FLC Based Performance Analysis of High-Voltage Gain DC-DC Converter for Induction Motor Drive

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ABSTRACT

New High-Step-Up DC-DC Converter has been used and powered by solar-PV system for induction motor drive application. The provided topology includes a boost converter using coupled inductors to increase the voltage gain. This converter uses hybrid switched inductor technique to enhance its overall voltage gain. The inductors of the gain extension network are all charged together in parallel and get discharged simultaneously in series to obtain the high voltage gain (>10). Resultantly, the voltage stress experienced by the switches of the proposed converter is reduced to 55% of the desired output voltage. The main characterization of Fuzzy-Logic Control (FLC) scheme is constituted by emblematic path along with knowledge proficiency for prediction of optimal switching states to proposed high-step up DC-DC converter. The main intension of the FL controller is used to regulate the sudden disturbances coming from the load and getting enhanced performance over the formal PI controller. The main objective of this work is proposing a novel dual switch high step-up DC- DC converter fed VSI based induction motor (I.M) drive is controlled and powered by solar PV system with intelligent control schemes. The well-recognition of proposed scheme is validated under constant and variable DC-link voltage conditions by using intelligent Fuzzy-logic controller which is demonstrated through Matlab/Simulink tool and results are conferred with proper comparisons.

Keyword: - *DC-DC Converter, Fuzzy-Logic Controller, High Voltage Gain, Induction Motor Drive*

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1. INTRODUCTION

Due to the increasing need for the electrical energy and due to the depletion of conventional sources of energy along with the rising cost of those, renewable energy resources are getting more importance. When solar energy is considered, electricity production from it, is very eco-friendly and available in plenty in nature [1]. The high cost of PV panels and its low efficiency limited its use earlier but with the increase in technology. The efficiency of solar cells are also getting increased which encourages the use of PV system in present days to drive the electric motor drive applications like adjustable speed drives [2]-[5].

The DC-DC converters plays a key role in drive applications, in that boost converter is highly preferred for transforming low-level Photo-Voltaic (PV) voltage into high-level DC-link voltage. Numerous DC-DC converters are proposed to meet the high voltage gain (>10) requirement. Isolated converter topologies proposed to provide the required voltage gain by varying the turns ratio of the transformers. The transformers' leakage inductance causes high voltage spikes on semiconductor devices. Compared to isolated DC-DC converters, non-isolated high step-up converters are more efficient and smaller in size employing one or more coupled inductors (CIs) with appropriate turns ratio is indeed an option to obtain a high gain non-isolated converter [6]-[9].

However, similar to transformer based converters, CI based converters too suffer from the drawbacks caused due to the leakage inductance. Switched inductor (SI) and switched capacitor (SC) based converters are another breed of high gain converters. By including many SI (or SC) cells and repeating the charging and discharging operations, the voltage level at the output is significantly enhanced. A hybrid combination of SI and SC gain extension techniques is used to synthesize a high gain converter. The converter presented offers an excellent voltage gain of 6 with low voltage stress across the switches. However, the switches are operated at extreme duty ratio values. The proposed converter has several advantages like low conduction losses, smaller component size and ripple free output voltage is proposed [10]-[15].

In this work, a new High-Step-Up DC-DC Converter has been used and powered by solar-PV system for induction motor application. The provided topology includes a boost converter using coupled inductors to increase the voltage gain. This converter uses hybrid switched inductor technique to enhance its overall voltage gain. The inductors of the gain extension network are all charged together in parallel and get discharged simultaneously in series to obtain the high voltage gain (>10). Resultantly, the voltage stress experienced by the switches of the proposed converter is reduced to 55% of the desired output voltage. The main characterization of Fuzzy-Logic Control (FLC) scheme is constituted by emblematic path along with knowledge proficiency for prediction of optimal switching states to proposed high-step up DC-DC converter [16]-[20]. The main intension of the FL controller is used to regulate the sudden disturbances coming from the load and getting enhanced performance over the formal PI controller. The main objective of this work is proposing a novel dual switch high step-up DC-DC converter fed VSI based induction motor (I.M) drive is controlled and powered by solar PV system with intelligent control schemes. The well-recognition of proposed scheme is validated under constant and variable DC-link voltage conditions by using intelligent Fuzzy-logic controller which is demonstrated through Matlab/Simulink tool and results are conferred with proper comparisons.

2. HIGH VOLTAGE GAIN DC-DC CONVERTER

Fig.1 shows the power circuit of the proposed high gain Hybrid Series Inductor Capacitor (H-SLC). The proposed converter comprises of one high and one low side switch and two legs of switched inductor (SI) cells. Inductors L1, L2 and L3 along with diodes D1, D12, D2a, D2b, D23, and D3 form the first SI cell.

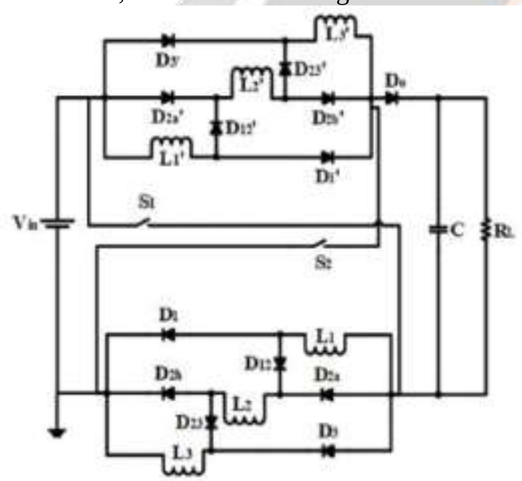


Fig.1. Power circuit diagram of the proposed converter

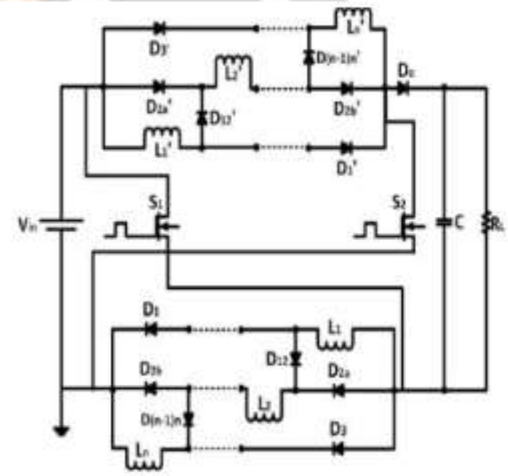


Fig.2. Power circuit diagram of the generalized proposed converter family

The first cell is connected to the positive polarity of the DC supply through switch S1 and is operated by turning the switch S1 ON and OFF periodically. The second SI cell is an exact replica of the first; the second SI cell is connected to the negative terminal of the supply while S2 aids in charging and discharging the SI cell. Diode Do acts as output diode while capacitor Co serves as output capacitor. The voltage gain of this converter can be further extended by adding “n” number of SI in each cell. Fig.2 shows the circuit configuration of a generalized H-SLC with “n” switched inductor in each cell. In this work, a 3-level H-SLC is explored in detail.

