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Isolated DC-DC Converter Fed DC Motor For Bidirectional Electric Vehicular Application

Bade Abhishek
M. Tech Student from Power Electronics and Electrical Drives,
Mahatma Gandhi Institute of Technology, Gandipet, Hyderabad, 500075

Dr. P. Ram Kishore Kumar Reddy,
Professor and Head, Power Electronics and Electrical Drives,
Mahatma Gandhi Institute of Technology, Gandipet, Hyderabad, 500075

Dr. P. Nagasekhara Reddy,
Associate Professor, Power Electronics and Electrical Drives,
Mahatma Gandhi Institute of Technology, Gandipet, Hyderabad, 500075

***Abstract*—**This paper presents the modelling, simulation, and control of an isolated Dual Active Bridge (DAB) DC–DC converter fed DC motor drive for bidirectional electric vehicle (EV) applications. The proposed system consists of a lithium-ion battery, an isolated bidirectional DAB converter with a high-frequency transformer, an LC output filter, and a separately excited DC motor representing the traction motor. Unlike conventional isolated converters that employ fixed-gain Proportional–Integral (PI) controllers, the proposed system employs an Artificial Neural Network (ANN) controller to regulate the converter output voltage by processing the voltage error and change in error through a trained feed-forward neural network. The ANN output determines the optimal phase-shift angle between the two full bridges, which is converted into switching pulses by a discrete PWM generator for the DAB converter switches. The proposed control strategy adapts to the nonlinear characteristics of the converter and motor without requiring manual gain tuning, providing faster transient response, reduced overshoot, lower steady-state error, and improved bidirectional power transfer during motoring and regenerative braking. MATLAB/Simulink results demonstrate stable motor speed regulation, smooth torque and current characteristics, regulated battery voltage and current, and efficient state-of-charge management, confirming the suitability of the proposed ANN-based isolated DAB converter-fed DC motor drive for next-generation electric vehicle application.

***Keywords*— Dual Active Bridge (DAB) Converter, Artificial Neural Network (ANN) Controller, Isolated DC–DC Converter, Bidirectional Power Transfer, Electric Vehicle (EV), DC Motor Drive, Regenerative Braking, Lithium-Ion Battery.**

I. INTRODUCTION

The growing prevalence of EVs has led to a need for highly effective, compact, and smart energy electronic converters that can facilitate bidirectional energy shift [1], [6]. In electric vehicles, energy needs to transmit from the battery to the engine while driving and from the engine back to the accumulator while regenerative braking. A separated DC–DC converter offers galvanic separation, enhanced safety, and effective voltage transformation between the battery and the motor operate. Conventional DAB converters generally employ Proportional–Integral (PI) controllers for voltage and current regulation. However, PI controllers often exhibit reduced performance under nonlinear operating conditions, varying battery voltages, and sudden load changes because of their fixed controller parameters [4], [10]. The proposed system is developed and analysed using MATLAB/Simulink to evaluate motor speed, electromagnetic torque, armature and field currents, battery voltage, battery current, and battery State of Charge (SOC), confirming the effectiveness of the proposed ANN-based drive for bidirectional EV applications.

II. LITERATURE OVERVIEW

Extensive research has been carried out on isolated bidirectional DC–DC converters for EV applications. Bathala et al. [1] presented an overview of high-frequency isolated DAB converters, reporting high efficiency and reliable bidirectional energy transfer suitable for battery charging and discharging. Zhang et al. [2] proposed a three-level high-frequency link converter that reduced switching losses and voltage stress while achieving effective bidirectional power transfer. Savrun and Atay [3] developed a multiport converter integrating PV, battery, and supercapacitor sources, improving transient response during load variations. Williamson and Emadi [10], and Gorji et al. [9] emphasised those isolated converters provide superior safety and voltage matching, while highlighting the importance of intelligent control for improved transient response. Luo et al. [8] demonstrated a phase-shift-controlled DAB converter with soft-switching operation and fast dynamic response for EV energy storage systems. Building on these works, the present paper replaces the conventional PI controller with an ANN controller to further improve dynamic performance and adaptability under nonlinear operating conditions.

