Closed Loop Controlled Double Forward Converter Analysis Using PI, Fuzzy logic and ANN Controller

Abstract: *Closed loop controlled DC to DC double forward converter is a requisite for the server SMPS system. High efficiency, Isolation, Steady state voltage, Transient response, High switching frequency, reduced noises and range of steady state are all necessary requirements for the double forward converter. In this paper, a 40 V double forward converter for charging the battery of server SMPS is proposed. Simulation of closed loop controlled DC-DC double forward converter using proportional integral (PI) controller, fuzzy logic controller (FL) and artificial neural network controller (ANN) converter are simulated, analyzed and discussed. In this paper, from comparison of performance in the closed loop model by using the three controllers, a suitable converter is proposed for the sever SMPS system. The proposed circuit achieves steady state voltage, when the disturbance occurs. Its circuit operation in closed loop control model and the performance of the double forward converter is described and the simulation results are presented.*

.***Key words:*** *Transient response, steady state range, peak over shoot, fuzzy logic and Ann controller.*

1. Introduction

In relevant years, the switching mode power supply (SMPS) system has been achieved the good regulation of power conversion with high power density and high-quality performances by using power devices such as IGBT, MOS-FET etc... However, by using these switching power devices in the SMPS system, the problems which are very closely occurs based on the switching loss and interference noises. For adherence with the restriction, the SMPS system must add its noise filter to the system and for the interferences such as EMI/RFI noises add its metal and magnetic component shield to the PFC converter circuit and for the input harmonic current, large input filter must add to the circuit to reduce. On the other hand, the power semiconductor device technology expansion, which can achieved high frequency switching function in the SMPS system. The increases of the switching losses have occurred by this high frequency switching operation. The size of the inductor and transformer has been highly reduced by increasing the frequency in switching strategy, while the increase of the switching losses, the size of cooling fan could be enormous.

II. Configuration of SMPS System

Figure 1 shows a circuit configuration of the SMPS system. This system comprises of bridge rectifier with boost converter with filter capacitor (C_1), high frequency inverter circuit, isolation transformer and the half wave rectifier. It produces the DC voltage required by the variety of power electronics applications in industrial, server SMPS, consumer, micro-electronics based automation, aerospace etc. In this configuration, a 230 V AC supply is stepped down to scaled voltage and converted into a DC by using a bridge rectifier circuit, by the same output is

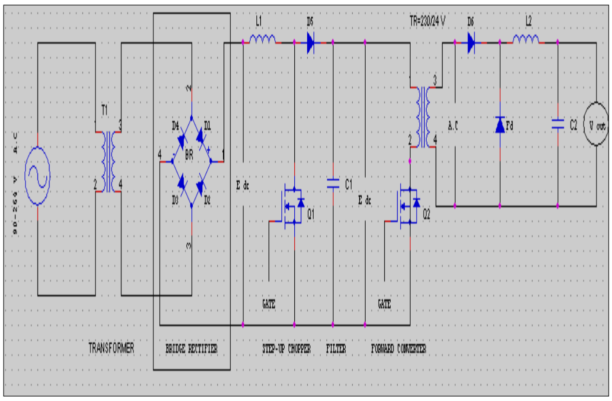

Fig.1. Circuit diagram of a SMPS system.

smoothened by filter circuit. The fixed DC voltage source is converted into a variable DC voltage source by using the boost converter circuit. When the chopper Q_1 is ON, the inductor L_1 stores the energy. When the chopper Q_2 is OFF, the stored energy in the inductor L_1 adds to the source voltage; the inductor current is forced to flow through the diode and the load. The output of the boost converter circuit with lesser ripple is filtered by the capacitor C_1. When the MOSFET Q_2 is turned ON, the variable DC voltage is converted into AC by high frequency inversion switching. The scaled up voltage is induced in the transformer primary and the scaled down voltage appears across the transformer secondary and it is converted into DC voltage by means of the half – bridge rectifier circuit. The output is filtered by the LC, which is transferred to the load.

