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CLOSED LOOP CONTROLLED FORWARD CONVERTER WITH RCD SNUBBER USING PI, FUZZY LOGIC AND ARTIFICIAL NEURAL NETWORK CONTROLLER

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Abstract: The research described in this work aims to find a better forward converter for DC to DC conversion. Simulation of the conventional closed loop controlled model with RCD snubber is developed for the determination of time domain specifications, transient response and steady state analysis. Simulation of the proposed closed loop controlled forward converter with snubber, which is implemented with PI controller, fuzzy logic controller and artificial neural network (ANN) controller is presented in this paper for the switching mode power supply applications. The comparison has been done between the conventional circuit and to the proposed circuit with the determination of time domain specifications, transient response and steady state analysis, which is used to find the better converter for the SMPS system. Simulation results of the conventional circuit and the proposed circuits are presented. Its circuit operation in closed loop control model and the performance of the forward converter is described and the simulation results are presented.

Keywords: Steady state analysis, time-domain specifications, transient response, Fuzzy systems, Neural networks and controllers.

1. INTRODUCTION

In recent years, power semiconductor devices used by the SMPS systems have achieved high performances and with high power. During turn ON and OFF the switching losses and stress occur in the power semiconductor devices used in the SMPS system. The voltage ripple during conversion and the harmonics oscillations occur in the non-linear loads. In the high frequency switching sub harmonics occur. Large signal transients and radio frequency interference (RFI) have been closed up. The special committee like CISPR and the electro-technical committee like (IEC), which aim to control the harmonics and ripple by the Electro Magnetic Compliance (EMC) limitation. To reduce the harmonics in the SMPS system it can be designed with large input filter, keeping the above given constraint in mind. The metal shield to attenuate the electromagnetic interference or radio frequency noises should be provided. The tremendous improvement of technology in the power semiconductor device is such that the size of the components has been reduced in the SMPS system, when the switching frequency is increased. To reduce the harmonics when it is operated at high frequency, without the switching losses, this is to acquire the steady state voltage in the output by using the controllers which are PI, Fuzzy logic (FL) controller and the artificial neural network (ANN) controller.

2. CONFIGURATION OF SMPS SYSTEM

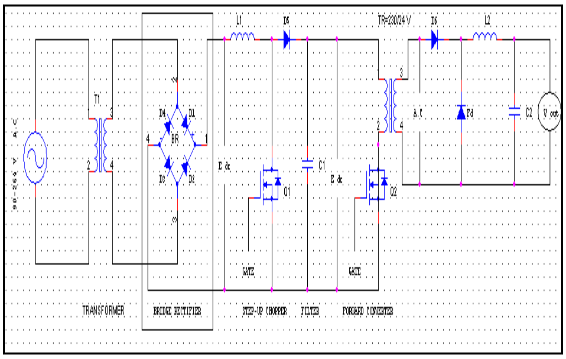

Fig.1. Circuit diagram of a SMPS system

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 DC by using a bridge rectifier circuit and the output is 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.

2.1. Configuration of the closed loop system

Figure 2 shows a closed loop circuit model of the SMPS, which is used to implement with fuzzy controller and artificial neural network (ANN) controller. In this closed loop configuration, a 230 V AC supply is connected to the bridge rectifier circuit. The output of this circuit is DC. The output voltage of the rectifier is converted into a variable DC voltage by the boost converter with frequency circuit. When the chopper is OFF, the inductor voltage adds to the source voltage and current in the inductor (i_L) is forced to flow through the diode and the load (R_L).

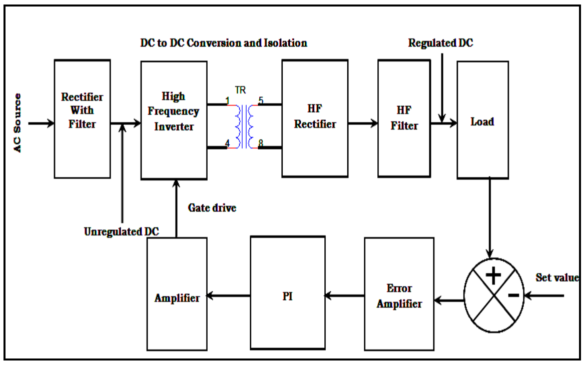

Fig.2. Closed loop model of a SMPS system

The output of the boost chopper circuit with lesser ripple is filtered by the capacitor. Conversion of DC voltage into AC source is done by the high frequency switching. In high frequency switching scaled up AC voltage is induced in the transformer primary and the scaled down voltage appears across the transformer secondary. The AC voltage obtained from the secondary of the transformer is converted into DC by the half – bridge rectifier circuit, and the noise is filtered by the LC-filter, and transferred to the load.

