Comparison of LLC and LCC Resonant Converter Using Conventional and FUZZY Controller

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Abstract — **Resonant converters are desirable for power conversion due to their comparatively smaller size and lower power losses. The two most promising topologies of resonant converter are LLC and LCC resonant converters. Our paper is focus on closed loop operation of LLC and LCC converters. The satisfactory response under line and load disturbance is achieved by using conventional and fuzzy controllers. Finally, the paper brings out the best result and overall efficiency among the LLC and LCC with PI controller & fuzzy controller. The open loop analysis and closed loop control has been provided in this paper.**

Index Terms – Fuzzy controller, LCC resonant converter, LLC resonant converter, PI controller.

I. INTRODUCTION

The combination of high switching frequencies together with hard switched PWM converters suffers from several drawbacks [1], which can normally be eliminated by resonant converters. Consisting of two resonant elements the series - resonant (SRC) and the parallel-resonant converter (PRC) represent the two simplest members of the resonant converter family.

Although reducing the reactive currents to a minimum and thus providing excellent part load efficiency, the SRC converter cannot regulate its output voltage in case of no - load condition. On the contrary, using the PRC converter makes handling of no-load situation possible, but changing part load efficiency for the worse at the same time.

Hence, resonant converters with at least three or four storage elements can be used in order to avoid these disadvantages [2]. These so called multiresonant converters can be classified by the number, kind and arrangement of their reactive components in the resonant tank. Despite the numerous possible combinations of LC circuits, mostly the LCC [3] and the LLC converter [4] in Fig. 1 and Fig. 2 are proposed by literature.

This paper deals with the comparison of the resonant LCC and LLC converter using PI and FUZZY controllers. In the first step, based on their individual configuration and principle of operation, both converter topologies are compared. In the second step, two converters are controlled by PI controller. In third step, they are controlled by FUZZY controller.

Finally the constant output voltage under line and load disturbances are obtained. And also the performance analysis of both the converters are compared and proposed.

II. OPEN LOOP ANALYSIS

A. LLC resonant converter

The LLC resonant converter is composed of two inductors and a single resonant capacitor. The LLC converter is able to operate at no load. LLC resonant converter design needs to find a suitable magnetizing inductor to ensure small conduction losses and switching losses.

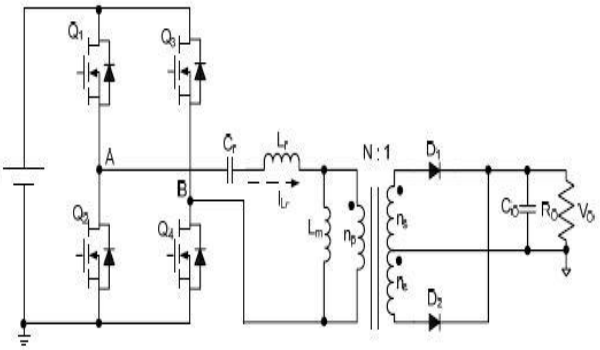

Fig. 1. Simplified Electric circuit for LLC Resonant Converter

For the purpose of modeling the LLC resonant converter, the equivalent electrical circuit shown in Fig.1 has been considered. Basics on such a technology are given along with an experimental analysis of the power device to highlight its features. The issue of the transformer design has been also treated, proposing a solution suitable for a 500MHz switching frequency. The LLC resonant DC-DC converter, as shown in Figure 1, is composed of the bridge driver; the LLC resonant tank and the rectified DC load.

The input is powered from a high-voltage DC source. This is normally the regulated output of the boost PFC pre - regulator. The circuit comprises of a½-bridge power stage (Q1, Q2), which is connected to the series elements of an LLC resonant circuit.

TABLE 1. DESIGN SPECIFICATION AND OPTIMIZED PARAMETERS

Input voltage range	V_i = 200V…..400V
Output voltage range	V_o = 19V
Output power	P_o = 100W
Max Switching Frequency	f_{max}= 200KHz

The LLC resonant circuit is formed by the series combination of the magnetizing inductance and low-value leakage inductance of the main transformer, and the combined capacitance on the passive side of the bridge.

Input voltage range of 250 V to 400 V and an output voltage of 19 V. The dc-bus voltage is generated by a pre-regulated ac-dc stage with power factor correction and minimized conducted emissions, in order to fulfill requirements of EMI regulations. The converters provide a maximum output power of 100 W and a half bridge configuration is used, reducing the effective DC input voltage by half to Vi/2. An important design goal was a height constraint of 10 mm.

