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Closed-Loop Identification with Digital Regulator Converter for Resonance and PID Controller Design LTI System

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Abstract: *In this paper switch mode power supplies is a good way for power utilization. From the past few years, resonant converters obtained more and more attention. In this research mathematical representation is a little fiddly. So we are chosen a method for simplifying this calculation, which is very fetching like first switching circuit and second is one resonance tank. While a steady-state solution for these methods might be acceptable or too close for an expected solution, then with a simplified solution we have predicted zero voltage switching characteristics is disrepair or making simple. We know that zero voltage switching characteristics with all focused directly related to the voltage transfer function results which are too positive approximated to the obtaining of range operation zero voltage switching. Therefore, in this paper focuses on a more accurate investigation of the resonant LLC converter's zero voltage switching behaviour and proposed approximation methods, which are also based on simplified assumptions allowing a fast estimation of different converter designs. The proposed method will require one closed-loop step set point response experiment using a proportional only controller, and it mainly uses information about the first peak (overshoot) which is very easy to identify. In this research, high efficiency has main role with resonant-based converter.*
Keywords-*High Voltage Gain, voltage regulation, Switched Capacitor, Switched Inductor, Power supply, mode power supply, Resonance tank ,Zero voltage switching, Metal Oxide Semiconductor Field Effect Transistor, Bridge circuits,Switching frequency.*

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I. INTRODUCTION

Now a day many different industrial applications have been using switched-mode power supplies and their applications. In recent trends, most of the process industries use proportional-integral-derivative (PID) controllers because of there are several advantages and cost to benefit ratio it provides in terms of simplicity in control structure, easy to understand, low cost, easy to maintain and satisfactory performance in many applications. Various designs Methodologies are prevalent in the literature like model based design methods, optimization of integral error performance criteria, design methods utilizing frequency response data, loop shaping method, robust controller design, etc. [1].

Most tuning approaches are based on an open-loop plant model (g) as shown in Fig.1; typically given in terms of the plant's gain (k), time constant (τ) and time delay (θ); see O'Dwyer [3] for an extensive list of methods. Given a plant model g, one popular approach to obtain the controller is direct synthesis (Seborg et al., [4]) which includes the internal model control-proportional integral controller tuning method of Rivera et al. [5]. The original direct synthesis approaches, like That of Rivera et al. [5], give very good performance for set point changes, but give sluggish responses to input (load) disturbances for lag-dominant (including integrating) processes with τ/θ larger than about 10. To improve load disturbance rejection, Skogestad [6] proposed the modified SIMC method where the integral time is reduced for processes with a large value of the process time constant τ. There are two problems here.

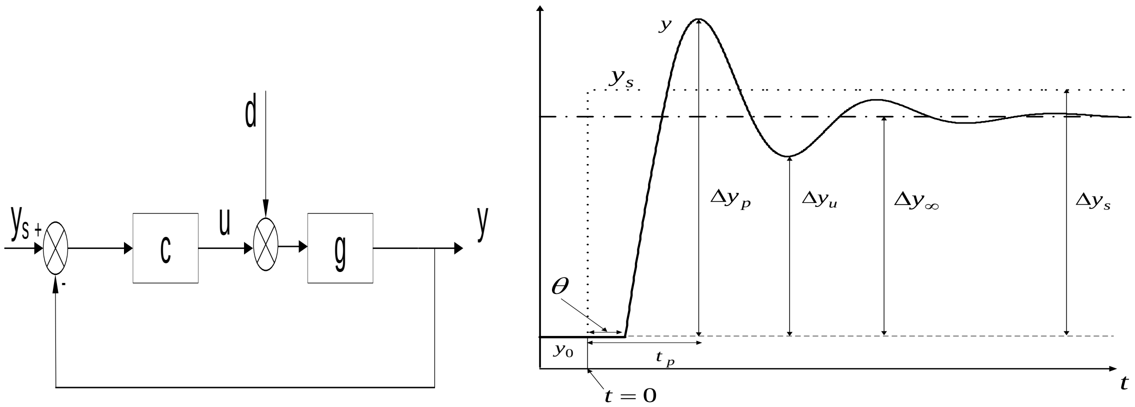

Fig.1. Showing the basic structures

a. Block diagram of feedback control system
b. Closed-loop step set-point response with P-only control.