III. PROPOSED SYSTEM DESCRIPTION

The proposed system consists of a battery source, a DAB isolated DC–DC converter, a high-frequency transformer, an LC output filter, an ANN controller, a PWM pulse generator, and a separately excited DC motor, as shown in Fig. 1. The battery supplies DC power to the primary full-bridge converter, which converts it into high-frequency AC. This AC is transferred through the transformer to provide galvanic isolation, and the secondary bridge converts it back into regulated DC power for the DC motor.

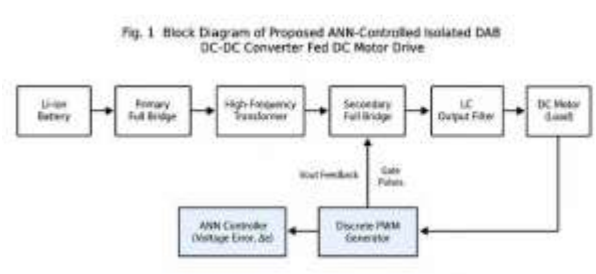

Fig. 1 Block Diagram of Proposed ANN-Controlled Isolated DAB DC–DC Converter Fed DC Motor Drive

The ANN controller continuously receives the reference voltage, actual output voltage, voltage error, and change in error. These inputs are processed by the trained neural network, which predicts the optimal control action required to regulate the converter output. The ANN output is supplied to the PWM generator, which produces switching pulses for the converter switches, adapting to nonlinear operating conditions without requiring manual gain tuning.

During motoring mode, power flows from the battery to the motor. During regenerative braking, the DC motor operates as a generator, and the generated electrical energy is transferred back through the DAB converter to recharge the battery, with the ANN controller rapidly adjusting the phase shift between the bridges.

A. Dual Active Bridge (DAB) Converter

The DAB converter consists of two active full bridges interconnected through a high-frequency transformer, as shown in Fig. 2, enabling bidirectional power transfer through phase-shift control. Compared with Flyback, Forward, and conventional Full-Bridge converters, the DAB converter inherently supports bidirectional energy flow with soft-switching operation, reduced EMI, and high power density, making it well suited for battery charging, discharging, and regenerative braking in EVs.

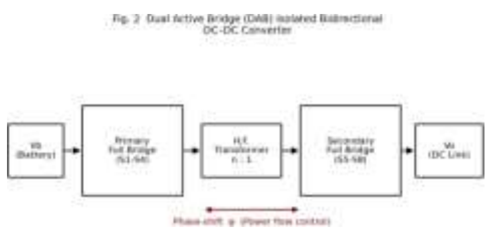

Fig. 2 DAB Isolated Bidirectional DC–DC Converter

B. Forward and Reverse Mode Operation

In the forward mode, power flows from the battery through primary bridge, transformer, and secondary bridge to the DC motor (Fig. 3). In the reverse mode, the DC motor operates as a generator and power flows in the opposite direction back to the battery (Fig. 4), with the phase-shift polarity between the two bridges reversed.

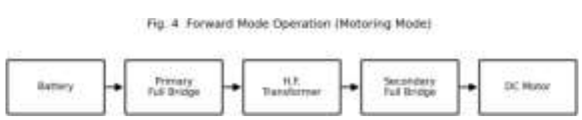

Fig. 3 Forward Mode Operation (Motoring Mode)

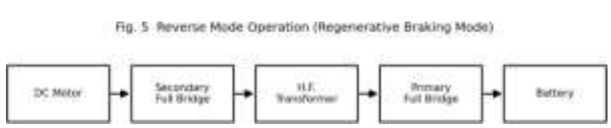

Fig. 4 Reverse Mode Operation (Regenerative Braking Mode)

IV. MATHEMATICAL MODELLING

which determines the optimal phase-shift angle φ and

A. Battery Model

The terminal voltage of the battery is

$$V_b = E_b - I_b R_b \tag{1}$$

Where, Vb is the terminal voltage, Eb is the open-circuit voltage, Ib is the battery current, and Rb is the internal resistance. The State of Charge is given by

$$\mathrm{SOC} = \left(\frac{Q_{\mathrm{remaining}}}{Q_{\mathrm{nominal}}}\right) \times 100 \tag{2}$$

and the battery power loss due to internal resistance is $P_{\mathrm{loss},b} = I_b^2 R_b$

B. DAB Converter Model

The power transferred through the DAB converter using single phase-shift control is

$$P = \left(\frac{V_1 V_2}{\omega L}\right) \delta \left(1 - \frac{\delta}{\pi}\right) \tag{3}$$

where V1 and V2 are the voltages on the two sides, ω is the angular switching frequency, L is the leakage inductance, and δ is the phase-shift angle. The transformer voltage relationship is Vs = Vp / n, and the converter efficiency is η = (Po / Pi) × 100.