2.1 Operating Modes

Mode 1[t0-t1]: Mode 1 commences at time t=to. Both the switches S1 and S2 are turned ON simultaneously. Inductors of the upper cell L1, L2, L3 begin to store energy and charge towards the input voltage through S2 while the inductors L1’, L2’, L3’ charge through the switch S1. As the inductors continue to store energy, diodes D12, D23, D12’, D23’ and Do are reverse biased. The output capacitor Co discharges and meets the load requirement. Mode 1 comes to an end when the inductor current reaches its maximum value and the switches S1 and S2 are turned OFF at t=t1. Fig.3 shows the equivalent circuit during Mode 1. The equation during Mode 1 is given by (1).

$$i_{L1}(t)=i_{L2}(t)=i_{L3}(t)=i_{L1'}(t)=i_{L2'}(t)=i_{L3'}(t)=\frac{V_{in}}{L} \quad (1)$$

Mode 2[t1-t2]: In Mode 2, S1 and S2 are simultaneously turned OFF and the six inductors transfer energy to the output in series. During this mode, diodes D12, D23, D12' and D23' are forward biased, while the rest of the diodes become reverse biased and do not conduct. Fig.4 shows the equivalent circuit for this mode. The equation governing Mode 2 is given by (2).

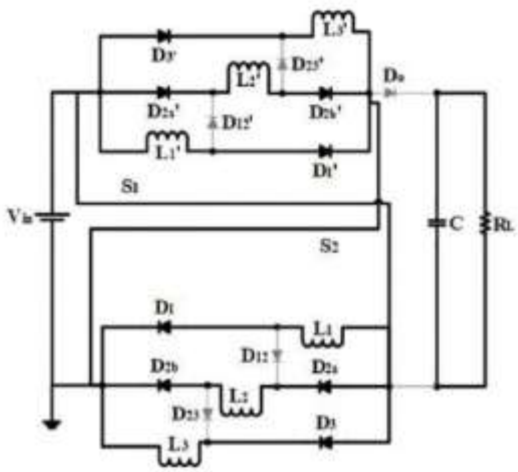


Fig.3. Equivalent circuit during Mode 1

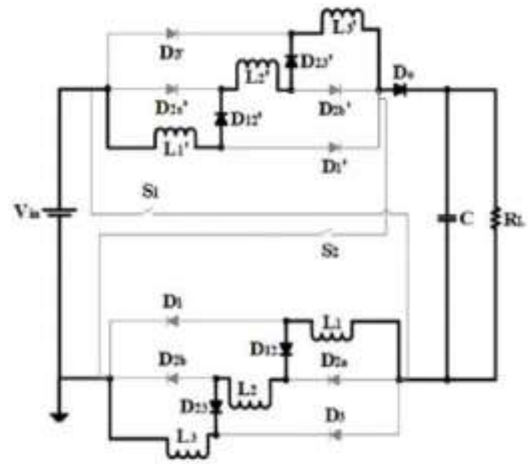


Fig.4. Equivalent circuit during Mode 2

$$i_{L1}(t) = i_{L2}(t) = i_{L3}(t) = i_{L1}'(t) = i_{L2}'(t) = i_{L3}'(t) = \frac{V_{in} - V_o(t)}{L} t \qquad (2)$$

2.2 Analysis under Steady-State Conditions

In this section, expressions for voltage gain and design details of switches and diodes are derived. The steady state voltage induced across inductors in Mode 1 is given as

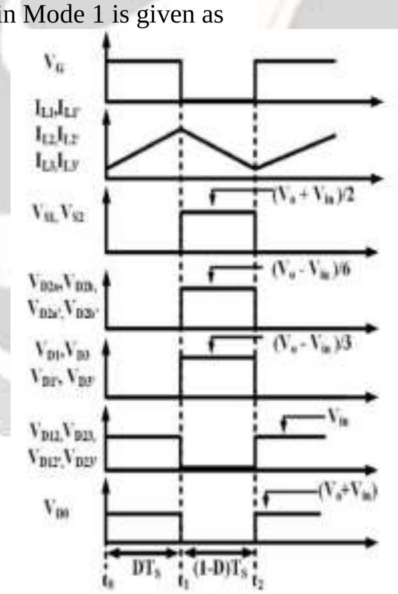


Fig.5. Characteristic waveforms of the proposed converter

$$V_{L1} = V_{L2} = V_{L3} = V_{L1'} = V_{L2'} = V_{L3'} = V_{in} \qquad (3)$$

During Mode 2, the voltage induced in the inductors is given by

$$V_{L1} = V_{L2} = V_{L3} = V_{L1'} = V_{L2'} = V_{L3'} = \frac{V_{in} - V_o}{6} \tag{4}$$

Using volt-second balance concept, expression for voltage gain is deduced as

$$G_{CCM} = \frac{V_o}{V_{in}} = \frac{1+5D}{1-D} \tag{5}$$

For a generalized structure, voltage gain expression is

$$G_{CCM} = \frac{V_o}{V_{in}} = \frac{1+(2n-1)D}{1-D} \tag{6}$$

At D=0.6, the converter yields an ideal voltage gain of 10 which is sufficient enough to connect the load to a 380V DC bus from a 35-40V input.

3. CLASSICAL PI CONTROLLER

The overview of classical control scheme is highly preferred in many closed loop applications. Generally, there are four types of controllers namely; proportional (P) controller, proportional-integral (PI) controller, proportional-derivative (PD) controller, proportional-integral-derivative (PID) controller. Above controllers are best suited for a specific application that depends on type of controlled objective. This classical PI controller is used to generate the switching states to proposed DC-DC converter with the help of gate drive circuitry. The main function of PI controller is more capable to regulate the forced oscillations, minimizing the steady state error that results the ON/OFF of the controller performance respectively. The integral section with corresponded over-all stability is affected by changing the certain values of the system. Essentially PI control objectives never possess the capable of certain estimation of the expected PI controller gains. There is certain way to settle down the introducing integral mode which makes the capable of error prediction, which is near future and may settle down the certain concern by regulating the controller reaction time.

