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Design and Development of DC-DC Converter (SIMO) for Electric Vehicle Applications

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***Abstract* - This paper proposes an ANN controlled single input multi output (SIMO) DC–DC converter for electric vehicle (EV) auxiliary power application. The conventional SIMO converters typically experience the disadvantages of cross-regulation, limited dynamic response, output voltage variations and degraded performance under different operating conditions, due to the use of conventional PI controllers and battery-fed architectures. To overcome these limitations, the developed framework utilizes an intelligent ANN-based control strategy is proposed. The proposed system involves using a rectifier stage to convert the AC grid into a regulated DC voltage source, which is then connected to a multi-output DC–DC converter that can generate multiple output voltages simultaneously, including boost, buck-boost and buck output. Adaptive switching control in the ANN controller leads to better voltage regulation, faster transient response and output stability. The results presented in the simulation results confirm that the proposed ANN controlled converter exhibits lower ripple, shorter settling time, lower oscillations and better dynamic performance than the conventional PI controlled converter.**

Keywords - Single Input Multi Output (SIMO) converter, Artificial Neural Network (ANN) controller, Grid connected converter, Electric Vehicle (EV) applications, AC grid integration, MATLAB/Simulink.

I.INTRODUCTION

With the advancement of electric vehicles (EVs) and the incorporation of renewable energy systems, there has been an expanding need for efficient and compact power conversion systems. For EVs, several voltages are needed to provide power to different subsystems like motor drives, battery management systems, sensors, and loads. There are several usually autonomous DC–DC converters that satisfy these requirements, which are complex and expensive, consume much power, and require a high amount of space [1] [2]. These problems have inspired the development of multiport DC–DC converters and SIMO converters, which have the ability to produce several regulated output voltages from a single input voltage.

Advantages associated with the adaption of SIMO converter include a lower number of components, a smaller structure, higher power density and simplified converter architecture. The efficiency, controllability and performance of SIMO converter for EV and renewable energy application is the subject of recent research [3]–[5]. But for conventional SIMO converter topologies, there are still significant drawbacks, including cross-regulation, where variation in one output voltage impacts the other ones, resulting in a decreased voltage regulation capability and/or system stability [6, 7]. These problems are more serious when loading the converter in a dynamic manner and can affect the overall converter performance.

Besides cross-regulation issues, conventional converter system also suffers from voltage ripple, harmonic distortion and slow dynamic response, which adversely affect the output voltage quality and system efficiency [8, 9]. Some control approaches including adaptive control (AC) [10]–[11], predictive control (PC) [12]–[13] and optimized voltage-mode control (OVMC) [14] and intelligent control strategies have been reported in the literature to enhance the operation of the converter. These techniques have been developed in order to enhance some of the operating characteristics, but many of them result in

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increased complexity of the control and computation.

In recent years, Artificial Neural Network (ANN) based controllers have become more and more important for power electronic applications because they can adapt their control, they have non-linear control properties, and they have a very fast dynamic response. ANN controllers can be used to tackle the system nonlinearity, parameters changes, load disturbances, and enhance the voltage regulation and transient response. For DC-DC conversion applications, ANN controllers show better stability, lower ripple content, less oscillations and reduced settling duration relative to the (PI) controller [15]-[17].

This paper presents the design and development of an ANN controlled grid-connectedDC–DC converter with multiple outputs for Ev application. The proposed system comprises two stages, rectifier to regulate the AC grid into regulated DC source, and SIMO DC–DC converter that generates boost, buck-boost and buck output voltage simultaneously. The suggested converter topology may be intended to overcome the problem of cross-regulation by feeding energy into each output path separately, thus achieving independent output regulation. Moreover the ANN controller can reduce the ripple present in the output, enhance its dynamic response associated with PI controller and output voltage stability relative to PIsystem. The effectiveness of the developed system is demonstrated by performing MATLAB/Simulink simulations under different operating conditions.

The remaining sections are organized as follows. The developed converter strategy and operating principle are described in section II. The converter analysis and system design parameters are given in Section III. The proposed ANN control strategy and methodology of its implementation are explained in section IV. Simulation results and comparative performance analysis are discussed in section V. The major findings and contributions of the proposed work are concluded in the last section, VI.

