

# **An Optimal Flyback Converter Based Power Supply for Smart Meters**

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**ABSTRACT:** Smart Meters help the utilities to remotely measure, monitor and control the electrical energy consumption from anywhere in the world. The design of power supply for smart meters is challenging since it has to meet the no load power consumption limits of energy conservation initiatives like Energy Star. Since the smart meter is ultimately going to be placed at consumer end, accidental connection of single phase meters to three phase should be taken care in the power supply design. This paper proposes a flyback converter based optimal power supply which has low standby power consumption with multiple cross regulated DC outputs, and high voltage protection which makes it best suited for smart Meters.

**KEYWORDS:** Smart Meters, Low standby power, Burst mode control, Cross regulation.

## **I. INTRODUCTION**

In these days of energy crisis, it is high time that we save energy by all the possible means so that our future generations are not left in dark. Smart meters help the customers not only to save their wallets but also make them more aware of energy misuse thereby helping them to make better use of planet's limited resources. The smart meter comprises a measurement engine consisting of microcontroller and memory, Real Time Clock (RTC), relay for remote connection/disconnection of load, communication interface and a power supply with multiple DC outputs, for powering all these. Power supply used for these meters should have standby power consumption less than 1W as per IS 13779 . Hence the efficiency at light loads is the key factor [1]–[2] which determines how suited the power supply is for application like smart meters.

Flyback converter is an ideal choice in low power application like smart meters because of its features like ease of implementation, minimum bill of materials (BOM) and isolation between output and input. Several modifications are done in the conventional flyback converter to reduce no load power consumption to the specified limits. In order to limit power consumption of the PWM controller, the switching frequency and operating current are reduced [3]. A feedback network using a reverse type shunt regulator that automatically adjusts the currents flowing through the optocoupler to zero under the no-load condition is another alternative to reduce standby power consumption [4]. In order to reduce switching losses, many techniques like pulse skipping [5]–[6] and burst mode control [7]–[8] are also in use in many of commercial products. Low standby power consumption is achieved in the smart meter proposed using a technique called burst mode control.

Since the power supply of smart meters should have multiple ripple-free and regulated DC output voltages, cross regulation of the outputs should be ensured. Cross regulation is one of the serious drawbacks of flyback converters with multiple outputs. The energy stored in the primary of flyback converter during on time is unequally transferred to the multiple secondaries due to difference in the leakage inductances. The secondary voltage which is corrected via feedback remains regulated but the other secondary voltages get affected by the load. To overcome this, variety of techniques like weighted voltage control [9] and power distribution control are already in use. Since the output of the power supply of smart meters is used to feed microcontroller which only draws small amount of current, the effect of cross regulation is removed using a voltage regulator at the output. High voltage protection for the power supply is obtained using a helper MOSFET.

This paper is organized as follows. Section II analyses the standby power consumption of conventional flyback topologies used for low power applications. Section III presents the proposed flyback topology modified to meet the requirements of smart meters. Section IV compares the simulation results of burst mode control with conventional pulse width modulation (PWM) technique and it is observed that burst mode control reduces switching losses .

## II. STANDBY POWER OF CONVENTIONAL TOPOLOGY

The duty of the power supply in smart meters is to convert the high-input AC voltages into low DC voltages for micro controllers and other circuitry. Converting high AC voltage into low DC voltages like 12V, 5V or 3.3V with a low BOM can be obtained using fly-back converters. An important drawback of the conventional fly-back converter is that it has poor cross regulation and high standby power consumption.

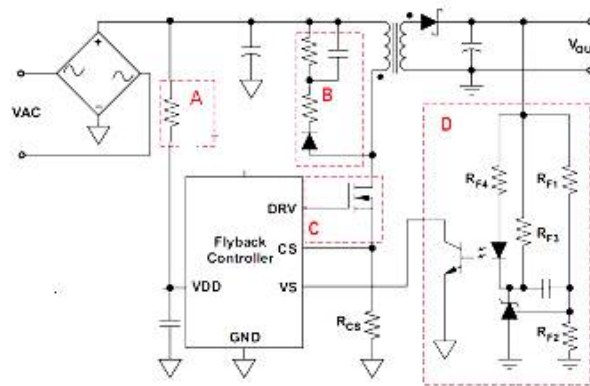


Fig. 1. Conventional flyback topology

The AC mains is converted to DC using diode rectifier and is further filtered using capacitor. The PWM controller switches the MOSFET at high frequency. The auxiliary winding supplies  $V_{CC}$  required for the PWM controller. Among the two secondary DC outputs, one is regulated using opto-coupler feedback whereas DC output from other secondary is not closed loop regulated . Fig. 1 shows conventional fly-back converter with four key elements that contribute most to standby-power loss. These include loss due to startup resistors, snubber circuit, switching losses and other losses the detailed analysis of which is done in the following section.