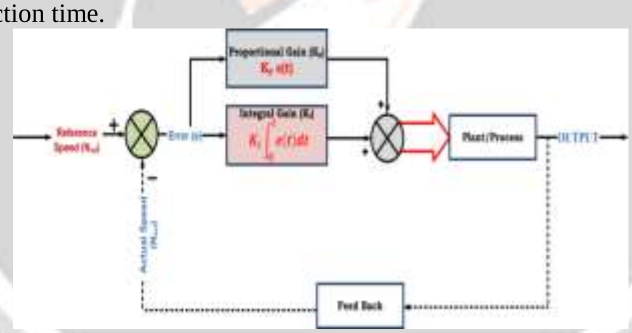


Fig.6 Schematic Diagram of Classical PI-Controller

The schematic diagram of classical PI controller, are quite popularly by several application particularly when the reference signal is not in the main concern. A specific controller doesn't have any deployment of D-mode; the key characteristics are as follows;

- It is more constraint for attaining the fast response.
- The process is comprised of large disturbance and prevail the system noise.
- Energy storage existence should be either inductive or capacitive.
- Presence of inherent should be high transport delays.

The DC link voltage regulation in conventional PI control scheme is not suitable for getting enhanced features. But, this controller is unpopular due to tuning issues of current controller; the above-mentioned issues are regulated by using novel intelligent based Fuzzy-Logic controller achieving good performance features. The main characterization of Fuzzy-Logic Control (FLC) scheme is constituted by emblematic path along with knowledge proficiency for prediction of optimal switching states to proposed high-step up DC-DC converter. The main intension of the FL controller is used to regulate the sudden disturbances coming from the load and getting enhanced performance over the formal PI controller.

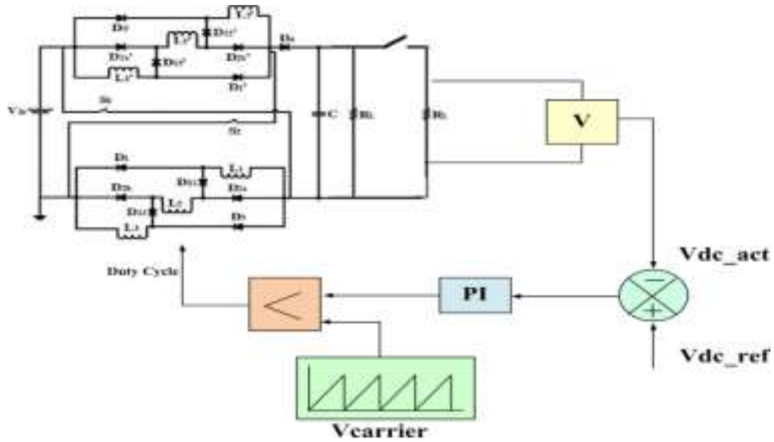


Fig.7 Closed-Loop Controlling of High-Voltage Gain DC-DC Converter under Sudden Load Using Classical PI Controller

4. PROPOSED FUZZY LOGIC CONTROL SCHEME

The proposed fuzzy controller has been used extensively for many applications in control engineering, automation which is related to associate problems is designed easily. By utilizing the fuzzy evolution method which is relative functions of qualities work for designing the real time control objective. The fuzzy system in the process/plant is reflected by the control action of the design capabilities in both experience as well as intuitive specific functioning manner. It is mostly commanded for the control scheme of resembled on efficient mathematical plant model. The fuzzy control strategy uses the linguistic information which has many advantages may include the high robust performance, greater strength, model free, attain the universal approximation theorem with rule based algorithm has been selected.

The fuzzy logic controller has been distinctly characterized by the input data coming from the fuzzy scheme as depicted in Fig.8. Automatic translation of fuzzy from the overall fuzzification process, this fuzzy process is carried out by the effective control action. The creation of input information with the evaluation of the IF....THEN rules which are produced by the several linguistics logics. After the fuzzification process the rule processing stage reaches at the point of outcome summary, de-fuzzification process is started. The de-fuzzification process is carried during the final stage; the coming inferences are transformed to real data output by fuzzy enhancer. Hence, data is utilized as interfaced module for the need of processing.

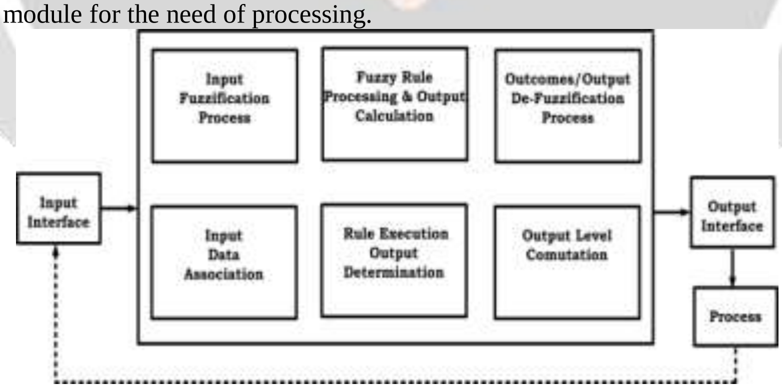


Fig.8 Block Diagram Representation of Fuzzy Control Logic

The operational logics of the fuzzy logic control objective have been illustrated by linguistic nature is differentiated from the mathematical notations. In spite of linguistic terms delivers the derived methods that are most enhanced and feasible operational characteristics. This fuzzy logic control objective belongs to the symbolic nature control action that regards to a special class. The configuration of fuzzy logic inference control objective is depicted in Fig.9.