C. DC Motor Model

The armature circuit equation of the separately excited DC motor is

$$V_a = E_b + I_a R_a + L_a \left(\frac{dI_a}{dt}\right) \tag{4}$$

the back-EMF is $E_b = K_e \omega$, the electromagnetic torque is $T_e = K_t I_a$, and the mechanical equation is

$$J\left(\frac{d\omega}{dt}\right) = T_e - T_L - B\omega \tag{5}$$

D. ANN Controller Model

The proposed controller employs a feed-forward ANN with an input layer, one hidden layer of 10 neurons, and an output layer, as shown in Fig. 5. The inputs are the voltage error $e(k) = V_{\mathrm{ref}} - V_o$ and the change in error $\Delta e(k) = e(k) - e(k-1)$. Each hidden neuron computes

$$\mathrm{net}_j = \sum_i w_{ij} x_i + b_j \tag{6}$$

processed through a hyperbolic tangent sigmoid (tansig) activation function, and the output layer generates the control signal

$$y_k = f\left(\sum_j W_{jk} h_j + b_k\right) \tag{7}$$

the resulting PWM duty cycle applied to the DAB converter switches. The training error function used during ANN training is

$$E = \frac{1}{2}(V_{\mathrm{ref}} - V_o)^2$$

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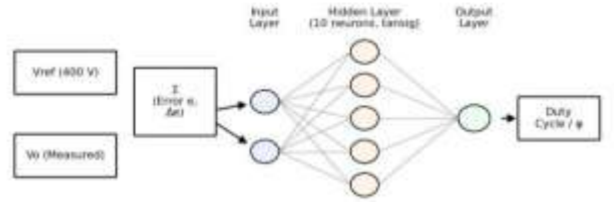

Fig. 5 Feed-Forward ANN Controller Structure

V. ANN-BASED CONTROL STRATEGY

The ANN controller continuously monitors the converter output voltage, computes the error and change in error, and processes them through the hidden layer to generate an optimal control signal. Unlike the conventional PI controller, which requires precise mathematical modelling and fixed gains, the ANN controller learns the nonlinear relationship between operating conditions and the required control action from training data, enabling it to rapidly predict the appropriate phase-shift angle without repeated tuning.

Consequently, the controller provides faster dynamic response, minimises voltage fluctuations, reduces overshoot and settling time, and maintains stable operation under sudden load changes and battery voltage variations, while improving overall conversion efficiency by optimising the power transfer process and reducing unnecessary switching losses.

VI. SIMULATION PARAMETERS

The proposed system was modelled and simulated in MATLAB/Simulink using a 220 V, 50 Ah lithium-ion battery, a 5 kW. Dual Active Bridge converter switching at 20 kHz with a 1:1 high-frequency transformer, a 5 HP, 220 V, 1500 rpm separately excited DC motor, and a feed-forward ANN controller with 2 input neurons, 10 hidden neurons (tansig activation), and 1 output neuron trained using the Levenberg–Marquardt algorithm.