II.SYSTEM DESCRIPTION

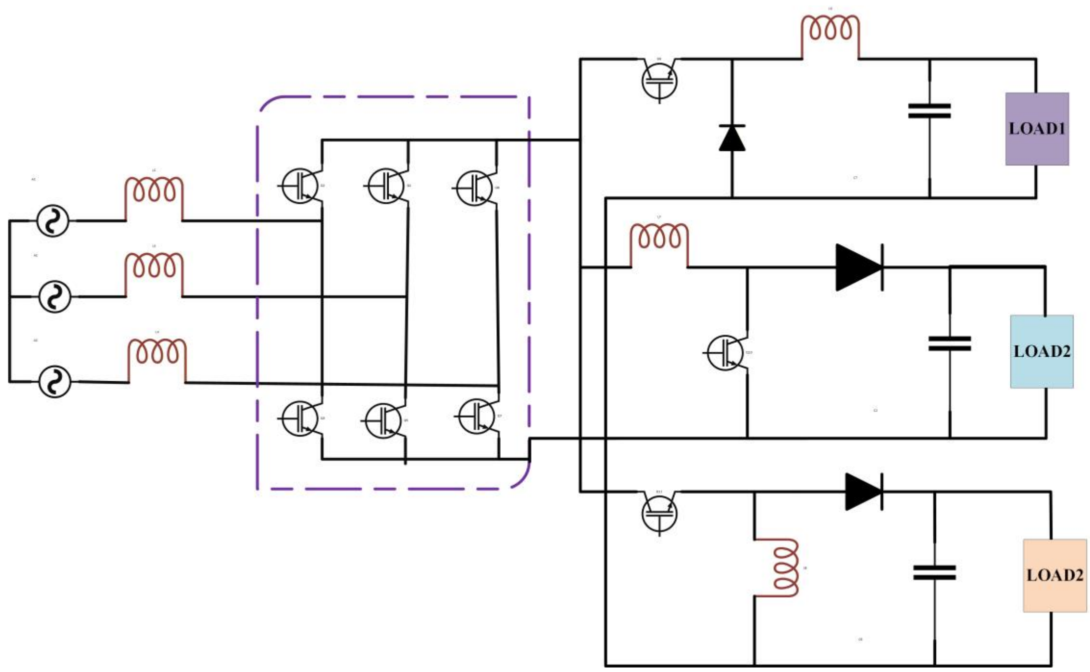

Fig1 Proposed Grid connected System Structure

The proposed system is shown in fig1 a three-phase grid connected SIMOconverter for EVs auxiliary power system. The system is to be able to derive several regulated output DC voltages from a single DC source with a compact and integrated converter structure. The full system is comprised of a three-phase AC grid, a three-phase conversion stage and a SIMO DC-DC converter that can deliver multiple voltage levels at the same time.

The three phase AC power is transformed into the desired DC power and fed in to the multi output converter portion in the proposed configuration. The SIMO converter is used to split the input power into multiple output branches to create different voltage levels to drive different EV

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auxiliary loads. The converter structure is designed to be independent of the energy transfer path in each output stage to minimize interaction between output stages.

The generated multi output voltages are supplied to Ev motor loads for validating dynamic performance of the proposed converter.

The arrangement proposed here avoids some of the cross-regulation issues that are often seen in traditional multi-output converter systems. Thus, the variation in one output branch causes only minor variations in the other output branches, and voltage regulation and stability of operation at different load conditions are improved. Furthermore, the integrated structure eliminates the need for separate individual converters, minimizing the complexity of the power conversion system and enhancing the power conversion capability.

The overall control of the converter is achieved with a control method based on ANN. The controller monitors the behaviour of the system all the time and adjusts the operation of the converter as per load variation and operating conditions. The intelligent control approach is used to enhance the dynamic response, output voltage fluctuation, ripple content and overall system stability. The proposed system can operate multi-output with good reliability and has better performance, suitable for auxiliary power in EV.

III. CONTROL STRATEGY

Artificial Neural Network (ANN) is a smart computational approach that is modeled after the human brain. Made up of inter-connected processing elements known as neurons, which can learn the correlation between input and output data during the training process. The ANN controllers have been widely adopted in the power electronic applications due to their adaptive learning ability, nonlinear mapping property and rapid dynamic response.

