Fractional Order PI Controller based Bidirectional DC-DC Converter

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Abstract : In this paper, the auxiliary switch control using a lookup table using FOPI is proposed to enhance the efficiency of the bidirectional DC/DC converter used in electric vehicle, which performs soft switching. Continuous current data are difficult to obtain during a resonant operation due to the limit of ADC capacity. The control method properly controls the auxiliary switch turn-on time according to the required load current; this auxiliary switch control brings the more efficient control in generative and regenerative mode operation. This work proposed a design methodology of auto-adjustable PI controller using Artificial Intelligent controller technique. The proposed AI method can adjust the controller parameters in response to changes in plant and disturbance that specifies properties of the desired control system. In order to analyse the performances of the proposed system using PI and FOPI controllers tuned with Improved Particle Swarm Optimization algorithms. The work has been implemented with MATLAB / Simulink 7.13 software environment**.**

***IndexTerms* – DC/DC Converter, Fractional Order PI Controller**

I. INTRODUCTION

DC-DC converter is commonly used to convert from one DC voltage level (often unregulated) to another regulated DC voltage level. Depending on the converters configuration, the resulting output voltage can be a step-up or step-down function of the input voltage and can appear as a positive or negative voltage to the load. The first DC-DC converters were invented in the 1920’s. While the transformer provided an efficient way for an AC voltage source to be converted to other AC voltages, there was no simple apparatus for efficient DC-DC conversion.

PID controller is a well-known controller which is used in the most application. PID controller becomes a most popular industrial controller due to its simplicity and the ability to tune a few parameters automatically. According to the Japan electric measuring instrument manufacture’s association in 1989, PID controller is used in more than 90% of the control loop. As an example for the application of PID controller in industry, slow industrial process can be pointed, low percentage overshoot and small settling time can be obtained by using this controller.

The performance of the PID controller can be improved by making the use of fractional order derivatives and integrals. This flexibility helps the design more robust system. Before using the fractional order controller in design an introduction to the fractional calculus is required. The first time, calculus generation to fractional, was proposed Leibniz and Hospital for the first time afterwards, the systematic studies in this field by many researchers such as Liouville (1832), Holmgren (1864) and Riemann (1953) were performed.

II. BIDIRECTIONAL DC-DC CONVERTER

The environmental and economical benefits from commercial electric vehicles have stimulated global interest in developing electric vehicles. To improve the efficiency of electric vehicles, the auto industry has financially invested significantly in batteries, various types of charging equipments, inverters and bidirectional dc/dc converters, and traction motors for EVs. Among them, various topologies for the bidirectional dc/dc converter have been proposed for many EVs [1]–[10]. The bidirectional dc/dc converter on board electric and hybrid vehicles should boost the low voltage of batteries to the high voltage of the inverter dc-link [4]. It should also be operated in the buck mode to charge the battery bank with regenerative energy during vehicle deceleration and braking. The importance of a bidirectional dc–dc converter is getting increased. Because the structure of the converter is simple, and its control is comparably easy, it is used as the topology of conventional bidirectional converter. However, the drawbacks of the conventional bidirectional dc–dc converter are the large switching losses and the long reverse recovery time of antiparallel diodes.

Particularly, during the reverse recovery time of the diodes, it can be caused of circuit damage and electromagnetic interference problems due to high current spikes. Thus, in order to improve the shortcomings of conventional pulse width modulation (PWM) methods, and increase the efficiency of the system, the study using series resonance, parallel resonance, and quasi-resonance methods have progressed [11], [12]. However, due to the common characteristic of resonant converter, lots of conduction losses occur because of high circulating energy. To overcome the drawbacks of the resonant converter, the zero voltage transition (ZVT) and zero current transition (ZCT) methods are proposed [13]–[16]. The ZVT and ZCT methods are that switches turning ON and turning OFF under zero voltage and zero current condition using resonance. The ZVT and ZCT methods can be applied to the conventional bidirectional dc–dc converter through adding auxiliary circuit to the converters. However, since the added auxiliary circuit is operated under hard-switching condition, the other losses occur [13]. Moreover, lots of other circuits are weak in high resonant current and voltage, and the range of load for resonant circuit is limited. The composition of the proposed resonant bidirectional dc/dc converter is an auxiliary circuit added form to the conventional bidirectional buck–boost converter. The fundamental operation equals the conventional bidirectional buck–boost converter [18]–[20]. The resonance of the proposed converter is caused by the resonant capacitor and inductor of the auxiliary circuit. The auxiliary switch is operated in boost mode and buck mode. The soft switching is carried out by the main switches, diodes, and auxiliary switches. To perform the soft-switching action, the conventional control method has to calculate the time difference between the gate signals of the main and auxiliary switches. The aim of this work is to introduce the auxiliary switch turn-on time control for the bidirectional dc/dc converter in an electric vehicle system.

