Design of Quasi-Resonant Flyback Topology for wide range input

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***Abstract*—A standard flyback converter that selects the best operating conditions among different control scheme (converter Load and Input voltage), to achieve minimum turn-on losses, low electromagnetic interference (EMI) emission, with short-circuit protection and optimized efficiency, is presented in this paper. The control schemes used are: Quasi Resonant mode, valley-skipping mode and Burst-mode. Quasi resonant mode takes place at heavy load or/ converter low input voltages. The converter operates close to boundary conduction mode (BCM) and continuous conduction (CCM). Valley-skipping mode operates at medium/ light load or converter medium input voltage. Externally programmable oscillator of Power IC L6566BH, synchronized to turn on MOSFET, operates at converter maximum frequency. Burst mode operates at no load or very light load or at converter high input voltage. This converter has unique advantage of operating either on fixed frequency mode or variable frequency mode depending on the wide range of input voltage and load.**

***IndexTerms*—Quasi-Resonant; Valley-skipping; Power IC; Flyback Converter**

Nomendature

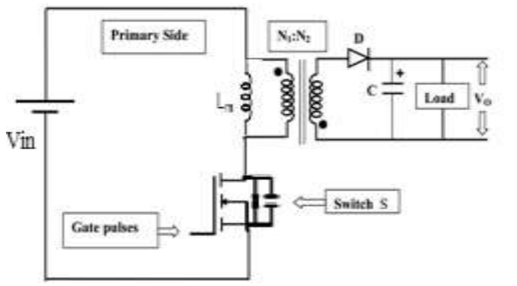
η =efficiency
P_{in_max} = Maximum input power
P_{out} = output power
f = switching frequency
$Ipri_{pk}$ = primary peak current of transformer
I_{avg_pri} = primary average current
$I_{RMS,pri}$ = primary rms current
I_{avg_sec} = secondary average current
$I_{RMS,sec}$ = secondary rms current
Lpri = primary inductance of transformer
Lsec = secondary inductance of transformer
Vin = input voltage
VR = reflected voltage of primary side
CD = capacitance of drain
$VDC._{min}$ = minimum input voltage
$VDC._{max}$ = maximum input voltage
Fsw_min= minimum switching frequency
Vac = AC input voltage
V_{ACmax} = AC maximum input voltage
dcharge = duty ratio of DC link capacitor after bridge rectification.
D*max* = Defining transformer turns ratio and Maximum Duty cycle of controller
N_{Pri} = turns in primary winding
N_{Sec} = turns in secondary winding
N_{aux} = turns in auxiliary winding
V_{out}^* = total output voltage
V_{out} = output voltage
V_D = voltage drop across diode
F_{line} = input voltage frequency.
Cin = input capacitor after bridge diode
n = turns ratio
Dmax = maximum duty ratio
A_e = Cross-Sectional Area
B_{sat} = flux density
A_w = Winding Area [9]

I. INTRODUCTION

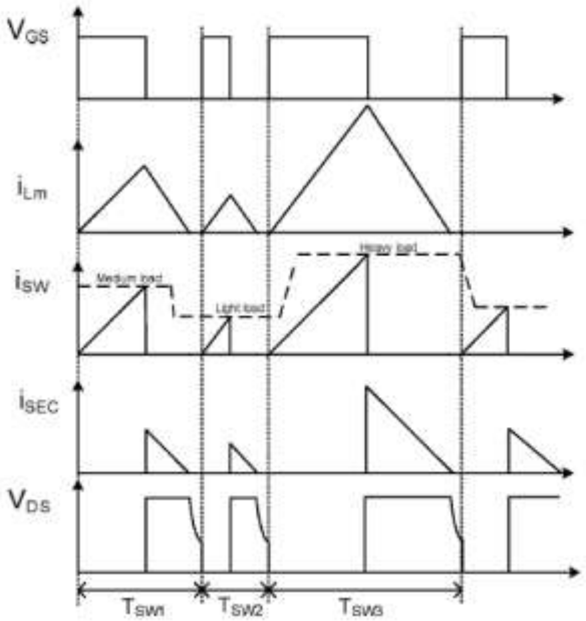
The use of power electronics in various industries is becoming more and more extensive because of the highlighting features of power electronics devices including high efficiency, better properties to withstand rough environmental conditions and longer life [6]. These features are met by using switch-mode power supplies and also modern electronics offers complex device that contain various kinds of applications, such as LED ballast display, radio communication, navigation, audio, video, automation, control, etc. Therefore, Analog and digital signals, high and low frequency signals, high and low power levels, etc., are taking place in the same package, or even more, on the same Printed Circuit Board (PCB).

