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Analysis of Single Phase AC-DC Isolated Zeta Power Factor Converter

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ABSTRACT

The power electronic converters and systems finds wide, ample and unexampled applications including defense sector, Industrial sector, automotive sector and other sectors. Still Total harmonic distortions and low power factor in power systems are major concerns created by Power converters. There are major impact of using conventional technique Single phase AC-DC conversion using a power semiconductor diode bridge with huge capacitor like as low order harmonics injection into AC power supply, low power factor, high peak current, line voltage distortion, increased electromagnetic interference and various additional losses. In this paper, Single phase AC-DC isolated ZETA converter with one power electronic switch is embraced to subjugate the several issues. By espousing the essential methodology such as Proportional Integral controller with Hysteresis current controller, it will meliorate the overall power factor and efficiency as well as subdue Total Harmonic Distortion and Voltage ripples will be reduced to the desired levels.

Keywords : PI Controller, Hysteresis Current Control, Power Factor, THD and Zeta Converter.

I. INTRODUCTION

Power electronics is a growing field due to the improvement in switching technologies and the need for more and more efficient switching circuits. Power electronics refers to the control and conversion of electrical power by power semiconductor devices wherein these devices operate as switches. AC/DC power converters are extensively used in various applications like power supplies, dc motor drives, and front-end converters in adjustable-speed ac drives, HVDC transmission, SMPS, utility interface with non-conventional energy sources, in process technology like welding, power supplies for telecommunications systems, and aerospace, military environment and so on [4,7,12-17]. Most power supplies are designed to meet regulated output, isolation and power factor correction (PFC). By applying the power factor correction circuit, the input current can be forced to be a sine wave with the same phase as the input voltage. Therefore, it is of great necessity to apply the PFC to the switch mode power system.

Power factor correction (PFC) converters aim to increase the power factor (PF) and decrease the total harmonic distortion (THD) of the input current. Power factor correction (PFC) is necessary for ac-to-dc switched mode power supply in order to comply with the requirements of international standards, such as IEC-1000–3–2 and IEEE-519. [1-7].It is a well-known fact that the input current of an SMPS tends to have a non-sinusoidal, distorted waveform [18-23]. The distorted line current of a power converter is composed of the line frequency component and higher frequency harmonic components of the current.PFC can reduce the harmonics in the line current, increase the efficiency and capacity of power systems, and reduce customers' utility bills. In order to achieve unity power factor in the switched mode power supply, many control methods can be used including average current control, peak current control, hysteretic control, nonlinear carrier control, etc. [6-11]. In this work PI with hysteresis current control is employed.

The conventional technique of AC – DC conversion using a diode bridge rectifier is no longer in use due to various problems such as low order harmonics injection into AC power supply, low power factor, line voltage distortion etc [1]. Various topologies are introduced to overcome the above mentioned problems. Recently, single stage AC – DC Zeta converters have been widely used to improve the power factor and to reduce the harmonics [2]. A single stage Zeta converter is chosen for implementing a low cost and a low power converter [3]. The operation of Zeta converter in continuous conduction mode is discussed in [4] and [6]. Zeta converter is originally a buck boost type but it can be regarded as a fly back type when isolation transformer is incorporated [24]. By using high frequency transformer, Zeta converter provides high safety at the output side and provides flexibility for output voltage [25-28].

II. OPERATION

The isolated Zeta converter is a single stage converter which consists of a single switch, output capacitor, a coupled inductor, one flying capacitor, and a diode. Figure 1(a) shows the circuit diagram of an isolated Zeta converter.

