Comparison Analysis of LLC Resonant Converter using PI and Fuzzy Controller Techniques

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***Abstract*— The advancement of telecommunication and computer systems in the distributed power architecture and point-of-use power supplies is becoming essential. While operating at a constant frequency, these supplies are required to produce high efficiency, high power density and low switching losses. Furthermore, operation at high frequencies not only increases the power density but also reduces component size. The performances are measured accurately by the conventional controllers with better understanding of the system. These control methods ensure stability and good control only in small vicinity around operating. In this paper the performances of the LLC with PI and Fuzzy controllers are evaluated under the line and load disturbances to maintain the constant voltage using MATLAB based simulation.**

***Index Terms*— Fuzzy Controller, LLC resonant converter, PI controller, Series Loaded Resonant Converters, Zero Current Switching.**

I.INTRODUCTION

The LLC resonant converter is becoming more and more popular for its high efficiency, because of both zero-voltages switching for the primary side main switches and zero-current switching (ZCS) for the secondary-side rectifiers. Today, with the explosive increase in consumer electronics the demand for high-power-density converters is growing. Thus, the LLC resonant converter is required to operate at high frequencies. The controllable switches are operated in switch mode where they are required to turn the entire load current on and off during each switching cycle. Under these conditions, the switches are subjected to high switching stresses and power losses. There are three basic configurations of such converters namely series, parallel and series-parallel loaded resonant converters. Series loaded Resonant Converters (SRCs) have their load connected in series with the resonant tank. SRCs are suitable topologies for high frequency operation because of their lower power losses. Parallel loaded Resonant Converters (PRCs) have their load connected in parallel with the resonant tank capacitor. The main advantage of PRC is that the output voltage can be regulated even under no-load conditions as long as the operating frequency is above resonance but the disadvantage is that the current carried by the power semiconductor switches and the resonant components is relatively independent of the load.

The main disadvantage of the SRC is that it cannot be regulated at a load while the PRC circuit has a circulating current flow irrespective of load current. The SPRC topology possesses combined advantages of both SRC and PRC. The output is controllable for no load or light load and the light load efficiency is relatively high. The SPRC works satisfactorily for a wide range variation of supply voltage and load current. However, one drawback of resonant converters is their non-linear nature giving rise to different transient responses for different loading conditions and operating frequencies.

Without proper control, a resonant circuit can take a long time to settle to the new required state. To alleviate this problem, intelligent controllers have to be developed for such converters. This chapter provides a detailed description of control for series-parallel loaded resonant converter.

II.COMPONENT MODULE DIAGRAM

The LLC resonant converter is required to operate at high frequency. High circulating energy and high switching loss will occur at high input voltage. They are not suitable for front end DC/DC application. For a resonant tank, working at its resonant frequency is the most efficient way. This rule applies to SRC and PRC very well. For SPRC, it has two resonant frequencies. Normally, working at its highest resonant frequency will be more efficient. The DC characteristic of LLC resonant converter could be divided into ZVS region and ZCS region. For this converter, there are two resonant frequencies. One is determined by the resonant components Lr and Cr. The other one is determined by Lm, Cr and load condition. As load getting heavier, the resonant frequency will shift to higher frequency. ZVS and ZCS are achievable over entire operating range. This LLC resonant converter can be designed to operate over wide input voltage. It can be operate under no load condition.SRC has lower circulating current then the PRC.LLC can operate at resonance at nominal input voltage.

III. CONTROL TECHNIQUE FOR LLC RESONANT CONVERTER

A. PI Controller

A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used. The controller output is given by

$$K_P \Delta + K_I \int \Delta \, dt \qquad (1)$$

Where Δ is the error or deviation of actual measured value (PV) from the set point (SP).

$$\Delta = SP - PV \qquad (2)$$

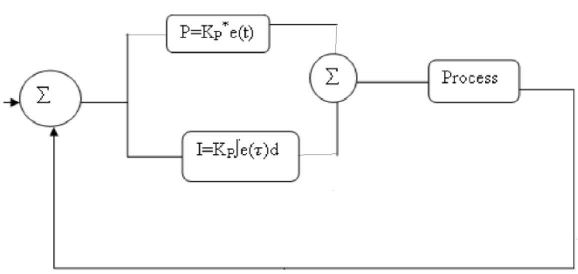

Fig.1 Block diagram of PI controller

A PI controller can be modeled easily in software such as Simulink or Xcos using a "flow chart" box involving Laplace operators:

$$C = \tau \frac{G(1+\tau s)}{\tau s} \qquad (3)$$

Where

K_P = proportional gain

K_I = integral gain

Setting a value for is often a tradeoff between decreasing overshoot and increasing settling time. The lack of derivative action may make the system steadier in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher-frequency terms in the inputs.

B. Proportional Term

The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant Kp, called the proportional gain constant.