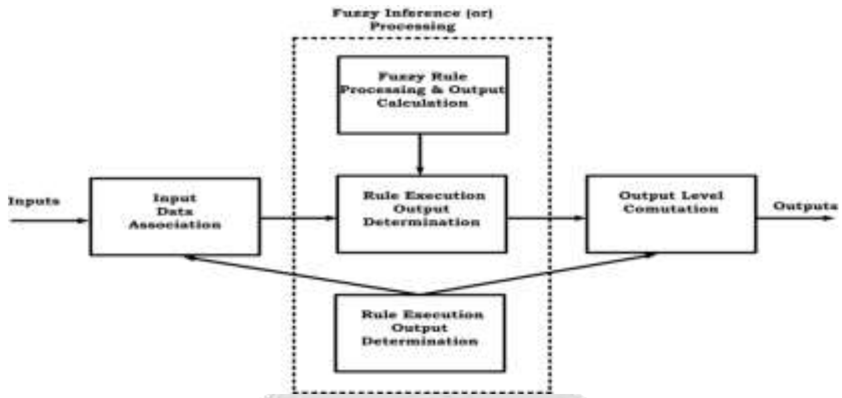


Fig.9 Configuration of Fuzzy Logic Inference Control Objective

The proposed fuzzy-logic controller membership functions are depicted in Fig.10 and the rule base is illustrated in Table.1. The block diagram of proposed Fuzzy-Logic Controlled High-Gain DC-DC Converter with induction motor drive system is depicted in Fig.11.

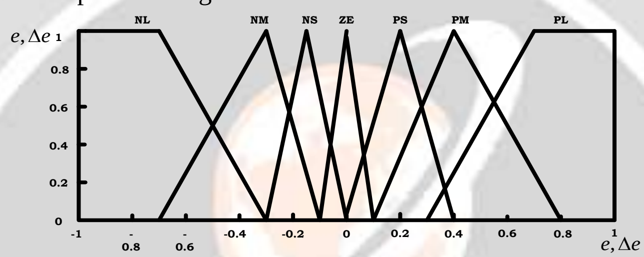


Fig.10 Fuzzy Logic Membership Functions

Table.1 Fuzzy Logic Rules

Δe \ e	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	NM	NS	ZE	PS	PM	PB

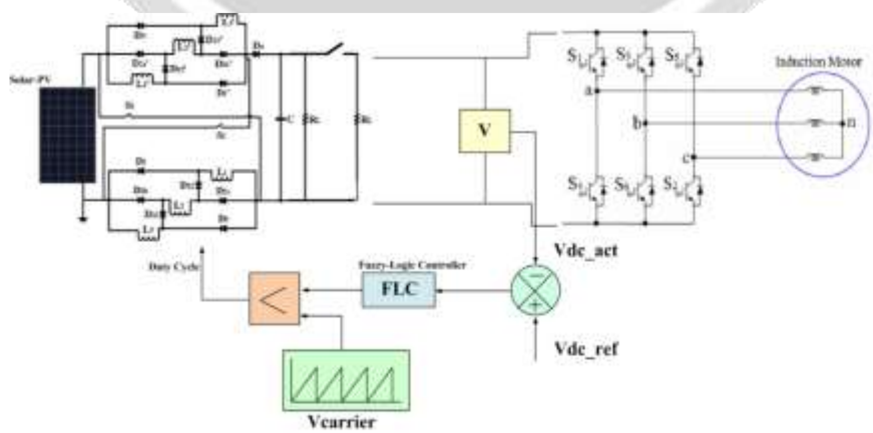


Fig.11 Block diagram of proposed Fuzzy-Logic Controlled High-Gain DC-DC Converter with induction motor drive system

5. MATLAB/SIMULINK RESULTS & ANALYSIS

The Matlab/Simulink modelling is carried based on various cases and the proposed models are developed by using described system specifications illustrated in Table.2.

Table.2 System Specifications

S.NO	System Specifications	Values
1	Input Source Voltage	Vin-35V-40V
2	Proposed Converter	L_1, L_2, L_3, L_1', L_2', L_3'- 180μH, Co- 47μF, R-Load-650Ω.
3	DC-Link Voltage	Vdc-380V
4	Switching Frequency	Fs-50KHz
5	Induction Motor	V-380V, 1430 rpm, P-4KW, Rs-1.4Ω, Ls-0.058mH
6	PI Controller	Kp-5, Ki-0.5

5.1 DESIGN OF PROPOSED HIGH-VOLTAGE GAIN DC-DC CONVERTER UNDER CONSTANT R-LOAD

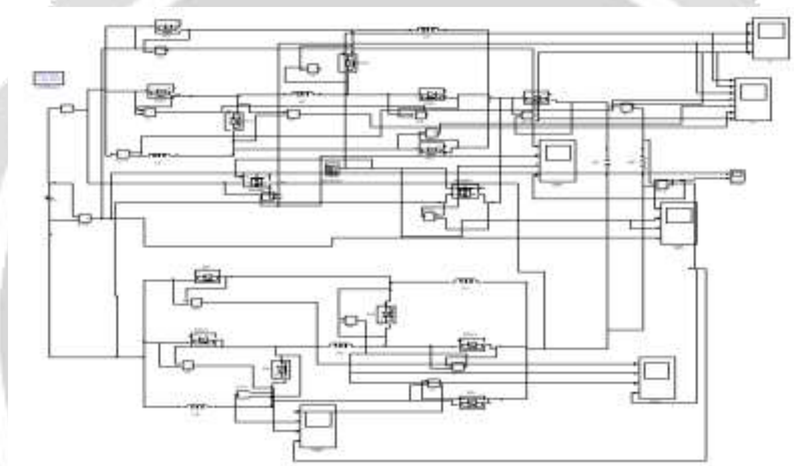
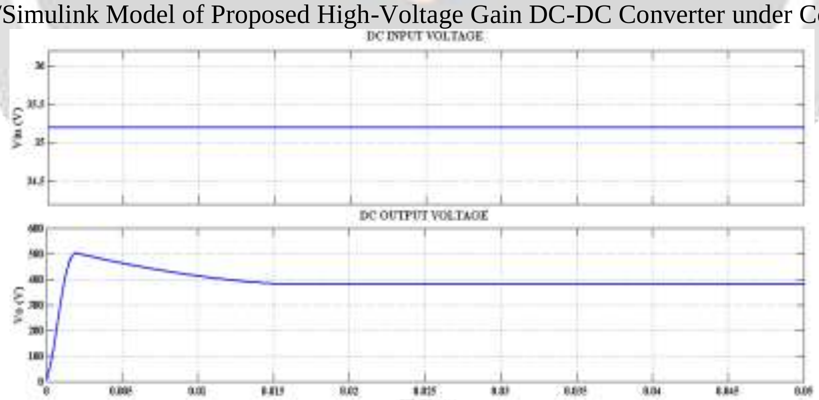
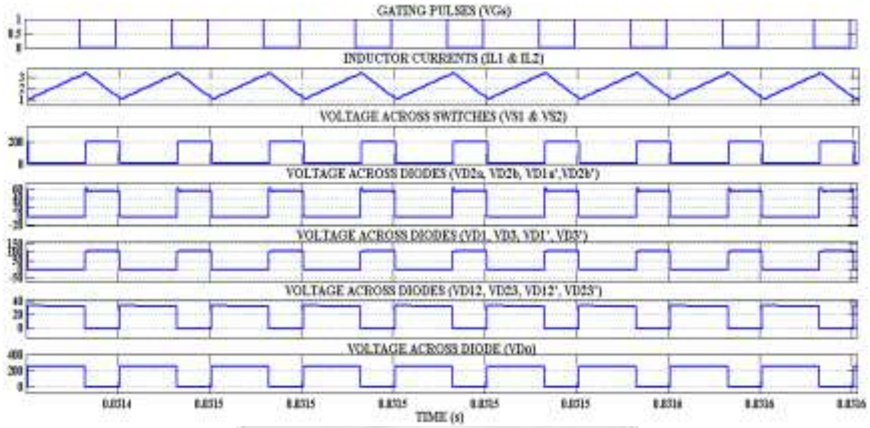