Flyback topology has been fruitful in low power off-line switching converters for its simplicity and versatility.[18] Diverse control plans and strategies have been utilized as a part of get better efficiency or different viewpoints[1]. In order to reduce conduction losses with no adjustment in circuit topology the Quasi Resonant control (QR) control plan has been effectively utilized. The fundamental point of preference of QR is the low voltage over the power MOSFET switch at its turn-on that permits low conduction losses [3].

Fig.1 shows the Quasi-resonant converter circuit and its waveform. In this circuit the process turning on of MOSFET is synchronized with the instant of complete demagnetization of transformer and the instant of negative going edge of voltage in biasing twisting of transformer. In this manner, the converter works close tothe boundary conduction mode (BCM) and continuous conduction (CCM) of thetransformer. [19] As a result, the switching frequency is diverse for various line voltages and load conditions. Hence this converter has advantages of operating withminimizing the conduction losses, low electromagnetic interference. And safe conduct against short-circuit conditions. [1]



(a)



(b)

Fig. 1 Quasi-resonant converter, (a) Topology (b) waveforms

II. TYPE STYLE AND FONTS OPERATION OF QR FLYBACK CONVERTER TOPOLOGY

A. Principle of operation

Following assumptions are made for the ease of analysis of circuit operation. [2]

1. All parts are ideal. Except the magnetizing inductor Lm, and hostile to parallel diode, the channel source capacitance C_{DS} of MOSFET switch.
2. The output capacitance C_o of the converter is large enough to maintain steady voltage.
3. The leakage inductance is streamlined to make the investigation basic.

The components magnetizing inductor Lm, antiparallel diode of MOSFET switch, and stray capacitance of switch play an important role in the operation of QR flyback converter.[2]

The operation of converter in one switching cycle is explained by the following three modes according to current flow in the circuit [2], as shown in Fig.2. The corresponding waveforms are shown in Fig.3.

Mode 1: During interval t_0<=t<=t_1, **t**he MOSFET switch is turned on by gate pulse, the output diode is reversed biased with output capacitor voltage, and so diode is in off state. The voltage across the diode is

$$V_D = \frac{V_{in} + V_0}{n} \quad (1)$$

The C_o capacitor provides the energy to load, $R_{load.}$ During this period, the magnetizing inductor L_m stores energy due to supply voltage V_{IN}, and the current i_{Lm} in L_m increases linearly. This mode concludes with turning off the switch S and next mode begins.

Mode 2: During this mode---, MOSFET switch S is in off state.[12] The output diode D is forward biased and starts to conduct. The output voltage is reflected on to the primary side of transformer and hence the voltage V_{DS} across switch S is

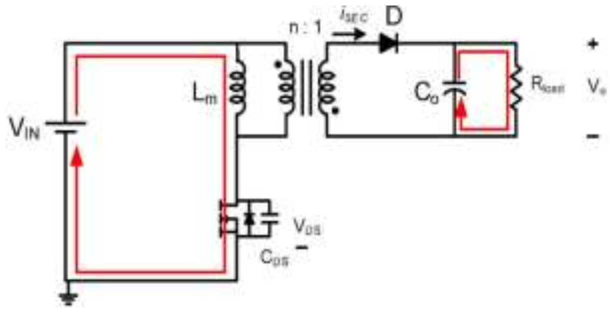
$$V_{DS} = n * V_O + V_{IN} \quad (2)$$

The energy stored in magnetizing inductor L_m is transferred to the C_o capacitor, and load. As the magnetizing current i_{Lm} of transformerreaches zero, this mode concludes and mode 3 begins.

Mode 3: During this mode---, the output diode D and MOSFET switch S both are in off state. As the transformer inductor L_m demagnetized with output. The vitality put away in the capacitance C_{DS} of MOSFET switch S, starts resonating with the magnetizing inductance L_m. The vitality required by the load is given by the C_o and V_{DS} achieves the valley voltage, as appeared in equation (3). Then, the MOSFET switch S, is turned on, and next exchanging cycle begins.[2]

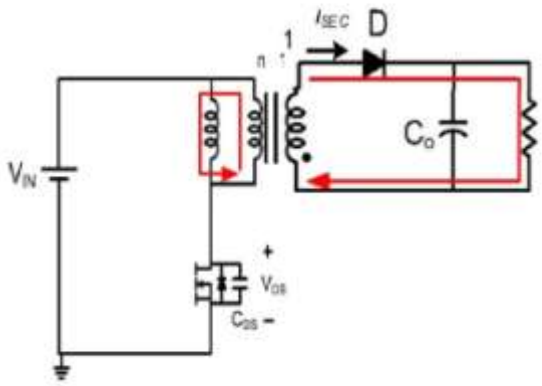
$$V_{valley} = V_{IN} - n * V_O \quad (3)$$

