Multiple Input Single Output (MISO) DC-DC Converter
For the DC House Project

By Owen Jong

Senior Project

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic University

San Luis Obispo

2012

Abstract

This senior project report explains the design of a Multiple Input Single Output (MISO) DC-DC converter for the DC House Project. MISO DC-DC converter interfaces multiple different power sources such as Wind and Solar Energy sources as the inputs to a DC house. The report demonstrates the functionality and the performance of the proposed converter using Flyback topology by showing the theoretical simulation and hardware testing results. Results show the ability of the proposed MISO converter to supply up to 150 Watts from three sources while maintaining maximum efficiency of 92% at full load.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

I.   Introduction

During War of Current, sometime in the late 1880, Thomas Edison promoted Direct Current (DC)

for electric power distribution over George Westinghouse's Alternating Current (AC) distribution system.

"It was at this time that Edison launched a propaganda war against alternating current. Westinghouse
recalled:

I remember Tom [Edison] telling them that direct current was like a river flowing peacefully to the sea,
while alternating current was like a torrent rushing violently over a precipice. Imagine that! Why they
even had a professor named Harold Brown who went around talking to audiences... and electrocuting
dogs and old horses right on stage, to show how dangerous alternating current was. "[1]

During the early years of electricity distribution, Edison successfully established the direct current

standard for United States. He believed DC was better than AC due to several reasons such as DC

worked well with incandescent lamps, motors. DC systems could be directly connected to energy

storage devices such as batteries to provide backup power during interruptions of generator operation.

DC generator could be easily paralleled to allow using smaller machines during low light load period and

it improved reliability the generation side.

However, in terms of power transmission, AC had couple advantages over DC due to the

simplicity to reduce or increase the voltages. Edison realized this limitation and suggested to generate

power closed to where it was consumed. Unfortunately this solution proved to be very expensive and

nearly impossible for larger rural areas to afford to build a local station. On the other hand, AC could be

transmitted over long distances at very high voltage, thus reduced the current and lowered the

transmission losses. AC could be stepped down with low cost for residential use or factories. Soon after

Tesla and Westinghouse introduced AC generators, transformers, motors, wires and lights, DC lost its

stand over the war.

Without considering how stepping up or down the voltages are done in DC, DC transmission

system is overall better in terms of efficiency over AC transmission system due to the AC losses. AC

transmission lines have capacitive and inductive losses that do not exist in DC transmission lines. Skin

effect reduces the effective surface area of a conductor and is related to the operating frequency; the smaller the effective surface area the greater the line resistance as explain in [2]. Due to the operating frequency, the line inductance will cause voltage drops along the line which needs to be fixed typically using shunt capacitor to increase the voltage again. The reactance along the line causes the lagging power factor which leads to drawing more current from the generator to produce the same amount of real power required by the load, thus introducing more transmission loss. While in DC, power factor is always unity, hence it only transmits real power.

In developing countries, such as Indonesia, there are a lot of rural areas where electricity is scarce. People in such countries still depend on oil lamp for lighting during the night and use oil stove to cook which increases the fire hazard. However, aside from the scarcity of the electricity, such countries usually have abundant renewable energy resources such as solar, hydro and wind energy. It would be advantageous for rural areas to be able to utilize these renewable resources instead of depending on oil as the main energy source.

Many research have been conducted to utilize the renewable energy resources such as PV panels to use solar energy. However, most of them convert only one type of source to electrical energy. One major disadvantage utilizing a single renewable energy source is when the generator side stops supplying power due to natural condition. As PV is relying on the sunlight, its converter will not supply any power at night. A better approach would therefore be combining multiple renewable resources such as PV and hydro. This way during night, the hydro generator will keep delivering energy to the load.

The focus of this study is to design and build Multiple Input Single Output (MISO) DC-DC Converter to interface multiple sources to a single DC bus output. As mentioned previously, in rural areas DC system would be more advantageous and efficient by utilizing renewable energy resources such as solar, hydro and wind energy. Using renewable energy resources may potentially be the cheaper solution and thus it is also the purpose of the DC House Project. This in turn will help people who live in

the rural areas to enjoy electricity without burdening them too much with the cost of electricity. The initial study and prototype has been done by Taffy Chi Kin Wong in California Polytechnic University as his Master thesis using full bridge topology to achieve 600 Watts of MISO Converter [3]. However, the previously designed MISO Converter lacks of isolation and output power. Therefore, and alternative solution is necessary and is being proposed in this report to address issues faced by the previous MISO converter.