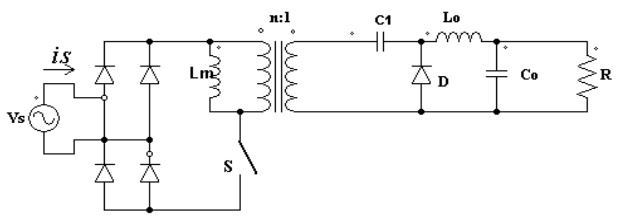

Figure 1(a) : Circuit diagram of an isolated Zeta AC-DC converter

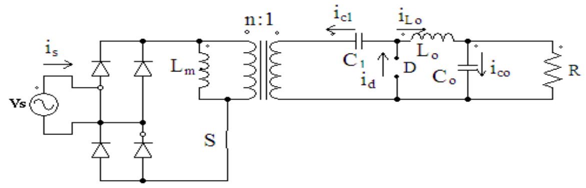

Figure 1(b): When the switch is in ON condition

Figure 1(b) shows the operation of isolated Zeta converter, when the switch is in ON condition. When the switch S is in ON condition and the diode D is in OFF condition, the inductor Lm stores the energy from the rectifier. The capacitor releases the energy to the load through the inductor Lo. As the diode is in reverse bias condition, no current flows through the diode. The current flowing through the inductors Lm and Lo increases.

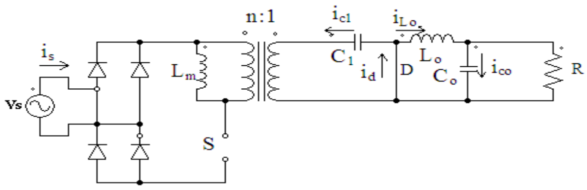

Figure 1(c) : When the switch is in OFF condition

Figure 1(c) shows the isolated Zeta converter operation, when the switch is in OFF condition. During this time, diode D is in ON condition. It is forward biased because the polarity of the voltage across the inductor Lm gets reversed and the current flowing through the inductors Lm and Lo decreases. The stored energy in the inductor Lm is transferred to Capacitor C1 and the load receives the energy through inductor Lo.

III. PI VOLTAGE CONTROLLER

Proportional Integral (PI) control is the most common closed loop control method used in industry today. The popularity of PI controller can be attributed to its effectiveness in a wide range of operating conditions and their functional simplicity.

In general, PI controller provides better regulation. It acts as a voltage regulator and it is used to compensate the DC-link voltage and reduce the voltage ripple across the capacitors .The PI controller takes into account the desired output of the converter (set point) and its actual state and thus finds the error. Based on this error, it works to apply the input necessary to obtain the desired output. In general PI controller provides better regulation. It acts as a voltage regulator and it is used to compensate the dc-link voltage and reduce the voltage ripple across the capacitors. PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller [9].

A proportional controller (K_p) has the effect of reducing the rise time, but never eliminates the steady-state error. An integral control (KI) has the effect of eliminating the steady-state error, but it may make the transient response worse.

IV. HYSTERESIS CURRENT CONTROLLER

Hysteresis controller shown in Figure 3 is used to control the output value within boundary. The hysteresis control is used in AC/DC converter mainly to force the AC line current to follow a given reference. Such a control is mainly required in boost converters so as to improve power factor and reduce inductor current ripples.

In zeta converters, the hysteresis controller is used to control the inductor current. So regardless of the current starts, the switch action pick up as soon as a boundary is encountered. The current rises from 0 to I_{Lhigh} amps at a rate limited by the L and C values. The MOSFET's then turns off and remains off until the current falls to I_{Llow} [7]. Once the inductor current is between the boundaries, the switch action keeps it in the vicinity of the boundaries under all conditions. The general operation becomes independent of the line, load, inductor, and capacitor values. The hysteresis control eliminates the output variations other than the ripple and this is called robustness.

In the Figure 2, two references IL high and IL low are used, one speak and the other as valley inductor current. According to this control technique, the switch is turned on when the inductor current goes below the lower reference and is turned off when the inductor current goes above the upper reference, giving rise to a variable frequency control [7].

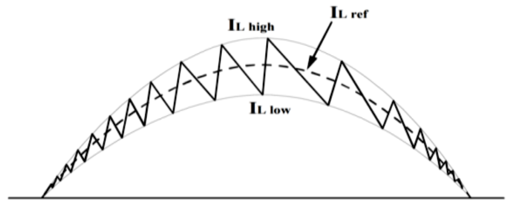

Figure 2. Inductor current waveform under hysteresis control

Current based hysteresis control can be implemented along the lines of the two-loop method.. A PI block can use the voltage error signal to provide a current value for a hysteresis control. A system based on this configuration is shown in Figure3.