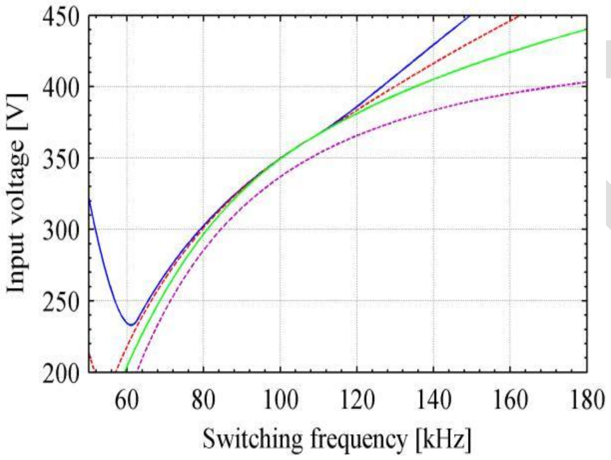

Fig. 2. Switching characteristics of LLC

B. *LCC resonant converter*

LCC resonant converter is composed of two capacitors and a resonant inductor. LCC resonant converter is able to achieve wide operation together with high efficiency .Due to low switching losses, LCC resonant converter is able to operate at high switching frequencies, while maintaining high efficiency.

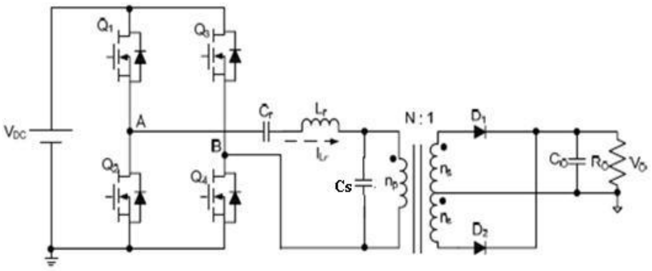

Fig. 3. Simplified Electric circuit for LCC Resonant Converter

The resonant tank of the LCC converter consists of two capacitors (Cs, Cr) and one series inductor Lr. Based on the cantilever model of the transformer, Ls can be integrated as the leakage inductance.

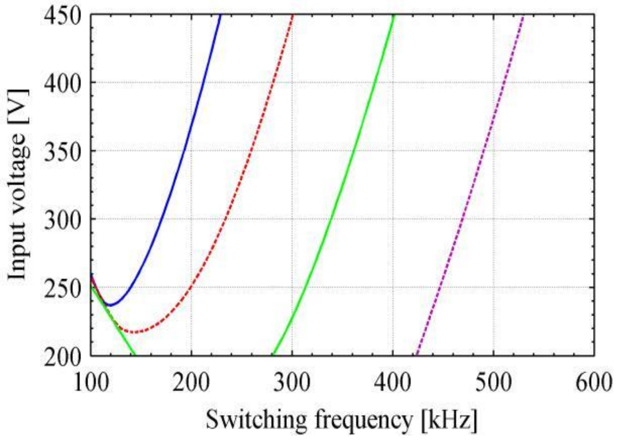

Fig. 4. Switching characteristics of LCC

III. CONTROLLERS

A. *PI Controller*

The Proportional-Integral (P-I) controller is one of the conventional controllers and it has been widely used for the speed control of dc motor drives. The major features of the P-I controller are its ability to maintain a zero steady -state error to a step change in reference.

The definition of proportional feedback control is

$$u=K_p e \qquad (1)$$

Where
e = is the "error"
K_P = Proportional gain

The definition of the integral feedback is

$$u = K_I \int e\,d\tau \qquad (2)$$

Where

K_I = Integration gain factor

In the PI controller we have a combination of P and I control, i.e.:

$$u = K_p e + K_I \int e \, d\tau \quad (3)$$

$$u = K_p e + \frac{1}{\tau N} \int e \, d\tau \quad (4)$$

$$u = K_p \left(e + \frac{1}{\tau N} \int e \, d\tau\right)$$

Where

τ_I = Integration time
τ_N = Reset time

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error.