Various techniques on designing the effective feedback control system for Inductor-Inductor Capacitor resonant converter are becoming a topic of considerable interest due to the increasing demand of the resonance conversions. After adopting the mathematical model of Inductor-Inductor Capacitor resonant converter, a digital compensator will be design to ensure better performance. First, an open-loop experiment, for example a step test, is normally needed to get the required process data.

The method will use a single closed-loop experiment with proportional only control. Compared to the open-loop system identification methods, closed-loop methods are often more desirable in industrial applications because they offer less disruption to the operation of the system [18].

II. LLC RESONANCE CONVERTER

There are nearly 40 possible options of three part resonant tanks other than the two part resonant tank arrangements. LLC resonant converter is the most common member of three part tank arrangement. There are two inductors L_r, L_m and one capacitor C_r in a LLC resonant converter as shown in Fig.2 The inductor L_m is connected in parallel with the load. The output voltage can be controlled by a voltage drop over inductor L_m at no load condition.

Also the current is basic limited by the inductor L_m at resonant frequency hence the circulating current through the resonant circuit can be maintained on an acceptable range. Operation under zero voltage switching is another advantage of the switching networks over the whole load. The output of the inverter is filtered using LC filter. This is stepped down by using a step down transformer. Further this is rectified and filtered using LC filter.

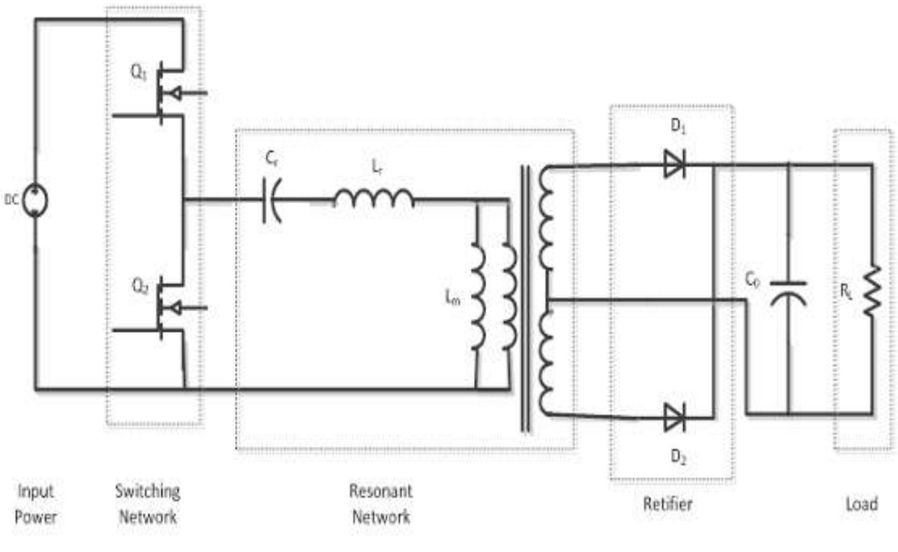

Fig.2. LLC Resonant Converter.

In order to compensate the perturbations in the input voltage, load, the component values, etc., feedback loop is introduced. The output voltage is first sensed and then digitized using analog-to-digital converter. The digitized output is then compared with reference signal to generate the error signal which is then processed by the digital compensator. The digital output of the compensator is transformed into its analog counterpart by using digital-to-analog converter. The signal is then applied to the LLC resonant converter to control the switches.

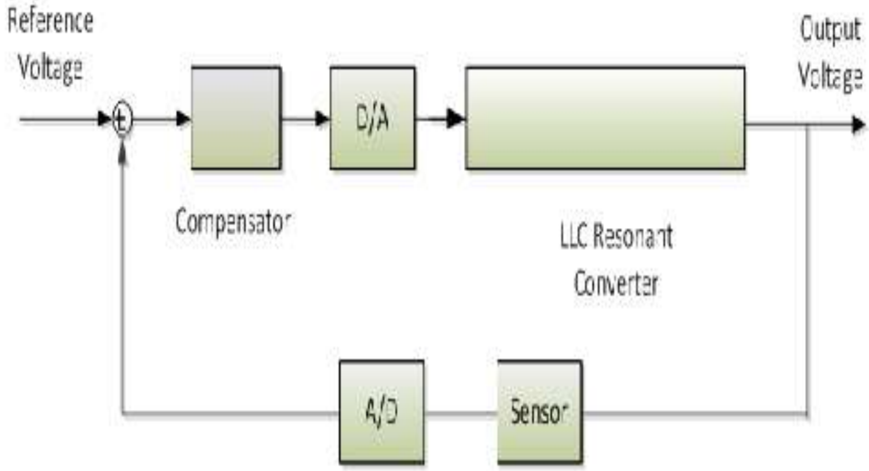

Fig. 3 Block diagram of the closed loop control system.