II.   Design Requirements

As mentioned in the previous chapter, this project has the objective to design and build a

Multiple Input Single Output (MISO) DC-DC converter for the DC House Project. Previously, a MISO

converter was designed and constructed by another student, but the converter still suffers from a few

shortcomings. One issue is the overall converter's efficiency. In this project, to improve efficiency not

only that the proposed DC-DC converter topology needs to be evaluated, but also the components in

the system need to be optimized. Solar Panel, DC wind turbine and DC hydro-turbine have been studied

by other groups of students in the DC House project to determine the output voltage of the sources that

give the best efficiency. For this project, it will be assumed that 24 volts output voltage gives the

maximum overall system efficiency. This means the nominal input of the MISO converter will have to be

24 Volts. In the second phase of the DC House project, MISO converter utilizes three different input

sources. Each renewable energy source is assumed to output 50 Watts, so the total maximum output

power of proposed DC-DC converter is 150 Watts. Another necessary assumption is devices used in the

DC House operate at 48 input voltages to achieve their highest efficiency; therefore the MISO converter

regulates the output at 48 Volts.

Since the MISO converter is used for home applications, isolation is necessary for safety reason.

This isolation can be achieved by using transformer while at the same time providing the step up or

down function. It was then determined that for this project the proposed solution had to be an isolated

topology. Increasing efficiency of the MISO system is one of the objectives of this project. Therefore the

proposed design is expected to operate with greater than 80% efficiency at maximum load. In order to

ensure quality of the output voltage, output voltage peak to peak ripple should be less than 2% of the

specified 48 V output at full load and nominal 24 V input. Line and load regulations are also targeted to

be less than 3% with input voltage variation from 20 to 28 Volts. Table 2-1 summarizes the design

requirements for the proposed converter.

Table 2-1: Specification of the Multiple Input Single Output DC-DC converter

Number of input source	3
Input source voltage	24V
Maximum output wattage	150W
Output voltage	48V
Line regulation	3%
Load regulation	3%
Output voltage ripple	2%
Efficiency at full load	≥80%

III.   Design and Simulation

Designing high-power high-efficiency MISO converter using Flyback topology has a couple of advantages. With Flyback, the converter requires only one switch and one winding per input as shown in Figure 3-1, thus reducing the cost and complexity of the control circuit. However, the difficulty lies in achieving the high efficiency due to the unique use of transformer as an energy storage rather than energy transferring device. This issue may be overcome by running the converter in boundary conduction mode (BCM). When operating in BCM, the switch turns on at zero current which reduces switching loss. The consequence of running the converter in BCM, however, is the high peak to peak current ripple seen by the transformer. Another critical disadvantage of the flyback topology is that the topology is prone to switch's high voltage spike due to leakage inductance from the transformer affecting the maximum drain to source voltage requirement of the MOSFETs.
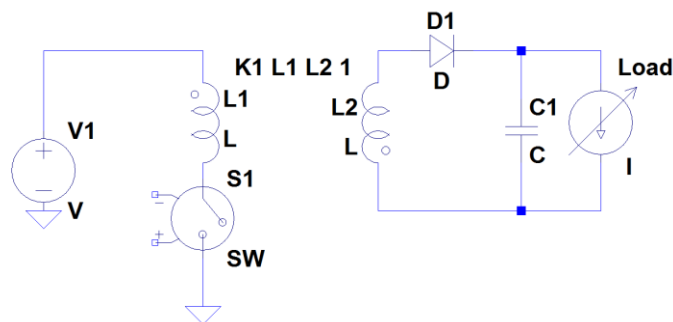
Figure 3-1: Isolated Flyback converter

When the switch starts conducting, current starts to flow from the input voltage source through the transformer's primary winding and in turn storing energy in a form of magnetic flux at a rate of the input voltage over the magnetizing inductance (V/L). When the switch stops conducting, the magnetic

flux is discharged through the secondary winding to the load and filtered by the output capacitor. However, due to the energy stored in the leakage inductance, the voltage spike occurs at node where the primary winding meets one end of switch as soon as the switch turns off.