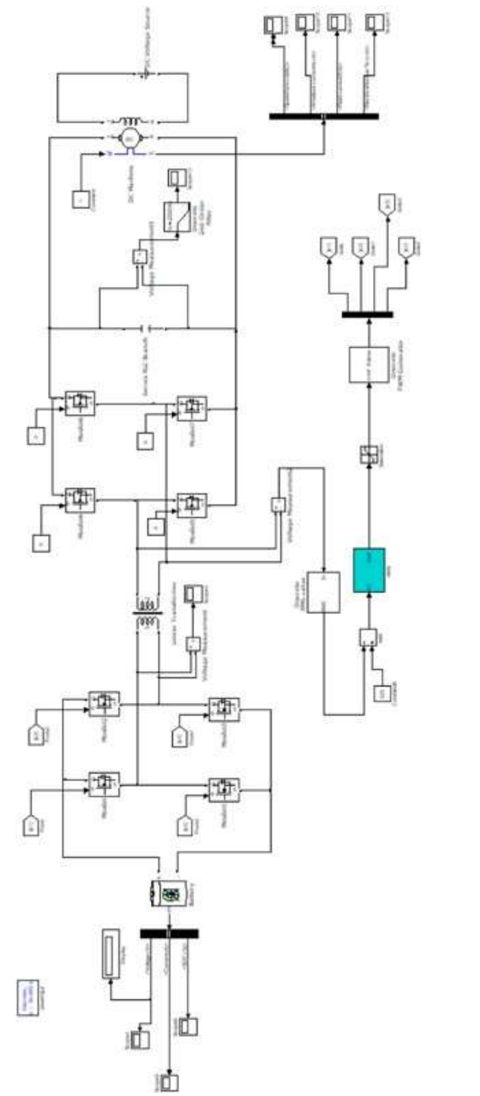

Fig. 6 Proposed model of a DC-DC converter by using Dual Active Bridge Converter

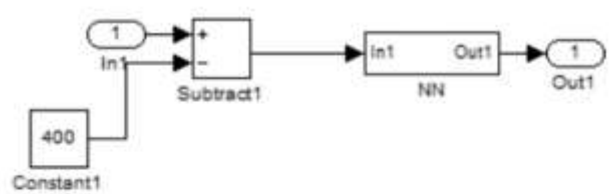

Fig. 7 Artificial Neural Network Sub-system

VII. RESULTS AND DISCUSSION

The proposed ANN-controlled isolated DAB converter-fed DC motor drive was simulated in MATLAB/Simulink for a period of 10 seconds. The dynamic and steady-state responses of motor speed, electromagnetic torque, armature current, field current, battery voltage, battery current, and battery SOC are presented below.

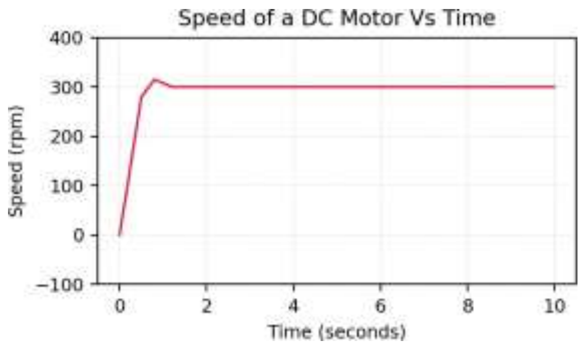

Fig. 8 Speed of DC Motor Vs Time

The motor accelerates rapidly from standstill, reaching a peak of approximately 320 rpm with a small overshoot before settling smoothly to the steady-state speed of 300 rpm within about 1.2 s, demonstrating fast response and negligible steady-state error.

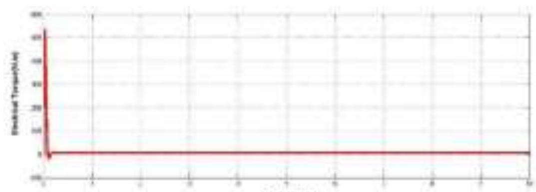

Fig. 9 Torque of DC Motor Vs Time

A high starting torque of about 50 N·m is developed to accelerate the motor, decreasing exponentially as the back-EMF builds up and settling to a steady-state value of approximately 7 N·m, confirming stable torque regulation with minor ripple attributable to converter switching.

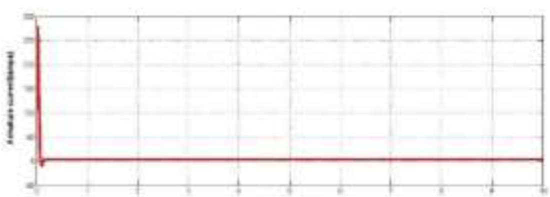

Fig. 10 Armature Current Vs Time

The armature current starts at a peak of about 26 A during starting and decays to a steady-state value of approximately 4 A, following the same trend as the torque response.

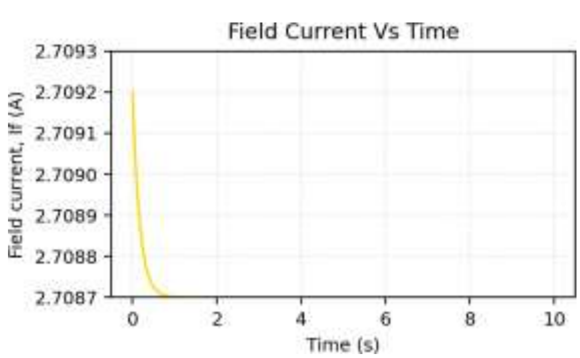

Fig. 11 Field Current Vs Time

From the above waveform fig: 11 it is observed that field current remains almost constant approx. at 2.708 A and maintained stable throughout the time period.