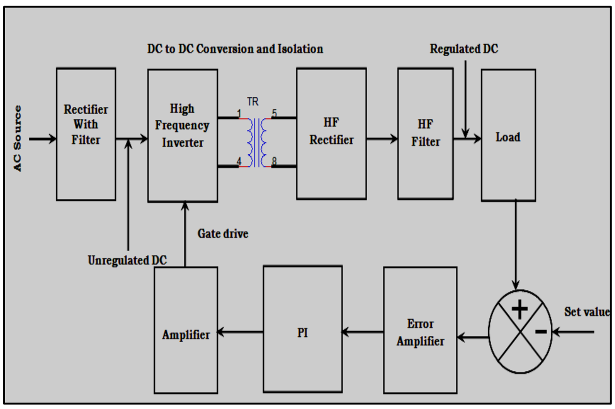

Fig.2. Closed loop diagram of a SMPS system.

Figure 2 shows a closed loop circuit configuration of the SMPS system. In this configuration, by using the set value is compared with the actual value which is observed from the response of the closed loop system. The differences of the values are amplified by the error amplifier and produce the required voltage to the controllers. The response of the controller is boosted by using the IR2110 amplifier, and it is used as gate pulse drive to turn on the power devices.

III.A Brief Literature Review

The new methodology is used to overcome the drawbacks and to improve the system for the society needs. Distributed Maximum Power Point Tracking architectures are one of the most promising solutions to overcome the drawbacks associated to mismatching phenomena in photovoltaic PV applications. This paper proposes a new DC to DC converter topology for PV applications. Its operating principle, static characteristics, comparison analysis between the proposed converter and the Non-Inverting Buck-Boost converter is carried out for three different scenarios are studied. The new methodology is used to overcome the drawbacks and to improve the system for the society needs. Distributed Maximum Power Point Tracking architectures are one of the most promising solutions to overcome the drawbacks associated to mismatching phenomena in photovoltaic PV applications. This paper proposes a new DC to DC converter topology for PV applications. Its operating principle, static characteristics, comparison analysis between the proposed converter and the Non-Inverting Buck-Boost converter is carried out for three different scenarios are studied.

The proposed converter provides higher efficiency than the NIBB converter is presented [1]. An appropriate topology of a ZVS based Phase Shifted full -bridge DC-DC converter is selected based on advantages of reduced switching losses and stresses with fixed switching frequency. A feed forward voltage mode control is utilized which is easier to design and analyze with good noise margin and stable modulation process and improved line regulation are given [2]. This study presents the analysis and design of a novel technique that improves the efficiency of the conventional forward DC-DC converter by reducing switching losses, along with a comprehensive analysis of the circuit and detailed information for designers. A 5 kW step-down prototype is presented [3]. The auxiliary circuit has only passive elements and thus, the control circuit is simple and is like a regular PWM DC-DC converter. The auxiliary circuit provides ZVS condition for primary switch at turn-off instances. A new soft switching forward-fly-back DC-DC converter is proposed [4]. A double-sided LCLC-compensated capacitive structure dramatically reduce the voltage stress in the capacitive power transfer (CPT) system is proposed for the electric vehicle charging applications with improved efficiency are given [5]. The method to step up the voltage gain by reducing the conduction and switching losses are presented [6]. A closed loop model is proposed for the critical applications and the methods to improve the quality by reducing the error are presented [7]. Due to the comparison between the converters, the simulation results of the double forward converter gives better performance is proposed [8]. Comparison between the converters with constant source and with constant load, which is used to check the maximum power transfer to the load is also presented [9]. The new application based fuzzy logic controller is also presented [10]. Fuzzy logic and the adaptive PID control for two-mass servo-drive system with elasticity and friction are analyzed with fixed and variable levels are proposed in [11]. Fuzzy adaptive PID control for two-mass servo-drive system with elasticity and friction are analyzed with simulation and experimental models with a range of fixed and variable levels are proposed in [12]. Design and implementation of closed loop controlled converters with different controllers are analyzed with simulation and mathematical models are proposed in [13]. Two methods of approaches for the adaptive control of the object with elastic connections which are the bases is reference model and the fuzzy logic controller algorithm is the modified method are proposed in [14]. Phase plane analysis and variable universe approach are used by using the fuzzy logic controller is also presented [15]. The above literature does not deal with the closed loop controlled double forward converter using fuzzy, PI and Ann controllers. The above cited papers do not deal also with the modeling of closed loop double forward converter system and do not identify a converter suitable for SMPS system.