Choosing a right controller has become the main challenge in designing the MISO converter. LT3748 was finally chosen to do the job due to its flexibility in adjusting the maximum output power based on the component used for the MISO converter. LT3748 is designed to operate only in boundary conduction mode to increase the total efficiency of a flyback converter. Operating frequency is set by load current and transformer magnetizing inductance. It regulates the output voltage by monitoring the voltage across the primary winding; hence providing complete isolation between primary and secondary sides of circuit without the use of a more costly opto-isolator or third winding.
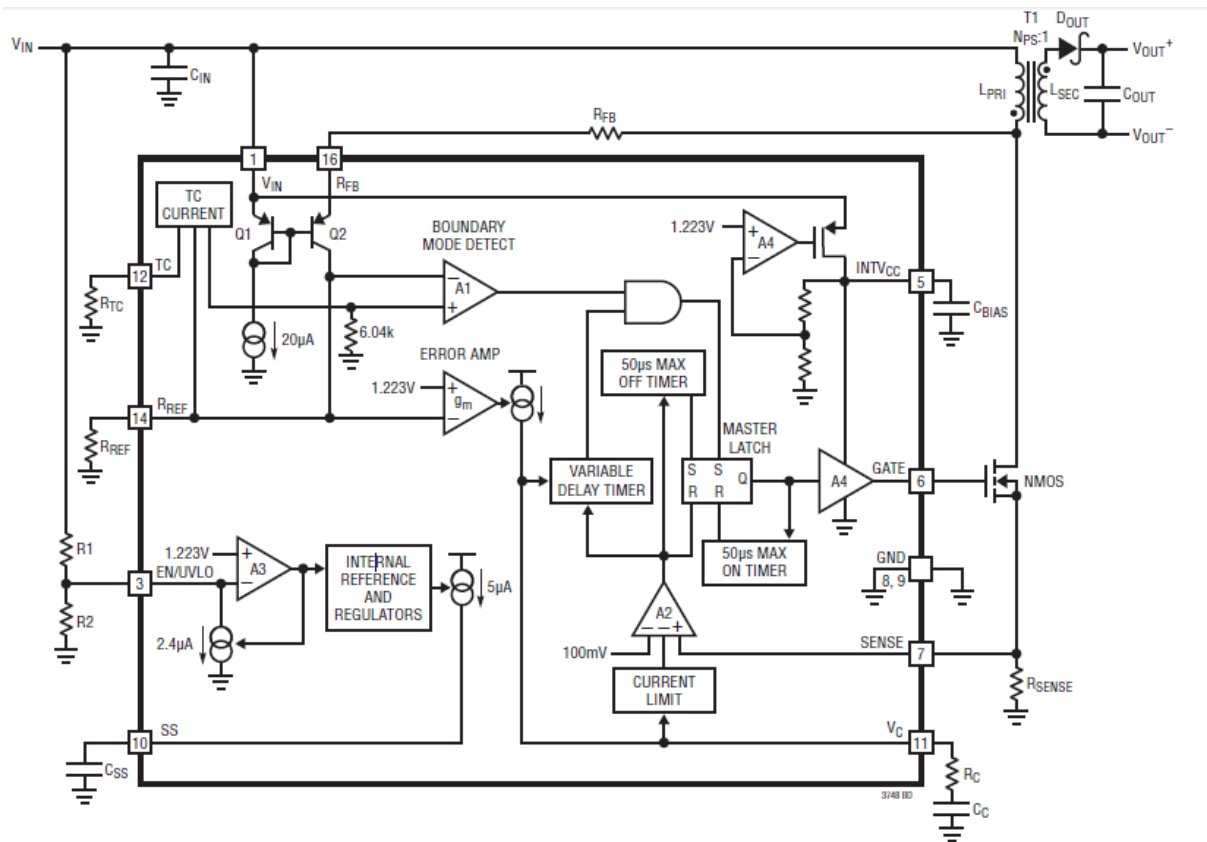

Figure 3-2: LT3748 Block Diagram

Looking at Figure 3-2, a couple of resistors have to be determined for LT3748 to regulate the output voltage. However, before these resistor values can be calculated, the turn ratio of the transformer has to be determined. Determining the turn ratio is a bit tricky because there are two limitations to consider; the current limitation and the voltage limitation on the primary side. Consider N to be a positive number and greater than one integer. To be able to draw maximum power from the input to the output, these current and voltage limitations have to be balanced. Using 1:N turns ratio will increase the current requirement on the primary winding. However, if N:1 transformer is used, the current will not be as high. However the voltage seen by the switch will be higher without considering the voltage spike. Therefore, 1:1 transformer is used for the MISO converter. In the block diagram, both pin 1 and 16 are connected by the biasing circuit, which indicates the voltage at pin 1 is reflected to pin 16 due to the PN junction characteristic. On the other node where Rfb is connected, the primary winding and the drain of the MOSFET meet and has a voltage of Vinput + Vout. This implies that the voltage across Rfb is Vout. The current through Rfb was set up by the comparator's reference voltage and the Rref. It is suggested that Rref should be 6.04kOhms. Therefore the current through Rfb is 0.2025mA (=1.223V/6.04k). Rfb is then determined to be around 230kOhms.