The output DC voltage is taken as feedback, to compare. The difference of error signal is amplified and it is applied to the microcontroller. The microcontroller generates switching pulses, and it is amplified by the amplifier circuit. The amplified pulses are used to turn on the circuit.

2.2. 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 proposed converter provides higher efficiency than the NIBB converter is presented (Lopez del Moral et al., 2015) 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 (Ahmed et al., 2015).

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 (Ibanez et al., 2015).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 (Khalilian et al., 2015).

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 (Fei Lu et al., 2015).

The method to step up the voltage gain by reducing the conduction and switching losses are presented (Yi-Ping Hsieh et al., 2014). A bi-directional adapter is proposed for the critical applications and the methods to improve the quality waveform are presented (Kai-Wei Hu et al., 2014).

Due to the non ideal factors in conversion, harmonic compensation with a resonant proportional controller is proposed (Abhijit Kulkarani et al., 2013). Tracking power point algorithm is used to track the maximum peak power and regulate the voltage during transitions, and the control method is also presented (Omar C.Onar et al., 2013).

The method to reduce the stress in dc distribution and the control laws to the switch for smooth transition in the inverter is presented (Yen-Mo Chen et al., 2013). The simulation and the experimental method of analysis are done for the low noise SMPS system which is demonstrated (P.Vijayakumar et al., 2015).

Simulation results of forward converter to improve the efficiency in the SMPS systems are described (P.Vijayakumar et al., 2013). Investigations on forward converter using different types of filters and experimental method of analysis for the forward converters are done, which is to compare it with the conventional circuit are clearly mentioned (A.Palamalai Vijayakumar et al., 2016).

Simulation results of the double forward converter which is used to find the better forward converter are analyzed using the simulation results are described (P.Vijayakumar et al., 2009).

The above literature does not deal with the comparison of forward converter with RCD snubber using the PI controller, fuzzy controller and artificial neural network (ANN) controller. The above cited papers do not deal also with the modeling of closed loop SMPS system and do not identify a converter suitable for SMPS system.

The present work aims to develop Simulink models for the above closed loop forward converter system using PI controller, Fuzzy logic controller and artificial neural network (ANN) controller. A comparison is also done to find the circuit suitable for the SMPS system.

2.3. Simulation Parameters

Table 1 illustrates the circuit parameters for the forward converter with RCD snubber.

Table 1. parameters for forward converter with RCD snubber.

S.No:	Parameters	Unit	Values and Items
1	Input Voltage	[V]	100
2	Output Voltage	[V]	38.8
3	Switching freq	[KHz]	20
4	Transformer ratio	[V_{rms}]	2:1
5	Snubber cap	[µf]	5000e-6
6	Snubber res	[Ω]	10

2.4. Design of the Forward Converter

The necessary specifications assumed for the forward converter with RCD snubber are as follows:

Input voltage V_{in} =100 V,
Inductance (L_f) =10e-6,
Capacitance (C_{f2}) =10e-6,
Snubber capacitance (C) =5000e-6,
Snubber resistance (R) =10 Ω and R_L=10 Ω.

By using the relation, f=1/T, Given time=50 µs, then f=20 kHz, By using the formula, $E_1 = 4.44\ f\ \Phi_m N_1$ Volt, then N_1=100 turns and by using the relation $N_2 = (E_2/E_1)\ N_1$, then N_2= 88 turns. The transformer voltage ratio $k=E_2/E_1$ = 0.9 and by using the relation, $I_0=V_O/R$=3.88 Amps. The voltage across the main switch during turn off, $M_{VDS}= V_{RST}+V_g$=Vg/1-D, by using the primary voltage=90.49 with the ratio of (1-frequency=20*10^3), M_{VDS}=-4.523*10^{-03}.