This work aims to develop simulink models for the closed loop double forward converter system using PI, fuzzy and Ann controller models. A comparison is also done from the simulation results to find the circuit suitable for the SMPS system.

IV. PI, Fuzzy and ANN Controller

In this work develop the simulink models for the closed loop double forward converter system using PI, fuzzy and Ann controller models. A comparison is also done from the simulation results to stumble on the circuit appropriate for the SMPS system. In the closed loop PI controller, the tuning is done by using a Ziegler-Nicholas method which is defined as the ratio between the rise-time and delay-time and the integral constant is define as 1.6 with delay-time. After tuning is done as by the given method, the fixed saw-tooth pulses using PWM and the sources are compared to get the steady state. In the closed loop fuzzy logic controller, tuning is done by using the number of variables which are five and it is stated as small, medium, large, very large and very small. Between the widths of the variables, which are lies from zero and one to be stated as manual, we used a fuzzy logic controller. Fuzzy logic means a fuzzification is the process of by which the crisp quantities are converted to fuzzy logic ones. By identifying several suspicions are present in the crunchy values, the fuzzy logic values such as zero and one’s are formed. The conversion of fuzzy set values is represented by (MA)-membership functions. This MA function which is a graphical illustration of the scale of contribution of each input value in a given set. The set value could be of any type, which is illustrated as Gaussian (GW), Triangular (TW), Trapezoidal (TRW), and Singleton (SW) etc... The fuzzification progression may absorb assigning (MA) membership function values for various levels of sets to the given quantities.

Fuzzy system which implements by using the rule-based reasoning such as if-then reasoning rules to determine an output response. The inference (IF) engine evaluates all the rules to perform the, if then rule-based reasoning process. Continuity, Consistency, Completeness and Interaction are the four types of properties, which has been considered by the rules based. The operators used mainly in the fuzzy set logic to erect compound based rules. AND, OR and NOT are the Rules considered have to satisfy the following. De-fuzzification is the progression of convert fuzzy to brittle values for further processing. There are some of the famous methods which are used for defuzzification such as Centroid, Weighted Average and Maximum membership method.

In the closed loop artificial neural network controller, tuning is done by using the state variables are: a (w) +b, where, a is the constant, w is the change of weights and b is the bias. As by the change of weighted variables which is given in the state model an auto-tuning is done after compared with the fixed saw-tooth pulses using PWM and the sources are compared to get the steady state. In the closed loop simulink model double forward converter system using PI, fuzzy and Ann controller, it operates at high frequency. The switching loss which is directly proportional to the frequency, when the switching frequency increases, the losses in the switching is decreased. In the closed loop simulink model double forward converter system DC supply of 100 V and the circuit breaker T_2 [0 2] with the switching time sequence of [0 0.5] sec are used. The step change is introduced in the input DC supply of 12 V and the circuit breaker T_3 [2 0] with the switching time sequence of [0 0.5] sec are used. The error in the output is reduced to get the steady state value. From the comparison of responses, it is seen that the closed loop system has reduced steady state error, which is maintain the voltage as constant.

V. Design Calculation

The design calculations for the double forward converter are: Input voltage (V_{in}) =100 V, Load resistance (R_L) =10Ω, time T= 50 μs, Capacitance (C_{f1}, Cf2) =90e-6, Inductance (L_f) =100e-3, Capacitance (C_{f2}) =0.3e-6, Primary voltage=99.62 and Secondary voltage=68.9. By using the relation Frequency (f) =1/T, the time T= 50 μs, then F= 20 KHz. The transformer primary voltage $E_1 = 4.44 * N_1 * \Phi * f$. By solving the equation to get the value of $N_1 = 110$, and by the equation N2= (E_2 / E_1) N_1 to get the value of $N_2 = 76$. By using the relation $I_0=V_0/R$, then $I_0=4$ Amps.