Zero voltage switching and its important parts how it will works and timing diagram from T0-T6 according to the switches Q_1 and Q_2 on-off states and relationship of the current and voltages.The LLC resonance converter has three major blocks. As shown in Fig. 2.

- Switching network(contains MOSFET as switch)
- Resonance Tank(Contains Capacitor C_r, Two inductors L_r ,L_m)
- Rectifier and filter

The LLC switching networks contains two MOSFET which operates at 50% duty cycle. The major reason for choosing MOSFET as switch due to the followings,

- They need voltage rather than current.
- Positive temperature coefficient so provides thermal runaway.
- Has lower on state losses as comparison to bipolar part
- Inherent body drains diode which will be used full for free-wheeling currents.
- High Input impedance
- The switching network produces a square wave equal to the frequency of the MOSFET. The MOSFET operates in such a manner that when the switch Q_1 is on Q_2 will be off and vice versa. Small dead time is introduced between these two switching cycles.

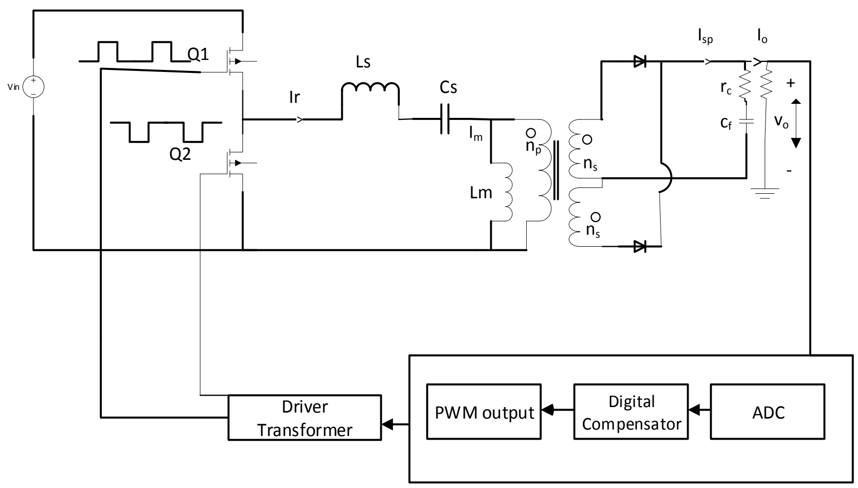

Fig. 4 LLC Resonant Converter schematic diagram

The LLC resonance converter shown in Fig.2 allows ZVS for half bridge MOSFET gives considerable advantages like lower switching losses and improve converter efficiency. The LLC resonance converter is working as follows. We know the signal of voltage used with frequency resonant.
Which is varies the related tank of impedance. From Fig.4 it can be concluded that increasing in switching frequency will result in reduction of the output gain. It means that with the increase in switching frequency the impedance of the resonance tank will be high and larger voltage drop will be occurred on the resonance tank and little watt voltage will be shifted to load.

From the Fig.5 it is shown that the output gain is inversely proportional to the switching frequency (f_s). With the Increase in switching frequency the reduction in output voltage gain is seen and reduction in switching frequency leads towards the increase in output gain.