3. SIMULATION RESULTS

The switched mode power supply (SMPS) converts the unregulated DC input voltage to a regulated DC output voltage. The diode (D) which is combined with the parallel connection of a resistor(R) and capacitor(C) to form a Resistor-Capacitor-Diode (RCD) snubber circuit is connected with the transformer primary in parallel. This circuit is modeled, simulated and implemented to find the suitable circuit for the SMPS system. This circuit is analyzed for different criteria.

The steady state error and its transient behavior are analyzed for the closed loop model and the open loop model. Performance analysis is also carried out to determine the steady state analysis. When the main switch 'M' is turned off, the diode (D) conducts and it provides a low impedance path to the parallel connection of a resistor(R) and capacitor(C). The negative reset voltage (V_{RST}) and the voltage (V_g) across the clamp capacitor (C) are used to reset the transformer.

The voltage stress is maximum in the main switch (M) and is the sum of reset voltage (V_{RST}) and the generated (V_g) input voltage which is given by $MVDS=V_{RST}+V_g$---- (1).

The charge balance in the capacitor (C) is maintained by the resistor (R), the excess of energy is dissipated in the resistor (R). The forward converter with RCD snubber circuit is modeled and simulated using the blocks of MATLAB SIMULINK. The open loop forward converter system is shown in figure 3.

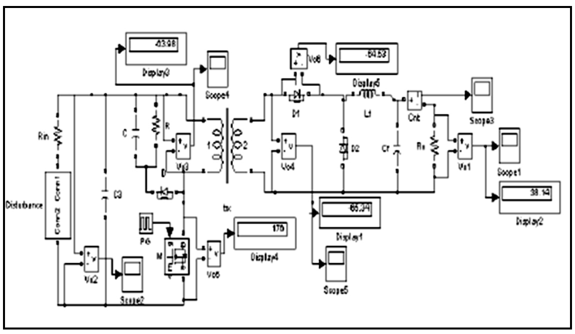

Fig.3. Open loop forward converter system

DC input voltage with disturbance is shown in figure 4. Closed loop controlled forward converter with RCD snubber using PI controller is shown in figure 5, and figure 6 shows the DC output voltage for this controller. Figure 7 shows the fuzzy controller and the DC output voltage for this controller is shown in figure 8.

Finally, figure 9 and 10 show the structure and the DC output of the ANN controller.

The summary of steady state error is shown in Table 2.

Table 2. Summary of steady state error.

Parameter	Open loop system	Closed loop system
Steady state error	3.8 V	1 V

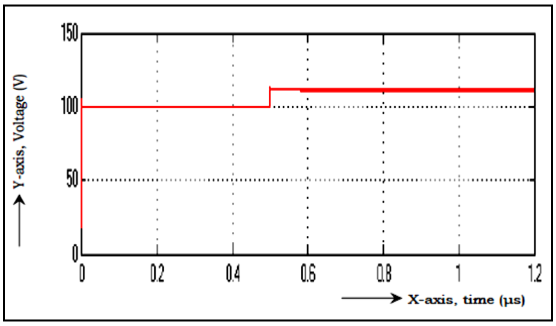

Fig.4. DC input voltage with disturbance.

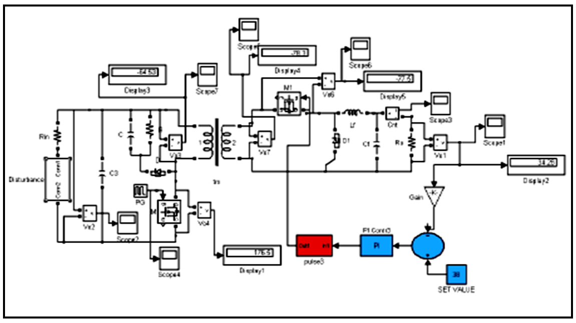

Fig.5. Closed loop converter using PI controller

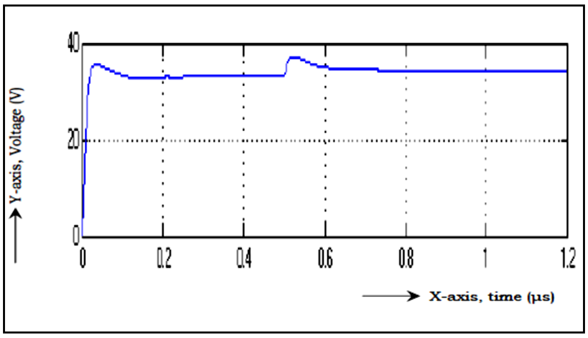

Fig.6. DC output voltage for the PI controller

From the table given below in 3, the comparison has been done from the PI controller, fuzzy logic controller and also with the artificial neural network (ANN) controller. The steady state response, range of transient and steady state and peak over shoot are described and given below in the table 4. The comparison has done to determine the steady state performance of the forward converter which is utilized in the SMPS system.

