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DESIGN AND DEVELOPMENT OF A PSO TUNED PI CONTROLLER FOR THE MANAGEMENT OF A FLY BACK CONVERTER

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ABSTRACT

A fly back converter is a DC to DC converter with galvanic isolation between the source and the load sides. The coupling between the source and the load is done with a step down transformer. The major circuit components include a power electronic switch and a diode which are non linear in nature. In practice the coupling transformer may also have non linearity. Therefore when it is required to design a PI controller for the fly back converter it becomes difficult to tune the PI controller. In this work the Particle Swarm Optimisation (PSO) based tuning technique has been adopted and the performance of the PI controller tuned with the PSO based tuning is compared against the performance of the PI controller tuned with the Zeigler Nicholas tuning technique. The entire design procedure has been carried out in the MATLAB SIMULINK simulation environment. An experimental verification setup was constructed to validate the proposed idea in real time.

KEYWORDS: Fly Back Converter, PI Controller, Zeigler Nicholas Method of Tuning the PI Controller, Particle Swarm Optimization (PSO), PSO Based Tuning of PI Controller & Stability Analysis of Systems.

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Original Article

1. INTRODUCTION

A fly back converter is a DC to DC converter with very high step down ratio [1]. Usually the fly back converter is sourced from the utility AC source. The utility AC source is, without passing through a step down transformer, rectified using a full bridge rectifier and filtered. Thus a DC source of high voltage, as high as the peak value of the utility AC source and typically the DC voltage is 230 * 1.414 = 325.22 volts.

This high DC voltage is switched through a power electronic switch with appropriate duty cycle and the current is set to pass through the primary of a step down transformer designed for high frequency operation. The pulsating current through the primary of the transformer induces an AC voltage across the secondary of the transformer and further, it is rectified using a single diode and filtered using a filter capacitor [2].

The advantages of the fly back converter are the electrically simple structure of the converter and the small size of the converter. The small size of the fly back converter is obtained by virtue of the high switching frequency usually in the range of 60Khz tor 100 kHz or even more[1,2,3].

The efficiency of the fly back converter is not very high [4]. However the power rating of the fly back converters that are used mostly in handy applications like the mobile phone charger, the lap top charger and the handy cam charger etc. sets aside the consideration of the reduced efficiency of the fly back converter considering the small size and small rating of power. Continual research activities are going on in different directions in order to increase the power transfer efficiency, control system performance and cost effectiveness.

Three directions of research are going on and they are the developments in the topological considerations[5] like changing the circuit arrangement including a feedback winding in the transformer, increasing and placing more components at strategic positions, push pull arrangements etc., the second direction of research is the development of PWM related considerations like the selection of frequencies as high as possible, the associated optical coupling systems, the PWM[6] generation circuit etc. The third direction of research is that an efficient control system [7] is developed that guarantees the regulated DC output voltage in the face of disturbed source side AC/DC voltages and the load side disturbances like inclusion or removal of loads.

This research is focused in the design of a suitable control system for the fly back converter. For the purpose of regulating the DC voltage at the output terminals of the fly back converter several control systems have been used and reported in the literature. First and the foremost is the use of PI and PID controllers [8]. The Zeigler Nicholas method of tuning of the PI controller has been used for a long time. Other than the PI controllers, with the advent of modern digital processor the fuzzy logic based controllers, the ANFIS [9] based controllers and the ANN [10] based controllers have also been used now a days.

The PI or the PID controller being a mathematically deterministic controller that considers the use of the mathematical model of the plant under control is considered as the best of the controllers in terms of the good performance parameters offered. The PI or the PID controller is fully deterministic control and it does not require the experience of the designer, while the fuzzy logic controller and other soft computing based controllers use the human experience of the machine gained experience and such controllers do not require the mathematical model of the plant under control. These makes the designs of the soft computing based controllers easier and are more attractive. If precision is compromised, for ease of design, the modern soft computing based controllers are opted for.