In the proposed system, ANN controller is used to control the grid connected SIMO DC-DC converter. The output voltage is constantly monitored by the controller and compared with a reference value set for the desired output voltage to give an error signal. The error information obtained is used by the ANN controller to decide the appropriate control action needed to maintain the stable output voltage at different operating conditions.

The developed ANN structure generally consist of composed of three stages input stage, hidden stage and output stage. The system variables (voltage error, change in voltage error) are entered in the input layer. These input signals are passed on to the hidden layer with weighted connections, where they are passed through the activation functions. Finally, the output layer generates the control signal to operate the converter.

The voltage error is defined as:

$$E\ (k) = Vref(k) - Measured(k) \quad (1)$$

Where:

- e(k) = error signal
- Vref(k) = reference voltage
- Measured(k) = measured output voltage

The change in error is expressed as:

$$\Delta e\ (k) = e\ (k) - e\ (k-1) \quad (2)$$

Where:

Δe (k) = change in error

E (k−1) = previous error value

The input signals are applied to the ANN neurons, where weighted summation is performed according to:

$$net_j = \sum_{i=1}^{n} \omega ij x_i + b_j \quad (3)$$

Where:

- netj = net input of neuron
- wij = connection weight
- xi = input variable
- bj = bias term

The neuron output is obtained using an activation function:

$$h_j = f_{(netj)} \quad (4)$$

Where:

- hj = neuron output
- F (.) = activation function

The final ANN output is generated as:

$$y_{(k)} = f\ (\sum_{j=1}^{m} \omega_{j0}\, h_j + b_o \quad (5)$$

Where:

- y(k) = ANN controller output
- wjo = output layer weight
- bo = output layer bias

The output of the generated ANN is sent to the converter and is converted to a control signal for controlling the operation of the converter. The ANN controller has the capability of learning, which allows it to appropriately deal with the nonlinear behavior of the system and load variations. In contrast to the conventional PI controller, ANN gives an improved transient response, reduced voltage ripple, minimized steady-state error, and better output voltage regulation.Hence, the dynamic performance, stability of the developed SIMO DC–DC converter and overall efficiency of the electric vehicle auxiliary power system are improved by the ANN controller.

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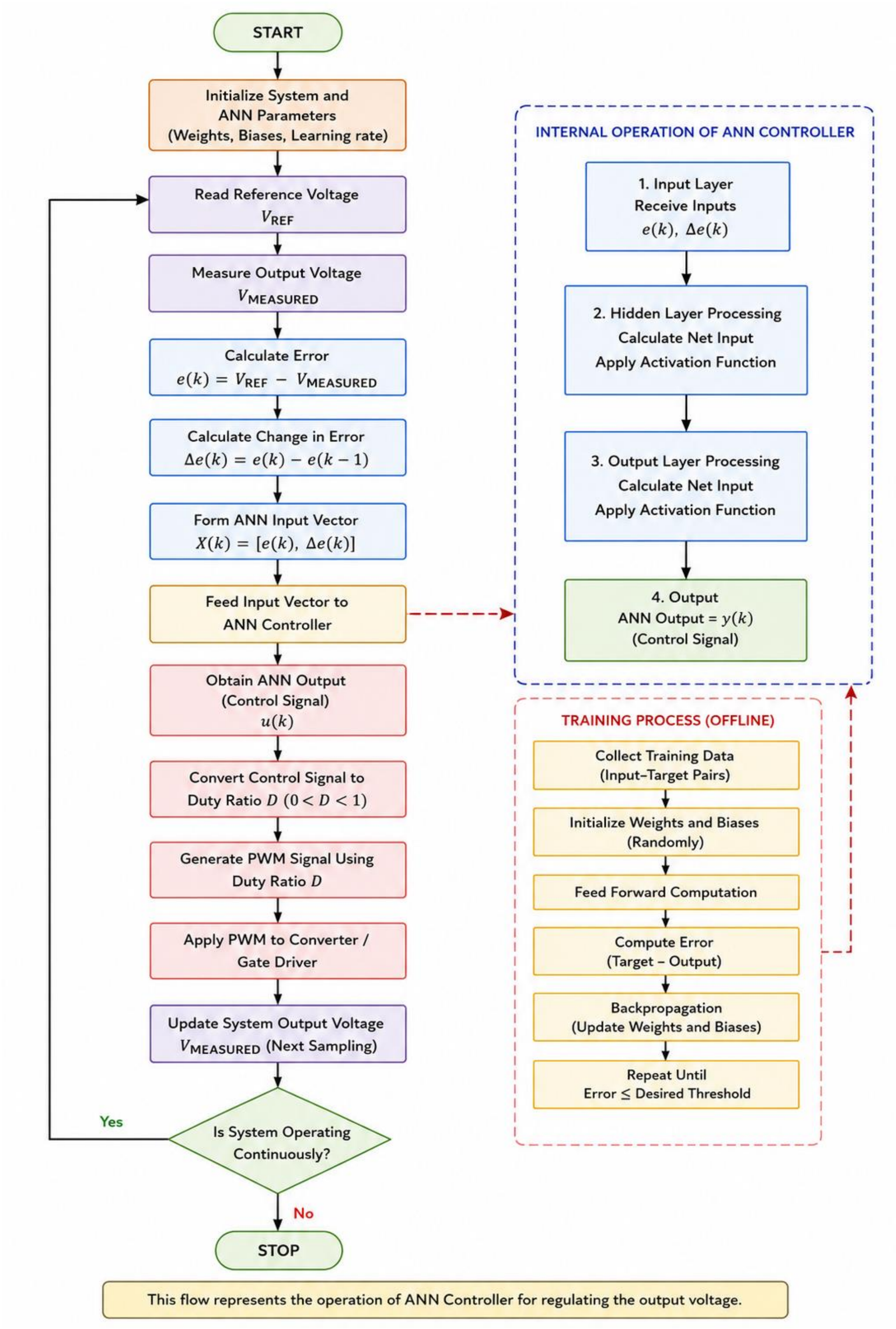