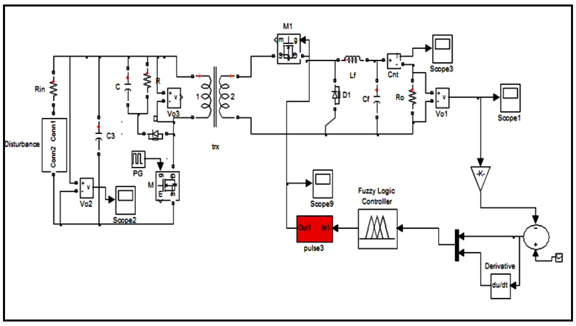

Fig.7. Closed loop fuzzy controller

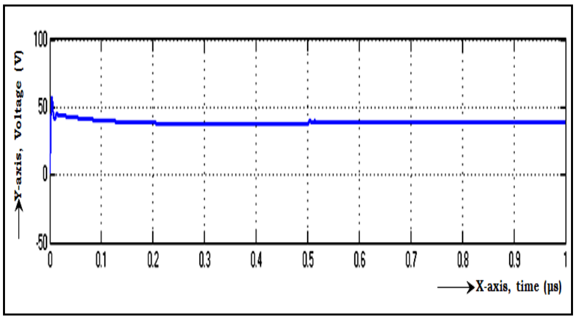

Fig.8. DC output for the fuzzy controller

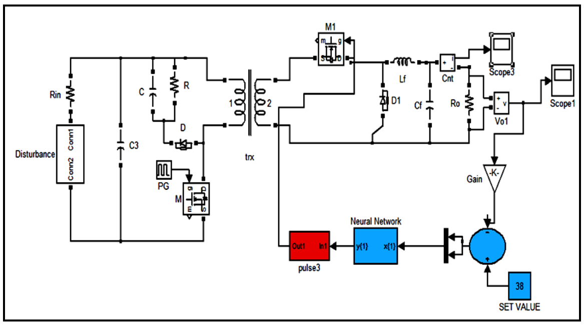

Fig.9. Closed loop converter using the ANN controller

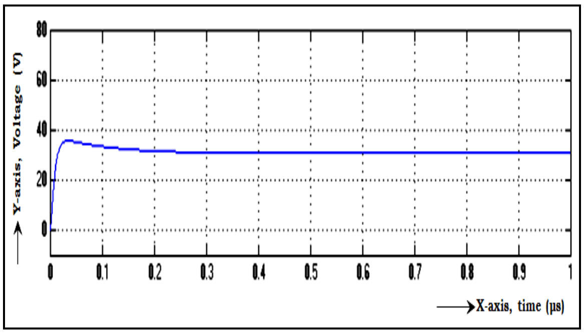

Fig.10. DC output of the ANN controller

Table 3. Summary of time-domain specifications and Steady state error.

RCD snubber	Tr	Ts	Tp	Vp	Ess
PI controller	0.0015	0.008	0.0062	2.3	0.9
FUZZY controller	0.0012	0.005	0.0031	0.02	0.3
ANN controller	0.0001	0.002	0.0012	0.01	0.1

Table 4. Summary of transient response.

Transient Response			
t_d(ms)	t_r(ms)	t_p(ms)	t_s(ms)
0.02	0.04	0.06	0.3
Transient and range of Steady state			
Transient State (ms)		Steady State (ms)	
0 – 0.3		0.3 onwards	
Peak over shoot Mp (A) =3.22 volts			

4. CONCLUSION

Closed loop controlled forward converter with RCD snubber is simulated using the blocks of Matlab-Simulink. To determine the steady state, the closed loop 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 three controllers, namely: forward converter with PI controller, forward converter with fuzzy logic (FL) controller and the forward converter with artificial neural network (ANN) controller, in order to determine the steady state performances. From the comparison of the above mentioned controllers, it results that the steady state error (Ess) is lower in the artificial neural network controller. This controller is suitable for the forward converter system.

