High-Power Factor Flyback Converter for an LED Driver with Ultra-Wide Output Voltage

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***Abstract*— In conventional AC-DC conversion, the bridge rectifier will convert the AC voltage to DC. However, the input current is not continuously flow through the circuit. Therefore, the input current shape will be deteriorated. Hence, the input power factor dropped. Furthermore, the conversion efficiency reduced and THD (Total harmonic distortion) level increased. This is due to the rectifier diodes which not in forward bias (turn ON) if the bulk capacitor voltage level more than peak input voltage. Additional power correction circuit will improve the input power factor. However, the number of components increase. On the other hand, some of the conventional power factor correction circuit increase the number of stages in power conversion. Moreover, ultra-wide output voltage for an LED driver is important because of the high-brightness LED's efficiency is keep improving, hence, the lighting lamps are using LED to replace the traditional lighting lamps. Therefore, LED driver need a highly precise output current regulation because the colour and the brightness of the LED are based on the LED current level. This research is to evaluate the performance of high-power factor LED driver with ultra-wide output voltage with circuit simulation and experiment. This research is necessary because it is significant to the policies maker decision on the high efficiency electrical appliances. As for the example, the 80 plus standard set up by Ecos Consulting in year 2004 encourage the power supply manufacturer/ designer to achieves the standard. Therefore, the continuous development of new approaches to improve the power conversion efficiency is necessary. Furthermore, better electrical power management will lead to sustainable usage of energy. A lot of methods proposed to achieve high power factor such as AC-DC bridgeless topologies, synchronous converter, employing silicon carbide power diodes, improve the control strategies and etc. However, this study focuses to produce high power factor LED driver using flyback circuit topology. The Primary Side Regulation (PSR) for LED driver achieve international regulation like Energy Star for Solid State Lightning (SSL) product. PSR use primary side of power supply to control the output current with information to take away the sensing loss of output current and removing the output secondary feedback circuit. Due to this issue, without increasing the cost of SSL application, it able to fit the driver circuit inside a small-form factor lamps and reach the international requirement.**

Keywords—LED Driver, Flyback Converters

I. INTRODUCTION

Light Emitting Diodes (LEDs) are the mainstream light sources around the world due to its advantages such as low energy, small size, high luminous efficiency, long lifetime (50,000h) and perfect colour rendering compare to the traditional lighting equipment like the incandescence, Compact Fluorescent Lamps (CFL) and down light are not efficiency and short life time (Dong et al., 2018). Therefore, to let the LED function, LED driver is the power supply for the LED. LED driver is a individual power supply, hence, it can adjust the power required for the LED. Therefore, the requirement of the LED drivers is specialized power supply because the brightness and the colour are depend on its current level. If using the not suitable LED driver for the LED, it may cause the LED over heating or working in bad performance (Dong et al., 2018). LED is a very sensitive electronic devices, thus, LED driver is important to the LED because it can supply the constant power for the LED to make sure that it is functioning at the perfect situation. If using the wrong LED driver to power up the LED, the lifetime of the LED will shorter than the expectation. Therefore, the working time of the LED driver is limited by the lifetime of the electrolytic capacitor (Dong et al., 2018).

Moreover, the input current for the LED driver is also based on the Power Factor (PF) and the Total Harmonic Distortion (THD), so that, power factor and total harmonic distortion is the key design requirement of the LED driver. Therefore, for each LED driver required an AC-DC converter with Power Factor Correction (PFC). This PFC technique is to change to input current same phase to the input voltage, hence, the output power is constant (Shagerdmootaab and Moallem, 2015). The idea case for high PF is to maximize the power transfer over the grid with lower noise and ensure stability (White et al., 2015). Therefore, to get high PF and low THD the waveform of the input current need to be same shape as the input voltage during the line cycle to get the pulsing input power. The requirement of the input current need to same shape to the input voltage is based on The International Electrotechnical Commission (IEC) published standard. The standard is to limit the harmonic emission of AC-DC converter especially for the low power lightning equipment (Dong et al., 2018).

Flyback converters widely used in low power application because of it characteristic. The characteristic of the flyback converter are wide input voltage range, low cost and low standby power. Therefore, due to the characteristic of the flyback converters are usually used in many applications especially in LED driver and battery charger. Buck-Boost converter is same as flyback converter if using a single inductor instead of a transformer.