Although the advent of high speed digital data processing systems are paving the way for soft computing based controllers with improved precision, the trend is to prefer the PI or PID controllers with assistance from soft computing for tuning up them. The use of PI or PID controllers is treated as a good engineering practice.[11]

In this work the PI controller is proposed for the management of the fly back converter and the tuning of the proposed PI controller will be carried out using the PSO based optimization technique [12].

Tuning of the PI controller using the ZN procedure [13] is partially deterministic and partially empirical. The ZN tuning procedure is considered to be the simplest and the best one and has been in use for several years since inception. Originally the ZN procedure was meant for slowly varying systems, typically mechanical or thermo dynamical systems. But with the development of modern control systems the ZN procedure is now implemented for electrical electronics systems as well.

As the PI control technique is used for single input single output systems the ZN procedure is used for systems with at least fairly linear characteristics. With single input single output linear systems with non linear characteristics the ZN procedure has reasons to fail or perform with degraded performance parameters. The modern tuning procedures based on soft computing techniques such as the Genetic Algorithm (GA), the Fuzzy Logic (FL) and the Artificial Neural Network (ANN) offer tuning solutions with significant improvement as compared to the ZN procedure.

With GA[14] and the PSO the problem of tuning the PI controller is formulated as an optimisation problem wherein the parameters Kp and Ki are estimated, after forming an objective function with the Kp and Ki as constituent variables. Minimisation of the Integral Square Error (ISE) is the objective [15], as considered in this work, and that, set of Kp and Ki that will achieve this objective is to be estimated. Thus, in this paper is proposed and validated, a technique to tune the PI controller using the PSO based optimization scheme.

Two cases of comparison of results are carried out. In the first case the results of the PSO based PI controller are compared against the results obtained using the PI controller tuned with the ZN tuning procedure. In the second case the results obtained with PSO based tuning procedure is compared with the PI controller that has been tuned by the GA procedure. Appropriate standard criteria for comparison of parameters have been carried out and the results are presented

The paper is arranged as follows. Section I explain the introduction part, the essentials of the fly back converter are presented in section 2. A detail of Simulation in MATLAB SIMULINK and Experimental verification is in section 3. Section 4 given the Results and Discussions. The conclusion is given in section 5.

2. THE FLY BACK CONVERTER

A fly back converter is a DC to DC converter that sources a DC load drawing power from a DC source through a galvanic isolation implemented through a step down transformer. Usually the power control using the fly back converter is carried out using a single power electronic switch connected in series with the primary of the transformer that comes in series with the DC source. The main input power may be drawn from an AC source followed by a rectifier and filter arrangement.

On the secondary side of the transformer is simple rectifier with a single diode and an LC low pass filter to remove the ripple content in the DC output.

Fly back converters are usually driven by switching frequency as high as 60 to 100 KHz. The high switching frequency leads to the small size of the entire converter unit by mainly reducing the size of the ferrite core transformer.

The use of high frequency switching enables reduction of the size of the passive filters used across the load side of the fly back converter.

In order that the saturation of the core is avoided the core material is appropriately selected and it is usually of ferrite with low hysteresis.

In the fly back converter the power control device is the power electronic switch typically a MOSFET and the power transfer media is the two winding transformer. The primary of the transformer is charged with the switch in the On state and the charged energy is transferred to the secondary by mutual induction.

The fly back converter exhibits first order characteristic and the only degree of freedom of control is the duty cycle of the switching pulses applied to the power electronic switch.

In general the fly back converter is used for low profile power conversion systems such as used in battery chargers of Lap top computers, mobile phones handy cameras etc. Essentially the fly back converter is a compact dc to dc converter with light weight and the design incorporates a closed loop control system that maintains the output voltage at the critically regulated level as required in the sensitive equipments as mentioned above. The control system employed in the fly back converter is of the PI type implemented in the embedded circuit format typically with a Micro controller. Figure 1 shows the circuit diagram of the proposed work.