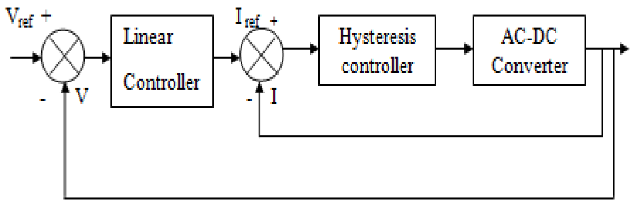

Figure 3 : Block diagram of proposed converter

V. DESIGN OF THE CONVERTER

The following equations show how to design isolated Zeta converter operating with Ac source voltage V_S, Dc output voltage V_o, Switching frequency f_s and Duty cycle D. In order for the circuit to function properly, the external components need to be calculated. Initially the calculated duty ratio of the converter is 0.74 which is expressed as

$$D = \frac{Vout}{Vout+Vin} = 0.74$$

Output inductance Lo is obtained by,

$$L_o \geq \frac{(1-d_1)R}{2f_s} \qquad (1)$$

Where,

d_1 =Duty ratio

R = Load resistance

fs=Switching frequency

Magnetizing Inductance (Lm) is given by,

$$L_m \geq \frac{(1-d_1)^2 R}{2n^2 f_s} \qquad (2)$$

The capacitance value of flying capacitor is given by,

$$C_1 \geq \frac{V_o d_1}{2R\Delta V_{c1}} \qquad (3)$$

Where,

ΔVc1=Voltage ripple across the flying capacitor

The capacitance value of output capacitor is given by,

$$C_0 \geq \frac{V_o(1-d_1)}{8f_s^2 L_o \Delta V_{co}} \qquad (4)$$

Where,

Vo =Output voltage

ΔVco = Voltage ripple across the output capacitor

Output voltage equation is given by

$$\frac{V_o}{V_g} = \frac{nd_1}{(1-d_1)} \qquad (5)$$

Where,

Vg is Input peak voltage

n is turns ratio

In this paper, simulation of isolated Zeta converter has been performed with resistive load. The isolated Zeta converter is fed by a 1φ supply which has a line voltage and frequency of 20 V and 50Hz, respectively. The switching frequency of the isolated zeta converter is 50 kHz. Magnetizing inductor (Lm=330μH), Output inductor (4mH), flying capacitor (C1=10mF), output capacitor (Co=1000μF) are calculated as per the design formulae. The isolated Zeta converter provides an output voltage of 48 V.

VI. RESULTS

MATLAB is a high performance language for technical computing. It integrates computation, visualization and programming in an easy to use environment where problems and solutions are expressed in familiar mathematical notation. To analyze the performance of the various AC to DC converters, detailed simulations are carried out on MATLAB platform. The converter is compared in terms of THD, power factor and efficiency.

A.OPEN LOOP SYSTEM

Figure7 shows the simulated circuit diagram of open loop control of single phase ac-dc isolated Zeta converter with resistive load.12volt single phase AC supply is fed to the bridge rectifier. A pulse generator is used to apply the gating pulses to power MOSFETs. In this circuit, voltage and current waveforms are measured with voltage and current measurement block. The input voltage and current waveforms are shown in Figure8.