II. LITERATURE REVEIW

Based on the journals written by the researchers White, Liu, Wang (2015) the journals are using different topology to increase the efficiency of the LED driver and the power factor on the single state and single switch designed. First, based on the circuit design of the two journals, the researchers (Brian, Liu, Wang and Liu, 2015) proposed applied average current modulation method to design single state LED driver to get high power factor and zero low frequency current ripple. Average current modulation is a simple control scheme that required a single low voltage MOSFET and same LED output voltage rate to ensure the zero low frequency current ripple for LED load. Therefore, this design can reduced the energy storage capacitance of the PFC stage and also avoid the need of electrolytic type capacitor. The point of the LED driver design by researchers are to operate the average current modulation method in the single stage PFC circuits that include significant AC voltage ripple while maintaining zero low frequency current ripple (Brian, Liu, Wang & Liu, 2015). Moreover, the researchers (Kim, Moon & Moon, 2016) proposed a single switch isolated driver for two channel LED strings designed with resonant blocking capacitor. The designed for the driver on the primary side is using on-time controlled forward-flyback inverter to get a huge output voltage range and the secondary side design with full-bride type rectifier. Therefore. this design can let the driver use a small leakage inductor as the resonant component, so that, it does not required external inductor and the driver also clamped voltage stress on the rectifier diodes, so the low voltage rated rectifier diode can used. Furthermore, the researchers able to reduce the cost effectiveness compared to the conventional converter because it eliminated external magnetic component and also due to the reduces of the voltage stress on the rectifier diodes, it achieves higher efficiency than conventional converter. Based on the result that show by the researchers (Brian, Liu, Wang & Liu, 2015) show the result that using the average current modulation method can drive the LED in single state power factor correction circuit. The peak duty cycle control method is included during the method design, so that, it can limited the maximum current pulse for the LED to prevent damage to the LED load. Moreover, the researchers (Kim, Moon & Moon, 2016) show that the result driver can achieve wide output voltage range and current balancing without external magnetic components and has much small voltage stress compared to conventional flyback driver on the secondary rectifier diodes. The advantages of these journals are the cost is cheap and get high efficiency on the LED driver. However, there are some limitation on the design, the designs are more suitable for the low voltage. Based on the journals written by the researchers Dong Xie, Lei Jiang, Jin, (2018) show that to get high power factor and electrolytic capacitor-less can use different type of topology to get. First, based on the design topology show that the researchers (Dong, Xie, Jiang & Jin, 2018) proposed to use One-and-a-Half Stage forward flyback topology and the researchers (Lam & Jain, 2015) proposed to use single switch topology. Both of the topologies have the same objective but the working principles each are different. The One-and-a-Half Stage forward flyback topology is designed because compared to traditional single switch forward flyback converter, it added DC-DC converter between the output of the forward sub-converter and the load in the converter to help the realize power decoupling, hence the output ripple current can reduced and become smoothly. The reason that the researchers design One-and-a-Half Stage forward flyback topology because only 1/4 of total energy will transfer to load pass the forward sub-converter and buck converter, so that, apply this topology it can achieve higher efficiency than the traditional two stage topologies. Furthermore, the single-switch topology is designed to simplify the controller design. It able to provide high frequency pulsating current and without using electrolytic capacitors to minimize the low frequency ripple. Therefore, the single-switch topology can reduce the capacitance energy storage to few micro farad ranges, thus, the film capacitor can replace the unreliable electrolytic capacitor. Based on the result show by the researchers (Dong, Xie, Jiang & Jin, 2018), the One-and-a-Half Stage forward flyback topology proved that the cascaded buck converter only required 1/4 of the total energy, thus, this topology has higher efficiency than the two-stage E-cap-less PFC converter and the output ripple voltage and output ripple current can reduce by using the film output capacitor and film bus capacitor. Furthermore, the researchers (Lam & Jain, 2015) show that the design can reduce the low frequency ripple on the LED current without using any electrolytic capacitor. The advantages for both designs are reducing the low frequency ripple on the LED current and the voltage, both designs also achieve high efficiency and low output ripple without using electrolytic capacitor. However, the limitation for both designs are the topologies are suitable for industrial applications such as low power AC-DC LED drivers. Based on the journals written by the researchers Poorali, Cheng, Chang, Hsieh (2016) used different types of topologies to get the high power factor AC-DC converter LED driver. Researchers (Poorali & Adib, 2016) proposed to use the Zero Current Switching (ZCS) condition. However, researchers (Cheng, Chang, Chang, Hsieh & Cheng, 2019) proposed to use Zero Voltage Switching (ZVS) condition to get the same objective. First, based on the circuit design of the two journals, the researchers (Poorali & Adib, 2016) created a new LED driver without the electrolytic capacitor and the LED driver's switch will turn on under the Zero Current Switching (ZCS) condition. The design of the LED driver is using a single-ended primary inductor converter with a flyback converter without using electrolytic capacitor. The point of the LED driver design by researchers (Poorali & Adib, 2016) are to decrease the turn on losses on the switch capacitive because the turn on voltage less than the nominal voltage and the leakage energy is absorbed, hence, when the switch turns off, no voltage spikes will across the switch. Furthermore, researchers (Cheng, Chang, Chang, Hsieh & Cheng, 2019) designed the circuit configuration with a low-pass filter, a diode rectifier and two flyback converters which are operated with 180degree phase shift. The reason that two flyback converter are needed to increase the output power and both active switches able to operate at ZVS without additional active-clamp circuit or snubber circuit because two flyback converter lost the capability of galvanic isolation. Moreover, the researchers (Cheng, Chang, Chang, Hsieh & Cheng, 2019) able to supply the energy stored in the leakage inductance of the coupled inductor or supplied to output load to get high circuit efficiency and low product cost in the result. Besides that, operated flyback converter in discontinuous current mode will obtain high power factor and low Total current Harmonic Distortion (THDi). Based on the result that show by the researchers (Poorali & Adib, 2016), the turn on voltage at the switch is lesser than the voltage stress and the leakage energy is recycled, so that, the low voltage rating and lower on resistance switches can be used. Furthermore, the result show that the ZVS topology is working because the parasitic capacitance of power