VI. Simulation Results

The forward converter circuit does not deliver the exact voltage required by the load. To improve the output voltage and efficiency, an active clamp method is used to recycle the stored energy. This method is used in the double forward converter circuit to improve the efficiency. This circuit was modeled, simulated and implemented to find the suitable circuit for the SMPS system.

The steady state and its transient behavior for the open and closed loop model were analyzed. In this circuit, an active clamp method is used to achieve soft switching to recycle the stored energy in the clamp capacitor ‘C’ and to increase the efficiency in whole load range. The active clamp consists of main switch (M_1) and auxiliary switch (M_2) which are connected in parallel with clamp capacitor voltage ‘C’, and is connected in series to the primary side of the transformer. The auxiliary switch (M_2) is connected to the negative polarity of the transformer; it is called a P-type clamp circuit.

The open loop controlled double forward converter is shown in Fig.6.1. DC input voltage and output voltage with disturbance are shown in Fig.6.2 and Fig.6.3.

The closed loop controlled double forward converter is shown in Fig.6.4. Simulink regulator is shown in Fig.6.5. Double forward converter simulink diagram is shown in Fig.6.6. DC input voltage and output voltage with disturbance are shown in Fig.6.7 and Fig.6.8. Summary of steady state error is given in Table.1.

Double forward converter using fuzzy logic controller is shown in Fig.6.9. DC input voltage and output voltage with disturbance are shown in Fig.6.10 and Fig.6.11. Double forward converter using artificial neural network controller is shown in Fig.6.12. DC input voltage and output voltage with disturbance are shown in Fig.6.13 and Fig.6.14. Summary of time-domain specifications is shown in Fig.6.15. Summary of time-domain specifications and steady state error is shown in Table.2. Summary of transient response is given in Table.3. Double forward converter with variable load and variable frequency are given in Table.4 and Table.5.

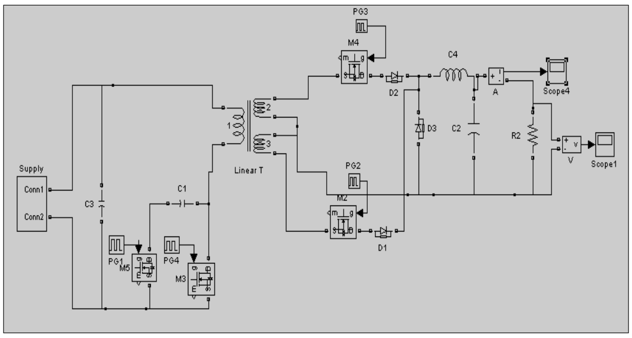

Fig.6.1. Open loop controlled double forward converter.

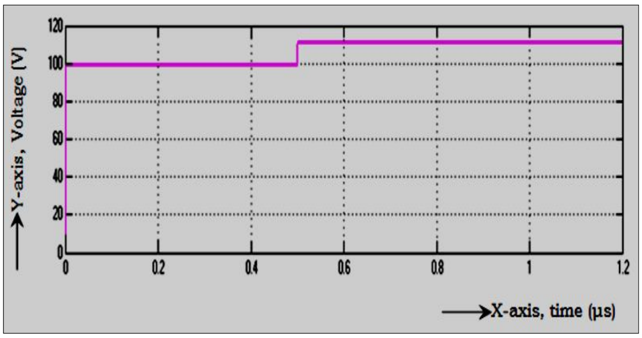

Fig.6.2. DC input voltage with disturbance.

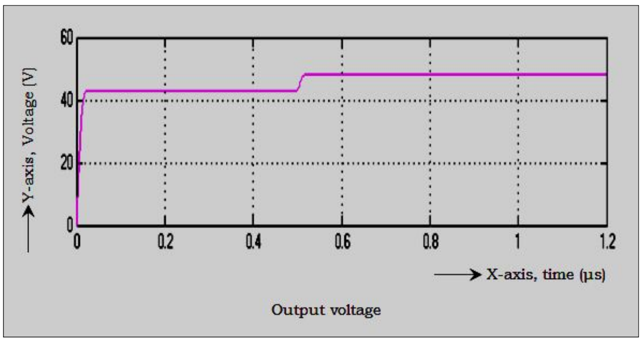

Fig.6.3. DC Output voltage with disturbance.