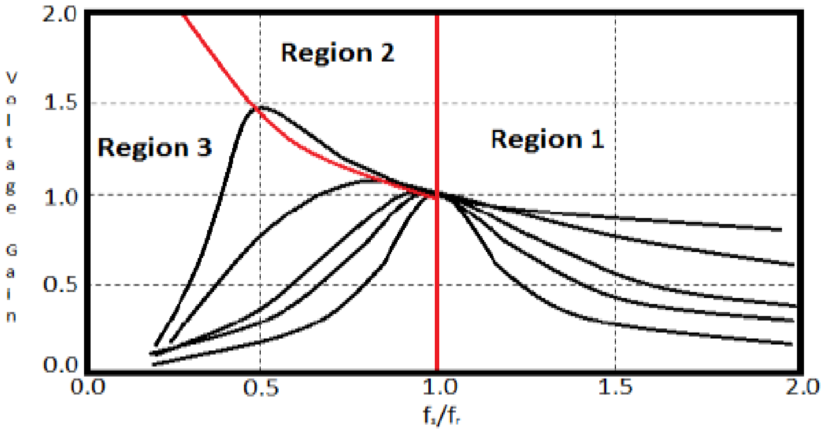

Fig. 5 Three Regions of Operation.

III. Digital Regulator For Inductor-Inductor Capacitor Resonant Convertor

Digital circuitry has several advantages over its analog counterpart. It is easy to modify or redesign. It provides great immunity to noise. Robustness and optimal control performance has dominant advantages over analog design.

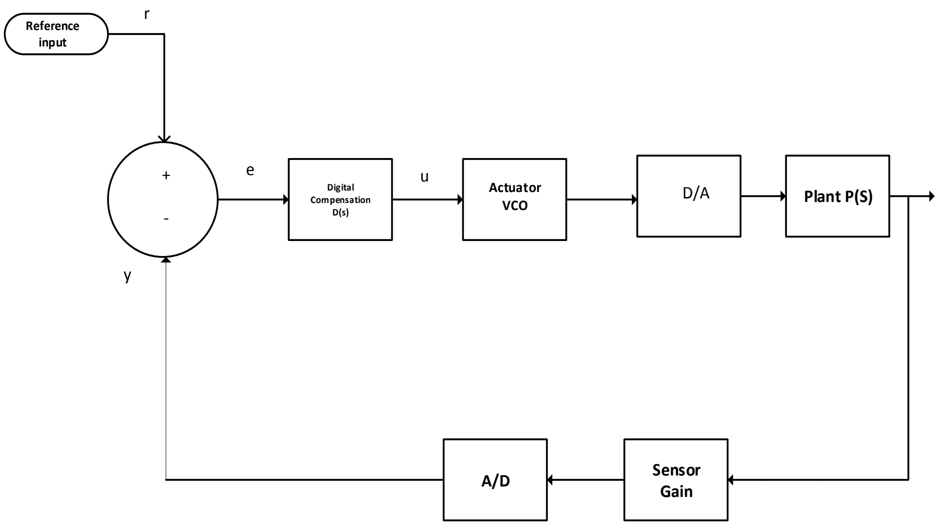

Fig.6 Block diagram of digital negative feedback loop

In fig.6.[24] [21]gives the suggested block diagram for the LLC resonance converter. Model in this method we used continuous-time and obtain good result in continuous-time form. This scenario changed into the discrete time z-domain by applying mathematical transformation.

Table.1. Hardware Descriptions of the LLC Converter

Component	**Value**
Series resonant inductor(L_s)	29.13µH
Series resonant capacitor(C_s)	0.606µF
Magnetizing inductor(L_m)	174 µH
Input Voltage(V_{in})	400v(DC)
Output filter capacitance(C_f)	1868.5 µF
Output Load resistance	1
ESR of output capacitor(r_c)	15mΩ
DCR of resonant inductor(r_s)	16mΩ
Switching frequency of LLC	116kHz
Duty ratio(D)	0.5
Sampling Time	1/45000
Transformer turn Ration (n)	22/3

We need here DC/DC converter for great results. We are searching a good form conversion of power sources its designed low cost product.The resonant converters such as single-ended and bridge type are also very popular in the last decade [2], [3]. And the basic switched-capacitor (SC) converters also have wide application as their advantages of nonmagnetic components employed and small size and high power density [4], [5]. As this trend continues, the requirements become more and more challenging. State-of-the-art voltage regulators apply switched-inductor converters combined with advanced nonlinear controllers [2]-[9] to minimize size and maximize the power processing efficiency.

Present-day switched capacitor technology has become an attractive alternative for volume-sensitive applications, featuring high efficiency and economical implementation [10], [11]. However, it lacks the capability of accurate voltage regulation without the penalty of introducing losses, and its transient characteristics are limited. These limitations stem primarily from the fact that the efficiency of SCCs depends on the voltage gain [12]-[15].