MOSFET completely discharge by freewheeling the inductor current, so that, both active switches able to turn on at zero voltage without additional required. Besides that, the losing galvanic isolation able to fulfil with high efficiency by the recycle energy in the leakage flux. The benefits of these journals are both can achieve high efficiency circuit, high power factor and lower cost. However, the design concept for both circuits is complicated. Based on the journals written by Lee, Do, Peng, Liu (2016) used different topology to get the high-power factor circuit. Researchers (Lee & Do, 2016) proposed to use soft-switching two-switch resonant to present high power factor in AC-DC circuit converter. However, researchers (Peng Fang, Yan-Fei Liu & Sen, 2015) introduces ripple cancellation method to remove the twice line frequency voltage ripple with a PFC to get high power factor. Based on the design for the soft-switching topology, to achieve high power factor the PFC circuit must operate in Discontinuous Conduction Mode (DCM) and the soft-switching can be achieved because of the leakage inductance between resonance and transformer. The reason that the researchers (Lee & Do, 2016) used two-switch resonant converter because the voltage across the main switches is limited to the DC-link voltage and the energy of the transformer leakage inductance is also recycled. Due to this issue, resonant manner and switching losses reduced and the overall efficiency is improved. Moreover, researchers (Peng Fang, Yan-Fei Liu & Sen, 2015) designed the circuit is based on flyback topology circuit and just change the converter to the ripple cancellation converter. Furthermore, researchers (Peng Fang, Yan-Fei Liu & Sen, 2015) able to reduce the storage capacitor for the LED driver and to achieve ripple cancellation. Due to this issue, the overall cost is cheap. Based on the result from researchers (Lee & Do, 2016) show that the PFC circuit operated in DCM able to get high power factor and the voltage stress of main switch and diodes is reduced because of the two-switching structure. Moreover, researchers (Peng Fang, Yan-Fei Liu & Sen, 2015). Sen show that ripple cancellation LED driver method able to reduce the component cost, but the efficiency is very closed to conventional single state LED driver, hence, this topology is not useful. Based on both journals show that the topologies that the researchers introduced only able to reduce the cost of the product and get high power factor, but the efficiency of the circuit do not increase much. Based on the journals written by researchers Zhang, Wu, Abdul (2017) are about the Variable-On-Time (VOT) control. Researchers (Zhao, Zhang & Wu, 2017) proposed an improvement strategy for Critical Conduction Mode (CRM) for flyback PFC converter. The reason that the researchers (Zhao, Zhang & Wu, 2017) purposed this problem because traditional CRM flyback PFC converter usually suffers low power factor and high THD because of the non-sinusoidal input current waveform. The way to improve the VOT control by adding an operational amplifier, two signal switches and RC filter into the circuit to control the turn on time of primary switch. However, researchers (Memon, Yao, Chen, Guo & Hu, 2017) proposed using VOT to get high power factor and low THD in CRM integrated buck-flyback PFC converter. Furthermore, the reason that researchers (Memon, Yao, Chen, Guo & Hu, 2017) proposed this problem is same as researchers (Zhao, Zhang & Wu, 2017). However, the way to solve the problem is different, this is utilizing the input and output voltage to modulate the on time of both switches and the input current harmonics can be eliminated, high power factor will be obtained. Based on the result from the researchers (Zhao, Zhang & Wu, 2017) show that by adding a simple and low cost analog divider circuit able to increase the input current power factor but also improve the THD compare to traditional CRM flyback PFC converter and the design is easy. Moreover, researchers (Memon, Yao, Chen, Guo & Hu, 2017) show that the power factor is closed to unity, the THD is low within the wide input voltage range and the efficiency is increased especially at low input voltage. Based on both journals show that, the advantages of this topology are cheap product cost and simple to design. However, the efficiency of the topology is not accurate. Based on the journals written by researchers Abdelmessih, Alonso and Costa (2018) are about using loss analysis to improve the efficiency of integrated buck flyback LED driver. The reason that the researcher proposed this solution because old design of the buck flyback converter has less efficiency and high output current ripple. The way that proposed by researcher is redesigning the converter parameter, traditional connection is ac input to buck converter, the new design is ac input connected to a bridge rectifier. Based on the result from the researchers show that by redesigning the circuit able to reduce the component and also increased the efficiency from 82% to 89%. The output ripple current decrease around 50% compared to old design. Based on the journals written by researchers Tamyurek and Kirimer (2015) are about the improvement of interleaved high power factor using flyback converter. The reason that the researcher proposed the solution is to use for photovoltaic application. The way that proposed by the researcher is using interleaving phenomenon of flyback converter. Based on the result from the researchers show that by using the interleaving phenomenon the interleaved flyback converter able to reduce the conduction loss and also efficiency of flyback converter. Based on the journals written by researcher Lodh and Majumden (2016) are about the used flyback Cuk integrated with DC-DC converter. The reason that the researcher proposed the method is to get high gain and high efficiency negative output. The way that proposed by the researcher is Cuk converter's inductor replaced by flyback transformer on the primary side and secondary side the flyback subpart connected to normal Cuk converter. Based on the result from the researchers show that the flyback transformer able to recover and transferred to output by Cuk converter, so the efficiency is increased and the voltage spike across the switch is reduced. Based on the journals written by researcher Kumar, Bhat and Agarwal (2017) are about the bidirectional energy transfer using flyback converter. The reason that the researcher proposed the method is to analysis the dual active bridge isolated that can have higher efficiency than normal flyback converter. Based on the result from the researchers show that the dual active bridge converter with single phase shift is design with two flyback converter, so have higher efficiency than single flyback converter because of having DC to AC converter connected back to transformer.