At full load, to reduce the switching loss, lower operating frequency needs to be considered. One assumption needs to be made is that MISO converter runs at 80 KHz at full load (3Amps).

$$D(V_{in}) + (1 - D)(-V_{out}) = 0$$

$$DV_{in} - V_{out} + DV_{out} = 0$$

$$D(V_{in} + V_{out}) = V_{out}$$

$$D = \frac{V_{out}}{V_{in} + V_{out}} = \frac{48}{24 + 48} = 0.667$$

From the duty cycle equation, peak current of the secondary winding of the transformer can be found to be 18 Amps. Divided evenly to three sources, each primary winding has peak current of 6 Amps. The

maximum voltage of the sense node is 100mV, therefore by following Ohm's law (V=IR), Rsense is found

to be 16mOhms. After figuring out the peak current and the operating frequency, the inductance of the

primary windings can be calculated using VL = L dIL/dT.

$$V_L = L \frac{dI_L}{dt}$$

$$L = \frac{V_L DT}{\Delta I_L} = \frac{24\ 0.667\ \frac{1}{80kHz}}{18A} = 11.11\ uH$$

Based on the calculated value, the MISO converter is designed and simulated as shown in the

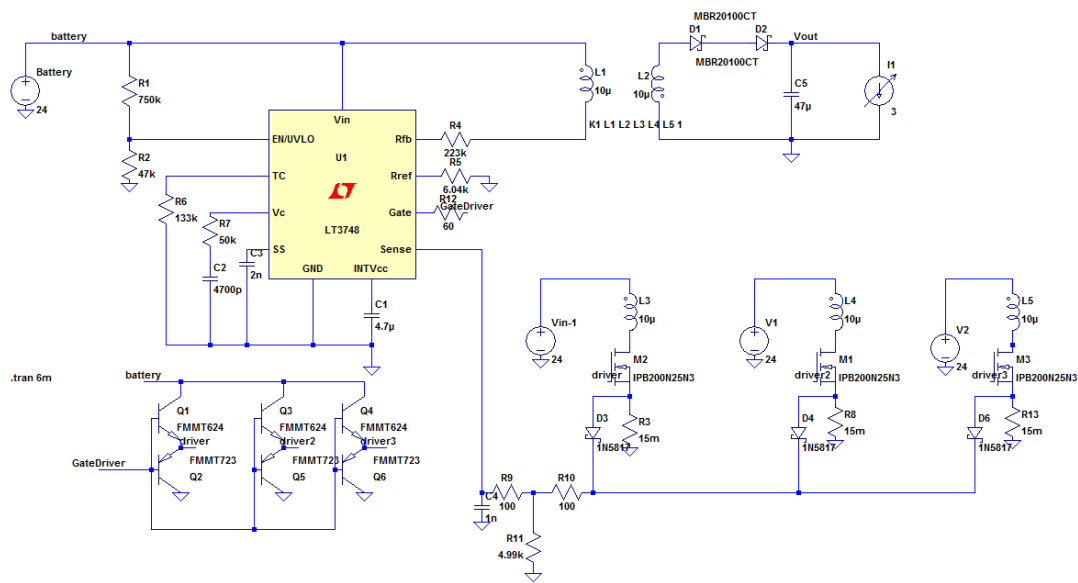schematic of Figure 3-3.

Figure 3-3: Schematic of MISO Flyback Converter Design

To be able to run independently, the "or diode" configuration is used. However, since the sense

pin needs a current path for its current to flow to sense the voltage, wye resistor configuration is used to

reflect the voltages built by the sense resistor. The simulation results are shown below in Figure 3-4.
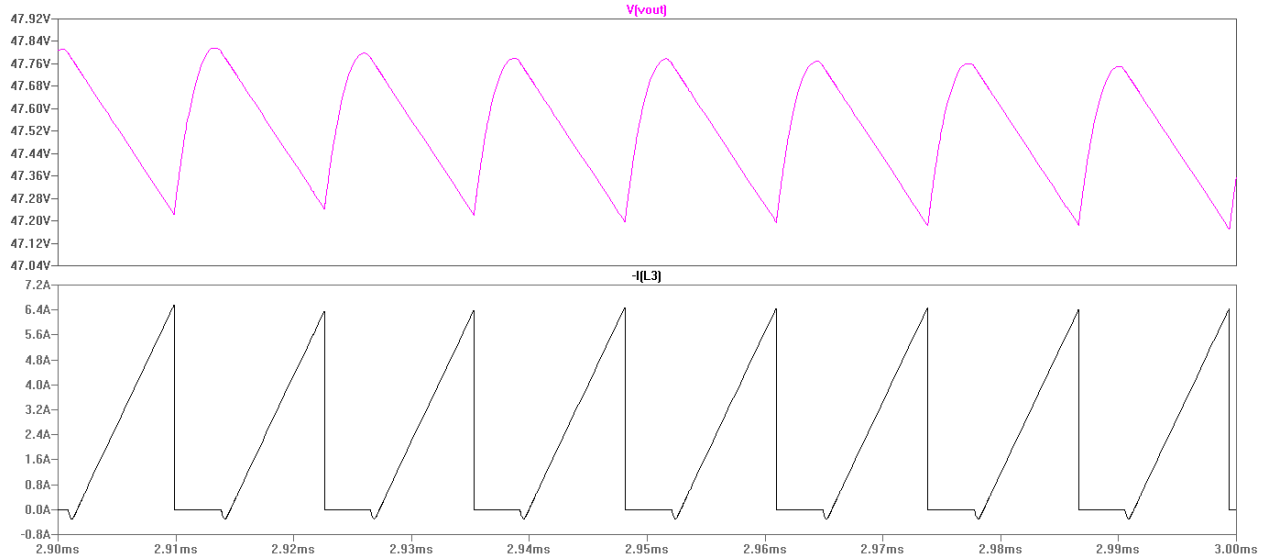
Figure 3-4: Simulation Result of the output voltage and one of the primary winding current of the

