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Comparison and Analysis of Control Techniques Implemented on Boost Converter for Renewable and EV Application

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Abstract*— This paper focuses on the hardware implementation of boost converter control techniques for renewable and EV application using real-time control dSpace MicroLabBox RT (1202) platform. The Output voltage of boost converter is regulated using Proportional-Integral (PI) control or Fuzzy Logic Control (FLC) at various applications like solar energy integration in agriculture, DC microgrid and Electrical Vehicle (EV) or space craft power system. The simulation of boost converter is built in MATLAB software. The control techniques including to regulate the output voltage, two control strategies Proportional-Integral (PI) and Fuzzy Logic Control (FLC) are implemented to achieve precise output voltage regulation to charge the batteries and other application. The experimental results are captured on 100watt boost converter laboratory prototype. The dSpace is powerful real time controller used to study power electronics devices and electrical drives in laboratories. The proposed work, both PI and FLC techniques are implemented and compared through simulation and experimental hardware results. This paper presents a comparative analysis highlights the performance, response time, steady-state accuracy, robustness and suitability of each control strategy for various real-world applications.

Index Terms*— Boost Converter, dSpace MicroLabBox, MPPT, Fuzzy Logic Control (FLC), MATLAB Software, Proportional Integral(P-I) Control, Solar Panel.

I. INTRODUCTION

DC-DC converters are important power electronic circuits used to efficiently change the voltage level of a source of direct current (DC) from one voltage to another efficiently. These converters offer improved energy efficiency, compactness and controllability, making them important in modern electrical and electronic systems. Depending on the required output voltage, DC-DC converters are broadly categorized into buck (step-down), boost (step-up), and buck-boost (both step-up and step-down) topologies. These Converters Various control strategies have been proposed to improve their performance, efficiency, and robustness under varying operating conditions. In advance the control technique Fuzzy Logic Controllers (FLCs) offer robust control even on low-cost platforms. One study demonstrated effective FLC implementation on an 8-bit microcontroller, highlighting its feasibility for DC-DC converters even with limited hardware resources [1]. Conventional PI and PID controllers are widely used for their simplicity. Improved tuning based on transient response, such as Ziegler-Nichol's methods, helps achieve better dynamic performance by using step response data [2]. In advance design AI-based technique of fuzzy logic control to DC-DC boost converters, highlighting improvements in voltage regulation and system stability [3]. As well as In the hardware domain, implements a low to high voltage closed-loop converter using a dSpace controller, validating real-time control feasibility and system robustness [4]. Comparative studies show that fuzzy logic controllers (FLCs) offer superior voltage regulation over PI controllers in solar-powered boost converters. FLCs perform better voltage regulation more robustly under varying solar irradiance conditions, making them ideal for renewable energy systems [5]. In the development designs Sliding Mode Control (SMC) and Fuzzy logic controller (FLC) for boost and buck-boost converters, in simulations and experiments confirm that SMC offers strong robustness and FLC delivers smooth, chatter-free control with stable voltage under dynamic conditions [6]. Recently researched evaluates the study compares FLC with PI control across boost, buck, and buck-boost converters, highlighting FLC's superior transient and steady-state performance under dynamic and nonlinear conditions, with reduced overshoot, ripple, and settling time [7]. In the study optimizes FLC design for second-order DC-DC converters, showing that proper tuning of rules, membership functions, and scaling factors enhances voltage regulation and dynamic performance beyond traditional methods[8].In also buck converter using fuzzy logic and PI controller demonstrating improved voltage regulation and response compared to traditional control methods[9].This study integrates fuzzy logic, PI and sliding mode control techniques to manage boost converters with variable input sources, aiming for robust and adaptive control[10]. Additionally, Fuzzy controllers using current slope data have been designed to boost dynamic performance in converters, improving stability under load and input voltage changes [11]. Implementing high-frequency PWM control has been implemented using dSpace MicroLabBox with RT Lib and C programming, enabling precise and efficient control for power electronic systems [12].