III. System Design

Figure 1 show that the circuit of the block diagram are build up by AC voltage source input, Electro Magnetic Interference (EMI) filter, bridge rectifier, flyback converter, Resistor-Capacitor-Diode (RCD) snubber circuit, controller, output. The AC input is supplied from the socket 240V based on Malaysia's electrical supply to each socket. The definition of EMI is an unwanted electrical signal that can interference the electronic devices by radiated emission or conducted. The different between conducted EMI and radiated EMI are the noise travel along the electrical conductor and noise travel through the air as magnetic field. EMI filter is installed to most of the electronic devices to reduce the high frequency electronic noise that may affected other devices or the results. The function of the bridge rectifier is to convert the AC input voltage to DC input voltage to the entire system. The bridge rectifier must be fast recovery diodes to rectify the high frequency like secondary rectification on switching power supply. The function of the flyback converter is to convert the DC input voltage to low level of DC output voltage. Flyback converter have isolation between the primary side and secondary side and no direct connection between both, so the high voltage is separate to one side and low voltage to another side. RCD snubber circuit is common applied with flyback converter. The function of the RCD snubber circuit is to limit the peak voltage on the drain of field effect transistor if the RC snubber is not enough to avoid switch overvoltage. The functions of the controller are to drive the MOSFET, current sensing and voltage feedback. As figure 4.1 show above, the red colour part is current sensing from bridge rectifier, blue colour part is sending duty cycle to flyback converter and green colour part is to receive the voltage feedback from the RCD snubber circuit. The output is to show the result of the entire circuit.