The objective of this study is to introduce a small and efficient voltage regulator that is realized by the GRSCC and a simple pulse density modulation control scheme (Fig.4). The new voltage regulator combines the virtues of both worlds: wide operation range with high efficiency (from switched-inductor converters) and reduced volume (from SCC). Following the recent proliferation of portable electronics, there has been a sharp increase in interest and demand for more compact, light, energy efficient and economical power sources [1].

IV. SIMULINK MODEL AND EXPERIMENTAL RESULTS

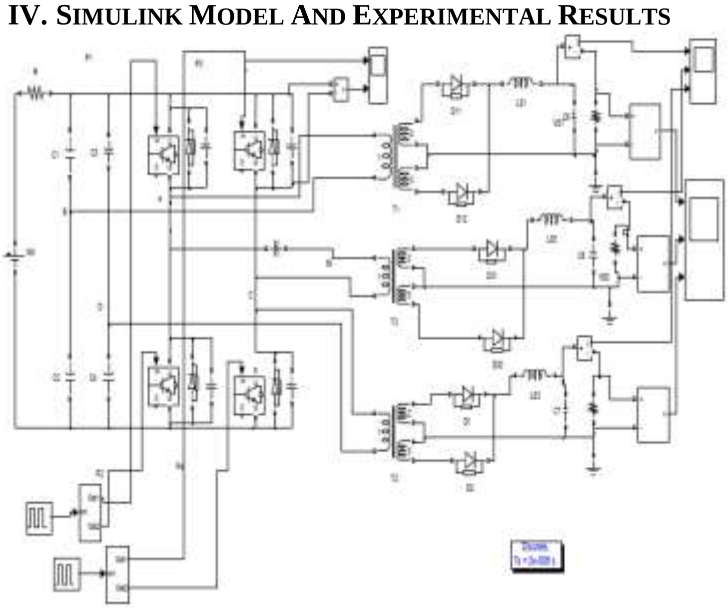

Fig.7. Simulink model

We have the plant transfer function obtained in Equation 3.30 and given below

$$G_{vw} = \frac{4.764e^{11}\left(s-4.031e^{5}\right)\left(s+3.568e^{4}\right)}{\left(s^{2}+1636+4.017e^{8}\right)\left(s^{2}+1.333e^{5}s+4.33e^{11}\right)}$$

Pole of function gives the information about the system transfer function where it will be undefined. Poles are obtained from the dominator of the transfer function polynomial. Poles are defined the states of the system whether they are stable, unstable, marginally stable. So in order to analysis of the system's response it is mandatory to find out its poles. With respect to pole location we have two types of system response.
1).Damped system. 2). Undamped system.
In undamped system we have damping ratio will be zero its poles having zero value of real components and imaginary poles (marginally stable) exists due to this the system behaviour will be oscillatory. We have further three categories of damped system as following-
1).Over damped. 2).Critical damped. 3).Under damped

Over damped system has no imaginary parts and it's all poles lies on the x-axis which means that all poles having only real part. The system whose poles lies on the x-axis on distinct points are called over damped system. Critical damped system has no imaginary parts it contains only real parts their poles exists near to each other. Under damped system has contains both real and complex poles. With respect to the system stability point of view if any pole of the system lies on the right half plane of the s-plane it will make the system unstable.
In order to stabilize such system we need some external force (compensator) which will relocate the pole to the left half plane. The Zero gives information about the function where its transfer function will be zero. After getting the plant transfer function $G_{vw}(s)$ in the continuous time domain by using MATLAB command "pzmap" ($G_{vw}(s)$) gives the pole and zeros map of the plant transfer function [22] which is given below in the following Fig.7.

