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A NEW MULTI-OUTPUT DC-DC CONVERTER USING PI, FUZZY AND ANFIS CONTROLLERS: A SYSTEMATIC LITERATURE REVIEW

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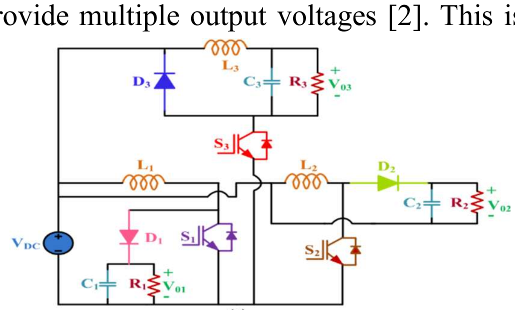
ABSTRACT:
The studies focus on designing and simulating a multi-output DC-DC converter using three modern control techniques: Proportional-Integral (PI) controller, Fuzzy Logic and Adaptive Neuro-Fuzzy Inference System (ANFIS). In this paper, we concern ourselves with understanding the different topologies of single-input multi-output (SIMO) converters. Together with these control approaches, this work discusses simulation to analyse the behaviour of the multi-output DC- DC converter under each of the three control techniques. The fuzzy and ANFIS controller results are also shown with minimized maximum peak overshoot, and the minimization of settling time. The current system also incorporates grid connection for improved efficiency and stability.
Keywords: Multiple-Output DC-DC Converter, SIMO Converters, PI Controller, Fuzzy Logic Controller, Adaptive Network – Based Fuzzy Interface System (ANFIS).

INTRODUCTION:
With the development of electric vehicles (EVs), the demand for power management systems that are efficient and dependable has grown massively. At the heart of such systems are DC-DC converters, which are tasked with converting high-voltage DC power from the primary battery of the vehicle into low-voltage power that is compatible with different subsystems, including the electric motor, auxiliary systems, and battery management. A new generation of DC-DC converters—Multiple Output DC-DC Converters with SIMO (Single Input Multiple Output) technology—has been presented, offering significant benefits for future EV applications [1].
SIMO converters play a vital role in causing significant reductions in weight and physical size by utilizing a single inductor to provide multiple output voltages [2]. This is as opposed to traditional



(a)

multi-output converters using separate inductors for every output. Such reductions are essential in enhancing automotive performance and range extension, where reduced weight and compactness contribute directly to higher energy efficiency [6]. In conventional designs, employing multiple inductors tends to incur greater power losses, thus reducing the overall efficiency of the system. In conventional designs, employing multiple inductors tends to incur greater power losses, thus reducing the overall efficiency of the system. In contrast, SIMO-based converters simplify power distribution, leading to reduced energy consumption, extended range capabilities, and overall cost savings.

Fig1: Diagram of conventional SIMO converter

LITERATURE REVIEW:

A new SIMO DC-DC converter for EVs to address cross-regulation, enhancing efficiency and compactness. This converter aims to replace multiple isolated converters, simplifying power management. It achieves independent voltage regulation for multiple outputs using a PI controller, eliminating common constraints. The PI controller ensures stable outputs under varying loads, though it has limitations with non-linear loads. A 200W prototype validated the design, confirming precise and efficient three-output regulation. The converter's simplicity and scalability make it suitable for EVs, renewable energy, and DC microgrids. Future work includes scaling the design and integrating advanced control algorithms. The research combines theoretical analysis and experimental validation to prove the converter’s effectiveness. The core advantage is the independent control of each output to mitigate cross-regulation can be found in [1]. The design interfaces various energy sources (PV, fuel cells, batteries) via isolated ports, crucial for hybrid systems. It achieves high voltage gain without transformers, simplifying the design. The paper thoroughly analyses converter operation in continuous and discontinuous conduction modes. Bidirectional power flow in one input port enables efficient battery interfacing for energy storage found in [2]. This feature supports both off-grid and grid-connected applications, without duty cycle limitations. A 300W prototype validated the design, demonstrating over 92% efficiency at full load. Experimental results confirmed the converter's performance under dynamic conditions. The research highlights the converter's suitability for practical renewable energy systems. The focus is on reducing voltage spikes and improving energy management.