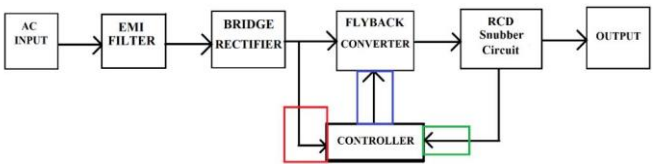

Figure 1: System Design

Figure 2 show above the wiring diagram of the entire circuit. The system is starting from left to right. The left-hand side of the figure 4.2 show that, the connection starting from AC input voltage then connected to EMI filter and bridge rectifier. The connection of the EMI filter is connected with two capacitors and an inductor to reduce the high frequency electronic noise that generated from switching of electrical current or electronic power supply. The bridge rectifier is connected to the EMI filter to get the AC input voltage. The output of the bridge rectifier is connected to a capacitor to smooth the output of DC voltage. The controller is designed in 8 pins IC. The function of pin 1 is current sense, as figure 4.2 above show that the pin is connected a current sense resistor to detect the MOSFET current for constant output current regulation. Then, the function of pin 2 is to send Pulse Wide Modulation (PWM) signal output to drive the MOSFET. Pin 3 is ground, so the function of ground in electronic is the reference point of all the signal in electrical circuit which voltages are measured. After that, pin 4 is the power supply of the controller, this pin supplied the IC operating current and MOSFET driving current. Moreover, pin 5 is the voltage sense to detect the output voltage and connected to the auxiliary winding of the transformer with resistor. Pin 6 is constant current loop compensation, hence, to be operate this pin must connected a capacitor between pin 6 and pin 3 for compensating the current loop gain. Pin 7 do not has function and pin 8 is high voltage pin that connected to the output of bridge rectifier with resistor. The blue colour part show in figure 4.2 is an extra VDD supply from auxiliary voltage to make sure the MOSFET is functioning. Then, all the components are connected to the primary side of transformer and stepdown the voltage to secondary side of transformer. RCD snubber circuit, capacitors and resistor are connected at secondary side of transformer. RCD snubber circuit is to filter noise, capacitors are used to smooth the DC output voltage and resistor is to show the load. Primary side and secondary side of transformer is using separated ground to make sure the entire system does not short circuit.

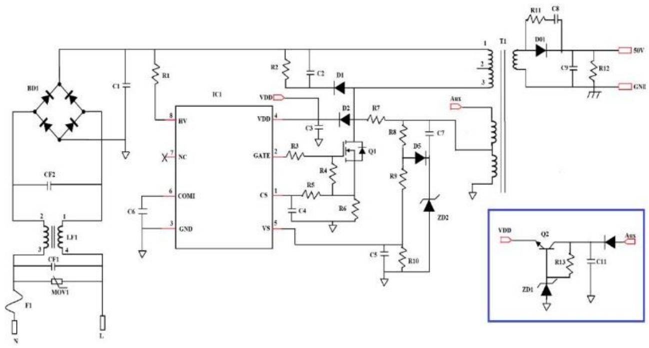

Figure 2: Wiring Diagram

Figure 3 above show that the programming of the entire circuit by using simulation software Simulink. The input voltage of the system is 240V AC and connected with a current sense and voltage sense to send the current and voltage. The reason that the current sense block and voltage sense block is different because designed for create a shortcut output block as the figure 4.3 show the Vs and Is. The 4 diodes are act as bridge rectifier to convert the AC voltage to DC voltage. A PWM output is supplied to the MOSFET for operate. The secondary side of the transformer is connected with voltage sense and current sense to see the output of the circuit. Primary side of the transformer and secondary side of the transformer are two different ground, thus, to make the Simulink understand the different, the Solver Configuration block is connected to a side of transformer to show that the side is different ground.