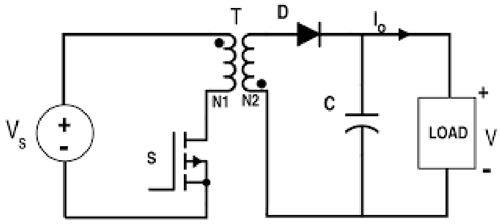

Figure 1: Circuit Diagram of Fly Back Converter

2.1. The Zeigler Nicholas Method of Tuning the PI Controller

The PI controller is predominantly used for the management of voltage regulation in a fly back converter. The PI controller is characterized by the proportional and integration constants Kp and Ki, respectively. The estimation of the values for Kp and Ki can be carried out, using trial and error method. The Zeigler Nicholas (ZN) method is a fairly easy method to find the values for Kp and Ki. The ZN method is partially deterministic and partially empirical. There are basically two methods of tuning the PI controller as suggested by the ZN technique. In the first method a reaction curve is drawn by exciting the system with a step input. The step input may be the power input to the system or the sudden application of the manipulated variable like the duty cycle from 0 to say 0.5. From the plot of the reaction curve and with some empirical rules the values for Kp and Ki are estimated. In the second of the ZN technique the frequency response of the output of the system with respect to the manipulating variable is observed. In systems that use DC quantities only and if the physical system can note be applied with sinusoidal exciting signal over a large frequency range then the mathematical model of the system can be used for the purpose observing the frequency response of the system for the purpose of tuning the PI controller.

In this work the reaction curve method has been adopted. With the input voltage of 220 volts applied to the fly back converter the manipulating variable viz. the duty cycle is suddenly changed from 0 to 0.5 and the output voltage is recorded. The time response of the output voltage is known as the reaction curve and is recorded from the MATLAB SIMULINK based simulation and is as shown in the figure 2.

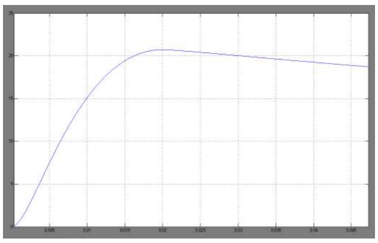

Figure 2: The Reaction Curve Plotted for Output Voltage for a Duty Cycle of 0.5

The reaction curve exhibits a concavity and a convexity with a changeover from concavity to convexity at the point of inflexion. A tangent is drawn at the point of inflexion and this tangent intercepts the positive x and negative y axis at points a and b respectively. This tangent also intercepts the steady state value level at a certain point k and this point k is projected normally onto the x axis to intercept the x axis at point c. Using the length of these three points along the respective axes and using the empirical rules as given below the Kp and Ki values are found to be x and y.

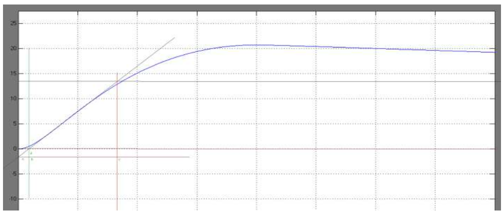

Figure 3: The Geometry used by Zeigler Nicholas Method for Finding the Constants required for Fixing Kp and Ki

The geometry used by Zeigler Nicholas method for finding the constants required for fixing Kp and Ki is shown in figure 3. The values Kp and Ki are used in the MATLAB SIMULINK simulation and the results are 0.027 and 0.57 respectively.

2.2. Particle Swarm Optimization Reviewed

Particle Swarm Optimization is a heuristic search technique that is meant to search the unique point in a multi dimensional space satisfying a certain set of conditions and an objective function coined using the number of variables equal to the number of dimensions of the search space.

Going by an example, consider the set of two linear simultaneous equations say

$3x + 4y = 14; 4x + 2y = 11;$

Rearranging these three equations

$$3x + 4y - 14 = 0; \quad (1)$$

$$4x + 2y - 11 = 0; \quad (2)$$

The objective function can be formed as follows

$$(3x + 4y -14)^2 + (4x + 2y -11)^2 = 0 \quad (3)$$

If this objective function is optimized using the Particle Swarm Optimization we get the solution as

$x = 1.6$ and $y = 2.3$;

Similarly the PI controller is characterized by the two constants Kp and Ki. These two factors decide the integrated square error. Therefore, in the estimation of appropriate values for Kp and Ki using MATLAB SIMULINK the model is run with an arbitrary values for Kp and Ki. Then, at the end of the simulation, as the model converges to a steady state the ISE is taken over to the work space and, the Kp and Ki values are adjusted and then the model is run again. This process is repeated again and again for 20 times or 10 iterations and the final value of Kp and Ki are finalized.