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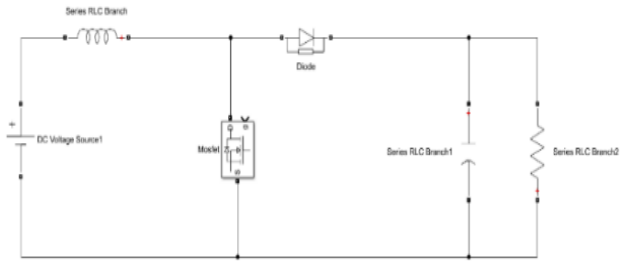


Fig. 1. Boost Converter circuit

II. SECTION (METHODOLOGY)

A. PI Controller

The PI control technique is a widely used control strategy in power electronics, including boost converters. In this work uses a PI controller to regulate the output voltage of a DC/DC boost converter. The controller adjusts the MOSFET duty cycle depending on the error between reference and desired voltage, with Kp ensuring fast response and Ki eliminating steady-state error. Parameters are tuned using the Ziegler-Nichols method, and real-time implementation is done on dSpace MicroLabBox with MATLAB for dynamic performance evaluation. This combination enables the system to achieve accurate and stable output voltage even in the presence of disturbances and non-linearities.

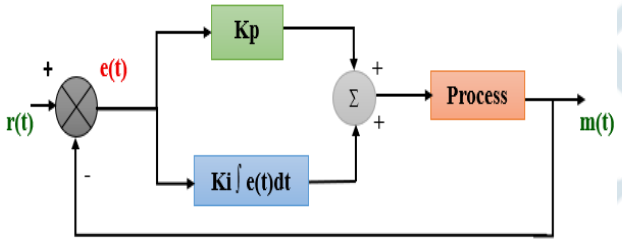


Fig. 2. PI Controller

B. Fuzzy Logic Controller

Fuzzy Logic Controller (FLC) is a free model-intelligent control technique that regulates nonlinear systems using fuzzy sets and linguistic rules making it simpler and more adaptable. In this work, a Mamdani-type FLC is implemented to regulate the output voltage of a DC-DC boost converter. In this work, a Mamdani-type FLC is implemented to regulate the output voltage of a DC-DC boost converter. The controller processes two inputs error (e) and change in error (de) derived from the difference between the reference and actual output voltages. These inputs are translated into linguistic variables through fuzzification and processed using a set of IF-THEN rules within the inference engine. The final output, representing the control duty cycle, is obtained through defuzzification and then used to generate PWM signals that control the switching behavior of the MOSFET. The FLC is designed in MATLAB/Simulink and implemented in real-time using the dSpace MicroLabBox platform enabling dynamic performance evaluation and precise control under varying load conditions.

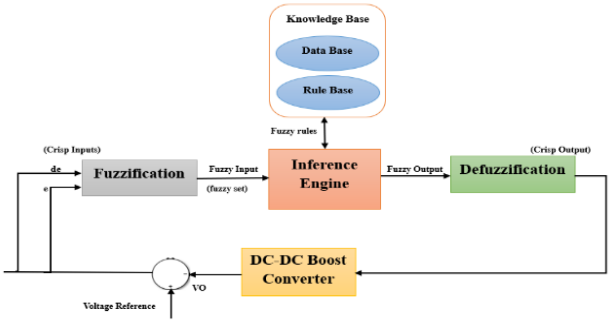


Fig. 3. DC/DC Boost Converter using Fuzzy Logic Controller.

In Fig.3. FLC use three parameters. Fuzzification, Inference System, defuzzification. Here, error(e)and change in error(de). This input gives to the fuzzy logic controller.

- Fuzzification: Fuzzification is the process of converting crisp input values into fuzzy linguistic terms for a fuzzy logic system.
- Inference System: Decision-making in fuzzy logic uses fuzzy inputs, a rule base, and a knowledge base to generate an output passed to the defuzzification process.
- Defuzzification: Defuzzification converts fuzzy output into a single crisp value to control elements like the MOSFET in a boost converter.

C. Block Diagram of Boost Converter using Solar Panel as a Input and DC load (output) to EV Application

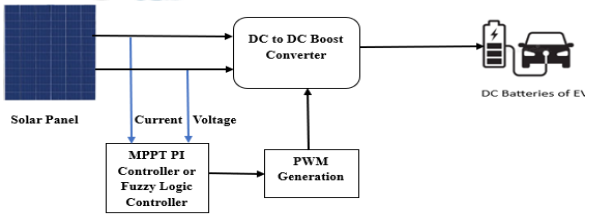


Fig.4. Block Diagram of Boost Converter using Input from Solar Panel and DC load output to EV Application

As an example, in this fig.4.system uses a solar panel (1Soltech 1STH-215-P) renewable energy source to power an EV battery through a DC-DC boost converter, which steps up the panel voltage.