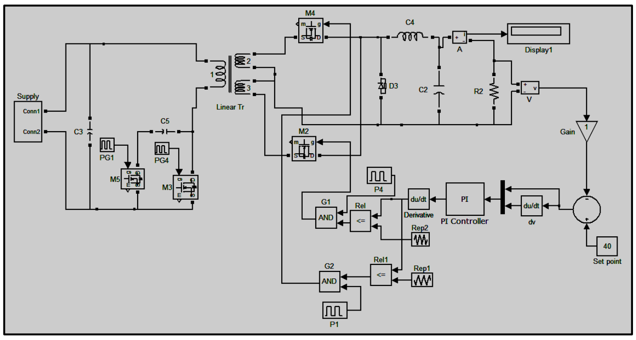

Fig.6.4. Closed loop double forward converter.

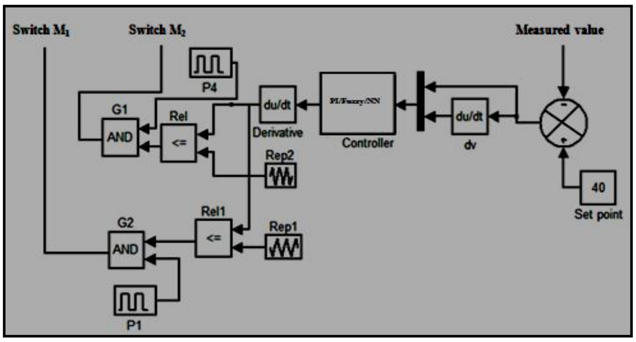

Fig.6.5. Simulink regulator diagram.

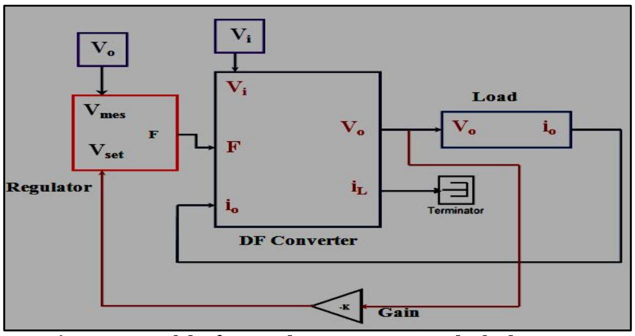

Fig.6.6. Double forward converter simulink diagram.

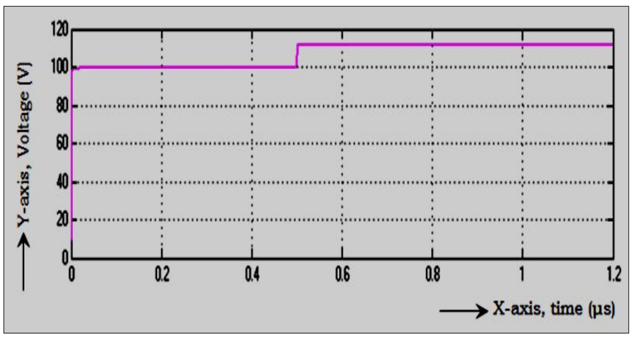

Fig.6.7. DC input voltage with disturbance.

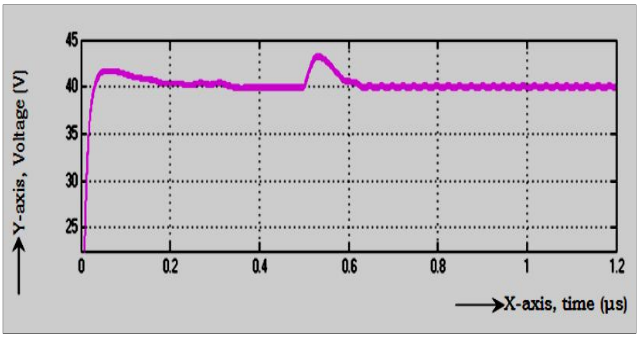

Fig.6.8. DC Output voltage with disturbance.