3. Details of Simulation in MATLAB SIMULINK and Experimental Verification

In this section the main SIMULINK model of the fly back converter and the sub systems are given. The main source of power is the 230 v 50 Hz utility source and this source, at the front end is rectified using a bridge rectifier without any step down action.

The high voltage rectified and filtered DC is used by the fly back converter. Depending upon the output voltage requirement the duty cycle of the power control switch is altered automatically using the PI controller and the output voltage is regulated.

There is only one degree of freedom and there are two modes of operation. In mode 1 the switch is closed and current flows through the primary of the transformer. The rising current stores energy in the primary winding and this stored energy rise as long as the primary current rises. When the switch is opened the stored energy is transferred into the secondary of the transformer.

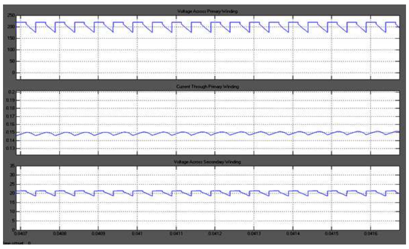

Figure 4: The Voltage across the Primary of the Transformer the Primary Current and the Secondary Voltage

On the secondary side the voltage induced in the secondary side is rectified and filtered and the resulting DC voltage is applied across the load. For a duty cycle of 0.5 the load current and the voltage across the 20 Ohms load are as shown in figure 4.

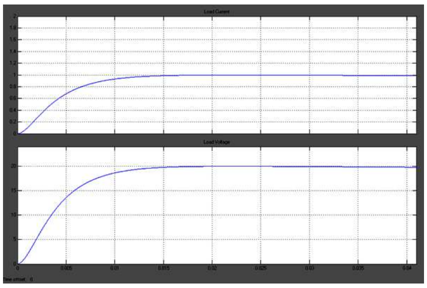

Figure 5: The Load Side Current and Voltages

With different duty cycles on the power control switch S the output voltage can be controlled and for a duty cycle of 0.2 with the same source side voltage of 220 V DC and for the same load resistance of 20 Ohms the load side current and voltages are as shown in figure 5.

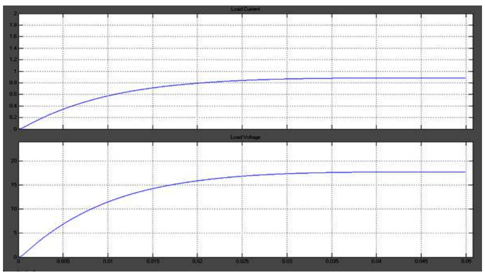

Figure 6: The Load Voltage and Current for a Duty Cycle of 0.2

Thus the steady state voltage output of the fly back converters with 0.5 and 0.2 duty cycles are respectively 23v and 35v respectively. With reference to the response of output voltages with respect to time for the two duty cycles used the system behaves like a first order system and a PI controller with appropriate tuning will be sufficient for the fly back controller of the design used. The load voltage and current for a duty cycle of 0.2 shown in figure 6.

The design parameters of the fly back converter are as given in table 1.

Table 1: Design Parameters of the Fly Back Converter

Parameter	Value
Source DC Voltage	220 volts
Primary Inductance	15.7mH
Secondary Inductance	0.157mH
Load side filter L	500e-6H
Load side filter C	2200MFD
Nominal Load Voltage	40v
Nominal Output Power	80w.2W

3.1. PSO based Tuning of the PI Controller

The following program segment is used for calling the program for tuning the PI controller using the PSO technique.

```
function ISE=Objective_fun(particle_pos_t)

xx= particle_pos_t;

Kp=num 2 str(xx(1,1));

Ki=num 2 str(xx(1,2));

set_param('kayal_Model_pso/PI','Kp',Kp);

set_param('kayal_Model_pso/PI','Ki',Ki);

simOut=sim('kayal_Model_pso');

Total_Error1=sort (ISE, 'descend');

TE1=Total_Error1 (1);

ISE=TE1;
```

The MATLAB function file runs the SIMULINK model and substitutes the values for Kp and Ki after each iteration and checks the ISE. The process continue for 10 iterations and the final value for Kp and KI as found by PSO are 0.041191 and 0.52782.