Mode 1



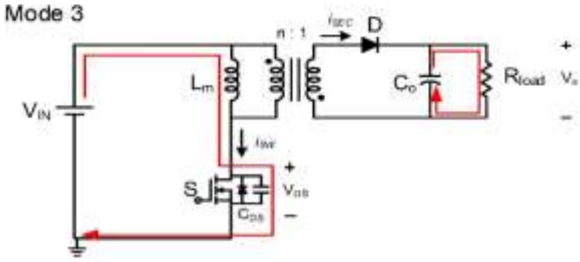
(a)

Mode 2



(b)

Mode 3



(c)

Fig.2 Current direction of the QR flyback converter (a) mode 1 (b) mode 2 (c) mode 3

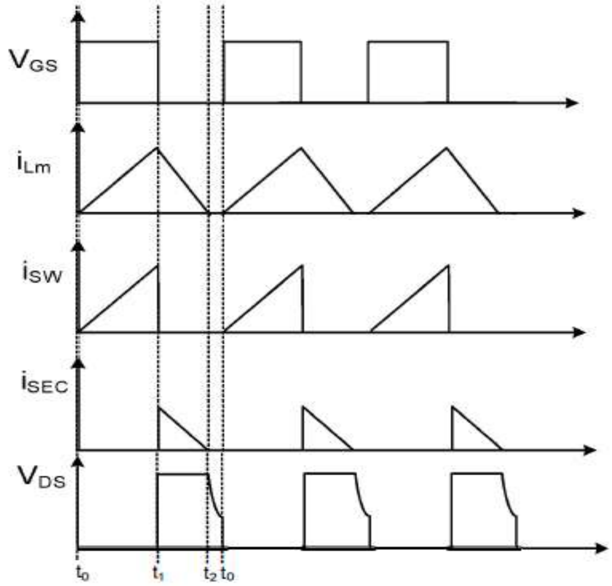


Fig.3 Key waveforms of QR flyback convert

B. Design and schematic of Flyback converter

The design of flyback converter depends on the range of switching frequency. In turn, the operating range of switching frequency depends on the range of input voltage variation and load requirement, efficiency, and maximum input power. The maximum input power required is presented by equation (4).[15]

$$P_{in\_max} = \frac{P_{out}}{\eta} \quad (4)$$

The switching frequency range is selected as function of offline input voltage as shown in equation (5). [5]

$$f = \frac{1}{\mathrm{Ipri}_{pk} * \mathrm{Lpri}\left(\frac{1}{V_{in}} + \frac{1}{V_R}\right) + \pi\sqrt{\mathrm{Lpri}*\mathrm{CD}}} \quad (5)$$

The primary inductance of transformer is selected for the minimum input voltage as shown in equation (6).[5]

$$L_{pri} = \frac{1}{\left[\left(\sqrt{2*P_{im\_max}*F_{sw\_min}}\right)\left(\frac{1}{VDC_{min}} + \frac{1}{VR}\right) + \pi*F_{sw\_min}*\sqrt{C_D}\right]^2} \quad (6)$$

Fig.4 shows the variation of voltage across DC link capacitor. VDC_{min} is minimum and lowest value of AC input supply voltage and VR is the reflection voltage primary side. this is $n*V_o$. d_{charge} is typically 0.2, C_{in} is the input capacitor and assumed between 1.5-2 uF per Watt. As per design concern of filter capacitor. and f_{line} is frequency of supply voltage.[5]

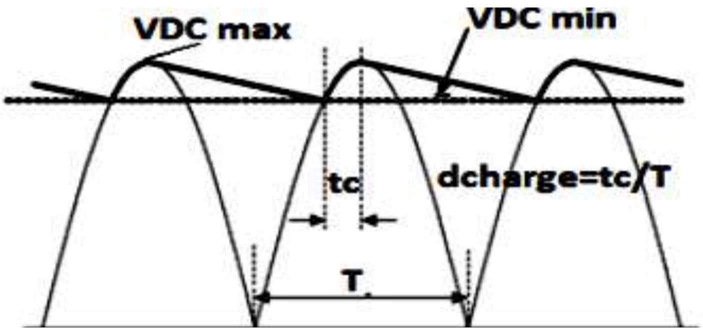


Fig.4 DC link capacitor max and min volt

$$VDC_{min} = \sqrt{2 * V_{ac}^2 - \frac{Pin_{max} *(1-d_{charge}}{C_{in} *Fline}} \quad (7)$$

D_{max} is the maximum duty ratio of transformer, and n is the turns ratio of transformer are represented in equation (8) [8].

$$D_{max} = \frac{1}{V_{DC\_min}} * \sqrt{2(P_{in\_max}) * Lpri * F_{sw\_min}}) \quad (8)$$

$$V_{out}^{*} = V_{OUT} + V_D$$

Selection of the core: the core of the transformer is selected from the Table 1 at the switching frequency is 100 kHz. The best selection is made from table no 1, based on best choice material, operating power and switching power. The core selected among power ferrite core and MnZn ferrite. Having permeability from 2000-2500. [6]

Table 1 Core geometries and typical pulse transformer operating at 100 kHz.