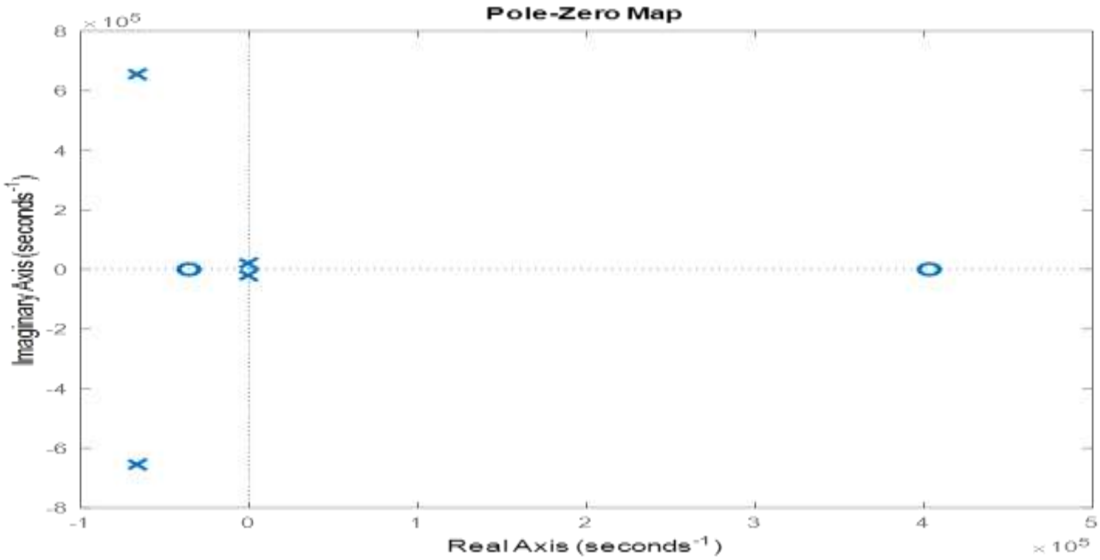

Fig.8. Pole zero map of the plant

From the Fig.8 it is shown that the system has 4 poles and 2 zeros in which two complex poles lies on the left half plane and remaining two poles lies on the y-axis with zero real part. The poles which lie on the y-axis make the system response marginally unstable. Surely we need produce compensator into the loop to move these poles to the appropriate position in order to avoid the system from instability. The same concept can also be illustrated by using the Bode plot. It gives the frequency response of the system.

The Bode plot off the LLC resonant converter (Open loop) is shown in Fig.8 It can be seen from the Fig.4.2.that the system shows phase margin of 39.1^{o} at frequency of $9.65e^{5}$. This phase margin is quite low it needs to be boosted up. For the system to give better static and dynamic response it need to be more than 45^{0}. So we need to introduce the controller into the loop to raise the phase margin.

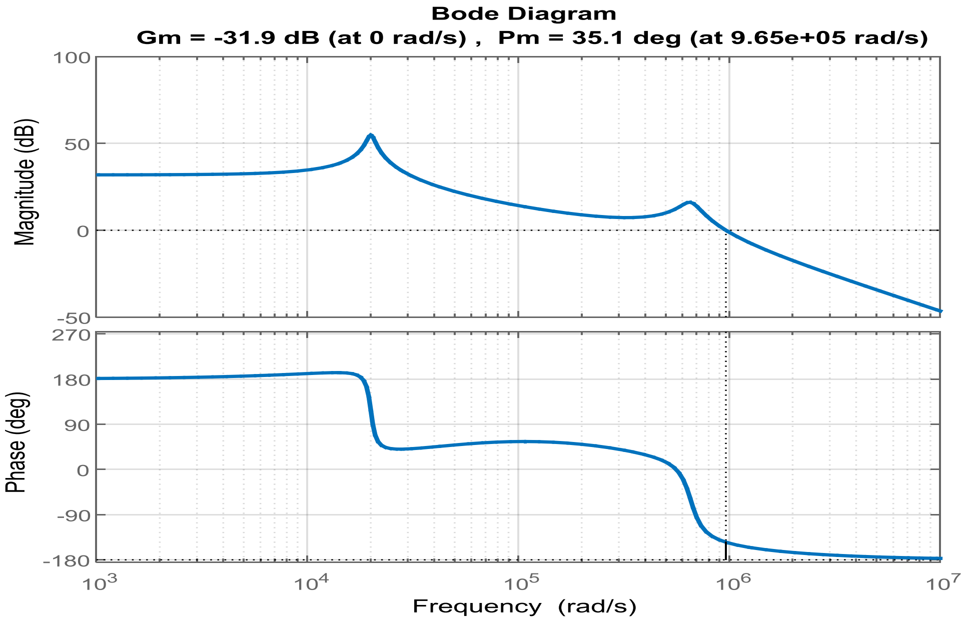

Fig.9. Bode diagram of the plant function.