The proportional and integral terms is given by:

$$u(t) = K_p e(t) + K_i \int e(t)dt \quad (6)$$

K_P and $k_i$are the tuning knobs, are adjusted to obtain the desired output. The following speed control is used to demonstrate the effect of increase/decrease the gain,K_P and k_i. A DC motor dynamics equations are represented with second order transfer function,

$$G(s) = \frac{\theta}{V} = \frac{Kt}{(Js+b)(Ls+R) - Ke\,Kt} \quad (7)$$

Where,

K_t= k_e= electromotive force constant = 0.01Nm/Amp b = damping ratio of the mechanical system = 0.1Nms J = moment of inertia of the rotor =$0.02 kgm^2 s^{-2}$
R = electric resistance = 1 Ω L =
electric inductance = 0.5H

After we include the PI controller, the closed-loop transfers function become:

$$G_p(s) = \frac{Y}{R} = \frac{Kt\,Kp}{(Js+b)(Ls+R) - Ke\,Kt - Kt\,Kp} \quad (8)$$

The effects of closed-loop response as we vary the integral gain K_i. The response yields that as K_i increasing; the response reaches the steady state faster with steady state error approaching to zero.

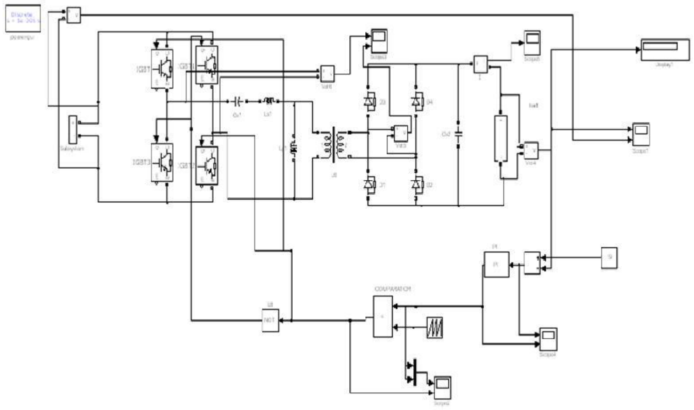

Fig. 5. Circuit diagram of LLC-PI Controller

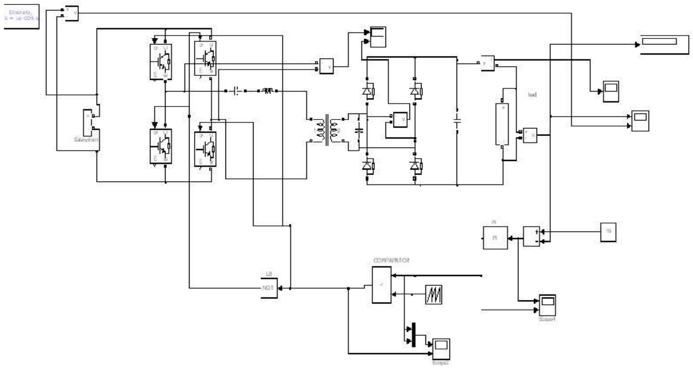

Fig. 6. Circuit diagram of LCC-PI Controller

B. FUZZY Controller

FUZZY controllers are work under the principle of FUZZY logic. Fuzzy logic provides a convenient and user-friendly front-end to develop control programs, helping designers to concentrate on the functional objectives, not on the mathematics. Fuzzy logic is a very powerful tool that is pervading every field and signing successful implementations. Here FUZZY controllers are used as feedback controllers.

In order to process the input to get the output reasoning there are six steps involved in the creation of a rule based fuzzy system:

1. Identify the inputs and their ranges and name them.
2. Identify the outputs and their ranges and name them.
3. Create the degree of fuzzy membership function for each input and output.
4. Construct the rule base that the system will operate under

5. Decide how the action will be executed by assigning strengths to the rules
6. Combine the rules and defuzzify the output.