Core geometry	Transformable power (W)		
	Flyback converter	Forward converter	Push-Pull Converter
ER 11/5	8.5	10	14
ER14.5/6	20	23	32
EFD15	26	30	42
EFD20	50	57	80
EE12.6	17	20	28
EE16	41	48	67
EE20	73	85	118
EE25	135	155	218

Evaluation of primary turns: according to equation (10) the primary turns depends on the primary inductance, primary peak current, flux density, cross sectional area.

$$N_{Pri} > \frac{L_{pri} * I_{Pripk}}{B_{sat} * A_e} \quad (10)$$

$$I_{Pripk} = \sqrt{\frac{2 * P_{in\_max}}{L_{pri} * F_{sw\_min}}} \quad (11)$$

$$I_{avg,Pri} = \frac{P_o}{V_{DC\_IN} * D} \quad (12)$$

$$I_{RMS,Pri} = \frac{P_o}{\sqrt{V_{DC\_IN} * D}} \quad (13)$$

$$I_{avg,sec} = \frac{I_o}{1-D} \quad (14)$$

$$I_{RMS,sec} = \frac{I_o}{\sqrt{1-D}} \quad (15)$$

$$L_{sec} = L_{pri} * \frac{N_{sec}}{N_{pri}} \quad (16)$$

The secondary inductance with aripple of 25% is given in (16). [16]

Wire cross section is selected from table 2 based on the power loass and temperature rise. [16]

Tab. 2 : wire gauges transformer windings

Wire diameter (mm)	AWG	Outer diameter (mm)	DCR/Turn (mΩ/Turn)							
			ER11	ER14.5	EFD15	EFD20	EE12.6	EE16	EE20	EE25
0.1	38	0.125	57.18	71.47	69.62	90.26	63.53	92.65	103.23	139.76
0.15	34	0.177	24.00	30.00	29.22	37.89	26.66	38.89	43.33	58.66
0.2	32	0.239	13.10	16.38	15.96	20.69	14.56	21.23	23.66	32.03
0.28	29	0.329	6.55	8.19	7.98	10.34	7.28	10.62	11.83	16.01
0.3	28	0.337	5.68	7.10	6.91	8.96	6.31	9.20	10.25	13.88
0.35	27	0.387	4.13	5.16	5.03	6.52	4.59	6.69	7.46	10.10
0.4	26	0.459	3.14	3.92	3.82	4.95	3.49	5.09	5.67	7.67
0.5	24	0.566	1.97	2.47	2.40	3.12	2.19	3.20	3.57	4.83

C. Design Schematic of AC/DC converter using QR Flyback topology

The topology of this converter is Quasi-Resonant flyback, working in Continuous and boundary conduction is between continuous and discontinuous conduction mode with variable switching frequency for variable load and line conditions, fit for the accomplishing synchronizing MOSFET turn-on the [1] Transformer's demagnetization by recognizing the subsequent negative going edge of the voltage over any twisting of the transformer, the conventional of AC/DC converter is in Fig. 5.