With reference to Fig.8.and Fig.9 it can observed that our system is marginally unstable. As discussed earlier the two poles of our system are lies on y-axis that's way we need to design a compensator which shift our system from marginally unstable to the stable and our system will remain stable as long as compensator force will continue. So in order to stabilize the system we design a compensator whose transfer function is given below in s-domain.

$$G_{ci} = \frac{0.004943s^2 + 8.085s + 1.986e^6}{s^2 + 1044s}$$

After analysing the step response of the loop compensator in which our system is stable its saturation value is 12-V and as shown in the Fig.4.3. Our system is approached to ideal in which the sampling time of our system is approximate to 0.15 second and the rise time of our system is approximate to 0.06 second. The compensator analog system is given step responses by the Fig.10.

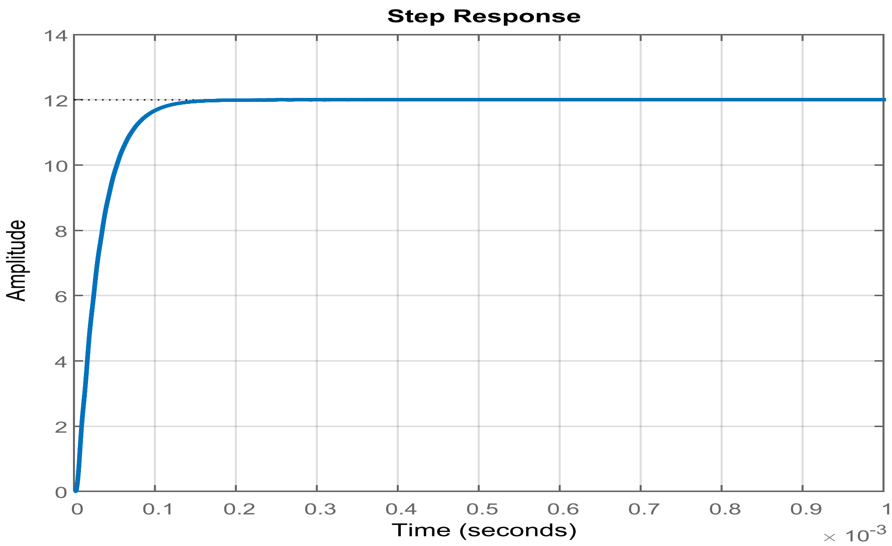

Fig.10. Step response of the analog controller

While shifting from continuous time domain to digital domain we have to adopt some transformation techniques like Numerical integration method, Matching or pole zeros mapping, whole equivalent technique. There are three categories of numerical integration technique as follows

- Forward rectangle rule
- Backward rectangle rule
- Trapezoid rule or Tustin method or bilinear transformation method

All these three methods are mapping methods which are used to shift the function from continuous domain to digital domain.All methods have pros and crones. The most effective and useful method among them is bi linear transformation technique. By using this method we are actually shifting our function from s-domain to z-domain. When we are shifting out system from s-domain to the z-domain we are using the following formula.

$$s = \frac{2}{T}\left(\frac{z-1}{z+1}\right)$$

Where: T = 1/FWith reference to the system stability point of view we have discussed the location of the poles either left or right side while we are taking about z-domain we will consider the location of the poles inside the unit circle.We have the transfer function of the analog compensator in Equ 3.31 as given below

$$G_{ci} = \frac{0.004943s^2 + 8.085s + 1.986e^6}{s^2 + 1044s}$$

Using MATLAB we are using the built-in function c2d (H, T,'Tustin') to change its domain from s-domain to z-domain. In this built-in function H is the representation of continuous transfer function, T represents time period and Tustin is the method name. After applying the bilinear transformation technique on the compensator we get a digital compensator as represented in the Equ 3.32 given below.

$$G_{id} = \frac{0.005218z^2 - 0.009288z + 0.00504}{z^2 - 1.9772 + 0.9771}$$

The step response of the digital compensator is given in the Fig.10. After analysing the step response of the loop compensator in which our system is stable its saturation value is 12-V and as shown in the Fig.11. Our system is approached to ideal in which the sampling time of our system is approximate to 0.15 second and the rise time of our system is approximate to 0.06 second.