3.2. Experimental Verification

An experimental verification system has been built for validating the proposed idea. The fly back converter was constructed using MOSFET IRF 840 as the power control switch. A ferrite core transformer with 1 : 6 turns ratio to suit the 240 v / 40 v requirement has been made ready with actual number of turns for primary and secondary respectively as 120 and 30 with SWG 21 wound on a double E ferrite core of base size 55mm.

The power control device IRF 840 was interfaced to the micro controller through an optical isolation circuit built around IC MCT 2E. The MOSFET was also provided with passive snubber circuit using Diode, Capacitor and resistor elements as shown in the circuit diagram given in figure 1. The master control unit is the PIC micro controller PIC 16F877A. It works with a 12 MHz crystal. Two of the many Analog inputs of the PIC micro controller were used to login the set value for output voltage (SP) and the actual output voltage (ACT).

For the set value SP a potential divider was used to attenuate a regulated +5 volts, available on board and +4 volts representing 40 volts was applied to the ADC A0, the output voltage expected to be in the order of 40 V was attenuated by a 10: 1 potential divider, with a fine calibrating potentiometer, and the derived low voltage in the order of +4 was fed to the ADC A1. For attenuating the output voltage a series resistive network comprising of a 10K fixed resistor in series with a 2.2k continuously variable resistor was used. The drop across the variable 2.2k resistor was fed into the A1 input of the micro controller as the ACT signal.

Separate digital voltmeters and ammeter were used to monitor the source voltage, load voltage and the load current. The various voltages, current and other waveforms were recorded in a digital 4 channel DSO brand RIGOL.

4. RESULTS AND DISCUSSIONS

The results of MATLAB SIMULINK based simulation and the experimental validation were recorded and presented in this chapter. The simulations were carried out in two different scenarios. The Source voltage disturbance and load disturbance were studied. The source voltage was changed from 220 to 250 v and the regulation of the output voltage was recorded. The load was changed in two stages with 80 W load and 160 W load by changing the load resistor as 20 Ohms and 10 Ohms respectively. The important performance indices are tabulated in table x. The results were recorded for the two cases of tuning the PI controller viz. ZN method of tuning and the PSO based tuning. All the results are tabulated and the relevant waveforms are presented herein.

4.1. Regulation of Output Voltage with PI Controller

With a load resistance of 20 Ohms and with a required terminal DC voltage of 40 V the PI controller with KP and KI values as suggested by the Zeigler Nicholas method was first implemented. The closed loop SIMULINK model and the results are given in the table.

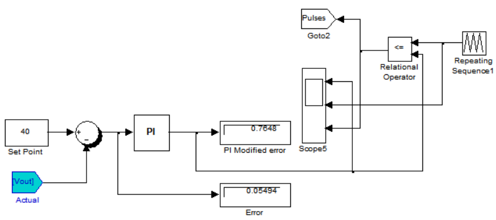

Figure 7: The Position of the PI Controller in the Closed Loop Control Scheme

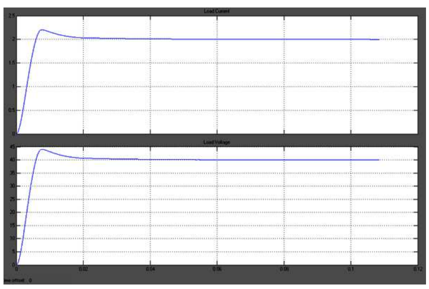

Figure 8: The Transient and Steady State Condition of the Output Voltage with V_{out} = 40 v with the PI Controller