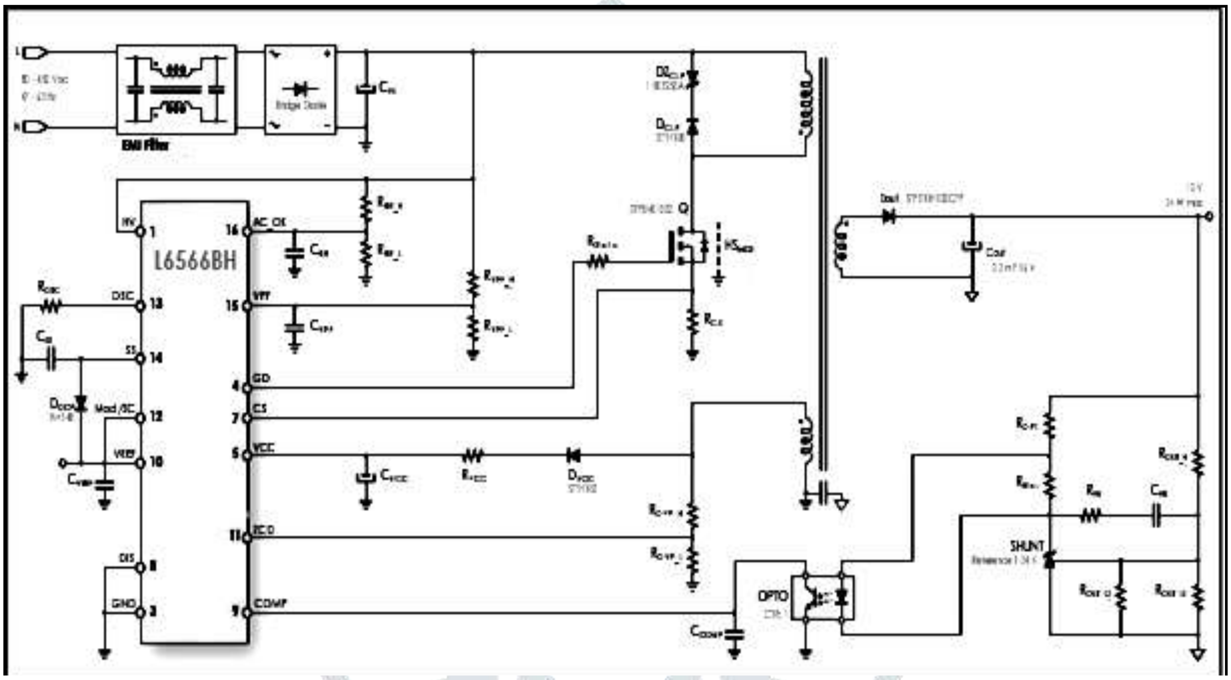


Fig. 5 Schematic of AC/DC converter

For the applications of LED ballast Video Display, power supply is designed on the requirement of 12V, 2A. the design specifications are as fallows with input supply ranges.

Input: 80 - 450 V_{ac} (47 - 63 Hz) - Nominal: 230 V_{ac}
Output: 12 V (2 % ripple) - 24 W_{max}
Switching Frequencyf_{sw}: 30 - 120 kHz
Expected Average Efficiency: 87%
Transformer design Specifications:
L_{Pri} : 1.38 mH **leakage** : 13.8 uH is 1% $L_{Pri.}$
I_{pripk} : 1.15 A **$I_{avg,pri}$** : 20 mA
I_{RMSpri} : 382 mA **$I_{RMS,sec}$** : 3.42 A
$I_{rms,aux}$: 34 mA
N_p/N_{aux} : 11.719, **N_{Pri}/N_{sec}**: 11.719,
Core:Type E25/13/7 **Area Product** 3202 mm^4
Volume (V_e) 3020 mm^3 **(A_e)** 52.50 mm^2 - **(A_w)** 61.00 mm^2 **Core gap:** 0.55mm
Primary:105T, **Secondary:** 9T, **Auxiliary:** 9 T, T-turns.

D. Controller functonal diagram and Operation modes with different loads conditions.

This controller operates with both fixed frequency and QR frequency by selecting the FMOD pin 6, for QR operation this pin left open, shown in Fig.5. and the controller functional diagram shown in Fig.6 [12], this have the functionalities like Transformer saturation detection through the pin 11 ZCD by auxiliary winding voltage of transformer goes negative it senses that. And under voltage protections, overload protection etc.

From the controller actions there are different operating modes 1) Quasi-Resonant Mode 2) Burst Mode 3) Valley skipping Mode. Shown in the Fig.7 the operating mode will be depends on load then controller selects the mode with switching frequency.[12][9]