Fig2 Operational flow chart of ANN strategy for proposed SIMO Converter.

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IV PROPOSED METHOD

The proposed approach is to use an ANN based intelligent control instead of the traditional control approach in a grid connected SIMO DC to DC converter operating in an electric vehicle auxiliary power application to enhance performance. Proposed system uses a 3-phase AC grid as primary source of input rather than a battery powered source. The grid voltage is first fed to a 3-phase converter that converts the AC input voltage into the desired DC value in the SIMO converter structure.

The resulting DC power is fed into the SIMO DC–DC converter, where several regulated output voltages are produced simultaneously by different parts of the converter. The proposed converter is able to generate boost, buck-boost and buck output voltage in one single converter structure. The proposed SIMO topology will be helpful in providing multiple loads with a single common input voltage source, reduce the circuit complexity and component count as different EV auxiliary loads have different voltage requirements.

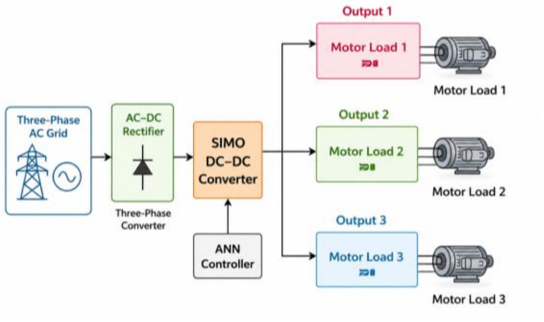

Fig3 Proposed System Structure

In normal converter systems, voltage regulation is generally performed by PI controllers. But, PI controllers has poor dynamic response in nonlinear operating conditions and load disturbances. Further, the conventional controllers might generate greater amplitude of voltage ripple, voltage oscillations and slow settling time. To address these drawbacks, an ANN based controller is added in the proposed work.

The reference voltage and the output voltage of the converter are continuously monitored by the ANN controller and the voltage error is calculated. The ANN controller is able to produce appropriate control signal for converter operation based on the error conditions. The control signal generated is then translated into pulse signals to control switching operations of the converter. The ANN controller continuously adjusts the control action based on the changes in load and output voltage during operation.

The proposed ANN-based control approach is capable of enhancing the converter performance by giving a faster transient response, better voltage regulation, less steady state error, minimum voltage output ripple and more system stability. In addition, the proposed SIMO structure has the advantage of independent energy transfer paths in each output stage, which is able to reduce the cross-regulation between the output branches.