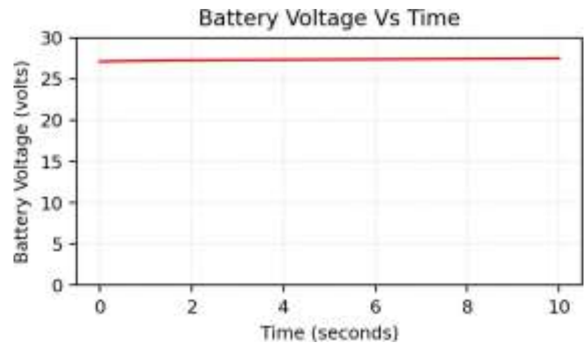

Fig. 12 Battery Voltage Vs Time

The above waveform fig.12 is of battery voltage response with respect to time in which it is clearly observed that battery voltage remains constant thorough out the time period approx constant at 27 Votls.

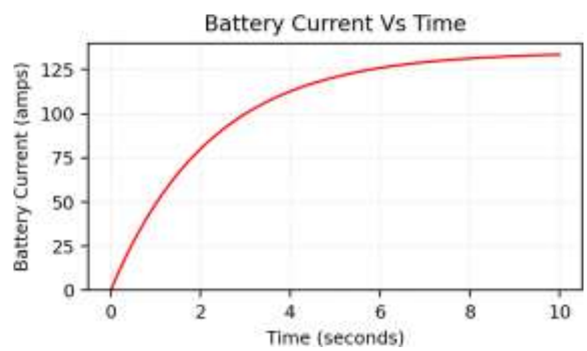

Fig. 13 Battery Current Vs Time

The above waveform fig.13 is of battery current response with respect to time in which it is clearly observed that the current waveform rising linearly until 7 seconds thereafter slightly remains constant approx. 135 amps.

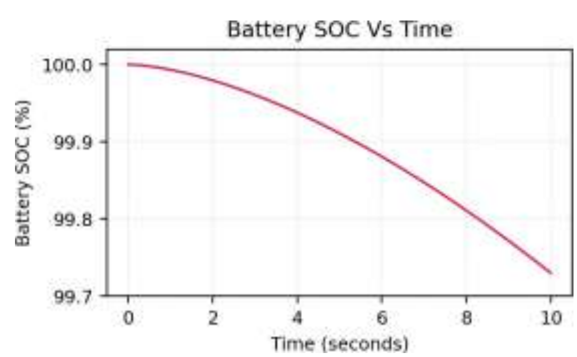

Fig. 14 Battery SOC Vs Time

The above waveform fig.14 it is observed that at the beginning of the simulation, the battery is fully charged with an initial SOC of 100%. As the system operates and supplies power to the DC motor through 60 the isolated DAB converter, the SOC decreases gradually and smoothly without any sudden fluctuations. By the end of the simulation, the SOC reaches approximately 99.73%, indicating that only a small amount of battery energy has been consumed during this interval.

The battery voltage remains stable at approximately 27–27.5 V, while the battery current rises smoothly to about 135 A without overshoot, and the SOC decreases gradually from 100 % to 99.73 %, confirming efficient and stable energy management by the ANN controller.

VIII. CONCLUSION

This paper presented an ANN-based isolated DAB DC–DC converter-fed DC motor drive for bidirectional electric vehicle applications. The proposed system integrates a lithium-ion battery, an isolated DAB converter with a high-frequency transformer, an LC output filter, and a separately excited DC motor, with an ANN controller replacing the conventional PI controller for output voltage regulation.

Simulation results demonstrate stable motor speed and torque regulation, smooth armature and field current responses, and efficient battery voltage, current, and SOC management during both motoring and regenerative braking. Compared with the conventional PI controller, the ANN controller provides faster transient response, lower overshoot, reduced torque ripple, and improved adaptability under nonlinear operating conditions, confirming that the proposed ANN-based isolated DAB converter drive is an effective solution for high-performance bidirectional electric vehicle applications.

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