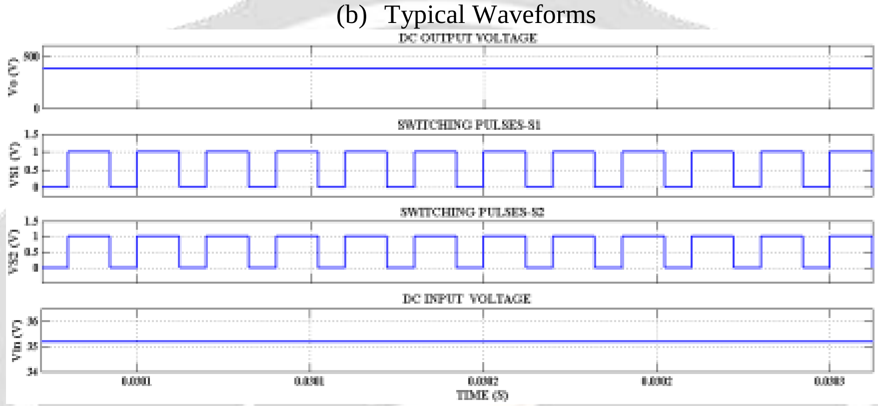
Fig.12 Matlab/Simulink Model of Proposed High-Voltage Gain DC-DC Converter under Constant R-Load



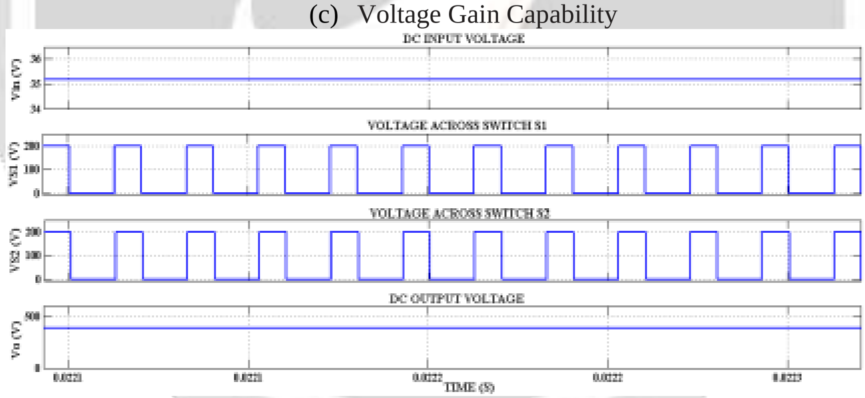
(a) DC Input Voltage & Output Voltage



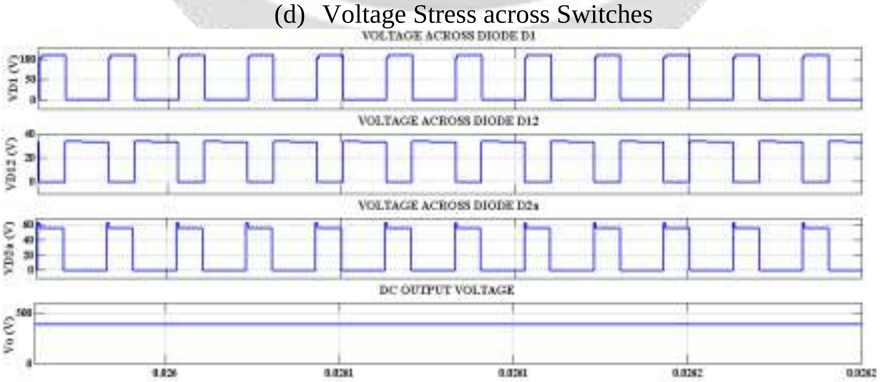
(b) Typical Waveforms



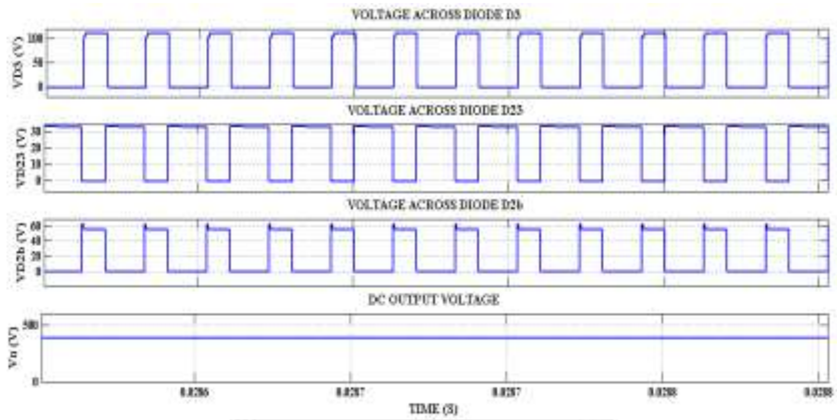
(c) Voltage Gain Capability



(d) Voltage Stress across Switches



(e) Voltage Stress on D1, D12 and D2a



(f) Voltage Stress on Diodes D3, D23 and D2b

Fig.13 Simulation Results of Proposed High-Voltage Gain DC-DC Converter under Constant R-Load