### i. Power Consumption in startup resistors

Even though the auxiliary winding of the transformer provide the required bias power for the PWM controller it needs some way to get started initially. Traditional way of providing the required starting current for the PWM controller is using a low value resistor from the rectified AC voltage to the VCC pin of the controller. Since the resistance is small excessive power dissipation occurs which could prevent achieving the desired compliance.

$$P_{loss} = \frac{(\sqrt{2} V_{in} - V_{CC})^2}{R_{strt}} = \frac{(\sqrt{2} 230 - 15)^2}{150k} = 641mW \quad \dots \dots \dots (1)$$

Where  $V_{in}$  is the RMS of the input AC voltage ,  $V_{CC}$  is DC voltage required for the switching IC to work and  $R_{strt}$  is the starting resistor.

### ii. Power consumption in snubber

Snubber circuit consisting of RC clamp which is used to reduce the ringing and voltage stress on the MOSFET is yet another prime area which contributes to standby-power loss.

iii. Switching Losses

Generally PWM controller switches at high frequency and hence there will be associated switching losses with becomes dominant in light load condition. Unless the controller is intelligent enough to judge the light load condition and switch to some other mode switching loss contribute to the most to standby power. The switching losses can be calculated as below.

$$P_{loss} = \frac{1}{2} C_{ds} V_{ds}^2 f_s = \frac{1}{2} .270pF . (325V)^2 70kHz = 998mW \dots\dots\dots (2)$$

Where  $C_{ds}$  is the drain to source capacitance of MOSFET ,  $V_{ds}$  is the drain to source voltage and  $f_s$  is the switching frequency .

iv. Power consumption in feedback circuit

In order to regulate the output voltage under various load conditions, a feedback circuit consisting of shunt regulator TL431 and optocoupler is commonly used. The feedback circuit compares the output voltage with the reference voltage of TL431 and the error is optically transferred via optocoupler to accordingly adjust the flyback controller's switching. But the problem with TL431 is that it requires at least of 1mA of current to guarantee regulation. Generally the required current is provided using a resistor ( $R_{F3}$ ) which somehow leads to nearly 15-50mW loss .The resistor combination to fix the voltage reference for TL431 dissipate another 15mW of power. The above mentioned two losses sums up to 20mW to 55mW which can be definitely eliminated by improving the feedback circuit.

v. Power consumption in PWM controller

The PWM controller is the brain of any power supply and is in fact the villain which contributes to most of the standby power consumption.

Assuming that the operating current of PWM controller ( $I_{op}$ ) is 11mA and VCC voltage is 15V, PWM controller consumption is obtained as

$$P_{loss} = V_{CC} I_{op} = 15V . 11mA = 165mW \dots\dots\dots (3)$$

vi. Power consumption in MOSFET drive

At light load condition, stray capacitance hidden in the MOSFET used for switching, contribute to losses which is given below.

$$P_{loss} = Q_g V_{gs} f_s = 127nC . 15V . 70kHz = 133mW \dots\dots\dots (4)$$

Summing the losses it is clearly understood that they exceed 1W which clearly goes against the compliance that the standby power consumption should be less than 1W. Since operating current is the minimum current required for the PWM controller to work and stray capacitance is something which cannot be avoided, there isn't much scope to minimize losses in MOSFET drive and PWM controller. Hence the proposed topology concentrates in eliminating the standby-power losses in prime areas like start up resistors, switching, snubber and feedback circuit and thereby make the smart meter power supply in agree with the energy compliances.

**III. PROPOSED TOPOLOGY**

The proposed topology is in short a flyback converter with a green Flyback controller having active start up circuit, burst mode of operation at light loads. Also in order to eliminate the feedback circuit losses TLV431 is introduced and to eliminate the snubber losses the clamp circuit is optimized. Fig 2. Shows the block diagram of the proposed power supply is shown below.