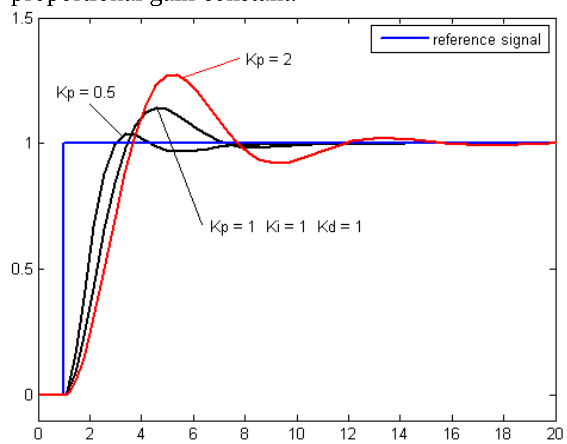

Fig.2 Waveform of proportional term

The proportional term is given by:

$$P_{out} = K_P \, e(t) \qquad (4)$$

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (see the section on loop tuning). In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change.

C. Integral Term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain k_i and added to the controller output. The integral term is given by:

$I_{out} = K_i$ (5)

IV. SIMULATION DIAGRAM

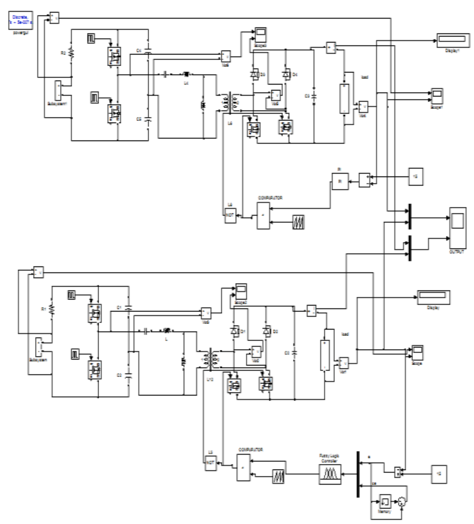

Fig.1 Simulation circuit for LLC resonant converter using PI controller and fuzzy controller.

The integral term accelerates the movement of the process towards Set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value (see the section on loop tuning).

Fig 1 Simulated output voltage and current of LLC resonant converter with sudden line disturbance (55V-48V-55V) under nominal load of 100 Ω. Fig 2 Simulated output voltage and current of LLC resonant converter with set point 15V and nominal load 100Ω. Fig.3 Simulated output voltage and current of LLC resonant converter with sudden load disturbance (80Ω –100 Ω -80Ω) at t=0.03 sec. Fig.4-5 Comparison of PI and FUZZY with output Current in both line and load disturbance

PI controller simulated regulates the output voltage of with resistive load within a maximum of after a line disturbance and a maximum of after a load disturbance. The simulated speed of motor is regulated with PI control within a maximum of after a line disturbance and a maximum of after a load disturbance. Then display respectively the start-up in the output voltage of resistive load. The start-up transient exists for in the case of with resistive load and for in the case of PI control.

Fuzzy controller simulated regulates the output voltage of with resistive load within a maximum of after a line disturbance and a maximum of after a load disturbance. The simulated speed of is regulated with fuzzy control within a maximum of after a line disturbance and a maximum of after a load disturbance. And display respectively the start-up in the output voltage of resistive load. The start-up transient exists for in the case of resistive load and for in the case of with PI and fuzzy control.

V. SIMULATION RESULT

A. PI Controller

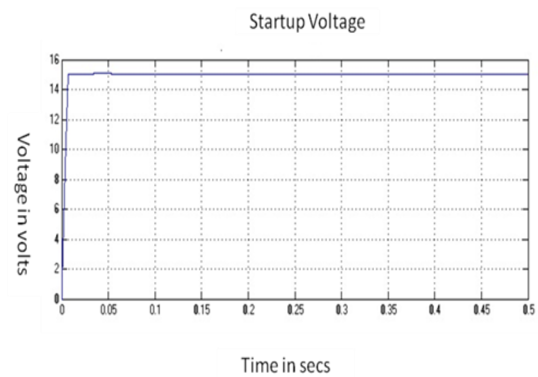

Fig.1 Simulated output voltage of LLC resonant converter with sudden line disturbance (55V-48V-55V) under nominal load of 100 Ω

B. Fuzzy Controller

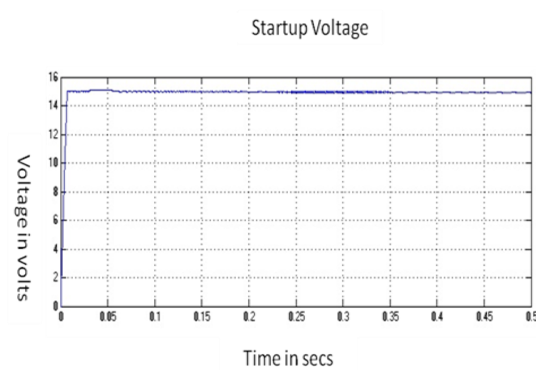

Fig.2 Simulated output voltage of LLC resonant converter with set point 15V (55V-48V-55V) under nominal load of 100 Ω