The Matlab/Simulink Model of Proposed High-Voltage Gain DC-DC Converter under Constant R-Load is depicted in Fig.12. The Simulation Results of Proposed High-Voltage Gain DC-DC Converter under Constant R-Load is depicted in Fig.13. It includes, (a) DC Input Voltage & Output Voltage, (b) Typical Waveforms, (c) Voltage Gain Capability, (d) Voltage Stress across Switches, (e) Voltage Stress on D1, D12 and D2a, (f) Voltage Stress on Diodes D3, D23 and D2b, respectively. The results were obtained at a power level of 210W with the input voltage being in range of 35-40V. To obtain the required output 380V at load terminal, the duty cycle (D) was varied from 0.61 to 0.55 respectively. An input voltage of 35.2V is stepped up to 381V at the output using the proposed voltage gain technique with a gain of >10 times. The switches are subjected to a voltage stress of (Vi+V0)/2 computed which is verified through the results shown. The voltage stress on diode Do is computed and works out to about 330V. The voltage stress across diode D1 is highest. This is because when D1 is switched OFF, the voltage impressed across the two inductors (L1 and L3) appears across D1. Diode D12 switches OFF during Mode 1 when the inductors are charging. Hence, the voltage stress on it is low. However, D2a experiences medium voltage stress compared to the other diodes. The voltage stress on diode D3 is highest while D23 experiences the lowest voltage stress. Since the cells behave in an identical manner, voltage stresses experienced by diodes located in each cell are also similar.

5.2 PERFORMANCE OF PROPOSED HIGH-VOLTAGE GAIN DC-DC CONVERTER WITH SUDDEN-SWITCHING VARIABLE R-LOAD WITH INDUCTION MOTOR DRIVE OPERATED UNDER OPEN-LOOP CONTROL SCHEME

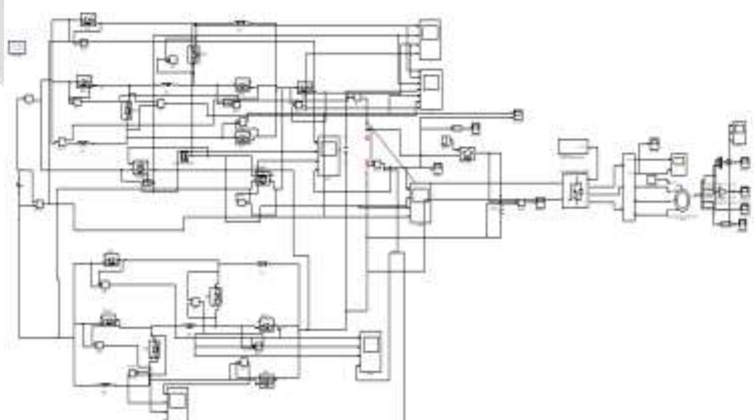
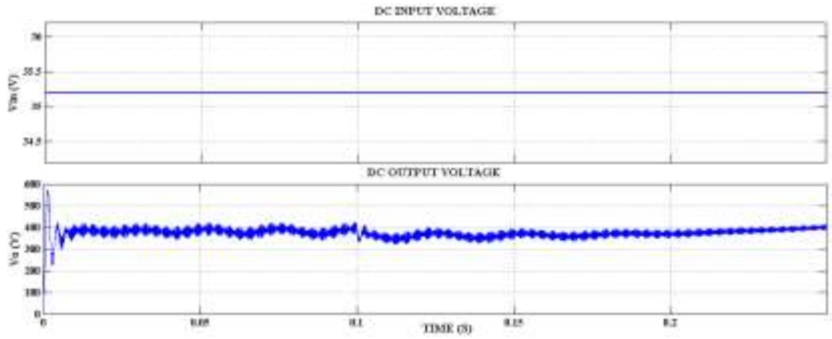
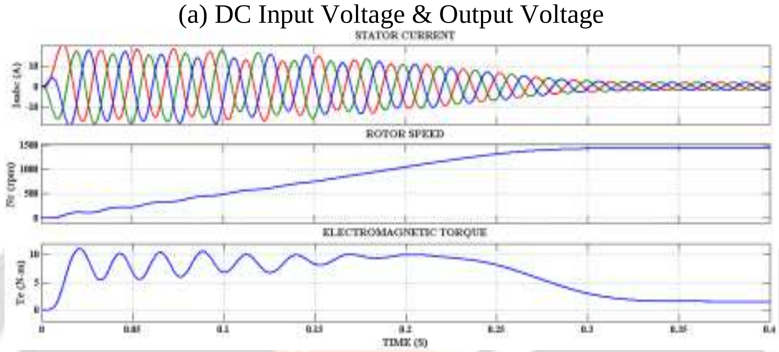


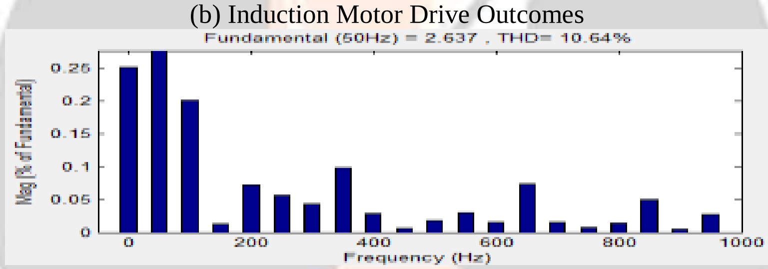
Fig.14 Matlab/Simulink Model of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Open-Loop Control Scheme



(a) DC Input Voltage & Output Voltage



(b) Induction Motor Drive Outcomes



(c) THD of Stator Current

Fig.15 Simulation Results of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Open-Loop Control Scheme

The Matlab/Simulink Model of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Open-Loop Control Scheme is depicted in Fig.14. Simulation Result of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Open-Loop Control Scheme is depicted in Fig.15. It includes, (a) DC Input Voltage & Output Voltage, (b) Induction Motor Drive Outcomes, (c) THD of Stator Current, respectively. Due to sudden switching of additional R-load and induction motor, the output voltage is fluctuated with same input voltage 35.2V. In this case, the converter is operated as open-loop condition and attains more error quantities which are eliminated by using closed-loop control scheme. The induction motor parameters like stator current is measured with a value of 2.2A, rotor speed is 1440 rpm and electromagnetic torque is measured as 1.4N-m with a settling time of 0.35 sec. The THD value of stator current is measured as 10.64%, it is un-comply with IEEE standards.