The author addressed the high switch count in traditional Multi-Port Converters (MPCs) by developing a novel synthesis approach. They aimed to create compact, cost-effective MPCs for multi-source energy systems. The method uses Input Pulsating Cells (IPCs) and Output Pulsating Cells (OPCs) to derive new topologies. These cells are combined strategically to minimize switches while maintaining power flow control. Graph theory aids in analysing and representing these structures. The research proposes Single-Inductor Multi-Input Multi-Output (SI-MIMO) designs, reducing components. Simulations and analysis demonstrate high efficiency and proper power sharing with fewer switches. The designs are suitable for renewable energy, EVs, and portable electronics. This work provides a theoretical and practical approach to simplifying MPC design. The reduced switch count enhances reliability and simplifies control strategies can be found in [5]. The core focus is to improve energy efficiency and reduce size without sacrificing flexibility.

The paper focused on enhancing SIMO buck/boost converter performance via duty-cycle and control-current predictors. This addresses cross-regulation and poor transient response, common in SIMO converters. The predictors enable faster load change response and improved voltage regulation. A 0.35 μm CMOS prototype with four outputs achieved 89% peak efficiency and fast transient response can be found in [7]. However, the study identifies gaps: lack of comparative control strategy analysis (PI, Fuzzy, ANFIS), insufficient multi-objective control analysis, limited real-time simulation with intelligent controls, and absence of grid-integrated converter research. Scalability and hardware implementation issues for advanced controllers, and a lack of standardized performance metrics, are

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also highlighted. Future research should prioritize real-time control and robust verification under dynamic conditions.

Parameter Specifications:
Input voltage (V_{DC}) = 50V
Output voltage (V_{01}, V_{02}, V_{03}) = 100/50/25V
Output Currents (I_{01}, I_{02}, I_{03}) = 2/2/2A
Switching frequency (f) = 50kHz

MULTIPLE OUTPUT DC-DC CONVERTER:

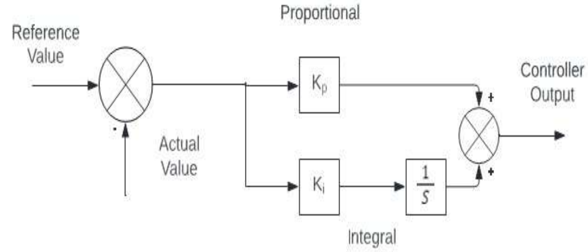
A Multiple Output DC-DC Converter is a power electronic circuit that converts a single DC input voltage into multiple DC output voltages, each with a distinct voltage level and current capacity can be found in [3]. These converters are broadly used in applications requiring various voltage levels, such as embedded systems, industrial electronics, and tele-communication can be found in [6].
There are 2 types of Multiple Output DC-DC Converters:
1. Isolated Converters
2. Non-Isolated Converters
We are considering Buck, Boost and Buck-Boost converters which fall under the category of Non-Isolated Converters.
Here three different output voltage stages which comprise of multiple inductors, capacitors, switching devices (MOSFETs), diodes and resistive loads are considered.
From fig 1, 50V input power source is distributed across three converter branches, each with inductors (L1, L2, L3) for energy storage, switching devices (S1, S2, S3) for energy transfer control, and diodes to prevent reverse current. Capacitors (C1, C2, C3) stabilize output voltages, while resistive loads (R1, R2, R3) represent power consumption. Voltage measurement blocks (V1, V2, V3) monitor the output voltages.
Challenges:
1)Cross-regulation: Changes in one output load can affect other outputs.
2)Design complexity boosts with more outputs.
3)Requires cautious component selection to balance loads.