Table.1. Summary of steady state error.

Parameter	Open loop system	Closed loop system
Steady state error	8 V	0.5 V

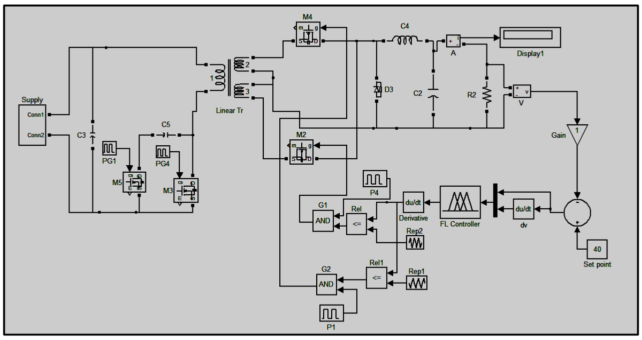

Fig.6.9. Double forward converter using fuzzy logic controller.

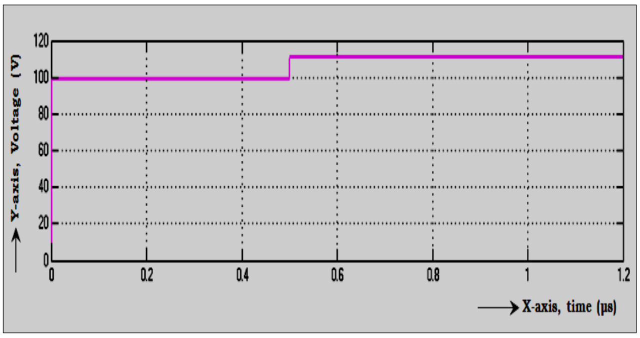

Fig.6.10. DC input voltage with disturbance.

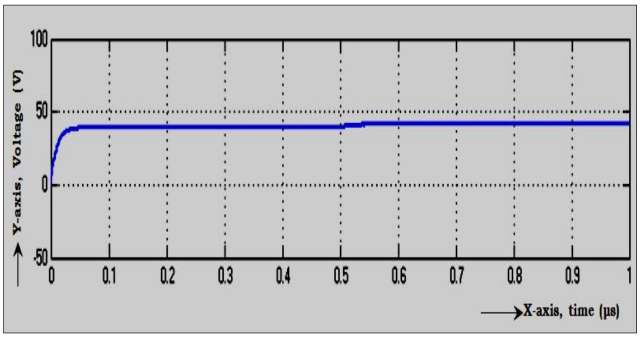

Fig.6.11. DC output voltage with disturbance.

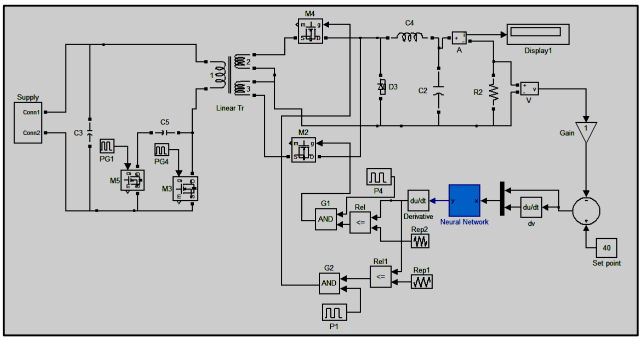

Fig.6.12. System using artificial neural network.