III. OPERATION AND ANALYSIS OF THE PROPOSED CONVERTER

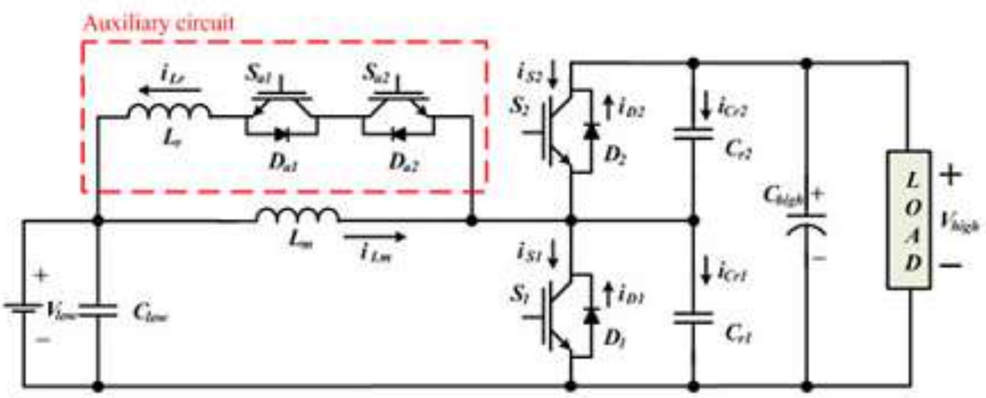

Fig. 1. Proposed bidirectional soft-switching dc/dc converter

Fig. 1 shows the proposed bidirectional soft-switching dc–dc converter, which is formed by adding one resonant inductor, two resonant capacitors, and two switches to the conventional bidirectional converter circuit. The soft-switching operation occurred by energizing L_r in the auxiliary circuit with the voltage difference $V_{high}-V_{low}$ just before turning ON the main switch. In order to maintain the voltage across L_r with $V_{high}-V_{low}$ before the main switch is turned ON, the upper converter should be operated in continuous conduction mode.

IV. FRACTIONAL ORDER $PI^{\lambda}D^{\mu}$ CONTROLLER

One of the possibilities for improvements in the quality and robustness of PID controllers is to use fractional order controllers with noninteger derivation and integration parts. The $PI^{\lambda}D^{\mu}$ controller involving an integrator of order λ and a differentiator of order μ.

The differential equation of the $PI^{\lambda}D^{\mu}$ controller is given as follows:

$$u(t) = K_P e(t) + K_I D^{-\lambda} e(t) + K_D D^{\mu} e(t) \qquad 1$$

The continuous transfer function of the FOPID controller is obtained by means of the Laplace transformation, as given by:

$$G_c(s) = \frac{U(s)}{E(s)} = K_P + K_I s^{-\lambda} + K_D s^{\mu}, \ (\lambda, \mu > 0) \qquad 2$$

For designing a FOPID controller, 3 parameters (Kp, Ki, Kd) and 2orders (λ, μ) with nonintegers should optimally determined for a given system.

This paper outlined the structure and the design procedure of IPSO based FOPI Controller. Also the block diagram representation of fractional order PI controller implemented with IPSO. By using the IPSO algorithm to find K_P, K_i, K_d, λ and μ values for fractional order controller.