MISO Flyback Converter

The key component of the proposed MISO converter is the transformer. The transformer has to be able to handle 18 Amps peak current at 80 kHz of operating frequency. Design of the transformer is done using what is known as the Area Product method.

$$A_p = \left(\frac{L_{mag} I_{prim-pk} I_{rms} 10^4}{420 \; 0.2 \; B_{max}} \right)^{1.31} \; (in \; cm^4) \qquad L_{mag} = \frac{0.4 \; \pi \; N_p A_e 10^{-8}}{l_g + \left(\frac{l_m}{\mu_r} \right)} \; (H)$$

$$N_p = \frac{L_{mag} I_{prim-pk}}{B_{max} A_e}$$

Note:

- Ap is area product
- Np is number of turns on the primary side
- μr is relative permeability of the magnetic material (from data sheet)
- Iprim-pk is primary side peak current (18 Amps)
- Irms is the root mean squared of the current
- Bmax is maximum magnetic flux density and assumed to be 300mT (for design purposes)
- Lmag is the magnetizing inductance (10uH from the simulation)
- Lg is air gap required by the flyback transformer
- Le is effective length of the core used for the transformer (from data sheet)
- Ae is the effective area of the core used for the transformer (from data sheet)

When choosing the type of material used as the core, R type material is chosen because it can handle 500mT of magnetic flux density and the operating frequency can go up to 1.5MHz. However, some values are adjusted to give the transformer safety margin. The peak current is assumed to be 30Amps and RMS primary current to be 6.5Amps. After calculating the area product of the required core, PQ4040 from Mag Inc.com was chosen. The area product of the required core is found to be 1 cm^4 while PQ4040 has area product of 5 cm^4. Assumed values and calculated values for the transformer design are shown on Table 3-1 below.

Table 3-1. Assumed and Calculated values of the required Flyback Transformer

Iprim max	in A	30		core type	PQ	#4040
Iprim rms	in A	6.5				
Bmax	in T	0.3		Ae	in mm2	201
Lmag	in H	1.00E-05		le	in mm	102
				ur	2300	R type
Ap	0.714678	in cm4				
Np	4.975124	5				
Lg	1.218572	in mm				
Lsec	1.00E-05					

In order to reduce losses such as DC losses and proximity effect between primary and secondary windings inside the transformer, the primary and secondary windings in the MISO transformer were constructed in sandwich winding patters and bifilar windings to achieve high efficiency and low leakage inductance. The sandwich winding pattern of MISO transformer is shown in Figure 4-1. NpA, NpB, NpC, NpD are the primary side coils, while NpD and NpE are the secondary side coils. NpD, however, is used only to send the output information to the controller. Terminal configuration of the MISO transformer is shown in Figure 4-2.
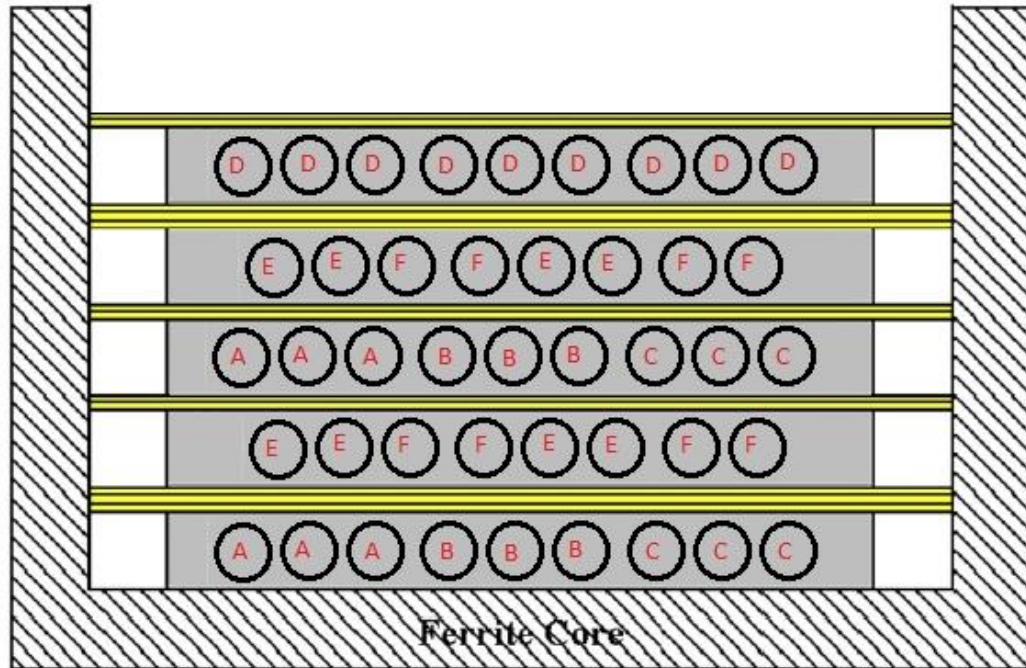
Figure 4-1: The MISO Sandwich Configuration Transformer