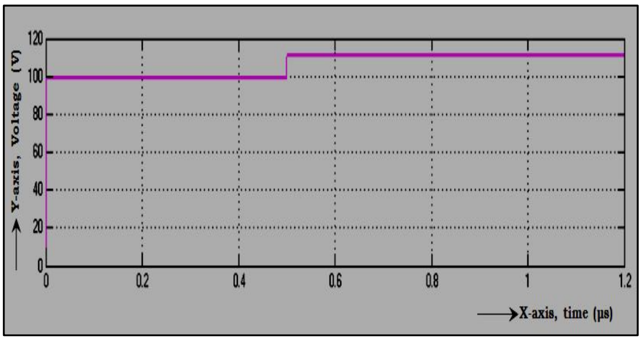

Fig.6.13. DC input voltage with disturbance.

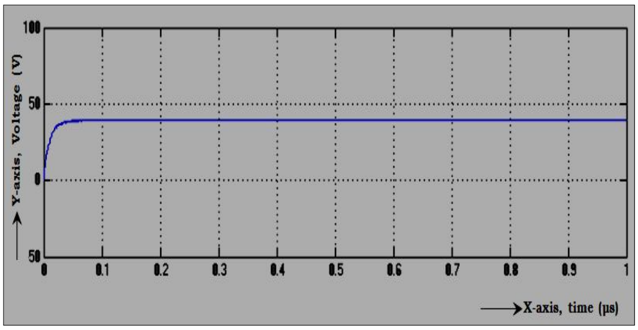

Fig.6.14. DC output voltage with disturbance.

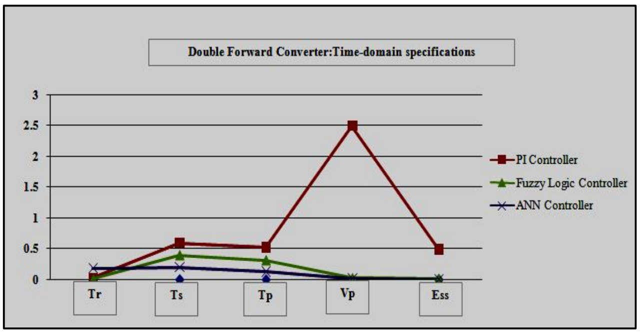

Fig.6.15. Time-domain specifications.

Table.2. Summary of time-domain specifications and steady state error.

Double forward converter	Tr	Ts	Tp	Vp	Ess
PI controller	**0.035**	**0.6**	**0.53**	**2.5**	**0.5**
FUZZY controller	**0.021**	**0.4**	**0.32**	**0.03**	**0.02**
ANN controller	**0.19**	**0.2**	**0.13**	**0.02**	**0.01**

Table.3. Summary of transient response.

Transient Response			
t_d(ms)	**t_r(ms)**	**t_p(ms)**	**t_s(ms)**
0.01	**0.04**	**0.1**	**0.3**
Transient and range of Steady state			
Transient State		**Steady State (ms)**	
0 – 0.3		**0.3 onwards**	
Peak over shoot Mp (A) =3.34 volts			

Table.4. Double forward converter with variable load.

S.No:	Load Resistance	Output voltage
1	10	40.07
2	20	40.38
3	30	40.49
4	40	40.54
5	50	40.57

Table.5. Double forward converter with variable frequency.

S.No:	Frequency	Load current
1	5	4.25
2	10	3.79
3	15	3.38
4	20	3.36
5	25	3.16

VII. Conclusion

Closed loop controlled double forward converter is simulated using the blocks of matlab-simulink. To determine the steady state, the closed loop controlled model is implemented as with PI controller, fuzzy logic controller and artificial neural network controller (ANN) controller and it is simulated using the simulink model. The comparison has been done from the three controllers, to determine the steady state analysis. The double forward converter using the PI controller in closed loop mode, the error is reduced to 0.5 V. By using the fuzzy logic controller in closed loop controlled mode for the double forward converter system, the error is reduced to 0.02 V and the same system in closed loop mode using the artificial neural network controller, the error is reduced to 0.01 V. From the comparison of the controllers used in double forward converter system in closed loop mode, the steady state error (Ess) is reduced in the artificial neural network controller, when compare it with using PI and fuzzy logic controller. By using the ANN controller, the error is reduced as high, which is 0.01 and it is suitable for the double forward converter system.

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