Hence, the proposed grid connected SIMO converter with ANN based intelligent control is found to be an efficient multi-output power conversion system with enhanced dynamic performance which can be used in the electric vehicle auxiliary power system.

V SIMULATION RESULTS AND DISCUSSION

Table1 Simulation parameters

Parameter	***Value***
Grid Voltage	70v
Frequency	50Hz
Switching Frequency	20khz
Inductor(L1/L2/L3)	0.6/0.9/1 e-3
Capacitor(L1/L2/L3)	360/200/470e-6

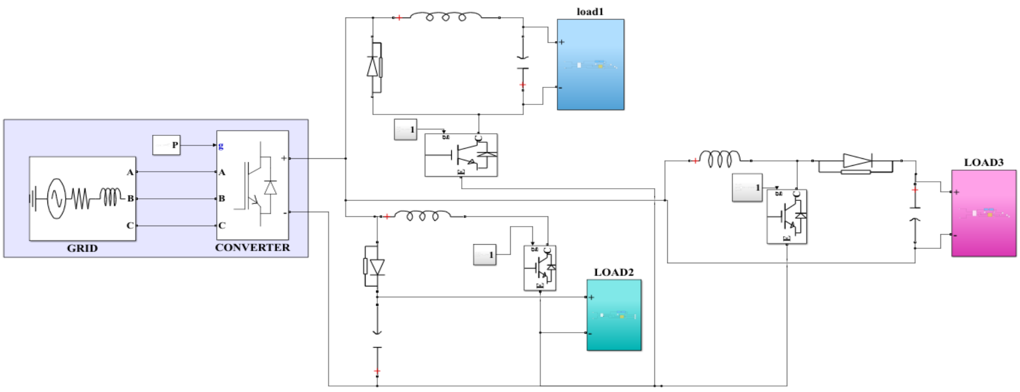

Fig4 Simulink Model of the proposed system

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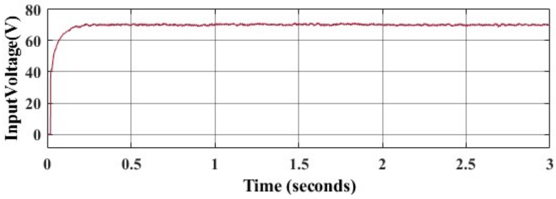
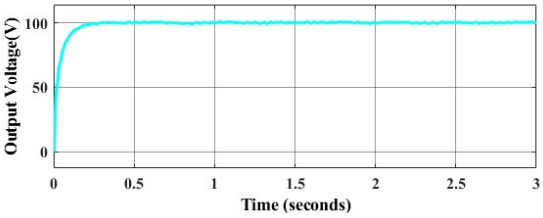
Case1: Performance Analysis under Load1



(a)



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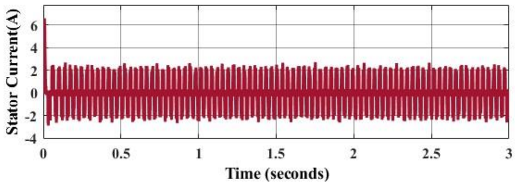

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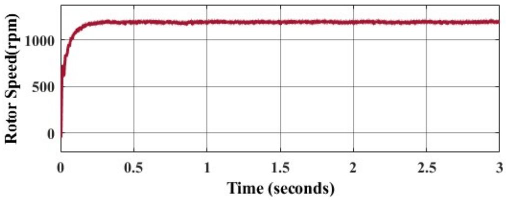

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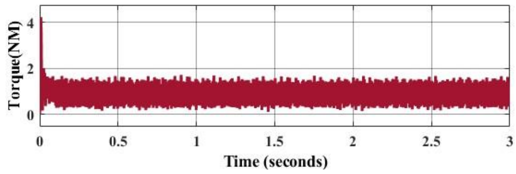
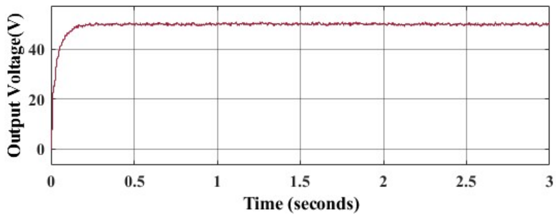


(e)