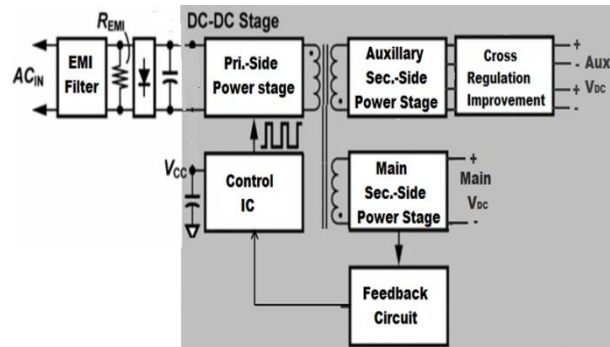


Fig. 2. Block Diagram of Proposed converter

The proposed converter basically consists of an Electromagnetic interference(EMI) filter, a bridge rectifier and DC-DC step down converter. The DC-DC step down converter includes a power stage, controller/switching IC and isolated feedback circuit. The DC-DC converter is designed for multiple outputs of which the DC output fed to the microcontroller of smart meter board termed as Main  $V_{dc}$  alone is corrected using feedback the other DC outputs termed as Aux  $V_{dc}$  are not corrected, hence are subjected to cross regulation. To eliminate the effect of cross regulation shunt regulators are used in the proposed circuit which constitutes cross regulation improvement circuit.

Table 1.shows the specification of the flyback converter proposed. Since the main AC input voltage can vary anywhere from  $V_{AC_{min}}$  (85V) to  $V_{AC_{max}}$  (265V) the converter designed should be capable to deliver constant DC output regardless of the wide range of varying input. To reduce the size of flyback transformer high switching frequency is desired but the same cannot be increased beyond a limit since high frequency switching can result in Electromagnetic Interference(EMI).So an optimal value of 100kHz is chosen.

Parameter	Value	Remarks
$V_{AC_{max}}$	265V	Maximum AC input voltage
$V_{AC_{min}}$	85V	Minimum AC input voltage
$f_{sw}$	100kHz	Normal mode switching frequency
$E_{ff}$	80%	Efficiency
$P_{out}$	10W	Output power(maximum)
$V_{DC_{main}}$	3.3V	Main DC output voltage for microcontroller
$V_{DC_{cross}}$	5V	DC output for other circuits
$V_{ripple}$	150mV	Output ripple voltage
No load input power	600mW	Standby power consumption

TABLE 1 SPECIFICATION OF PROPOSED FLYBACK CONVERTER

The microcontroller which is the heart of smart meter needs a regulated DC supply of 3.3 V which is termed as main output as it is corrected using feedback. The DC voltage(5V) required for other digital components are not corrected using feedback .The effect of cross regulation in these outputs is eliminated using shunt regulators thereby guaranteeing regulated ripple free output. Modifying the prime areas which contribute to standby power consumption in conventional circuit the standby power consumption of proposed topology is reduced to 500mW.

- i. Active startup to eliminate startup resistor losses

The flyback controller used( NCP 1053 )has a built in startup circuit thus eliminating the startup resistors and associated losses. From Fig 3. It is clear that the flyback controller is powered from auxilliary winding .The startup circuit is self- biasing and acts a constant current source .During starting the startup circuit diverts the current to

capacitor connected to Pin1 and this capacitor voltage provides the required VCC for the flyback controller to start switching.

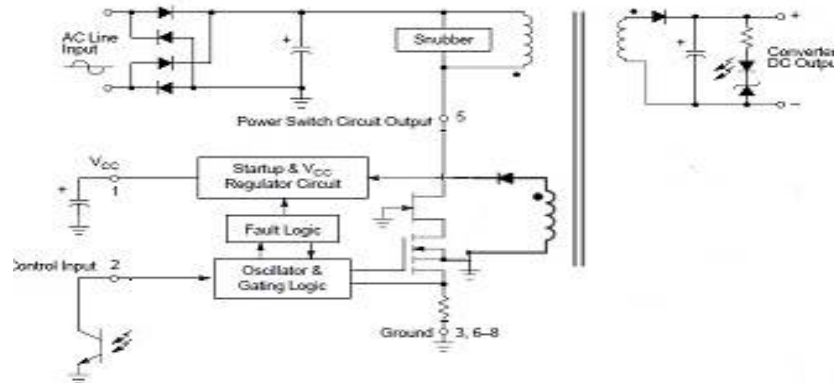


Fig. 3. Active startup circuit

ii. Optimized snubber with minimal losses

Snubber loss can be reduced by decreasing the transformer leakage reactance and increasing the resistance of clamp circuit. But increasing the snubber resistance can increase the reflected voltage across the MOSFET which it must be capable to withstand. However, an increased voltage rating results in either a more expensive MOSFET, or one with higher on-resistance which impairs the efficiency at heavier loads. Thus for low voltage application like smart meters reducing the clamp capacitance value is best choice to reduce snubber losses. When operating in burst mode a larger value of capacitance stores excess energy is stored and dissipated in off state. In order to reduce the snubber losses the RC time constant is to 10 times that of switching period.