5. REFERENCES

Lopez del Moral, D. Barrado, A. Sanz, M. Lazaro, A. Fernandez, C. Zumel, P."High efficiency DC-DC auto transformer forward-fly-back converter for DMPPT architectures in solar plants" IEEE Conference Publications, Pages: 431 - 436, 2015.

Ahmed, M.M. Usha, A. Shirsi, I. Singh, B.K. Prakash, B." (2105) A Feed forward Voltage Mode Controlled ZVS based Phase shifted 300W full bridge DC-DC converter for military application" Control Engineering (ICPACE), IEEE Conference Publications, Pages: 238-243.

Ibanez, F.M. Echeverria, J.M. Astigarraga, D. Fontan, L (2015) "Soft-switching forward DC–DC converter using a continuous current mode for electric vehicle applications" Power Electronics, IET, Volume: 8, Issue: 10, Pages: 1978 - 1986,

Khalilian, M. Adib, E. (2015.) "Soft-single-switched dual forward-fly-back PWM DC-DC converter with non-dissipative LC circuit" Electrical Engineering (ICEE), 23rd Iranian Conference, IEEE Conference Publications, Pages: 1562 - 1567,

Fei Lu, Hua Zhang, Hofmann, H. Mi, C. (2015) "A Double-Sided LCLC-Compensated Capacitive Power Transfer System for Electric Vehicle", IEEE Transactions on Power Electronics., Vol:30,Issue:11, Page(s):6011–6014.

Yi-Ping Hsieh, Jiann-Fuh Chenn, Lung-Sheng Yang, and Wei-Shih Liu, (2014) "High conversion ratio bidirectional DC-DC converter with coupled inductor," IEEE Transactions on Industrial Electronics.,Vol.61.No.1. 2014.

Kai-Wei Hu and Chang-Ming Liaw, (2014) "On a Bidirectional adapter with G2B charging and B2X emergency discharging functions," IEEE Transactions .on Industrial Electronics, Vol.61.No.1.2014.

Abhijit Kulkarani and Vinod John, (2013) "Mitigation of lower order harmonics in a grid connected single phase PV Inverter," IEEE Transactions on Power Electronics.Vol.28.No.11.2013.

Omar C.Onar, Jonathan Kobayashi and Alireza Khaligh (2013) ,"A fully directional universal power electronic interface for EV, HEV and PHEV applications," IEEE Transactions .on Power Electronics.Vol.28.No.12. 2013.

Yen-Mo Chen, Alex Q.Huang and Xunwei Yu (2013) "High step-up three port DC-DC converter for standalone PV/battery power systems," IEEE Transactions on Power Electronics.Vol.28.No.11.2013.

Vijayakumar.P and Rama Reddy .S (2015) "Simulation and Experimental Results of Low Noise SMPS System using Forward Converter" in the Asian Power Electronics Journals (APEJ), Vol.9, No.1,Dec 2015, DOI: 2010-01-0245. Page: 1-7.

Vijayakumar.P and Rama Reddy.S (2013) "Simulation Results of Forward Converter to Improve the Efficiency in the SMPS System" (EJSR), Vol.114. No.2, Page: 295-303.

Palamalai Vijayakumar. A and Ramakrishnan Devi (2013) "Simulation and experimental analysis of forward converters" LAP-Lambert Academic Publishing, Germany. Pages:121, ISBN-13: 978-3-659-95849-6.

Palamalai VijayaKumar.A and Ramakrishnan Devi (2016) "Investigations on forward converters using LC, PI and Bi-quad High Frequency filters" in the LAP-Lambert Academic Publishing, Germany. Pages:149, ISBN-13:978-3-659-97962-0.

Vijayakumar.P and Rama Reddy. S. (2009) "Simulation Results of Double Forward Converter" in the Annals of "Dunarea de jos" University of Galati, Fascicle III, vol.32, no.2, issn 1221-454x. Electrotechnics, electronics, automatic control, informatics, Page: 51-57.

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