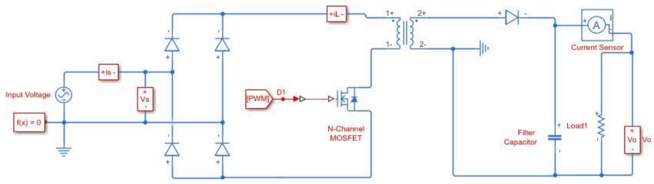

Figure 3: Circuit Simulation

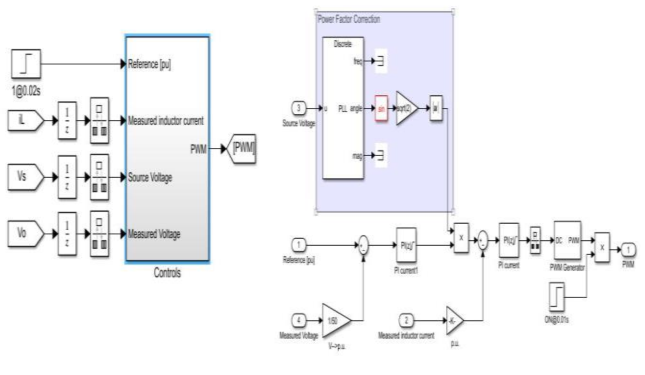

Figure 4: Power Factor Correction System

Figure 4 show that one of the main parts of the entire circuit simulation design. This power factor correction is designed to increase the power factor of the power supply. At the left side of figure 4.4 show the block that connected to the system and right side show the details way to design the power factor correction. The power factor correct is designed using Proportional Integral (PI) controller. The reason that selected PI controller due to the accuracy of the result and fast response in process.

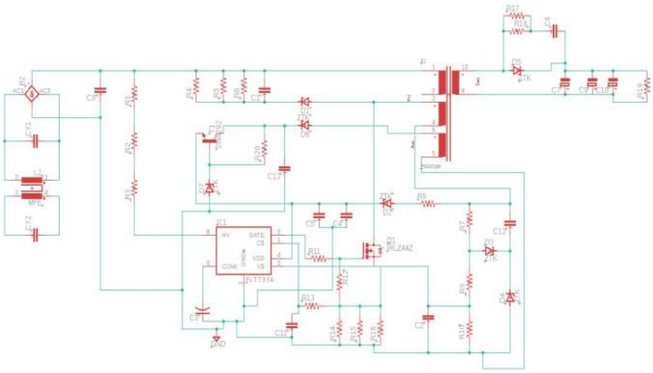

Figure 5: PCB Schematic

Figure 5 above show that the schematic design for the Printed Circuit Board (PCB). The software of PCB design is named as Eagle published by Autodesk company. The circuit is designed based on the figure 2. The circuit is slightly modified on the resistor and capacitor. Figure 4.6 is the board design of the PCB. The components that show in the figure is the actual size of the components and the position that printed on the PCB. Therefore, the connection of the components are special designed to prevent the connection crashing. The red colour wire on the PCB board design is the copper wire that printed out..

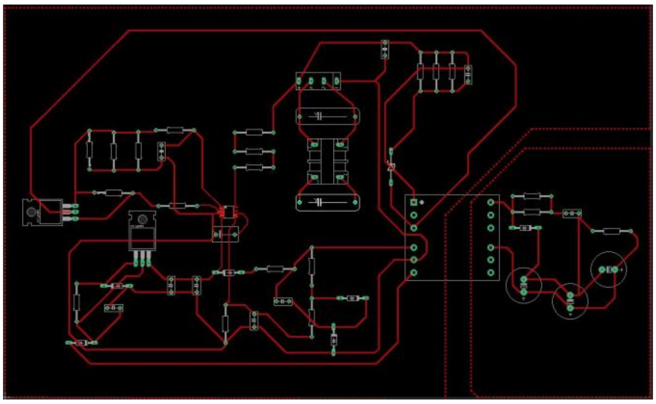

Figure 6: PCB Board

As figure 6 show, the two dot lines are to separate the primary side ground and secondary side ground. However, separate the primary side ground and secondary side ground is important because 1 side is doing input and other side is doing output, if no separate the ground, the circuit will be short circuit. The PCB board is designed with ground plane to absorb the noise that provide during the operation, thus, the larger the ground plane, the more noise can be absorbed. Moreover, figure 6 do not show the ground plane because of the simple view for the PCB board design, when applied the ground plane in the board design, the entire board will changed into red colour and the red colour wire connection is overlapped, so the software will create a black line to protect the connection of the wire to make sure the connection can be successfully printed out to PCB but hard to show the components on the figure. Therefore, when printed out to PCB, the copper of all the wire connection and ground plate are cover under an opaque substance, hence, by removing the opaque substance only able to solder the components to the PCB.