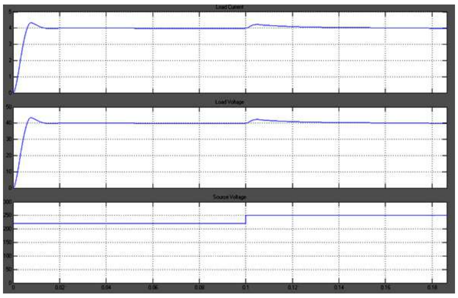

Figure 9: Performances for a Source Voltage Disturbance from 220 to 250v

With a load of 10 Ohms and at the rated voltage of 40v the fly back converter delivers 160 w. With a source side disturbance of 220v to 250v the PI controller maintains the load side voltage as 40v.

With Zeigler Nicholas Method of tuning the performance parameters are as shown in table2.

Table 2: Tuning the Performance Parameters

Steady state Error	0.01
Integral Square error	136
Peak Over shoot	43.3 v
Settling Time	0.02 sec
No of oscillations	Nil

The response of the PI controller with a load side disturbance of 100% loading from 80w to 160w is as shown in figure 10.

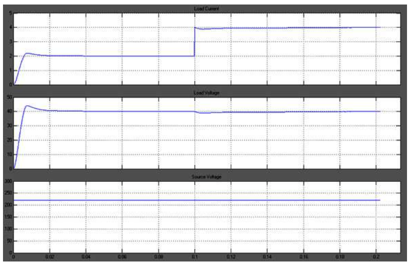

Figure10: Response for Load disturbance from 80 w to 160 w

With the sudden inclusion of the additional load of 80w increasing the total load from 80w to 160w the terminal voltage falls from 40 v to 38.8 v and recovers back to the set value of 40.01v in 0.18 second with a steady state error of 0.01v. The transient behaviour from 80w to 160 w load at 220v operation and the transient behaviour for 80 w load, for the operating voltage changeover from 220 v 250 v are presented as in figure x.

Table 3 gives a comparison of the performance of the two tuning schemes for tuning the PI controller with two different loading conditions individually.

Table 3: Gives a Comparison of the Performance of the Two Tuning Schemes

	80W Load	ZN Tuning	PSO Tuning
Source Voltage 220 V	Kp	0.027	0.041
	Ki	0.57	0.527
	Peak Over Shoot	51 V	46 V
	Settling Time	0.04 sec	0.032
	Steady State Error	0.12	.05
	ISE	132	78

	160 Load	ZN Tuning	PSO Tuning
Source Voltage 220 V	Kp	0.027	0.041
	Ki	0.57	0.527
	Peak Over Shoot	49	43
	Settling Time	.02	.018
	Steady State Error	.52	.23
	ISE	154	84

4.2. Total Control System Effort

The total control system effort is an important parameter that gives an insight into the power looses that could happen during the transient process. The integral of the traverse of the duty cycle from the previous equilibrium state to the new equilibrium state is an indirect measure of the effort exerted by the control system to bring out the required change in the system after the command has been given. In this research when the system was simulated in the MATLAB SIMULINK environment the control effort was calculated and has been presented herein in table 4 for the two cases of disturbances and the two tuning techniques.

Table 4: Control Effort

ZN Method of Tuning	Control Effort (Integral of Traverse of the Duty Cycle)
Load disturbance from 80w to 160 W	23
Source voltage disturbance from 220v to 250v	47
PSO Method of tuning	
Load disturbance from 80w to 160 W	12
Source voltage disturbance from 220v to 250v	18