A MPPT controller with PI or Fuzzy Logic continuously monitors the panel's voltage and current to maximize power output. The controller sends signals to a PWM generator, which controls the boost converter's switching. The boost converter then provides the right voltage to charge the EV battery efficiently.

D. Fuzzy Logic Membership Function

Fuzzy Logic Membership operates three main stages: fuzzification, fuzzy inference and defuzzification. In this work, a Mamdani-type fuzzy inference system is designed to regulate the output voltage of a DC-DC boost converter. The controller uses two inputs error (e) and change in error (de) to generate one output, the duty cycle. The input and output

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variables are described using five linguistic terms: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Big (PB), Positive Small (PS).

These five Membership Function use for input-1, input-2 and output Block.

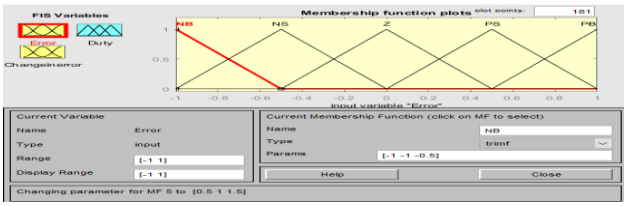


Fig. 5. Input-1 Error with Five Membership Function

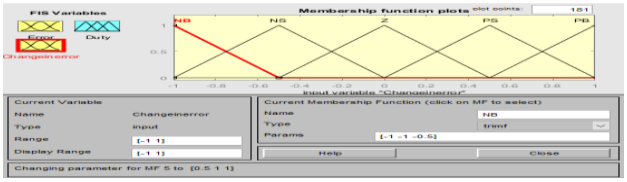


Fig.6. Input-2 Change in error with Five Membership Function

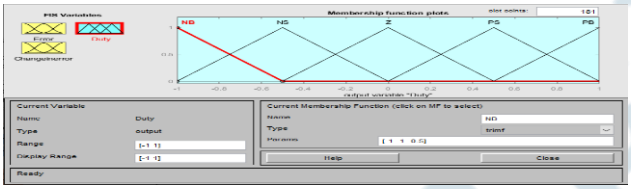


Fig. 7. Output with Five Membership Function

E. Single Output Fuzzy Logic Table rules

In a DC/DC boost converter, the output voltage is increased using fuzzy logic controller. The fuzzy logic controller is based on a fuzzy set of IF-THEN rules, which are known as fuzzy rules. A fuzzy controller boosts DC/DC output using error (e) and change in error(de) as inputs. De-fuzzification using the centroid method converts fuzzy output values into a precise, single crisp value for system control. This value adjusts the converter to maintain steady voltage.

Table I: Fuzzy Rule

de \ e	NB	NS	Z	PS	PB
NB	PB	PB	PB	PS	PS
NS	PB	PS	PS	PS	Z
Z	PS	PS	Z	NS	NS
PS	Z	NS	NS	NS	NB
PB	NS	NB	NB	NB	NB

Table II: DC-DC boost converter parameters and their values are listed for optimal design and simulation:

Number	Parameters	Values
1.	Input	12 V
2.	Output	24 V
3.	Reference Voltage	24 V
4.	Switching Frequency	10,000 Hz
5.	Inductance	6 mH
6.	Capacitor	500 µF
7.	Resistance	10 Ω

Table III: (1Soltech 1STH-215-P) Total Parameters of Photovoltaic cell

Parameters	Discriptions	Values
Vocr (v)	PV source's Open Circuit Voltage	37.14
Iscr (A)	PV Source's Short Circuit Current	8
Vmppr (v)	PV Source's Voltage's At MPP	3.72
Imppr (w)	Max Current that Our PV source can provide	7.2
niscT	The Temperature coefficient of short circuit current	0.05535
nvocT	The temperature coefficient of open circuit voltage	-0.35339
P (w)	Maximum Power	230.4
Ncell	Cell Per Module	60

III. SIMULATION STUDIES

A. MATLAB Simulation Close Loop Boost Converter Using PI Controller:

Closed loop boost converter is simulated with PI controller tuned via Ziegler–Nichol's method.