5.3 PERFORMANCE OF PROPOSED HIGH-VOLTAGE GAIN DC-DC CONVERTER WITH SUDDEN-SWITCHING VARIABLE R-LOAD WITH INDUCTION MOTOR DRIVE OPERATED UNDER CLOSED-LOOP PI CONTROL SCHEME

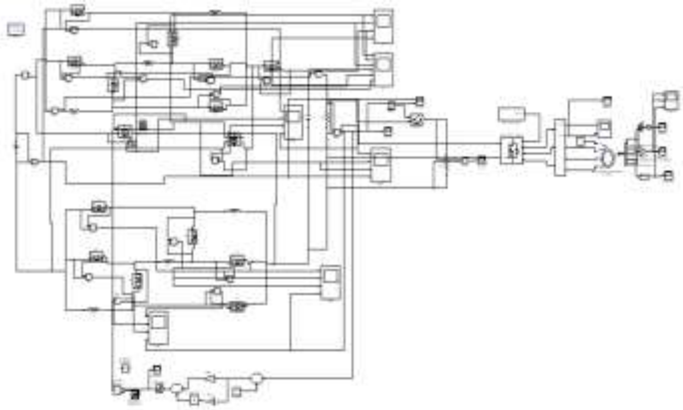
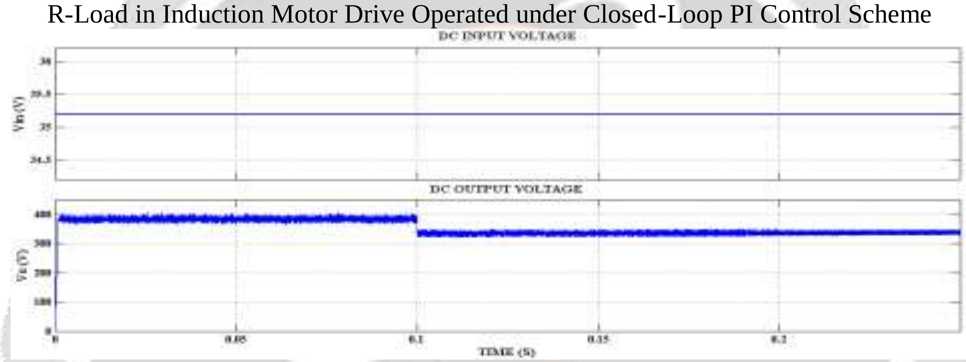
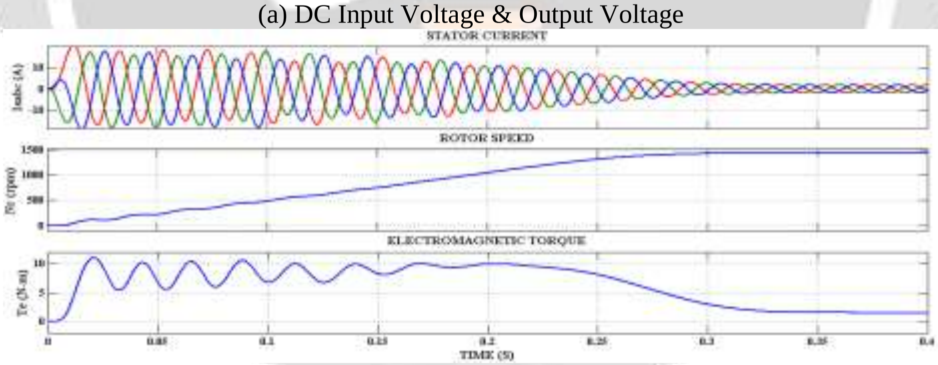


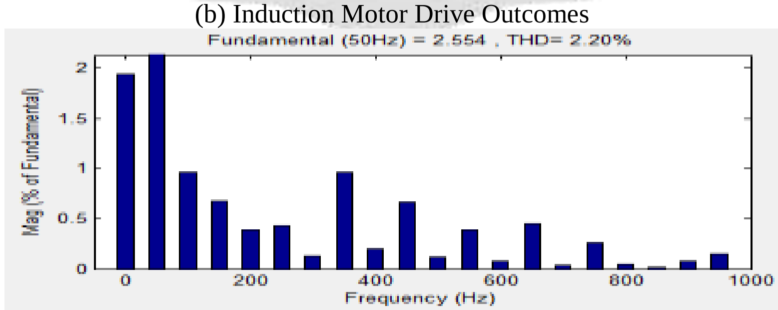
Fig.16 Matlab/Simulink Model of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Closed-Loop PI Control Scheme



(a) DC Input Voltage & Output Voltage



(b) Induction Motor Drive Outcomes



(c) THD of Stator Current

Fig.17 Simulation Results of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Closed-Loop PI Control Scheme

The Matlab/Simulink Model of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Closed-Loop PI Control Scheme is depicted in Fig.16. Simulation Result of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Closed-Loop PI Control Scheme is depicted in Fig.17. It includes, (a) DC Input Voltage & Output Voltage, (b) Induction Motor Drive Outcomes, (c) THD of Stator Current, respectively. Due to sudden switching of additional R-load and induction motor with presence of closed-loop PI control scheme, the output voltage is maintained as constant with a value of 380V. When switching the additional load, the output voltage slightly reduced with a value of 350V with same input voltage 35.2V. In this case, the converter is operated as closed-loop condition and attains reduced error quantities over the open-loop, but the output voltage is un-constant which can be eliminated by using closed-loop Fuzzy-Logic control scheme. The induction motor parameters like stator current is measured with a value of 2.2A, rotor speed is 1440 rpm and electromagnetic torque is measured as 1.4N-m with a settling time of 0.25 sec. The THD value of stator current is measured as 2.20%, it is comply with IEEE standards.

