized steady state error. Hence the converter efficiency is improved and shows improved transient response. Thus from the simulation results, the choice of optimal control for the proposed converter operating in buck mode is also chosen with FPID.

10. Conclusion

In this work, the performance of proposed IBDC was presented. Simulation was done for IBDC with various filters and controllers and their comparative analysis were presented for both boost and buck mode. IBDC was also simulated with and without hysteresis controller in MATLAB by changing the step input voltage value. Simulation results were analyzed and compared with the results obtained using hardware circuits and the simulation model is validated. Thus, the IBDC ensures better voltage gains with ripple minimization than the conventional bidirectional boost/buck converter.

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