SIMO CONVERTER USING PI CONTROLLER:

From the fig 1, provided is a simplified multiple output DC to DC converter with a Proportional Integral (PI) controller employed for voltage regulation. The PI controller is used to secure stable output voltages (V1, V2, V3) in the face of input voltage or load level variations. The figure is enhanced compared to the earlier one as it includes the incorporation of a closed-loop control method to improve stability and performance can be found in [1].

Fig2: Block diagram of PI Controller

The output voltage is regulated by the PI controller by steadily comparing it with a reference voltage



and adjusting the duty cycles of the switching devices i.e., S1, S2, S3. It delivers error compensation through a combination of proportional (P) and integral (I) control actions, so that:

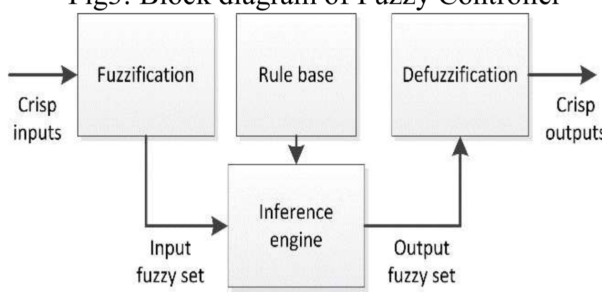
- Proportional term (P) removes the error at the current moment.
- Integral term (I) removes steady-state errors with time.

It provides a rapid transient response and minimizes voltage deviations under changing conditions. Hence, the addition of a PI controller greatly improves the performance of the DC-DC multiple-output converter to provide a regulated and stable output voltage even at no-load conditions. This performance boost is very important for EV application, where multiple levels of voltage must always be sustained for different subsystems such as traction, lighting, and infotainment.

SIMO CONVERTER USING FUZZY CONTROLLER:

Fuzzy logic is an arithmetic system that works with approximate reasoning rather than fixed and definite reasoning. It allows values to be in between two extremes.
From the fig-1, the circuit diagram shown is a multi-output DC-DC converter that is now implemented using the grid and controlled through a Fuzzy Controller. A fuzzy system consists of a set of fuzzy IF-THEN rules that describe the input-output mapping relationship of the networks [8, 9].

Fig3: Block diagram of Fuzzy Controller



The control method is a sophisticated alternative to the PI which is composed of several inductors (L1, L2, L3), MOSFET switches (S1, S2, S3), and output stages (V1, V2, V3), just like the original PI-controlled system. The controller tracks the output voltages (V_1, V_2, V_3) and compares them with the reference values to regulate the duty cycles of switches (S_1, S_2, S_3) dynamically.
Unlike a PI controller with constant proportional and integral gains, the Fuzzy Logic Controller (FLC) makes use of a set of linguistic rule bases and membership functions to handle system uncertainties and nonlinearities. It adjusts the output control actions based on real-time error and error rate, enhancing stability and efficiency. In grid-tied DC-DC converters, the FLC helps to manage the bi-directional power flow by dynamically regulating the output voltage and current.

SIMO CONVERTER USING ANFIS CONTROLLER:

ANFIS is a hybrid intelligent control method that integrates Artificial Neural Networks (ANN) and Fuzzy Logic Control (FLC) to provide self-learning and adaptive control. In the system, Fuzzy Logic assists in decision-making using rule-based logic and Neural Networks enhance system learning by dynamically adjusting parameters. The neuro-fuzzy approach in an ANFIS (Adaptive Neuro-Fuzzy Inference System) controller plays a central role by combining the strengths of fuzzy logic and neural networks. From the fig 1, circuit diagram shown is a multi-output DC-DC converter that is now implemented using the grid and controlled by an Adaptive Neuro-Fuzzy Inference System (ANFIS). The control method is a sophisticated alternative to the PI controller with improved adaptability to dynamic circuit i.e., composed of several inductors (L1, L2, L3), MOSFET switches (S1, S2, S3), and output stages (V1, V2, V3) just like the original PI-controlled system.