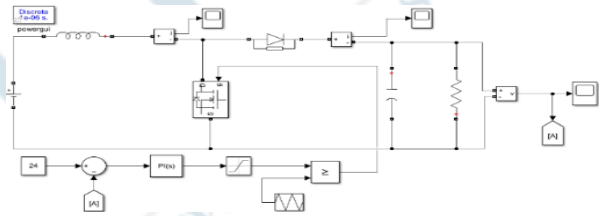


Fig. 8. Boost converter using PI controller simulation

Steady state output Waveform results:

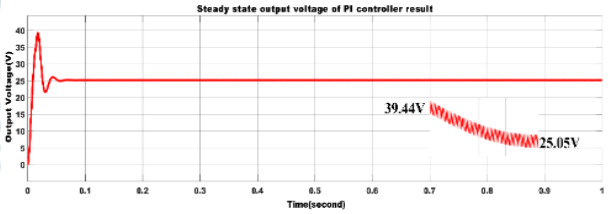


Fig. 9. Steady State output waveform of Boost Converter Performance Using PI at input Voltage 12V.

In this fig.9. waveform of output voltage boost converter simulation performance using PI results transient response is got 39.44V and after 59.29ms time output voltage waveform will be steady state condition on 25.05V. In this inductor current is CCM. it's value 5.27amp.

B. MATLAB Simulation Boost Converter Using Fuzzy Logic Controller:

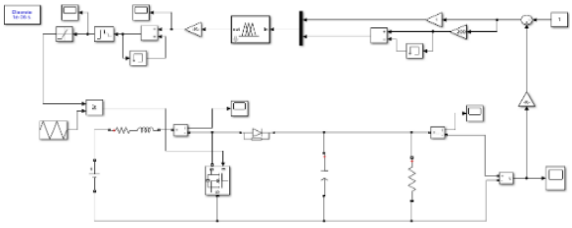


Fig. 10. Boost converter using Fuzzy Logic Controller

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Simulation Steady state output voltage waveform results:

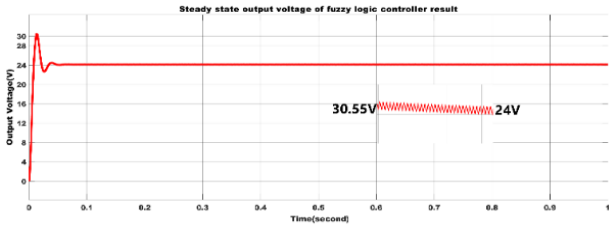


Fig. 11. Steady state output voltage waveform of boost converter simulation using fuzzy logic controller at input voltage 12V.

In Fig.11.In this output waveform got the transient state value 30.55V and after 42.220ms time will have got the steady state condition output voltage 24V. In this inductor current got CCM. It's value 5.43amp.

C. MATLAB Simulation of a Closed-Loop Boost Converter Using a Solar Panel Input with controlling MPPT and a PI Controller

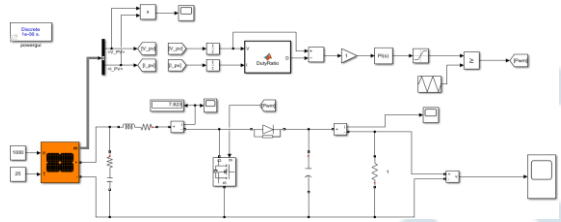


Fig. 12. Closed-Loop Boost Converter Using a Solar Panel Input with controlling MPPT and a PI Controller

Steady state output Waveform results:

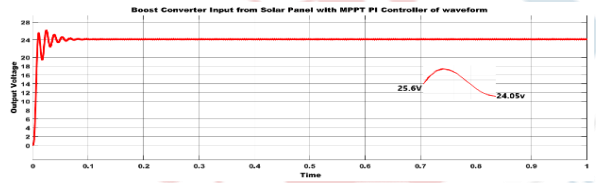


Fig. 13. Boost Converter using solar panel input with MPPT and a PI controller of waveform

In this Fig.13.waveform of output voltage boost converter simulation performance using PI results transient response is got 25.6V and after 73.136ms time output voltage waveform will be steady state condition on 24.02V. In this inductor current is CCM. it's value 7.89amp.