After the MISO Transformer was constructed, the magnetizing inductance of the primary windings was found to be 10.3µH and leakage inductance of 0.25µH was measured. The leakage is considered acceptable as long as less than 5% of its magnetizing inductance.
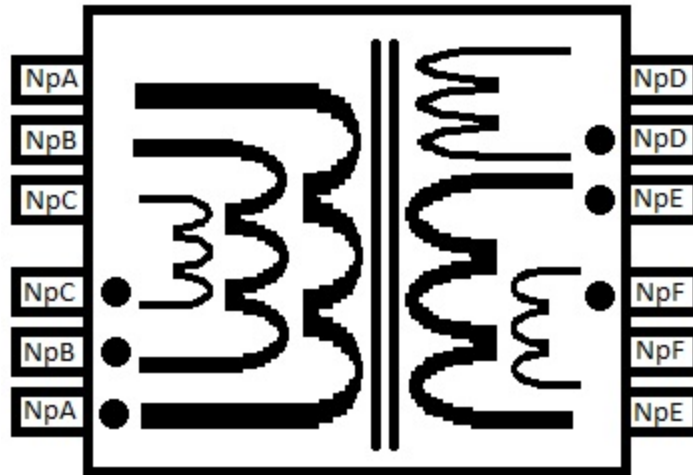
Figure 4-2: The terminals configuration of MISO Transformer

Based on the terminals configuration of MISO transformer and the schematic of Figure 3-3, a custom printed circuit board is designed to support the designed circuit. The MISO printed circuit board is designed using only two layers as shown in Figure 4-3, MISO printed circuit board layout. By using two layers, it is easier to make any modification as necessary. The controller has its own signal ground separated from the power ground to suppress the noise from environment and from the MISO transformer that might affect the current sensing node. The MISO printed circuit board use surface mount components for controller and sensing functions, and through-hole for power components such as MOSFETS and output schottky diode to ensure the reliability. Initially, to reduce the conduction loss due to MOSFET's Rds-on, three MOSFET slots are provided for each source, therefore to ensure the gate driving capabilities of LT3748, one NPN/PNP driver is set up to drive three MOSFETs for each source. However, to protect the gate driver of LT3748 from shorting to ground, 50 Ohms resistor is used to interface the gate driver pin of LT3748 to the bases of NPN/PNP drivers.
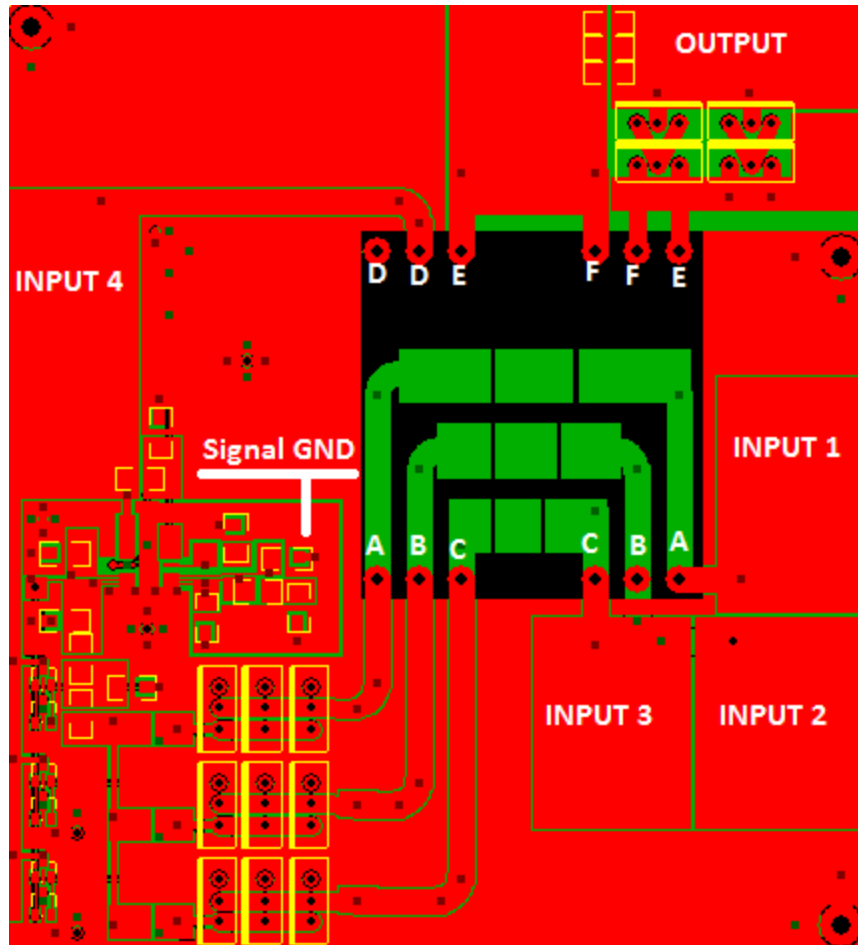
Figure 4-3: The Multiple Input Single Output (MISO) Flyback Converter PCB Layout