iii. Burst mode control to reduce switching losses

Techniques such as frequency reduction and skip mode are used to reduce the contribution of switching losses to standby power consumption. The problem with skip mode is that it has high audible noise but offers good regulation. The proposed Burst mode control technique offers good regulation with reduced audible noise. For reducing the switching losses fundamental switching frequency is reduced but this can increase the audible noise. To reduce the audible noise peak drain current is limited which on other hand results in poor regulation. Considering all the above, in the proposed technique switching frequency is made higher than the conventional burst mode but less than normal mode of operation. To overcome the losses which happen due to increasing the frequency of switching as compared to conventional burst mode, certain portion of signal is skipped as shown in Fig 4.



Fig. 4. Switching signal of the conventional and proposed burst mode operation

Here the switching signal is a function of feedback voltage. In the light load/no load condition the feedback voltage is very less and it is then when flyback controller enters burst mode of operation. The proposed technique generates switching signal in both the increasing and decreasing phase of feedback signal and hence gives better regulation characteristic. Incorporating the burst mode of control the switching loss was reduced to 600mW from 1w.

iv. TLV431 to reduce feedback circuit losses

Fig 5.shows the feedback circuit with TL431 replaced with TLV431 which requires just 80µA of quiescent current to guarantee regulation. Snubber loss can be reduced by decreasing the transformer leakage reactance and increasing the resistance of clamp circuit. Since the current through optocoupler is sufficient to power TLV431 the resistor  $R_{f3}$  is eliminated thus reducing the major cause of feedback loss.

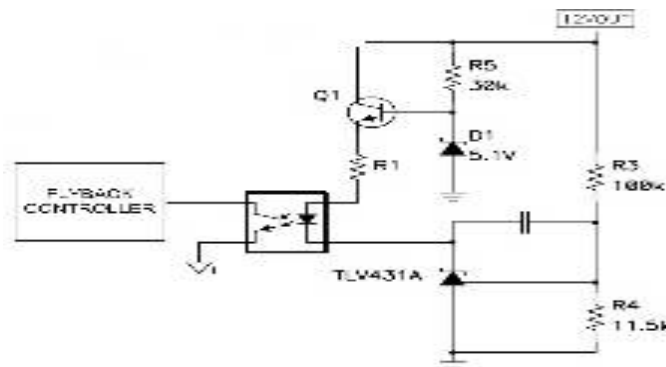


Fig. 5. TLV431 based feedback circuit

v. Helper MOSFET to withstand high voltage

Since there is chance of single phase meter being connected to three phase accidentally, high voltage protection should be given to the power supply of smart meters. For implementing the same the most cost effective way is to incorporate a helper MOSFET in series with flyback switcher as shown in Fig 6.