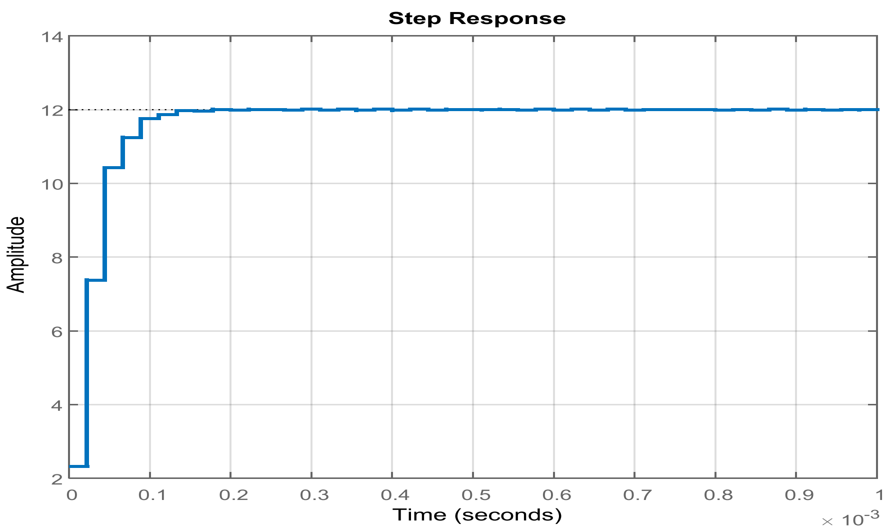

Fig.11.Step response of the digital compensator

From Fig.10and Fig.11 It has been observed that mapping has been done quite smoothly. The overall comparison of the step response of analog compensator and digital compensator is represented in the Fig.12.

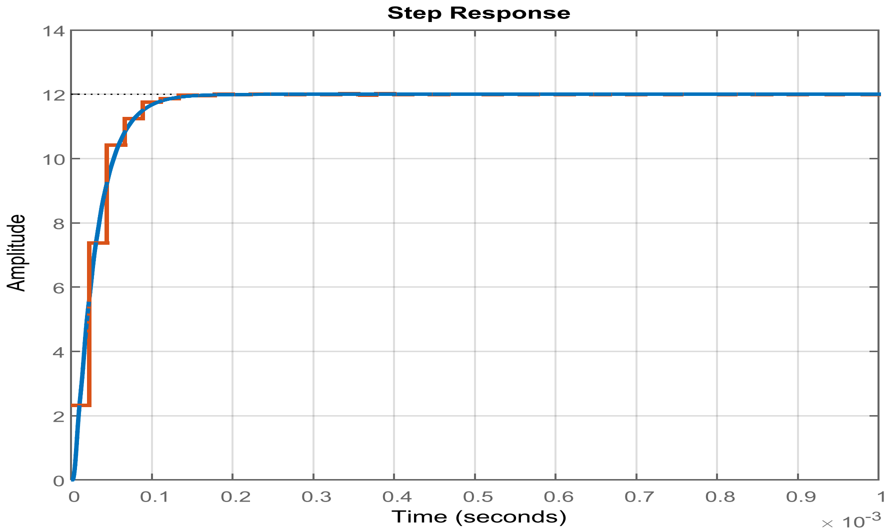

Fig.12. Overall comparison of analog and digital compensator

V. Conclusion

the proposed research work would be divided into two parts, first part is the identification and second part is the controller design and also we are investigate ZVS behaviour of the resonant LLC converter with switching network and resonance tank. We are done this investigation by assumptions and fast prediction of ZVS region of different converter designs. The proposed research work would be divided into two parts, first part is the identification and second part is the controller design. ZVS different regions of converter designs cannot do by voltage transfer function of LLC converter. It's based on the series current waveform only and they produced calculated results. Develop the closed-loop and the open-loop models using closed-loop test.

Find out mathematical analysis to develop the correlation between the process parameters and the data obtain in the closed-loop test. So, when a plant is in operation it is in closed-loop configuration and then the identification may be performed without disturbing the plant operation and existing controller may be re-tuned for performance improvement. Compared to the open-loop system identification methods, closed-loop methods are often more desirable in industrial applications because they offer less disruption to the operation of the system. In this research SC converter always keepvoltage stress is high because of using switches tank.

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