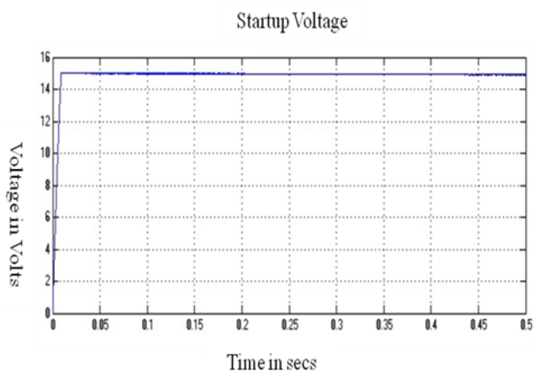

Fig.3 Simulated output voltage of LLC resonant converter with sudden load disturbance (80Ω –100 Ω -80Ω) at t=0.03 sec

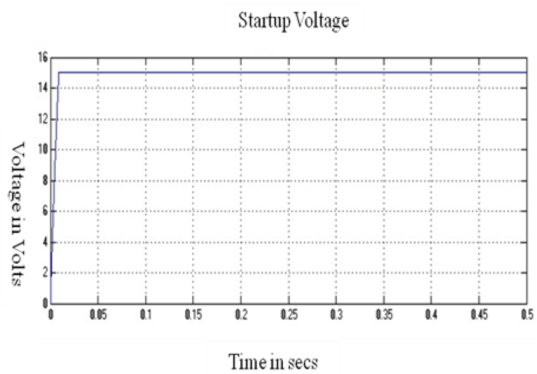

Fig.4 Simulated output voltage of LLC resonant converter with set point 15V (80Ω –100 Ω -80Ω) at t=0.03 sec

C. Comparison of PI and Fuzzy with Output Voltage

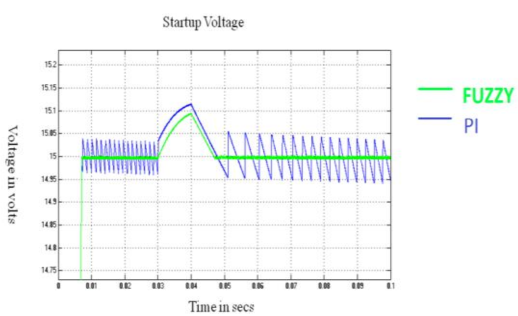

Fig.5 Comparison of PI and FUZZY with output voltage in both line and load disturbance.

C. Comparison of PI and Fuzzy with Output Current

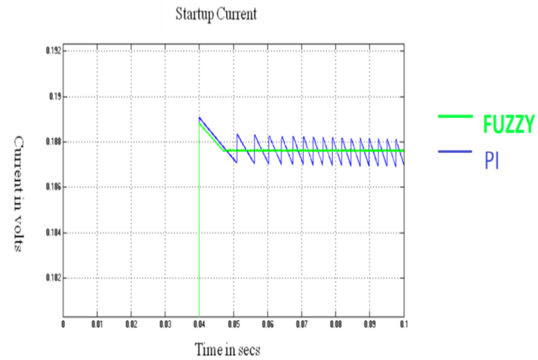

Fig.6 Comparison of PI and FUZZY with output Current in both line and load disturbance.

VI. CONCLUSION

The aim of this work is not to emulate conventional control where it can be applied but to suggest an alternative approach for those situations where conventional methods fail. However any control method whose results are not comparable with those of linear controllers for simple processes would probably not be effective when applied to more complex processes. Controllers for future power supplies will be required to be intelligent with fault tolerance, programmability, auto-ranging facility etc in addition to providing closed loop control. Expert system based control is found to provide an easy solution to this problem.

Design of load resonant converters is presented and verified using simulation. Deriving complete mathematical models for the chosen class of resonant converters is difficult because of the large non-linearity present and the proximity of the switching frequency to the resonant frequency. One way of solving this problem involves splitting the converters into different modes of operation and analyzing each of the modes independently.

Two different controller structures (PI/fuzzy controllers) are considered, developed and implemented for load resonant converters in this work. These controllers have been simulated to provide chosen converters with regulated output voltage/speed of motor load under line and load disturbances. It is found that the FLC based control a scheme performs better than PI control in this work. The fuzzy controllers developed have also advantages like simple structure and good learning capability. In comparison with PI controller, the developed intelligent controllers yield better dynamic performances with less settling time, zero steady-state error and less overshoot.

The simulation and experimental results for the chosen converters are satisfactory and closely match with each other. The above results indicate the validity and feasibility of the proposed control schemes for the various load resonant converters.

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