As figure 7 show that the flow chart of the entire system started when the AC input is supplied. The working principle of EMI filter is not explained at previous section, hence, the working principle of the EMI filter is the inductor installed at the AC input side to block high frequency current and allow low frequency current flow through. The inductor is operating at common mode, thus, the inductor has low electrical resistance and minimize the power loss in the process. Common mode inductor is construct by two or more coils of insulated wire on a single magnetic core and the winding is series to the conductor, thus, it produces high impedance to the noise signal when the wires combine. The capacitors are used to create a low impedance path to transfer the high frequency noise away from the input filter or back to power supply.

After pass through the inductor, the bridge rectifier is to convert the AC input to DC output. Bridge rectifier is designed by 4 diodes rectifier, so when the input voltage is positive, the current flow from the first upper diode to the circuit, then the opposite lower diode is negative output to ground. Therefore, when the input voltage is negative, the flow in the rectifier is reversed to the positive input voltage. The IC FL7733A is a PWM controller that able to supply the voltage to each pin. Based on the datasheet of the IC FL7733A show that the pin 8 required higher voltage than the pin 4 for starting up the controller. The pin 4 is required 16V for supply the IC operating current and MOSFET current, hence, the gate MOSFET can turn on and the pin 1 is connected with a resistor to detect the MOSFET current. The transformer in this circuit is designed to stepdown the voltage from primary side to secondary side and an auxiliary winding is connected to the transformer for doing the extra Vdd input. The RCD snubber circuit is construct after the transformer. The working principle of RCD snubber circuit is to absorb the current leakage in transformer when the voltage over the capacitor voltage. The output voltage of the circuit is 50V measured on the resistor.

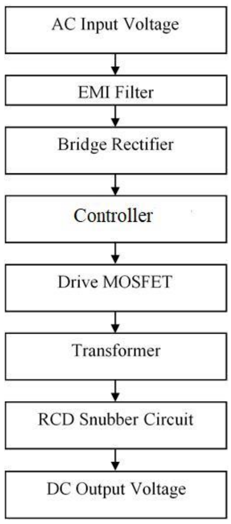

Figure 7: Flow Chart of Design

IV. Results and Discussion

Figure 8 above show the results of the full load condition. As figure 8 show above, all of the diagram is the result value show in a certain time frame. The first diagram is the input voltage and input current, in the diagram show that the input voltage is around 200V and input current is around 30A. The duty cycle turns on in every 50µs. The power factor of the circuit is 1 due to the components that used in the simulation is in idea case. Furthermore, the line voltage and current are around 26V and 24A separately. Moreover, the output voltage is around 50V. Besides that, the output current is around 1A. Lastly, the output power of the circuit is around 50W.

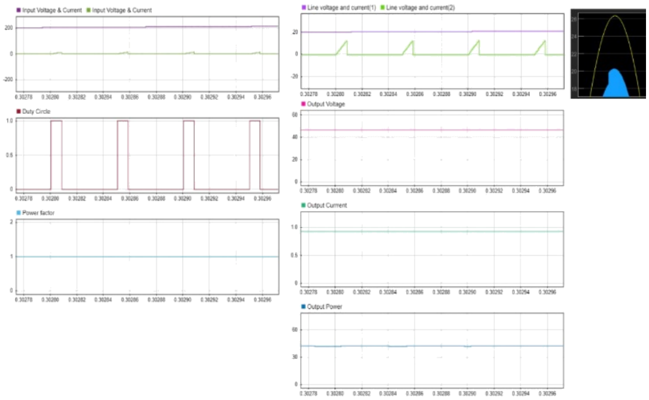

Figure 8: Full Load Condition

The second test of the simulation circuit is test the results show in 80% of the full load condition by changing the load resistor value to 62.5Ω.