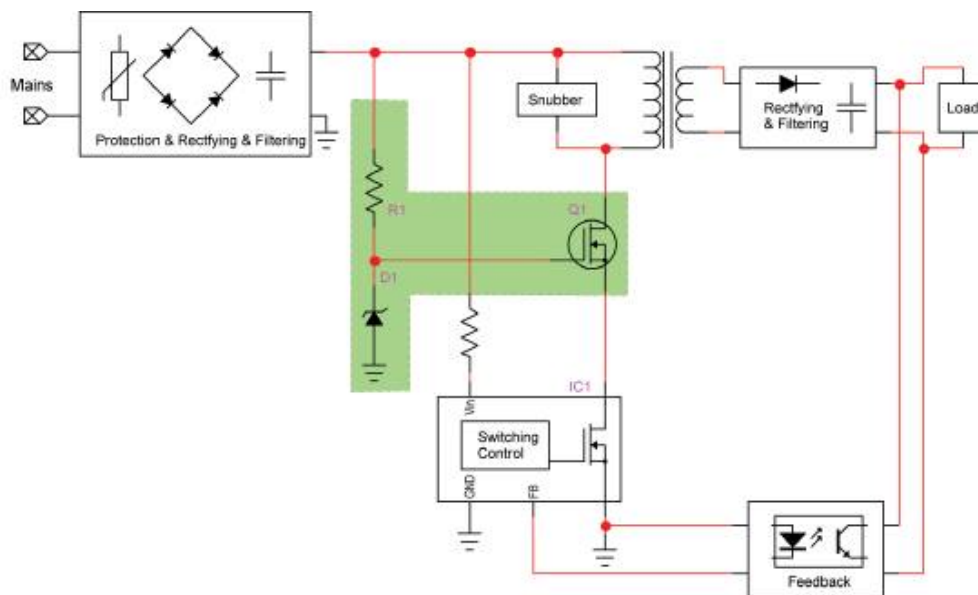


Fig. 6. Helper MOSFET incorporated flyback circuit





The flyback controller enters into burst mode of operation when feedback voltage becomes less than 600mV. It continues switching until feedback voltage becomes 500mV thereafter switching is skipped. When feedback voltage reaches 400mV switching resumes till feedback voltage reaches 300mV. Thereafter switching is stopped which causes the feedback voltage to increase. When feedback voltage rises above 300mV, switching resumes and same pattern of switching which was followed in the decreasing slope of feedback voltage occurs.

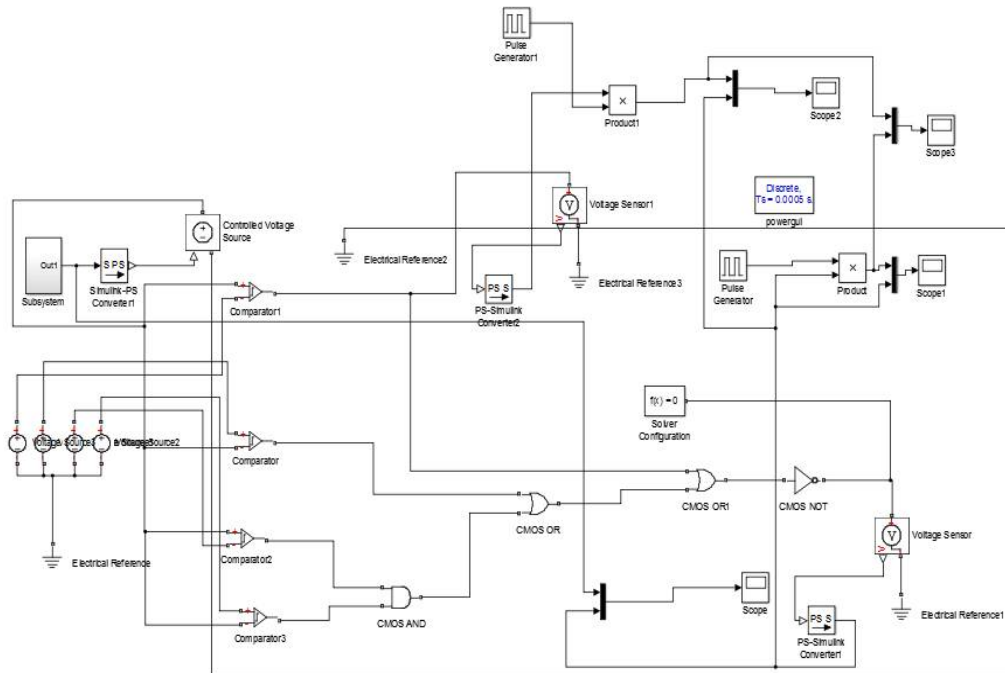


Fig. 8. Simulation of burst mode control circuit

ii. Simulation results

Fig 9. Shows the simulation result of the control and switching signal of burst control circuit. The blue colour indicates the normal operation switching signal (100 kHz) and green indicates burst mode switching signal (44kHz)