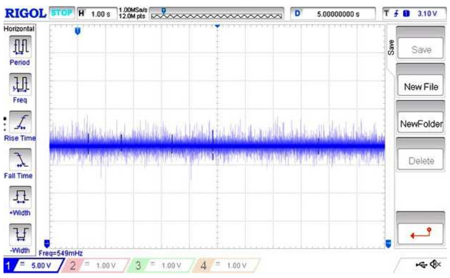

Figure 11: The Output Voltage of the Fly Back Converter at Steady State

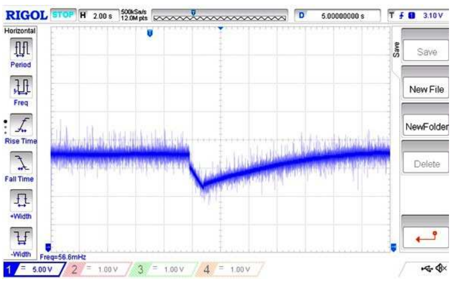

Figure 12: The Disturbance and Recovery of the Output Voltage against a Load Disturbance from 80w to 160 w with the PSO Tuned PI Controller

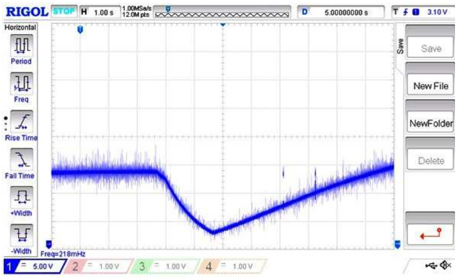

Figure 13: The Disturbance and Recovery of the Output Voltage against a Load Disturbance from 80w to 160 w with the ZN Tuned PI Controller

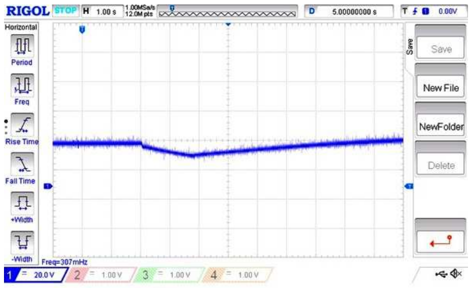

Figure 14: The Performance of the PSO Tuned PI Controller on the Output Voltage Regulation against a Source Voltage Disturbance

Figure 15: The Performance of the ZN Tuned PI Controller on the Output Voltage Regulation against a Source Voltage Disturbance

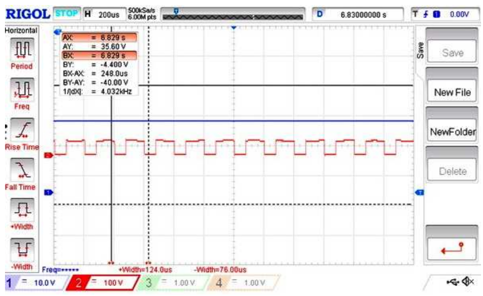

Figure 16: Zoomed in view of the PWM

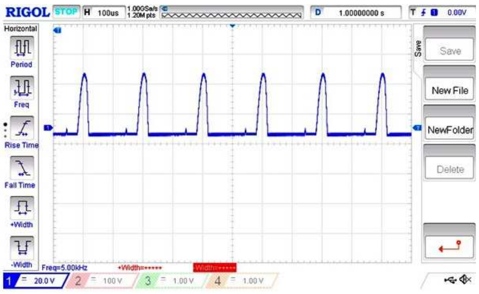

Figure 17: The Typical View of the Voltage across the Primary of the Fly Back Converter Transformer

5. CONCLUSIONS

A novel tuning technique for the PI controller to be used for a fly back converter has been presented in this paper after systematic design procedures. The MATLAB SIMULINK based simulation has been carried out and the findings have been recorded. With regard to simulation the PSO based tuning of the PI controller output performs the one tuned with the ZN technique in respect of the standard performance indices.

A novel performance parameter has been introduced and it gives an insight into the control effort. This parameter compares the representative of the power loss that could be utilized in bringing up the system from an initial equilibrium state to the desired state and for this purpose the integral of the duty cycle over the transient period is used to compare for various cases.

It has been observed that apart from the traditional performance indices the control effort parameter is also encouraging in the case of PSO tuned PI controller as compared to the ZN tuned PI controller, indicating reduced power losses while the controller is in a transient action.

An experimental validation setup was constructed to validate the proposed idea. The experimental setup was developed with a facility to modify the Kp and Ki values, thorough software and the results validated the proposed idea.

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