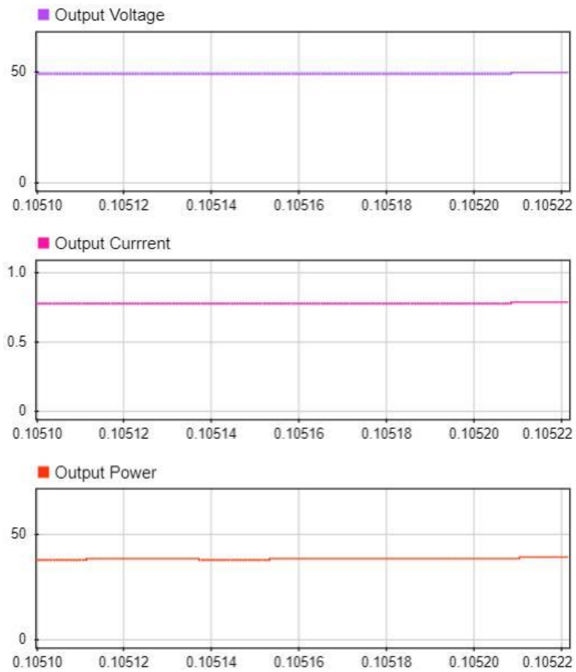

Figure 9: 80% of Full Load Condition

As mention on the previous, based on figure 9 the input voltage and input current are remain the same. The turns on time of the duty cycle is same and the power factor for the entire circuit also remain. Therefore, the changed of the load resistor affected the output current and output power. As figure 9 above show that to maintain the output voltage 50V, the output current is decreased to around 0.7A and the output power is also decreased to around 38W.

The third test of the simulation circuit is test the results show in 60% of the full load condition by changing the load resistor value to 83.33Ω.

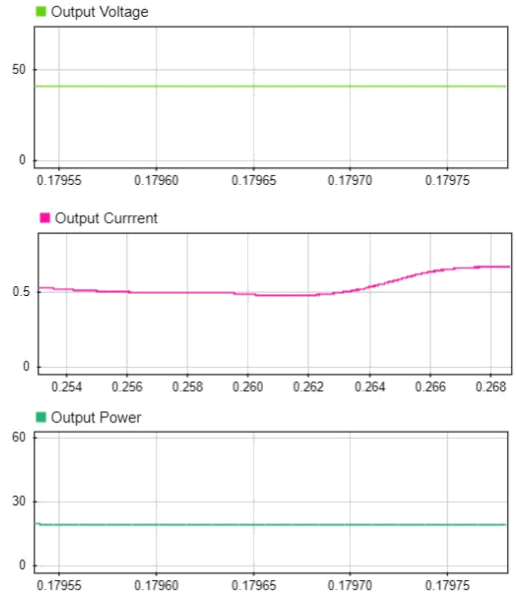

Figure 10: 60% of Full Load Condition

As figure 10 above show that the output voltage is still around 50V. The output current is around 0.5A and the output power is around 25W. The fourth test is changing the resistor load to 125Ω and the load condition run in 40%.

Figure 11 above show that the circuit run in 40% of full load condition. As mention, to get the output voltage in 50V, the output current is around 0.4A and the output power is around 18W. The fifth test is the 20% of the full load condition by used the load resistor in 250 Ω.

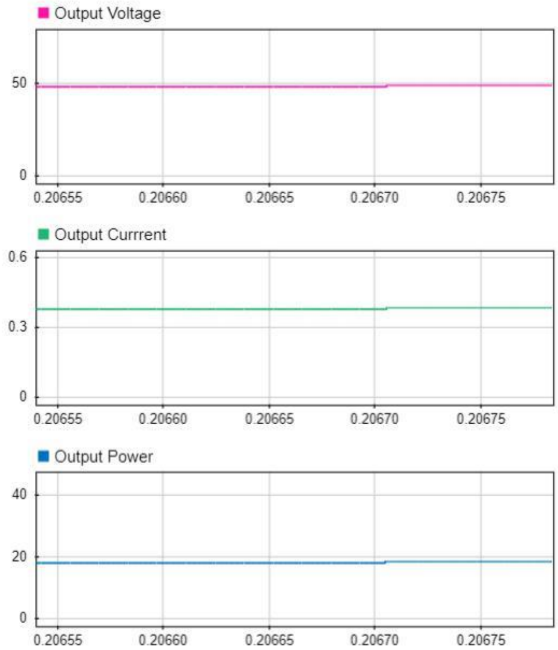

Figure 11: 40% of Full Load Condition

Figure 12 above show that the output result that run in 20% of full load condition. The output voltage is around 40V, the output current is around 0.18A and the output power is around 5W.

Figure 12: 20% of Full Load Condition

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