D. MATLAB Simulation Boost Converter Using Input Solar Panel with Fuzzy Logic Controller:

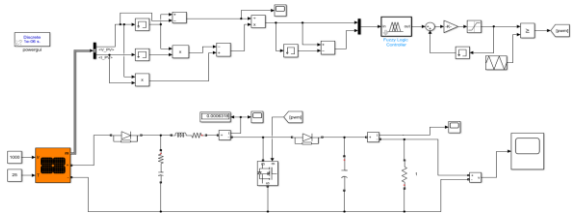


Fig. 14. Boost converter using input solar panel with using Fuzzy Logic Controller simulation

Steady state output Waveform results:

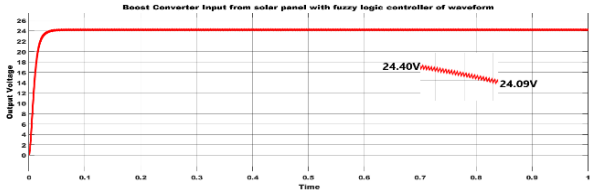


Fig.15. Boost converter from input solar panel using Fuzzy Logic Controller simulation of waveform results

In Fig.15.In this output waveform got the transient state value 24.40V and after 36.80ms time will have got the steady state condition output voltage 24.09V. In this inductor current got CCM. It's value 14amp.

E. Results in Dynamic Condition:

a. Close loop boost converter using PI controller

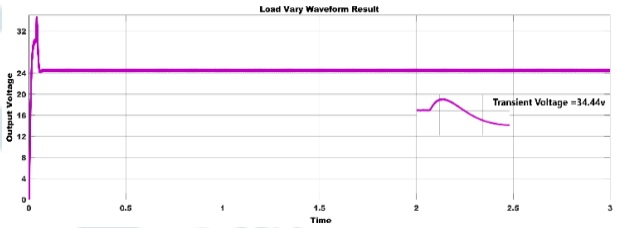


Fig. 16. Boost converter performance using PI controller at load variation by 50%

Fig.16.illustrates the boost converter's performance under load variation using a PI controller. When load is vary with a 10Ω, output voltage reaches a peak transient of 34.44 V before settling at 24.28 V. The inductor current operates in Continuous Conduction Mode (CCM). With a 25% duty cycle (pulse width), the output voltage drops to 23.55 V, while a 50% duty cycle results in an output voltage of 24.28 V.

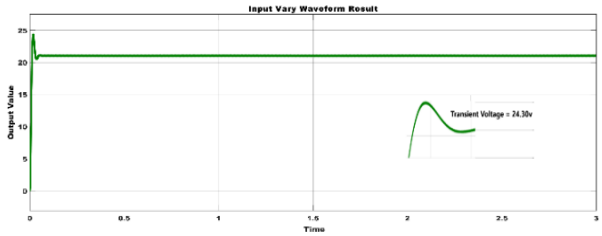


Fig. 17. Input voltage vary for boost converter performance using PI controller.

Fig.17.presents the performance of a boost converter regulated by a PI controller with an input voltage of 8 V. The transient response reaches a peak output of 24.30 V; however, the voltage settles to 20.94 V after approximately 43.925 ms, indicating limited regulation accuracy under steady state conditions. The inductor current remains in Continuous Conduction Mode (CCM) with a value of 6.069 A.

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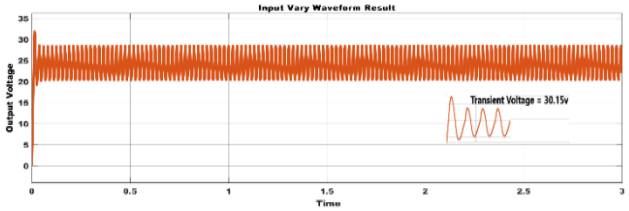


Fig. 18. Input voltage vary for boost converter performance using PI controller.

Fig.18. shows the boost converter performance using a PI controller when the input voltage is 10 V. During the transient period, the output voltage rises to 30.15 V and then settles to 22.04 V after 26.358 ms, which is lower than the desired 24 V. The inductor current stays in Continuous Conduction Mode (CCM) with a value of 4.704 A. In this dynamic condition, the output voltage ripple is high at 8.3%.