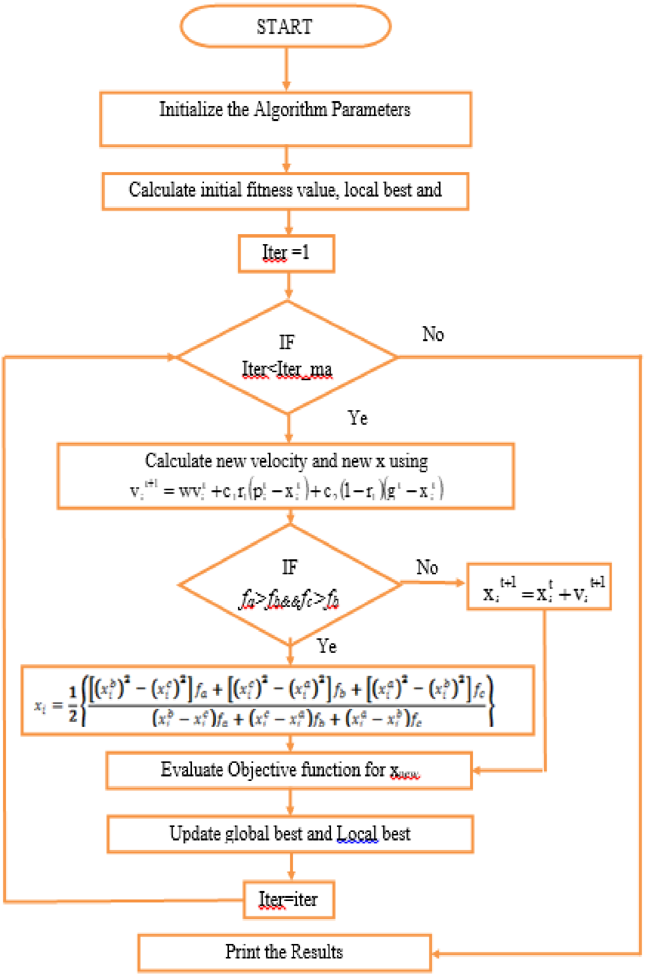

Fig. 2 Structure and design of IPSO-FOPID controller

V. RESULTS AND DISCUSSION

MATLAB / SIMULINK is one of the most successful software packages currently available. It is a powerful, comprehensive and user friendly software for simulation studies. Especially, functions are then interconnected to form a SIMULINK block diagram that defines the system structure. The response of the PI controller and Fractional order PI controller for Bidirectional DC –DC converter is depicted in Figs.