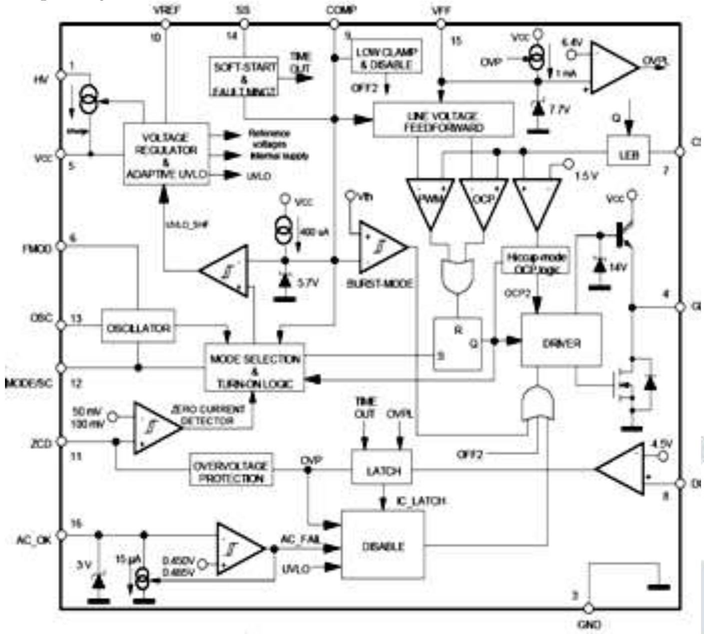


Fig.6 Controller functional diagram

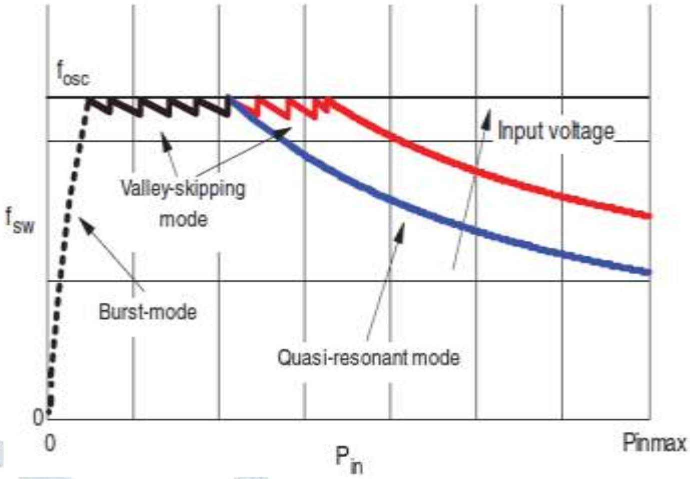


Fig.7 Different mode of operation with QR option.

The Fig .8 delineates operation portrayed so for under various working conditions for the converter is represented in the timing outline. [1] When the voltage at the COMP pin (9) falls 20 mV underneath an edge settled inside at a quality, V_{COMPBM}, contingent upon the chose working mode, the Controller IC is deliberated with the MOSFET kept in OFF-state and its utilization decreased to a lower value to minimize V_{CC} capacitor charge releases.[4]

A load diminish then causes a frequency reduction, which can go down even to couple of hundred hertz, in this manner minimizing all frequency-related misfortune and making it simpler to consent to vitality sparing regulations.[1]

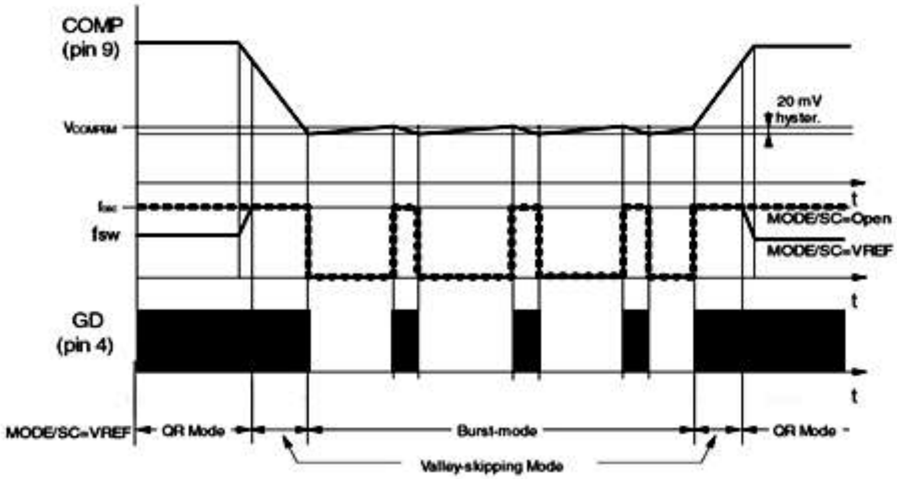


Fig.8 Load-dependent operating modes of timing diagrams

The operation depicted so far under various working conditions for the converter is delineated in the timing charts of Fig.9. On the off chance that the voltage on the COMP pin (9) immerses high, which uncovers an open control cycle, an inward draw-up keeps the ZCD pin stick near to 2 V amid MOSFET OFF-time to keep clamor from false setting of triggering in detection block. When this draw-up is dynamic the ZCD pin most likely be unable to go underneath the activating edge, which would stop the converter. To permit auto restart operation, however guaranteeing least working frequency in these conditions. [1]

The oscillator frequency that retriggers MOSFET turn-on is that of the outside oscillator partitioned by 128. Furthermore, to avert breakdown at converter startup, the draw-up is debilitated amid the soft-start. In any case, to guarantee a right startup, towards end of the soft-start stage the yield voltage of the converter must meet the condition. The controller oscillator frequency is set in (17).[1]