From Fig.16,17,18 input value 8V,10V,12V it indication PI controller regulate the boost converter output voltage irrespective input voltage to 8v or 10v to 24v.

b. Boost converter using Fuzzy Logic controller

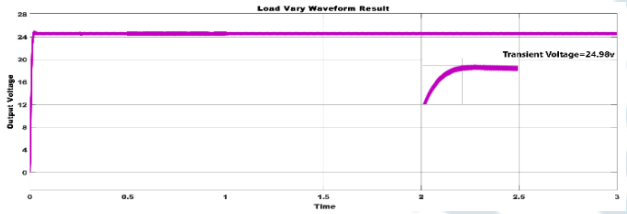


Fig. 19. Boost converter performance using FLC controller at load variation by 50%

Fig.19.shows the boost converter performance using a Fuzzy Logic Controller (FLC) under dynamic load variation with a 10 Ω resistor. The transient voltage reaches 24.98 V, which is close to the desired value. The inductor current operates in Continuous Conduction Mode (CCM) with a value 12.33 A. The output stabilizes at 24.33 V during the load variation. When a 25% duty cycle is applied for 1 second, the output remains stable at 24.33 V. Similarly, with a 50% duty cycle, the output voltage also remains stable at 24.33 V

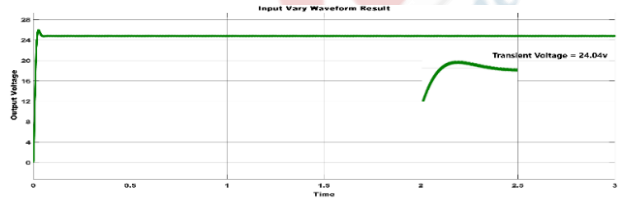


Fig. 20. Input vary for boost converter performance using FLC.

Fig.20.illustrates the simulation results of a boost converter regulated by a Fuzzy Logic Controller (FLC) under input voltage 8 V the output exhibits a transient peak of 26.04 V and stabilizes to the desired output voltage of 24.66 V within 35.286 ms. The inductor current operates in Continuous Conduction Mode (CCM), reaching a stable value of 9.973 A.

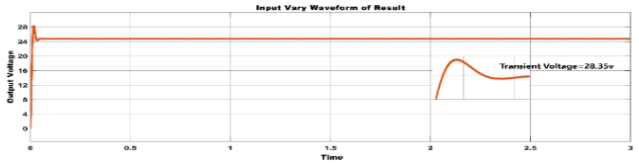


Fig. 21. Input voltage vary for boost converter performance using FLC

Fig.21.demonstrates the dynamic performance of a boost converter controlled by a Fuzzy Logic Controller (FLC) with a constant input of 10 V. The output initially overshoots to 28.35 V before settling to the target voltage of 24.64 V within 39.330 ms. The inductor current remains in Continuous Conduction Mode (CCM) and reaches a peak value of 7.14 A, indicating efficient voltage regulation under transient conditions.

From Fig.19,20,21 input value 8v,10v,12v it indication fuzzy controller regulate the boost converter output voltage irrespective input voltage to 8v or 10v to 24v.

c. Close loop boost converter from input solar panel with controlling MPPT and PI Controller of load variation

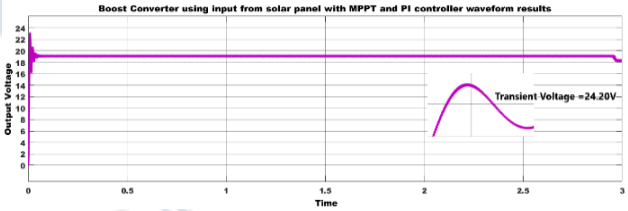


Fig. 22. Close loop boost converter from input solar panel using MPPT with PI controller of Load variation waveform

Fig.22.illustrates the boost converter's performance under load variation using a PI controller. When load is varied with a 10Ω output voltage reaches a peak transient of 24.20 V settling at 18.91 V. The inductor current operates in Continuous Conduction Mode (CCM) with value is 7.8A. With a 25% duty cycle (pulse width), the output voltage drops to 18.15 V, while a 50% duty cycle results in an output voltage of 18.91V

d. Boost converter input from solar panel with Fuzzy Logic Controller of Load Variation Waveform

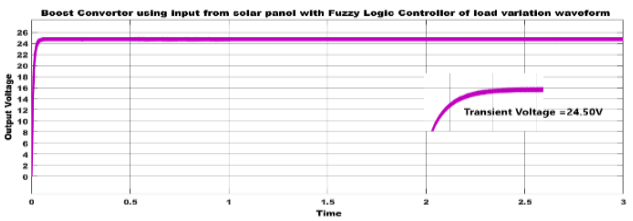


Fig. 23. Boost converter input from solar panel with Fuzzy Logic Controller of Load Variation waveform

Fig.23.shows the boost converter performance using a Fuzzy Logic Controller (FLC) under dynamic load variation with a 10 Ω resistor. The transient voltage reaches 24.50 V, which is close to the desired value. The inductor current operates in

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Continuous Conduction Mode (CCM) with a value 14.6 A. The output stabilizes at 24.05 V during the load variation. When a 25% duty cycle is applied for 1 second, the output remains stable at 24.05 V. Similarly, with a 50% duty cycle, the output voltage also remains stable at 24.05 V.