5.4 PERFORMANCE OF PROPOSED HIGH-VOLTAGE GAIN DC-DC CONVERTER WITH SUDDEN-SWITCHING VARIABLE R-LOAD WITH INDUCTION MOTOR DRIVE OPERATED UNDER CLOSED-LOOP FUZZY-LOGIC CONTROL SCHEME

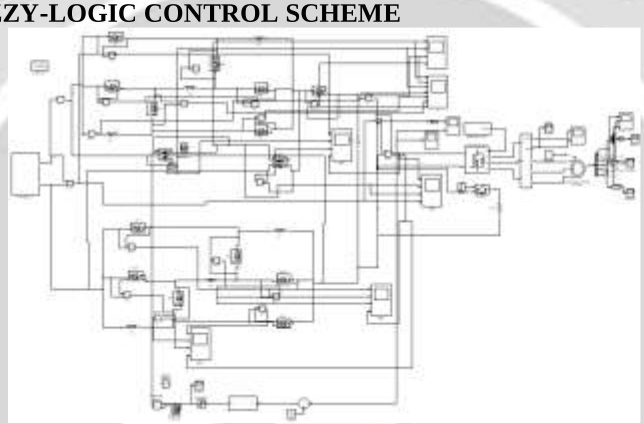
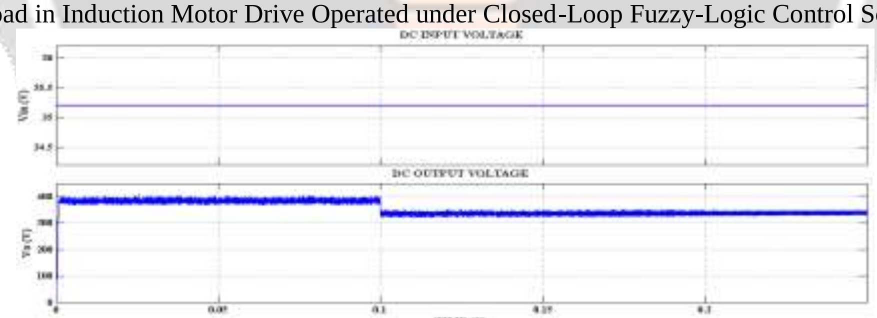
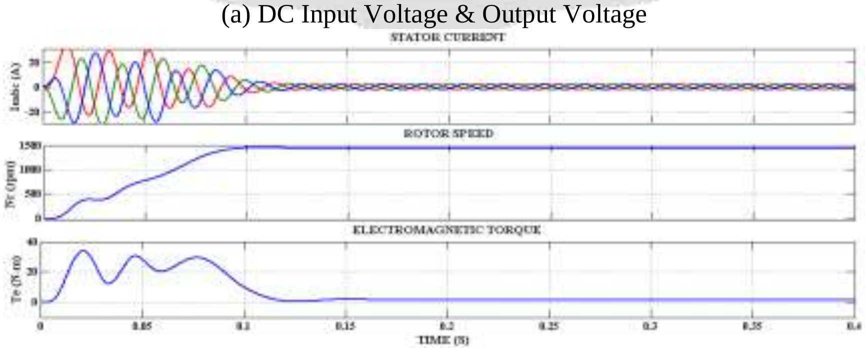


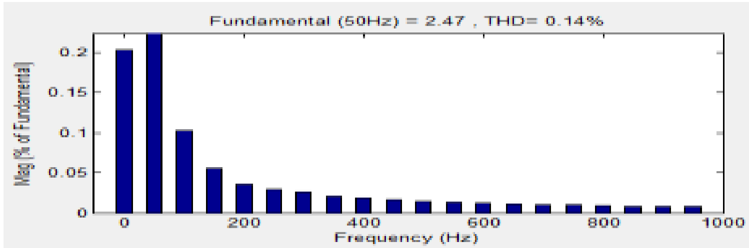
Fig.18 Matlab/Simulink Model of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Closed-Loop Fuzzy-Logic Control Scheme



(a) DC Input Voltage & Output Voltage



(b) Induction Motor Drive Outcomes



(c) THD of Stator Current

Fig.19 Simulation Results of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Closed-Loop Fuzzy-Logic Control Scheme

The Matlab/Simulink Model of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Closed-Loop Fuzzy-Logic Control Scheme is depicted in Fig.18. Simulation Result of Proposed High-Voltage Gain DC-DC Converter with Sudden-Switching Variable R-Load in Induction Motor Drive Operated under Closed-Loop Fuzzy-Logic Control Scheme is depicted in Fig.19. It includes, (a) DC Input Voltage & Output Voltage, (b) Induction Motor Drive Outcomes, (c) THD of Stator Current, respectively. Due to sudden switching of additional R-load and induction motor with presence of closed-loop Fuzzy-Logic control scheme, the output voltage is maintained as constant with a value of 380V. During switching of additional load, the output voltage maintained as constant with a value of 380V with same input voltage 35.2V. In this case, the converter is operated as closed-loop fuzzy-logic control scheme and attains low error quantities over the open-loop & PI control scheme. The induction motor parameters like stator current is measured with a value of 2.2A, rotor speed is 1440 rpm and electromagnetic torque is measured as 1.4N-m with a settling time of 0.12 sec. The THD value of stator current is measured as 0.14%, it is comply with IEEE standards.

Table.3 Performance Comparison of Open-Loop and Closed-Loop PI/FL Control Scheme in Proposed High-Voltage Gain DC-DC Converter fed Induction Motor Drive under Sudden Load Change

Condition	Modulation Index	Stator Current (Amps)	Rotor Speed (rpm)	Electromagnetic Torque (N-m)	THD (%)	Steady State (Settling) Time (sec)
Switching of Sudden Load with Induction Motor Drive Under Open-Loop System	1	2.2A	1440 rpm	1.4 N-m	10.64%	0.35 sec
Switching of Sudden Load with Induction Motor Drive Under Closed-Loop PI Controller	1	2.18 A	1440 rpm	1.4 N-m	2.20%	0.25 sec
Switching of Sudden Load with Induction Motor Drive Under Closed-Loop Fuzzy-Logic Controller	1	2.2A	1440 rpm	1.4 N-m	0.14%	0.12 ec

6. CONCLUSION

This work presents a high gain DC-DC converter based on modular switched-inductor network for solar-PV integrated induction motor drive system. Each SI cell in the proposed converter used 3 inductors which stored energy in parallel and discharged in series. Resultantly, the converter yielded a voltage gain of 10.8 at full load power rating of 210W. Since a hybrid voltage gain extension mechanism was employed, the switches were subjected to a lower voltage stress of 55% of output voltage. Due to the switched-inductor cells, the current stress on the individual inductors was reduced. Consequently, the stray loss due to the inductors was less and resulted in good operating efficiency. The modularity of the proposed gain extension technique is another advantageous feature of the proposed converter. Considering the high voltage gain ability, reduced voltage stress on the switches and the facility to scale up, this proposed converter is more preferred for solar-PV fed induction motor drive system under sudden load conditions.

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