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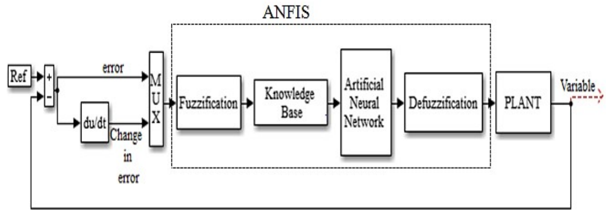

Fig4: Block diagram of ANFIS Controller

The architecture of ANFIS is structured in a way that enables it to process information in a flexible manner, making it suitable for various applications such as controlling multiple-output DC-DC converters, where the system's dynamics are nonlinear and subject to variations can be found in [8].

COMPARISON OF PI, ANFIS and FUZZY CONTROLLER:

Parameter	PI Controller	ANFIS Controller	FUZZY Controller
Control Strategy	Linear (Proportional +Integral)	Hybrid (Neural network+ Fuzzy)	Rule-based fuzzy logic
Tuning effort	Requires manual tuning (K_p, Ki)	Self-tuning via learning algorithm.	Rule-based tuning required.
Real-time performance	Fast, but not optimal in non-linear systems.	Moderate	Moderate to high depends on training data.
Response to disturbances	Slow recovery	Moderate	Fast adaptive
Settling time	Longer due to fixed gains and lack of learning ability.	Shorter due to adaptive learning.	Moderate, depends on fuzzy rule tuning.
Peak overshoot	Higher in non-linear systems.	Complex, requires rule tuning.	Moderate requires defining fuzzy rules.

Table 1: Comparison of PI, ANFIS and Fuzzy Controllers

SIMULATION RESULTS:

Waveforms under PI Controller:

Here we have used PI Controller and determined V01, V02, V03. The below figure shows the output voltages at each converter end can be found in [1].

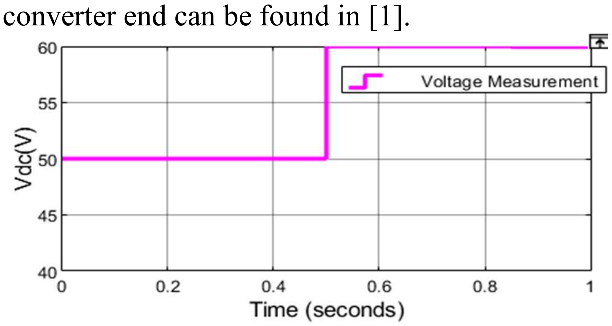

Fig5: Graphical representation of V_{dc}

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From the above figure, VDC ranges from 0 to 100V:
• Steady-State Voltage (50V before 0.5s), the current of the inductor is steady at 50V in the initial time period.
It shows a constant operating point prior to any input voltage or load change.
• Step Increase at 0.5s (50V to 55V-60V) The inductor current jumps suddenly at t = 0.5s, implying a change in load or input voltage.
• Steady Current Following Transition (55V-60V). The inductor current reaches a new steady state value, which means that the PI controller has successfully stabilized the system.

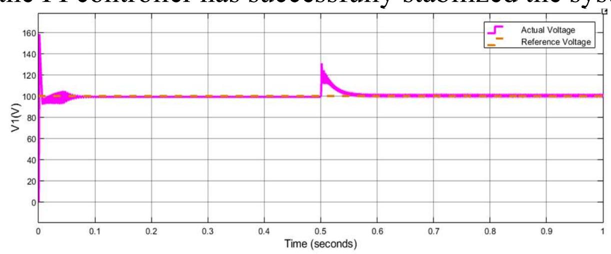

Fig6: Graphical representation of V_{01}

Above figure shows the graphical representation of V01 ranges from 0 to 200V:
• Initial Overshoot (150V): The output voltage first goes above the reference voltage, showing an underdamped transient response.
• Oscillations at Start-Up: The voltage settles after a first oscillatory response, which is typical in Pl-controlled power converters.
• Disturbance at 0.5s: A transient disturbance is introduced, perhaps caused by a load change, input voltage fluctuation, or controller adjustment.
• Final Steady-State Behaviour: The actual voltage tracks the reference voltage very well after the transient effects die out.