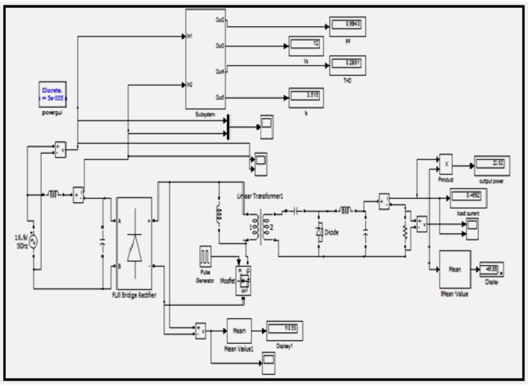

Figure 7. Open loop simulink model of single phase AC-DC isolated Zeta converter

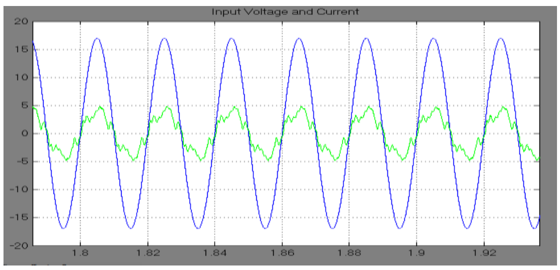

Figure 8. Input voltage and current waveforms in open loop

Fig. 9 shows the output voltage and current waveforms of the single phase ac to dc isolated zeta converter in openloop control.

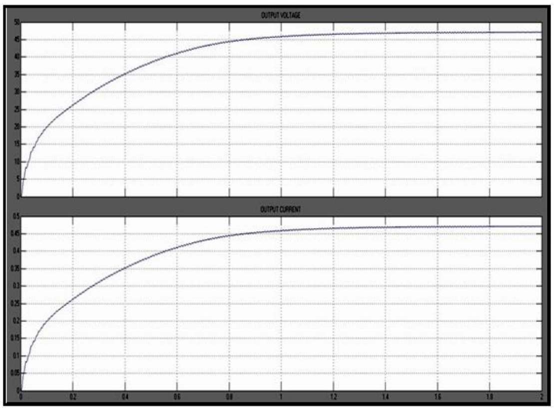

Figure 9. Output voltage and current waveforms in open loop

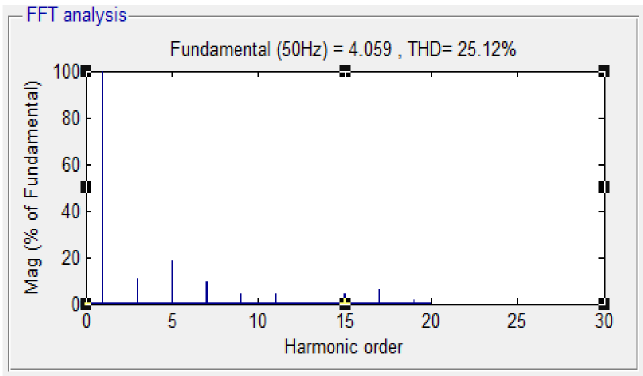

Figure 10. FFT analysis for open loop.

B.PI AND HYSTERSIS CONTROLLERS (CLOSED LOOP)

Figure 11 shows the simulated circuit diagram of closed loop control analysis using PI with Hysteresis current control of AC-DC isolated zeta converter. Here, the output voltage is compared with the reference voltage (Vref) which is then fed to the PI controller. In HCC, the rectified output voltage and the PI controller output are multiplied and provide the current reference. The inductor input current is compared with the current reference and it is processed by a relay and the output is fed to the switch as the gating pulses.

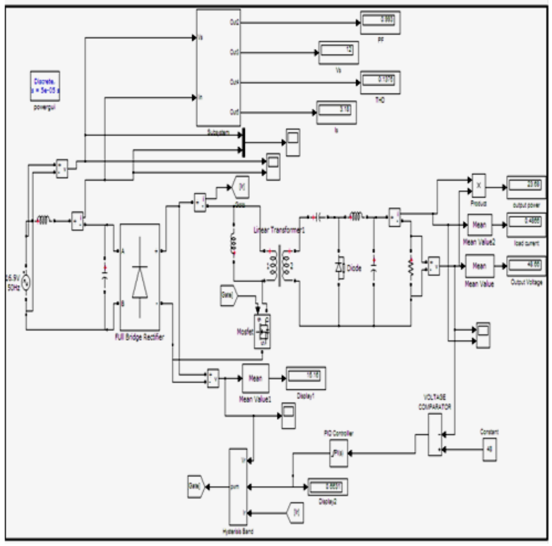

Figure 11 Simulink model of AC to DC isolated Zeta converter using closed loop

The input voltage and current waveform are shown in Figure 12, the resulted output voltage and current waveforms are shown in Figure 13.Here, the input current waveforms are less distorted when compared with open loop control. Therefore THD is reduced to 11.85%.