IV. HARDWARE RESULTS

A. Open loop Boost Converter MATLAB Simulation Implemented on a dSpace MicroLabBox (RT1202) Hardware for Real-time Control:

In this simulation use the dSpace MicroLabBox (RT1202) for digitally real-time control and analysis the boost converter of PWM generator duty ratio waveforms.

a. Open loop boost converter hardware results:

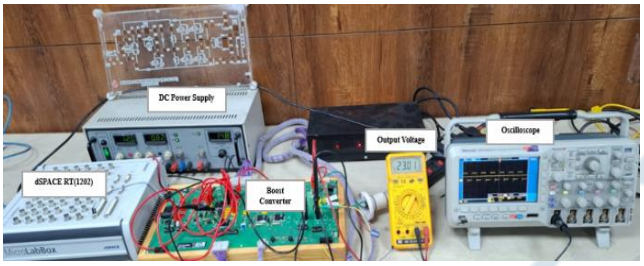


Fig. 24. Open loop boost converter hardware results

Fig.24.this is results of hardware boost converter using dSpace real-time control. Multimeter shows the output voltage value 23.01v.

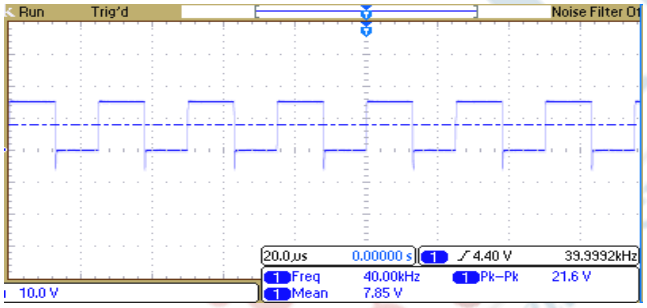


Fig. 25. PWM signal with constant duty ratio by dSpace

B. Boost Converter using PI Controller MATLAB Simulation Implemented on a dSpace MicroLabBox (RT1202) Hardware for Real-time Control:

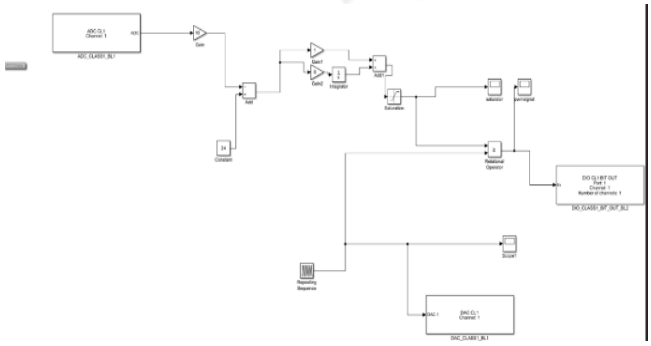


Fig. 26. PI controller implemented on dSpace MicroLabBox

b. Boost Converter Performance Using PI Controller Implemented on a dSpace MicroLabBox for Real-Time Controlling Hardware Results:

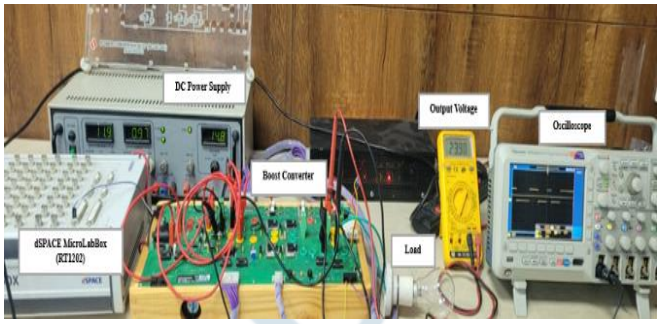


Fig. 27. Boost converter using PI controller implemented on a dSpace MicroLabBox for real-time controlling hardware results

In this Fig.27.the results of hardware close loop boost converter using PI controller implemented on dSpace MicroLabBox(RT-1202).In this multimeter shown the output voltage of dSpace real-time control. It is output 23.90v with duty ratio vary.