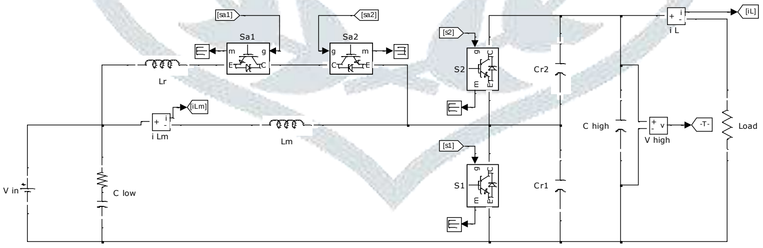

Fig. 3 MATLAB/Simulink model for proposed DC/DC Converter

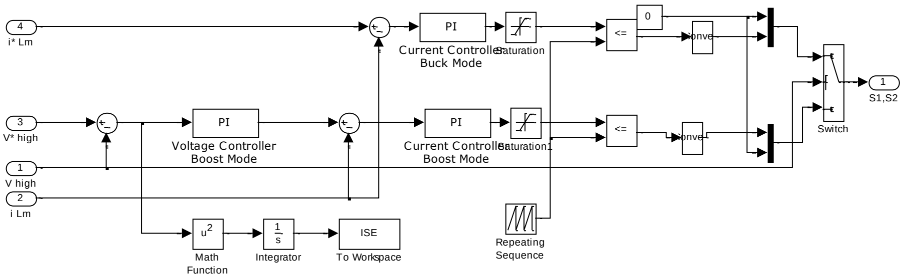

Fig. 4 Simulink Model for PI Controller for Proposed DC/DC Converter

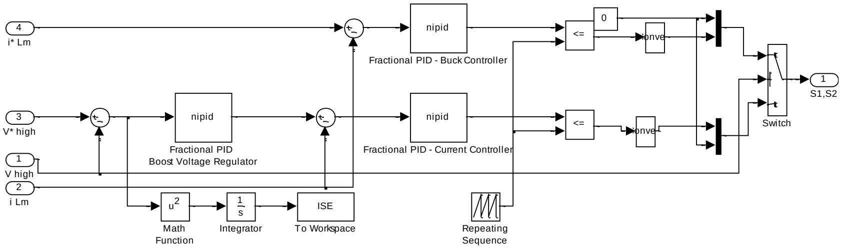

Fig. 5 Simulink Model for PI Controller for Proposed DC/DC Converter

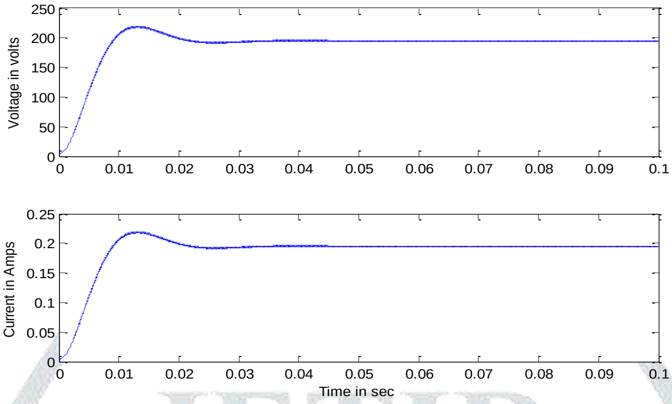

Fig. 6 Simulated Voltage and Current Response of Proposed DC/DC Converter with set value of 200 Volts

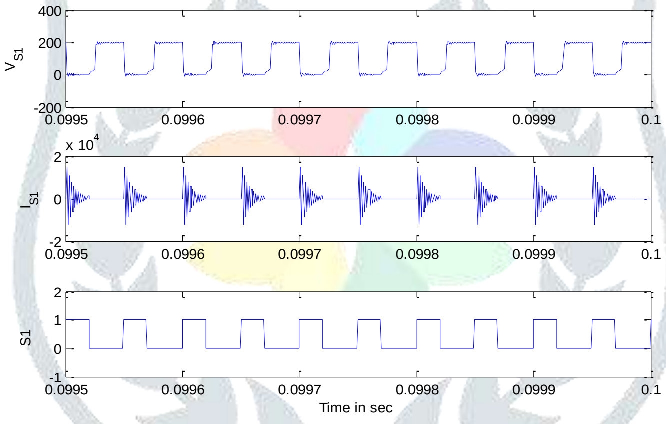

Fig. 7 Simulated Voltage and Current Response of S_1 for ZVS switching of Proposed DC/DC Converter with set value of 200 Volts with PI Controller

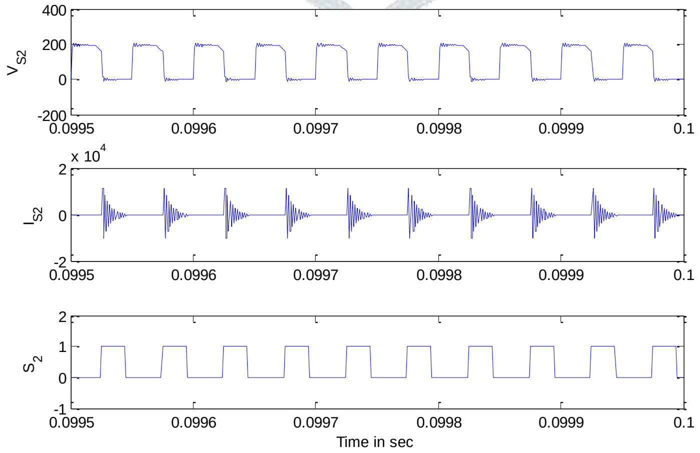

Fig. 8 Simulated Voltage and Current Response of S_2 for ZVS switching of Proposed DC/DC Converter with set value of 200 Volts with PI Controller