$$f_{osc}=\frac{2*10^3}{R_{osc}} \qquad (17)$$

Where f_{osc} = oscillator frequency in KHz of IC
R_{osc} = in KΩ

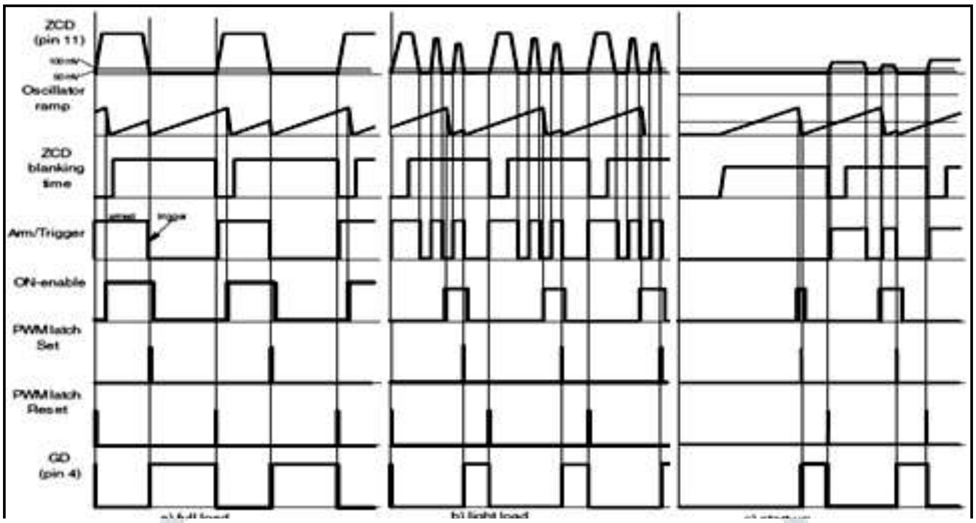


Fig.9. Operation of ZCD, triggering and oscillator blocks

III. SIMULATIIONS RESULTS

The proposed control circuit of AC/DC converter designed with controller IC L6566BH with output voltage 12V, 2A.[12]. for wide range of input voltage the circuit simulation gives analysis results of high efficiency, low losses, mode of operation with changing switching frequency[5][7]. The output voltage, output current, gate pulses of MOSFET. Simulation results as fallow.

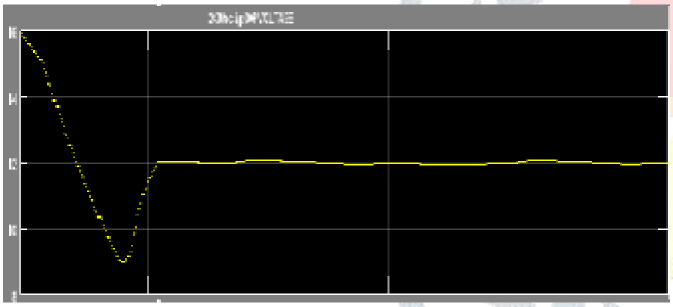


Fig.10. Output load voltage waveform

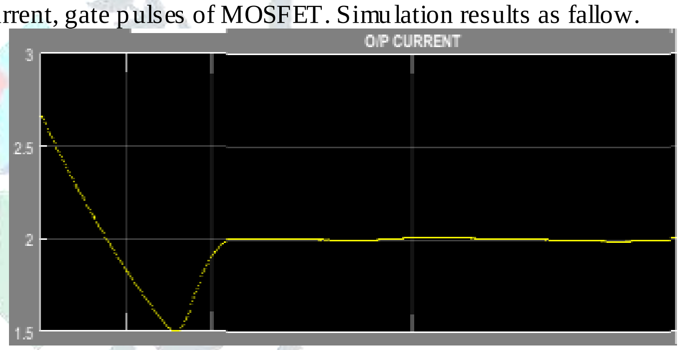
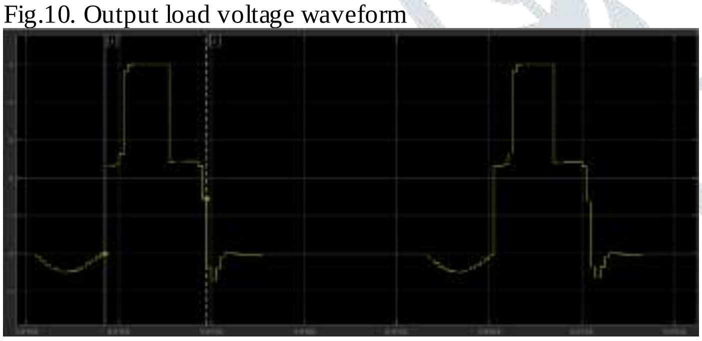
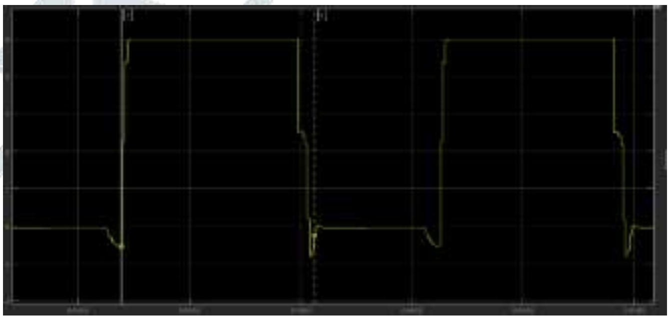


Fig.11 Output load current wave form.



(a)



(b)

Fig.12 Gate to drain voltage pulses waveforms a) minimum b) maximum duty ratio

From simulation the detailed analysis is fallowed with transformer currents and nominal input voltages, in the Fig.13. And efficiency of converter with offline input voltages represents in Fig.14. Switching Frequency of converter modulates with input voltage, in Fig.15. The compensation feed-back network Bode plot represents stability of closed loop network gives the phase margin 91.80^{o} cross over frequency of 1.963 kHz at nominal voltage in Fig.16. the total losses of converter in Fig.17.