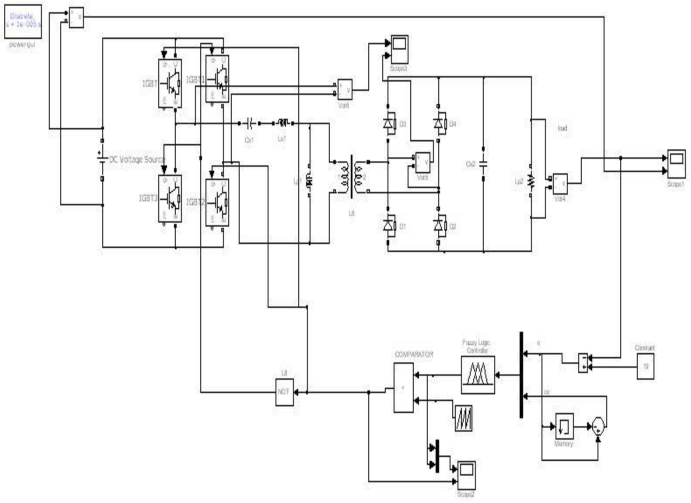

Fig. 7. Circuit diagram of LLC-Fuzzy Controller

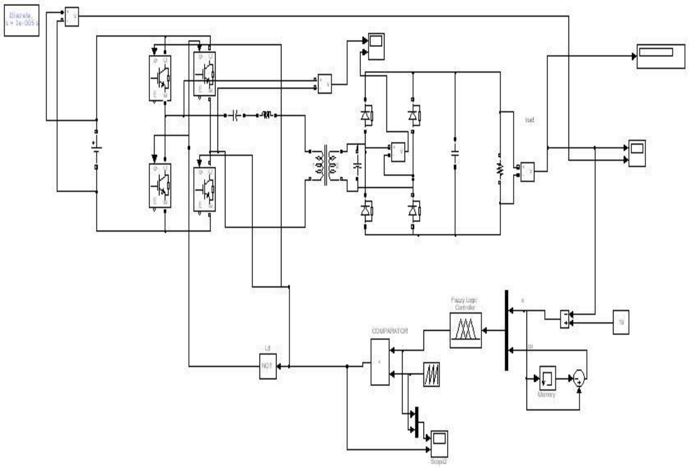

Fig. 8. Circuit diagram of LCC-FUZZY Controller

IV. SIMULATION RESULTS

Simulation results consist of three categories they are open loop results of LLC and LCC Converters, closed loop results with PI Controller and with FUZZY Controller.

Based on the simulation results the comparison of both the converters takes place. The line and load disturbances are given to the converters and their results also included here.

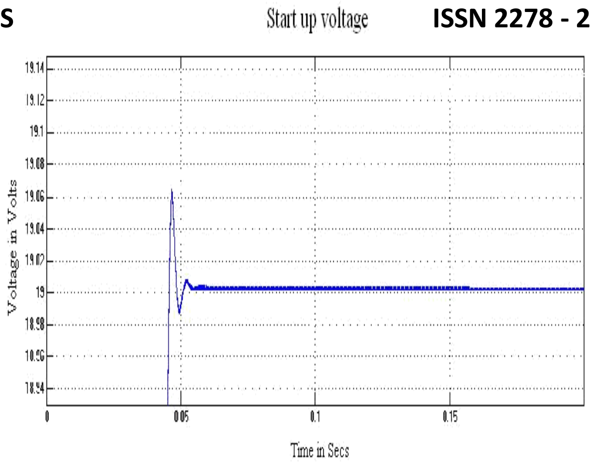

Fig. 9. Simulated start -up output voltage of LLC at Set point 19v and nominal load 100Ω

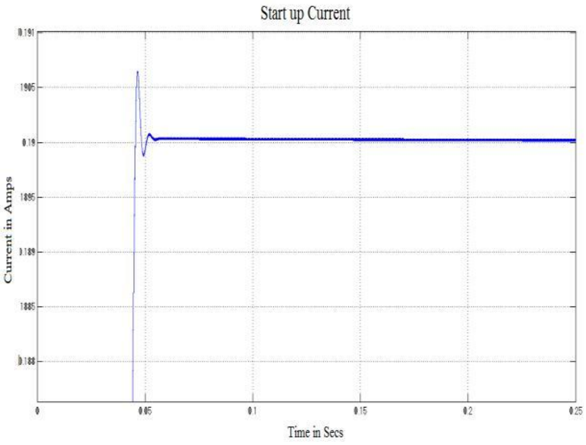

Fig. 10. Simulated start -up output current of LLC at Set point 19v and nominal load 100Ω

Fig. 11. Simulated start -up output voltage of LLC-PI at Set point 19v and nominal load 100Ω

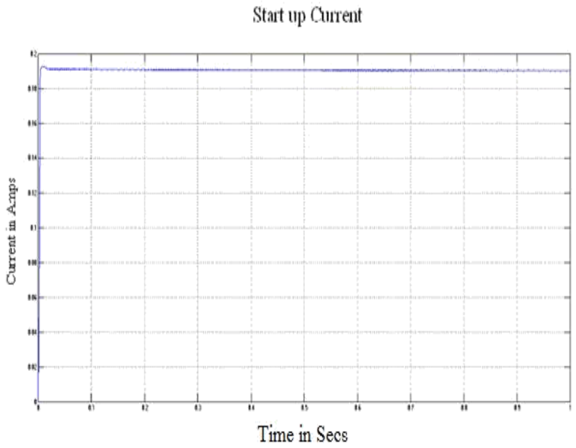

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Fig. 12. Simulated start -up output current of LLC-PI at Set point 19v and nominal load 100Ω