The proposed MISO converter hardware is shown in Figure 4-4. Inputs (1), (2) and (3) are the primary sides of the MISO flyback converter. Input (4) powers LT3748 controller separately from the MISO converter's input sources. For the DC House application, this can be replaced by using a 9 Volt battery which is then stepped up to 24 Volts using Boost converter so that the controller's operation is completely independent of the renewable sources.
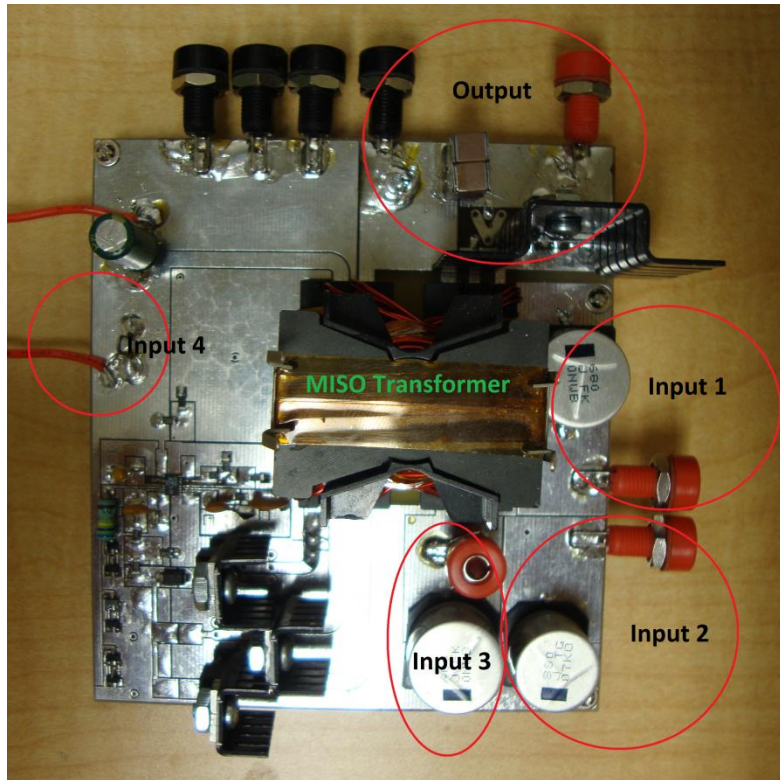
Figure 4-4: The Multiple Input Single Output (MISO) Flyback converter

Figure 4-5 shows the complete MISO converter test setup in the lab. Three high power DC

supplies, used to simulate the three renewable resources, are connected to Input (1), (2) and (3) of

MISO converter. The fourth DC source is connected to input (4) to power the controller. To simulate DC

house load, electronic load is used to the output terminals of the MISO converter. Shown in Figure 4-5,

the electronic load is drawing 3 Amps at 48.3 V from the MISO converter powered by three different DC

sources simulating the regulated renewable energy sources. The input (4) however is powered by a 9

Volt battery stepped up to 24 Volts using boost DC-DC converter to power the controller.