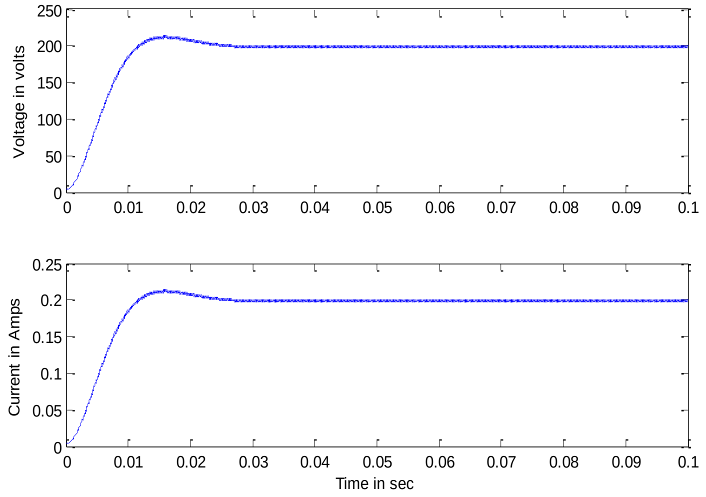

Fig. 9 Simulated Voltage and Current Response of Proposed DC/DC Converter with set value of 200 Volts with FOPI Controller

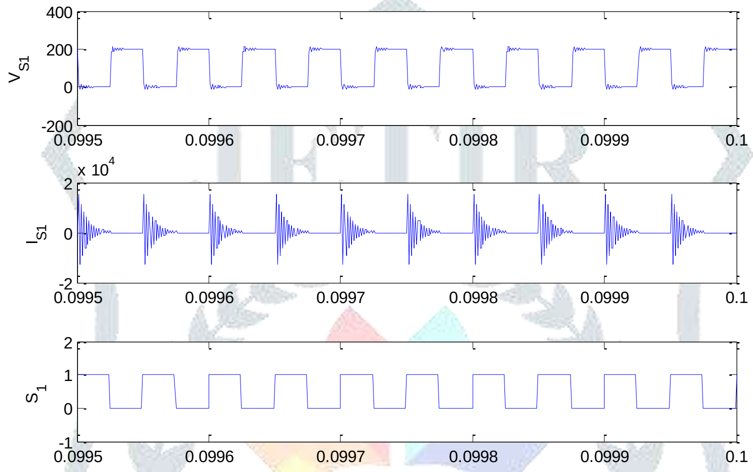

Fig. 10 Simulated Voltage and Current Response of S_1 for ZVS switching of Proposed DC/DC Converter with set value of 200 Volts with FOPI Controller

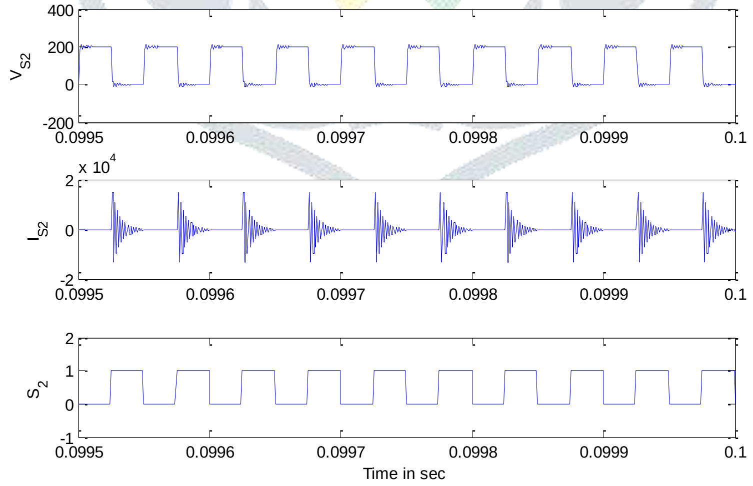

Fig. 11 Simulated Voltage and Current Response of S_2 for ZVS switching of Proposed DC/DC Converter with set value of 200 Volts with FOPI Controller

VI. CONCLUSION

A method for tuning of PI and fractional order PI controller tuning using Artificial intelligence has been proposed. The presented method is based determination of K_p , K_i and K_d for the conventional PI Controller. Similarly K_p , K_i, K_d, λ and μ have been found by using IPSO. The simulation results that demonstrate that controller has better response compare with the PI and FOPI controller using tuning of AI techniques from the observation .The PI and FOPI controller is tuned with IPSO. The IPSO based Fractional order PI controller has the best response compared with the performance of the other controllers and tuning method mentioned above.

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