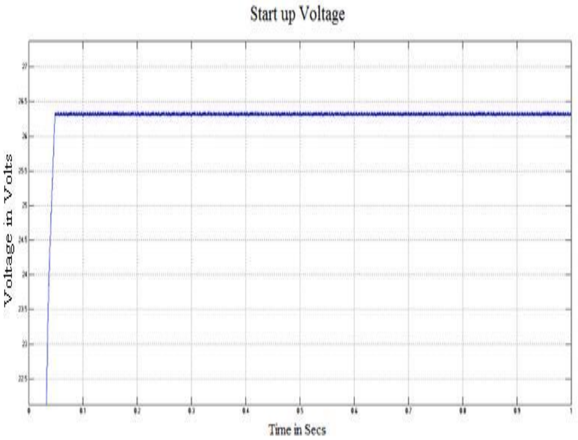

Fig. 13. Simulated start -up output voltage of LLC-FUZZY at Set point 19v and nominal load 100Ω

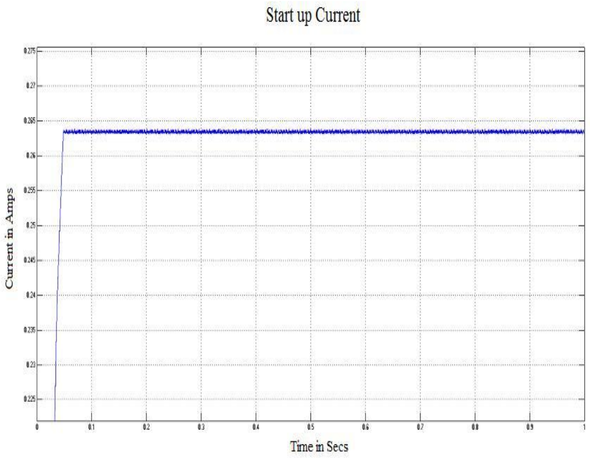

Fig. 14. Simulated start -up output current of LLC-FUZZY at Set point 19v and nominal load 100Ω

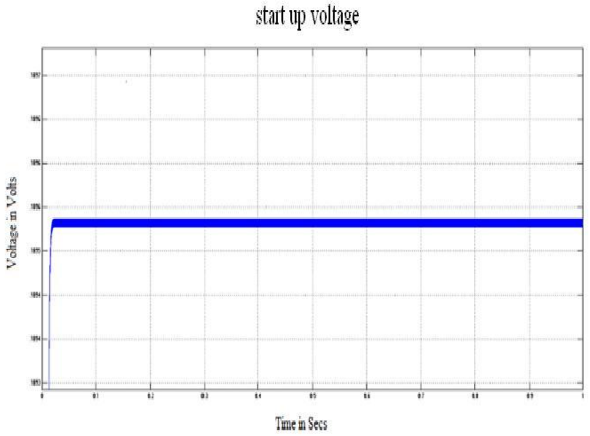

Fig. 15. Simulated start -up output voltage of LCC at Set point 19v and nominal load 100 Ω

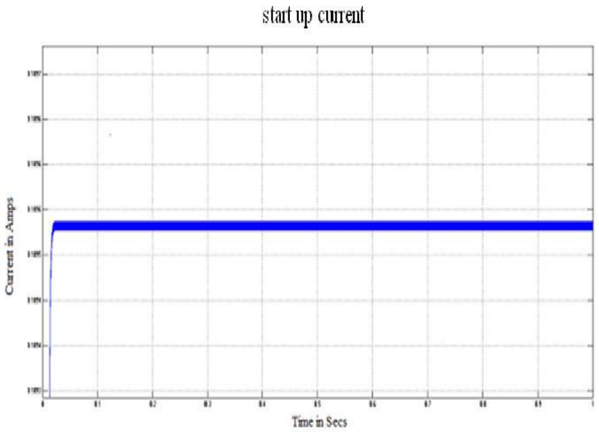

Fig. 16. Simulated start -up output current of LCC at Set point 19v and nominal load 100Ω