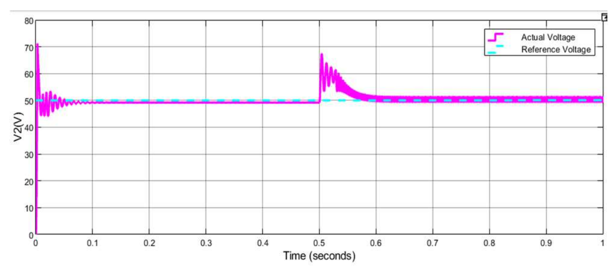

Fig7: Graphical representation of V_{02}

From the above figure V02 ranges from 0 to 100V:
• Initial Overshoot (70V-80V): The real voltage initially goes above the reference voltage. This indicates an underdamped transient response, possibly due to excessive proportional gain (Kp).
• Oscillations During Startup: Small oscillations are seen before the voltage settles. This may be due to inadequate damping or Pl controller tuning problems.
• Disturbance at 0.5s: A spike is seen at around 0.5 seconds, possibly due to a change in load or input voltage variation. The system is well recovered, exhibiting good control.
• Final Steady-State behaviour: The actual voltage follows the reference voltage closely once transients have passed. A small steady-state error indicates the Pl controller is functioning correctly.

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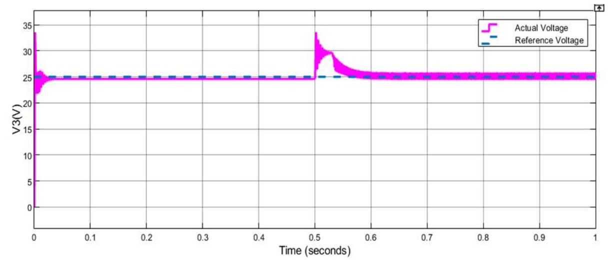

Fig8: Graphical representation of V_{03}

From the above figure V03 ranges from 0 to 50V:

• Initial Overshoot (40V): The output voltage begins greater than the reference voltage, demonstrating an initial V01 ranges from 0 to 200V: overshoot. This indicates an underdamped response, potentially caused by excessive proportional gain (Kp).

•Oscillations During Startup: Oscillations occur briefly before the voltage settles. These might be caused by Pl controller adjustment or parasitic action in the converter.

• Disturbance at 0.5s: There is a small temporary deviation at approximately 0.5 seconds, perhaps because of a change in load or fluctuation in the input voltage. The system settles smoothly, reflecting good performance by the controller.

• Final Steady-State Behaviour: The actual voltage closely tracks the reference voltage after transient periods.

WAVEFORMS UNDER ANFIS CONTROLLER :

Here we have used ANFIS Controller and determined V01, V02, V03. The below figure shows the output voltages at each converter end can be found in [1].

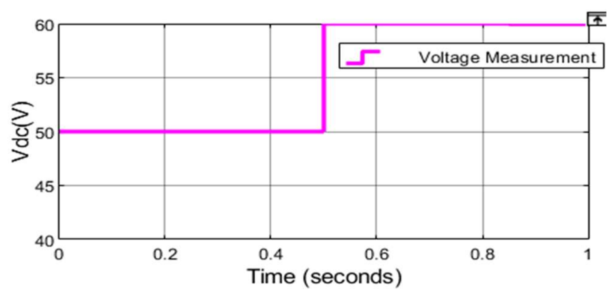

Fig9: Graphical representation of V_{dc}

From the above figure VDC ranges from 0 to 100V:

• Demonstrates a step change in voltage. It begins at around 50V, then increases to around 60V at around 0.5 seconds, and levels off. This is probably a change in the DC voltage input.