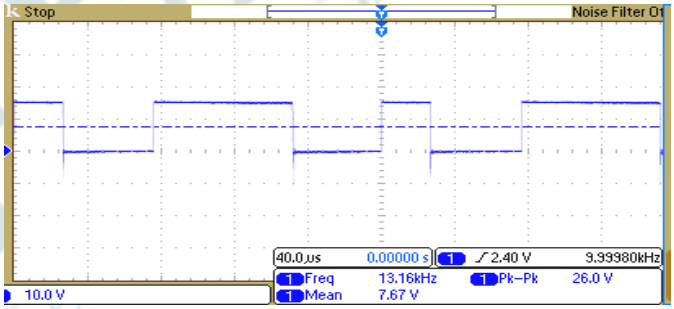


Fig. 28. PWM signal with variable duty ratio at closed loop control using PI by dSpace

V. COMPARISON BETWEEN PI CONTROLLER VS FUZZY LOGIC CONTROLLER FOR BOOST CONVERTER

Table III: Steady State Condition

SR No.	Parameters	Mamdani Fuzzy Logic Controller	PI Controller
1.	Transient voltage State Value	30.55 v	39.44 v
2.	Settling Time (ts)	49.810 ms	63.333 ms
3.	Steady state output voltage	24 v	25.05 v
4.	Ripple Value	0.25 mv	0.35 mv
5.	Rise Time(tr)	6.641 msec	8.095 msec
6.	Error (e)	0 %	0.0425 %

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Table IV: Results in Dynamic Condition

Load Variation (R= 10ohm)								
Controller	Vin	Vref	Vout	Transient State Voltage	Rise Time	Ripple Value	Settling Time	Error
PI	12 v	24 v	24.28 v	43.70 v	13.333 ms	0.57 mv	70.000 ms	0.01%
FLC	12 v	24 v	24.33 v	24.98 v	12.556 ms	0.53 mv	20.023 ms	0.01%
Input Variation (Vin= 8V)								
Controller	Vin	Vref	Vout	Transient State Voltage	Rise Time	Ripple Value	Settling Time	Error
PI	8 v	24 v	20.94 v	24.30 v	8.048 ms	0.27 mv	43.925 ms	-0.12 %
FLC	8 v	24 v	24.66 v	26.04v	13.375 ms	35.286 ms	35.286 ms	0.02 %
Input Variation (Vin = 10v)								
Controller	Vin	Vref	Vout	Transient State Voltage	Rise Time	Ripple Value	Settling Time	Error
PI	10 v	24 v	22.04 v	30.15 v	6.120 ms	8.46 mv	26.358 ms	-0.08 %
FLC	10 v	24 v	24.64 v	28.35 v	7.749 ms	0.31 mv	39.330 ms	0.02 %

Table V: Results in Dynamic Condition Input of Solar Panel to the Boost Converter

Load Variation (R= 10ohm)			
SR No.	Parameters	Mamdani Fuzzy Logic Controller	PI Controller
1.	Transient voltage State Value	24.50 V	24.20 V
2.	Settling Time (ts)	47.13 ms	52.85 ms
3.	Steady state output voltage	24.05 V	18.91 V
4.	Ripple Value	0.63 mv	0.49 mv
5.	Rise Time(tr)	14.28 msec	3.824 msec
6.	Error (e)	0.02%	0.21%

VI. CONCLUSION

In this study a dSpace MicroLabBox RT-1202 implemented for pwm signal generation in open loop as well as close loop operation of boost converter. Boost converter is tested extensively in simulation and through hardware. It is suitable candidate for operations with renewables in input variation mode and a promising candidate in EV application in both dynamic conditions by applying fuzzy control. The comparison and the analysis is presented from the results of overshoot, settling time, ripple value, rise time and error, stability in steady state condition. Simulation and experimental results show that the fuzzy logic controller technique is precise. Fuzzy logic control in steady state condition and dynamic condition shows less overshoot, less error, less settling time and less transient response than PI control. Fuzzy logic control method is to be implemented to achieve stability in dynamic conditions to enhance integrity in renewable energy and EV applications.

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