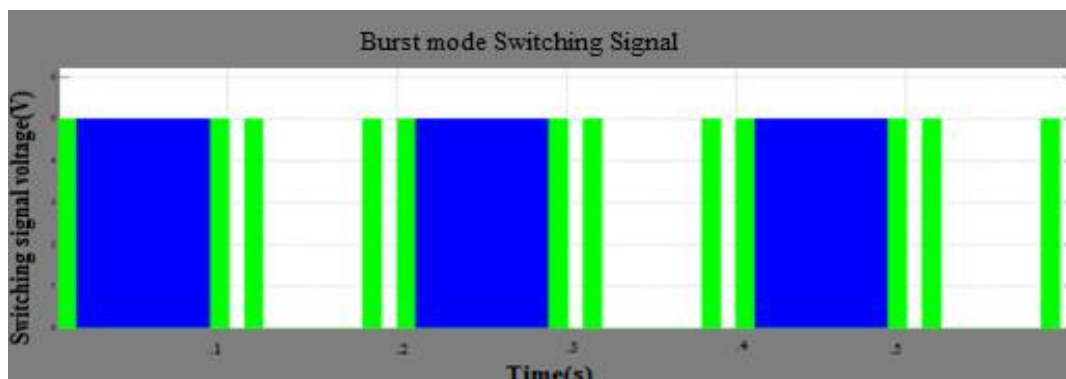


Fig. 9. Simulation result of burst mode control circuit

It can be seen that when the feedback voltage falls below 600mV controller enters into burst mode of operation i.e. it switches at a lower frequency (shown in green) till the feedback becomes 500mV thereafter switching is skipped to reduce losses. When feedback voltage reaches 400mV switching resumes till feedback voltage reaches 300 mV.



Fig 10.a shows the average MOSFET power in fixed frequency mode and Fig 10.b shows the average MOSFET power in burst mode control.

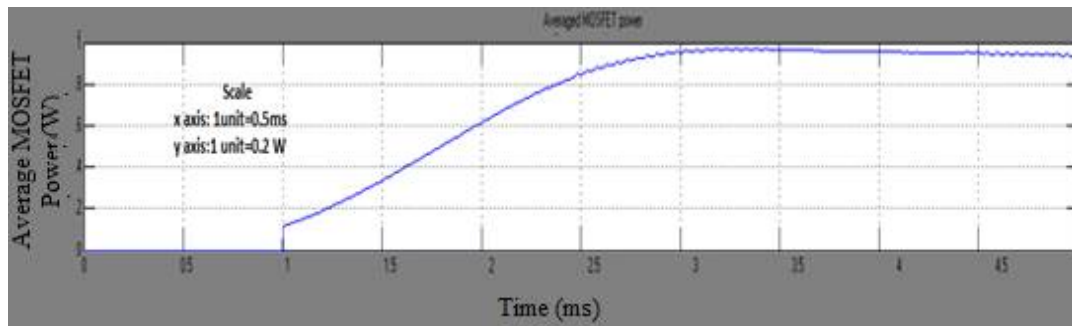


Fig. 10.a. Average power across MOSFET in PWM mode

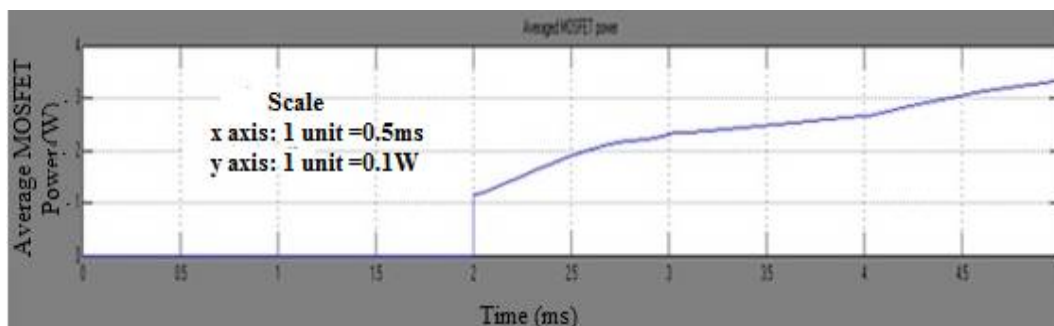


Fig. 10.b. Average power across MOSFET in burst control mode

From the simulation results it can be inferred that the average power lost across the MOSFET is reduced to less than 500 milli watt in burst mode, whereas the same is almost 1W in PWM mode.

## V. CONCLUSION

The Flyback converter based power supply with multiple regulated outputs, reduced standby power consumption and high voltage protection best suited for smart meters is proposed. Typical losses in conventional flyback like startup resistor losses, snubber losses and feedback circuit losses are minimized. Incorporating a green flyback controller which enters into burst mode of operation at light/no load switching loss is reduced by 30%. In short standby power consumption of the smart meter is reduced to less than 600mW which is well within the limits of various energy compliances.

## VI. ACKNOWLEDGMENT

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