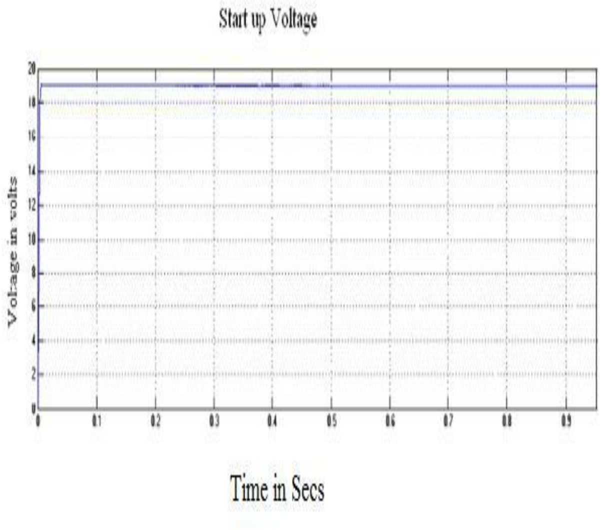

Fig.17. Simulated start -up output voltage of LCC-PI at Set point 19v and nominal load 100Ω

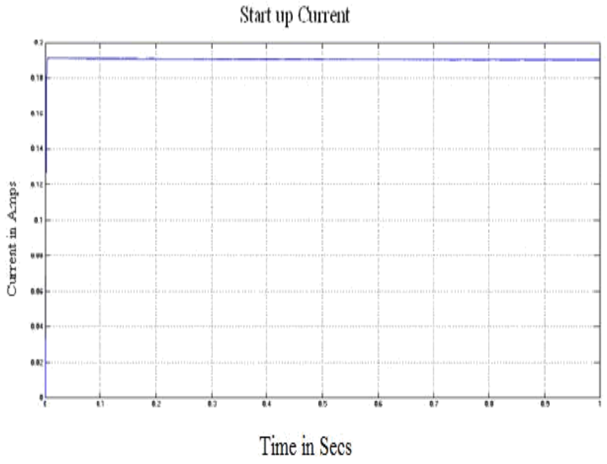

Fig. 18. Simulated start -up output current of LCC-PI at Set point 19v and nominal load 100Ω

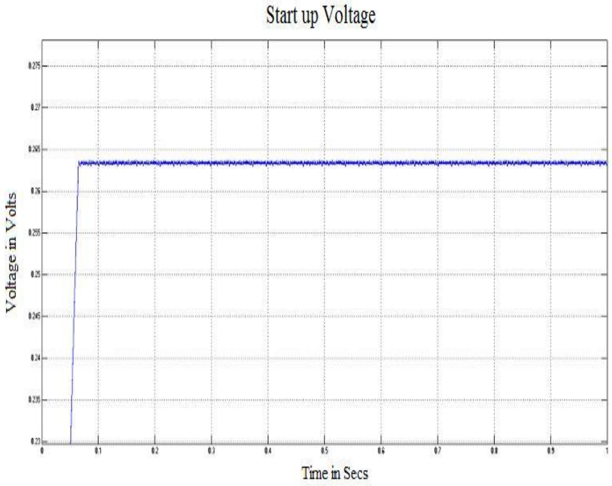

Fig. 19. Simulated start -up output voltage of LCC-FUZZY at Set point 19v and nominal load 100Ω

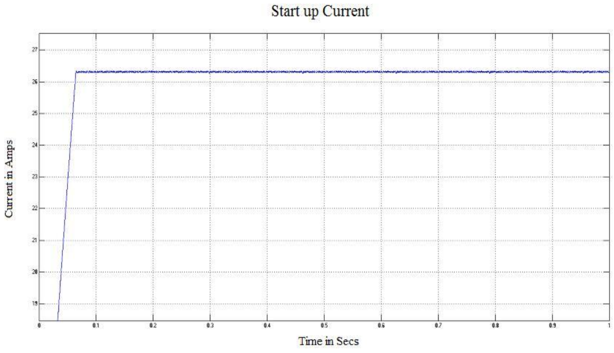

Fig. 20. Simulated start -up output current of LCC-FUZZY at Set point 19v and nominal load 100Ω

V. CONCLUSION

The topologies of LLC and LCC Resonant Converters using PI and Fuzzy controllers were designed and performance was compared with above said controllers. The Startup voltage and current was reduced when compared to open loop system and also response under line and load disturbance was satisfactory using PI and Fuzzy controllers.

The simulation result shows that the response of converters with Fuzzy controller has been better than PI controller. Comparing LLC and LCC in all situation, LCC converter is a suitable topology for high efficient power adapters, providing a high and nearly constant efficiency throughout the complete load and input voltage range.

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