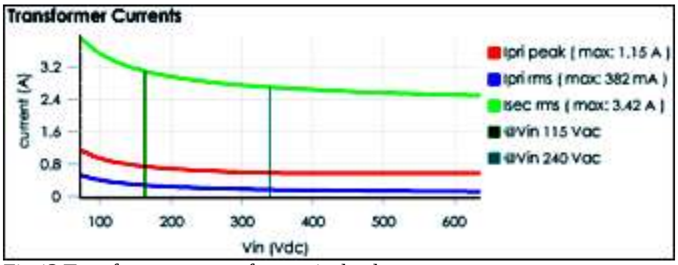


Fig.13 Transformer currents for nominal voltage

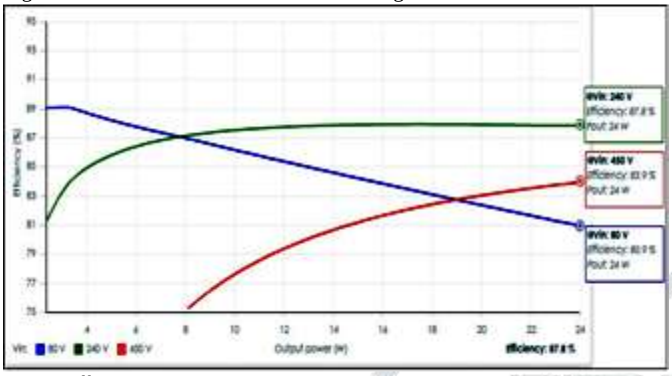


Fig.14 Efficiency verses output power

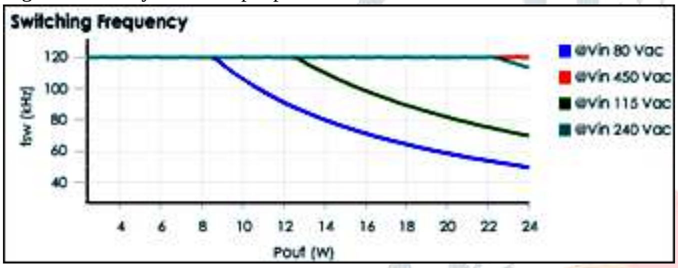


Fig.15 switching frequency verses output power

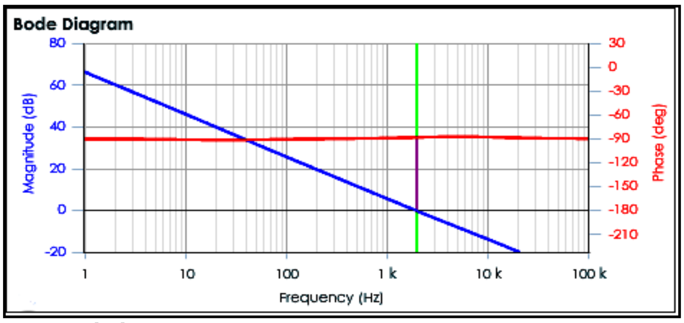


Fig.16 Bode diagram

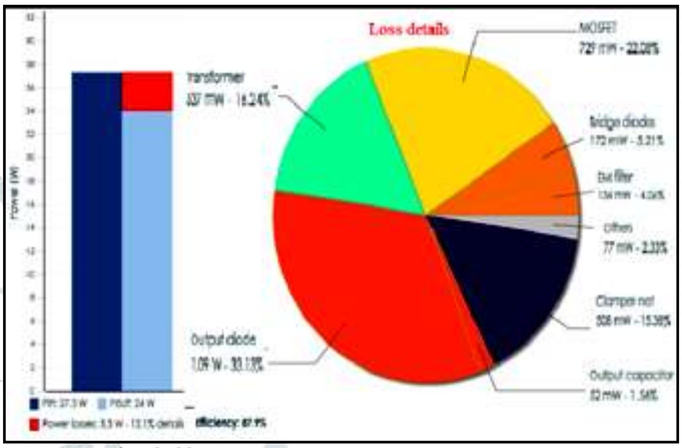


Fig.17 detailed losses.

IV. CONCLUSION

In this paper, a Quasi-Resonant flyback topology based AC/DC Converter was introduced and examined in subtle element.[11] In this Converter the controller IC provides reduced conduction losses [2] by modulating the exchanging (switching) frequency at heavy load, and its allowed to operate in boundary conduction mode (BCM) and continuous conduction mode (CCM) [10]. Power Factor Correction (PFC), high efficiency, low EMI emission, auto restart, and also output voltage regulation. Simulation result gives accommodated examination.

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