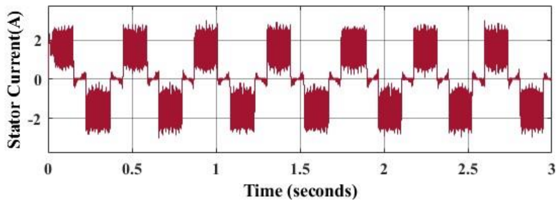
Fig5 Simulation results of input voltage, output voltage, stator current, rotor speed, Torque

The simulation results of Case 1 show that the proposed ANN controlled SIMO DC–DC converter is working effectively. The output voltage waveform is stable with a regulated voltage and less voltage ripple and Steady state performance is better. The ANN controller constantly regulates the switching operation of the converter based on the voltage variations, which can help to ensure better voltage regulation and reduce voltage oscillations. There is a smooth current wave form in the stator without much harmonic distortion; improving overall power quality. Furthermore, the desired operation is obtained very rapidly even with minimal fluctuations and with reduced settling time, with the rotor speed response. The torque waveform also shows a low ripple content, which is a sign of the better dynamic performance of the system. Overall, the proposed ANN-based control approach has better transient response and stable operation than the traditional control approaches while reducing the voltage fluctuation and improving the converter performance.

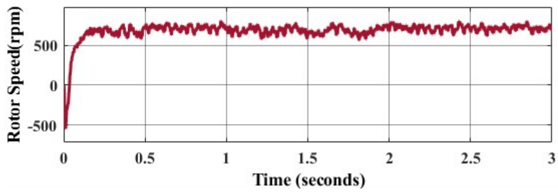
Case2: Performance Analysis under Load2



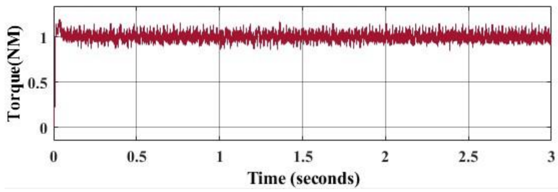
(a)



(b)



(c)



(d)

Fig6Simulation results of input voltage, output voltage, stator current, rotor speed, Torque

The obtained simulation results of Case 2 verify the successful working of the proposed ANN controlled SIMO DC–DC converter with varying loading conditions. The output voltage waveform demonstrates the better regulation, where there is a smaller steady-state deviation and ripple magnitude. The ANN controller produces proper switching signals for the converter, which leads to better transient response and stable operation of the converter. The wave shape of the stator current is a good one showing low harmonic content and good power quality, and hence good system performance. Moreover, the rotor speed stabilises to the desired operating value with much less fluctuation and quicker stabilisation. The torque

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response also has less ripple which means that the overall system has better dynamic behavior. Results obtained show the reliability of operation and the improvement in the converter performance of the proposed control method based on ANN for electric vehicle auxiliary applications.The rotor speed reaches the reference value quickly with a very little oscillating value, which means that it has better transient characteristics. Moreover, in the torque response, the operating behavior in the converter operation is stable and the ripple is small. The results obtained verify that the proposed ANN controlled SIMO converter is stable, fast in response and results in better output performance in electric vehicle auxiliary applications.

Case3: Performance Analysis under Load3

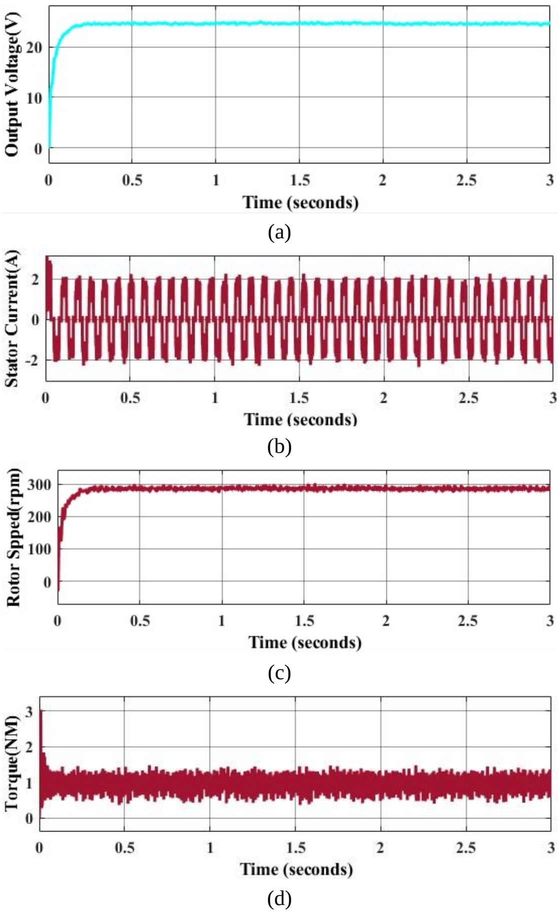

Fig7 Simulation results of input voltage, output voltage, stator current, rotor speed, Torque