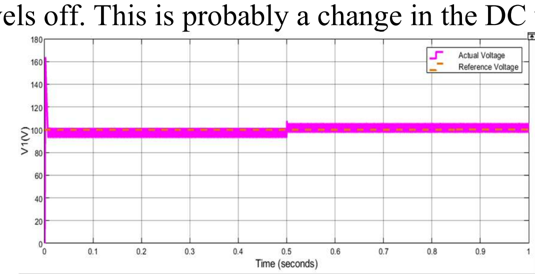

Fig10: Graphical representation of V_{01}

From the above figure V01 ranges from 0 to 200V:

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• "Actual Voltage" and "Reference Voltage" are both steady at approximately 100V, there is a sharp spike at approximately 0.5 seconds, corresponding to the shift in VDC.

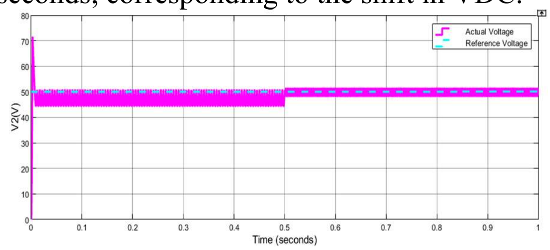


Fig11: Graphical representation of V_{02}

From the above figure V02 ranges from 0 to 100V:

• It is the same as the second subplot, except that it displays "Actual Voltage" and "Reference Voltage" lines. Both are steady at approximately 50V, with a slight spike at about 0.5 seconds, again corresponding to the shift in VDC.

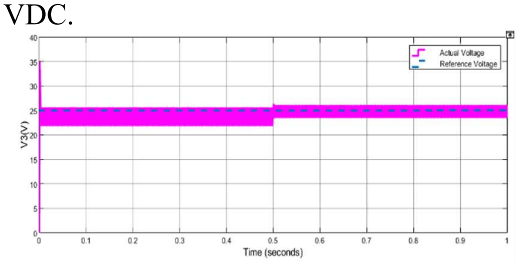


Fig12: Graphical representation of V_{03}

From the above figure V03 ranges from 0 to 50V:

• Displays two lines, "Actual Voltage" and "Reference Voltage," that are nearly identical and steady at approximately 10V. There is a slight fluctuation around 0.5 seconds, which coincides with the transition of VDC.

WAVEFORMS UNDER FUZZY CONTROLLER:

Here we have used ANFIS Controller and determined V01, V02, V03. The below figure shows the output voltages at each converter end can be found in [1].

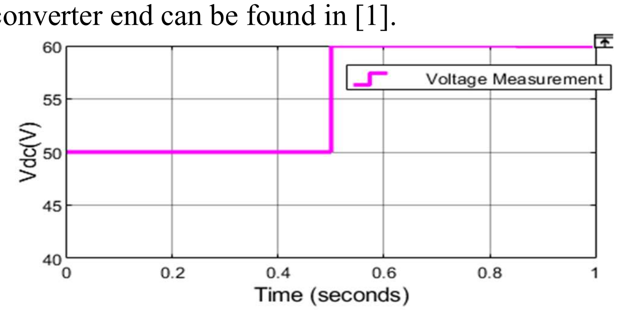
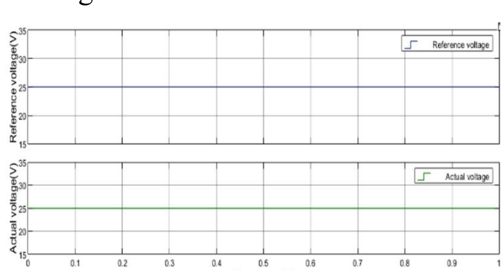


Fig13: Graphical representation of V_{dc}

From the above figure VDC ranges from 0 to 100V:



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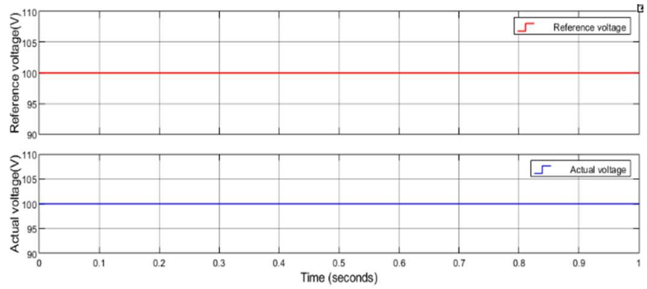
- Steady-State Voltage (50V before 0.5s) - The current of the inductor is steady at 50V in the initial time period. It shows a constant operating point prior to any input voltage or load change.
- Step Increase at 0.5s (50V) - After implying a change in load or input voltage, the inductor



voltage remains constant at t = 0.5s.

Fig14: Graphical representation of V_{01}

From the above figure V01 ranges from 0 to 200V:
Above Graph represents the Reference Voltage (Red Line)
• The reference voltage remains constant at 100V from 0 to 0.5s.
Bottom Graph represents the Actual Voltage (Blue Line)
• The actual voltage tracks the reference voltage closely.
• After introducing a disturbance at 0.5s, the output voltage remains unchanged.

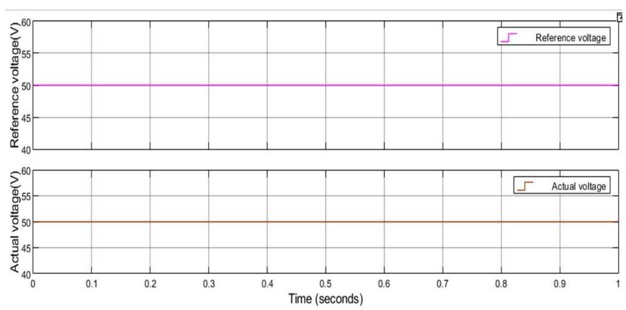


Fig15: Graphical representation of V_{02}

From the above figure V02 ranges from 0 to 100V:
Above Graph represents the Reference Voltage (Red Line)
- The reference voltage remains constant at 50V from 0 to 0.5s.

From the above figure V02 ranges from 0 to 100V:
Above Graph represents the Reference Voltage (Red Line)
- The reference voltage remains constant at 50V from 0 to 0.5s.

Bottom Graph represents the Actual Voltage (Blue Line)
- The actual voltage tracks the reference voltage closely.
- After introducing a disturbance at 0.5s, the output voltage remains unchanged.

Fig16: Graphical representation of V_{03}

From the above figure V03 ranges from 0 to 50V:
Above Graph represents the Reference Voltage (Red Line)
• The reference voltage remains constant at 25V from 0 to 0.5s.
Bottom Graph represents the Actual Voltage (Blue Line)
• The actual voltage tracks the reference voltage closely.
• After introducing a disturbance at 0.5s, the output voltage remains unchanged.

CONCLUSION:

This paper presents the design of a Single Input Multi Output (SIMO) converter, highlighting its operation and principles. The simple configuration efficiently generates buck, boost, and buck-boost outputs with independent regulation while preventing cross-regulation issues. When a PI controller is implemented, the peak overshoot voltage is relatively high, but with the use of an ANFIS controller, it decreases further. By utilizing Fuzzy Logic, this overshoot is minimized to an almost negligible level, making it virtually non-existent. It concludes that, with a PI controller, the system takes approximately 0.04 seconds to reach a stable state. However, when using an ANFIS controller, the settling time is nearly cut in half. In contrast, the Fuzzy controller stabilizes almost instantly, requiring nearly zero seconds to settle. Additionally, grid connectivity enables smooth integration, bidirectional power flow, and better energy management for renewables and EVs. Simulation and experimental results confirm the converter's efficiency, stability, and suitability for modern power applications.

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