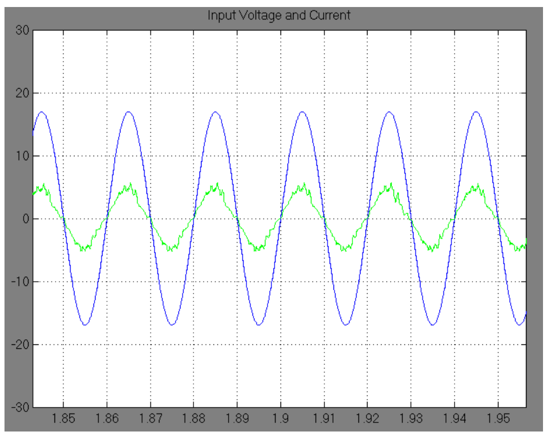

Figure 12 Input voltage and current waveforms using closed loop control

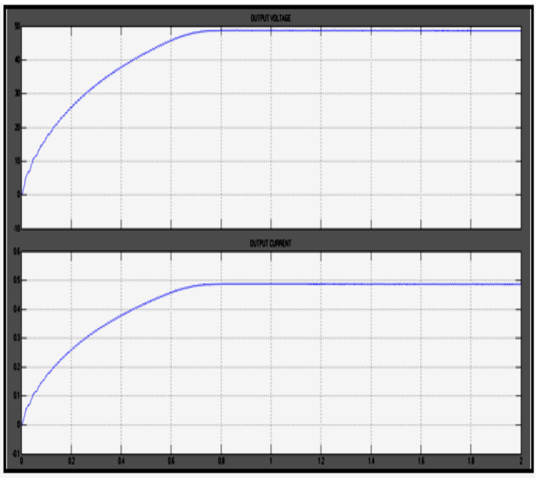

Figure 13 Output voltage and current waveforms using closed loop

Figure 14 shows the FFT spectrum of the single phase ac to dc isolated zeta converter in closed loop analysis using PI with HCC.

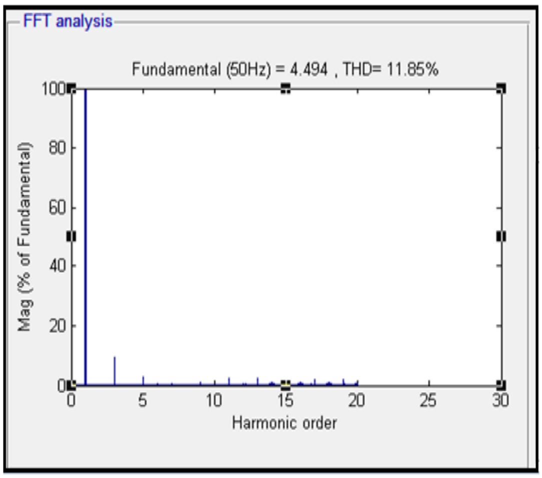

Figure 14 FFT Analysis of the converter using closed loop

C.COMPARISON OF OPEN AND COLOSED SIMULATION RESULTS

The performance factors such as THD, Power factor, Efficiency and regulation of the output voltage is compared in the single phase AC to DC isolated Zeta converter for various control techniques and it is tabulated in the table1.

TABLE I
COMPARISON OF PERFORMANCE PARAMETERS OF AC-DC ZETA CONVERTER

Parameters	Open loop	Closed loop
Output Voltage (volt)	49.6	48
THD (%)	25.1	11.85
EFFICIENCY (%)	68.22	88.6
POWER FACTOR	0.78	0.99

VII. CONCLUSION

The single phase AC to DC isolated Zeta converter's open loop analysis and closed loop analysis such as PI with hysteresis current control are done using MATLAB. In Higher up discourse and computer simulations depict trimmed down THD and power factor to unity with minimum harmonic distortion in PI with HCC compared to open loop analysis. For Dynamic tests the PI with hysteresis control demonstrated that its better compare to open loop control. By employing PI with Hysteresis control, the power factor value incurred is merely equal to unity and THD is also scaled down.

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