The results of the simulation for case 3 further demonstrate the effectiveness of the proposed ANN controlled grid connected SIMO DC–DC converter. During operation, the output voltage has a low ripple and it has a better output voltage quality. The adaptive operation of the converter with the ANN controller yields better voltage stability and minimizing oscillatory behavior under varying operation conditions. The current waveform of the stator has better characteristics with less harmonic distortion, and the power conversion performance is improved. Moreover, the rotor speed response reaches to the required operating speed in a short time, having a short settling time and stable operation. The torque waveform further exhibits smooth features with reduced torque ripple for enhanced mechanical performance of the drive system. In general, the proposed control strategy allows for a more stable converter operation, better dynamic response, less voltage fluctuation and reliable multi-output power conversion for the use of electric vehicle.

Comparative Analysis of PI and ANN

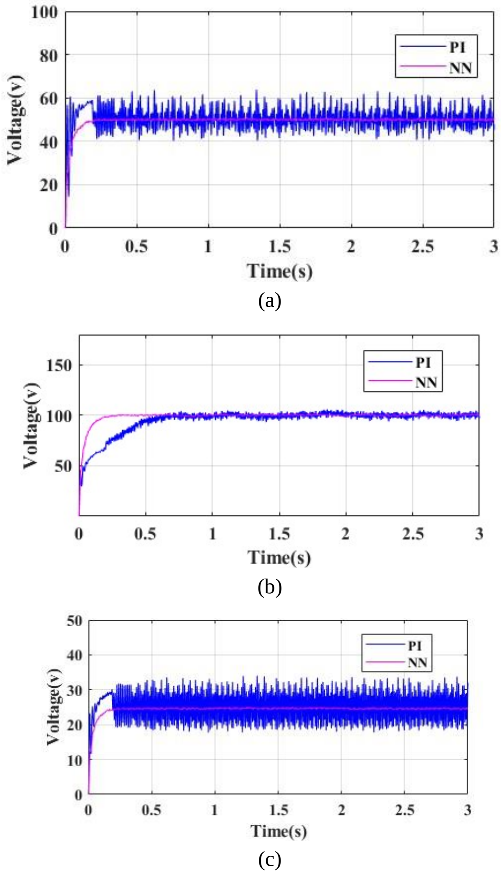

Fig 8 Comparison Results of multiple loads

The comparative performance of PI and ANN controller shows that the ANN control method has better regulation of the voltage and better transient's performance. The ANN controller successfully reduces the output voltage ripple and eliminates the unwanted oscillations during converter operation. Furthermore, settling time obtained with the ANN controller is also shorter than that obtained with the conventional PI controller. The stable operation of the converter under different load and operating conditions is also achieved by its intelligent control capability, which enhances the overall performance and reliability of the proposed SIMO DC–DC converter system.

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VI. CONCLUSION

This paper introduced an ANN based grid connected SIMO DC–DC converter used for electric vehicle auxiliary application. The proposed converter structure was able to generate a number of regulated output voltages on the same input voltage, which has led to a system simplification and thus to better converter operation. To improve the performance of the converter under various operating conditions an intelligent ANN control technique was introduced. The ANN controller has provided better voltage stability, smaller ripple, less oscillatory behaviour and quicker transient response than the conventional PI based controllers. The designed system was tested through simulation analysis which proved the system to be stable in multi-output operation with improved dynamic performance and reduced harmonic distortion. Moreover, the uni-directional energy transfer lines reduced the amount of energy that went from one output stage to the other one, thus enhancing the output regulation. Therefore, the efficiency, stability and reliability of the proposed ANN controlled SIMO converter makes it suitable for electric vehicle auxiliary applications and multi-output power electronics.

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