Unfortunately, the "or diode" configuration created noise at the sensing node and the MISO

converter was not regulated properly, thus the "or diode" configuration is then removed leaving just

one diode connected to one source. By using just one diode, the controller forces the MISO converter to

require one source to be running all the times for achieving regulation of the MISO converter.
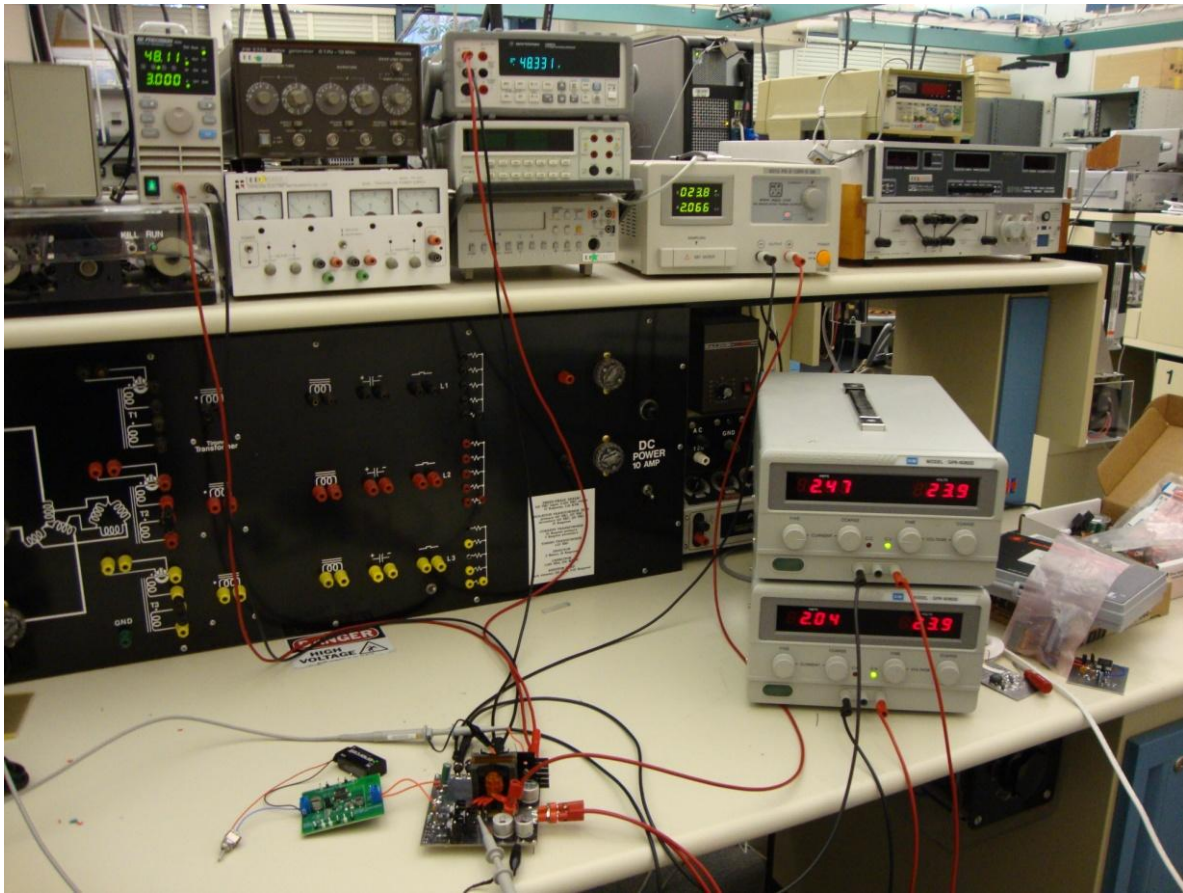
Figure 4-5: The complete MISO converter test setup

When the "or diode" configuration was removed, input A was chosen to become the main source that has to run all the times so the controller can regulate properly. In the hardware demonstration, The MISO converter hardware was tested under different conditions: only source (1) was turned on, source (1) and (2) were turned on, source (1), (2) and (3) are turned on. The current voltage waveform is monitored to ensure the MISO converter is running at maximum output before it hits the 100mV maximum current limit. All voltages and average currents from the input sources and output, %efficiency and % load regulation are recorded in table 4-1, 4-2 and 4-3. Performance data of the MISO converter, such as maximum output peak to peak ripple, maximum % load regulation and maximum load % efficiency are recorded in Table 4-4.

Table 4-1. Efficiency Measurement over the range of load from with one source

Vin_1	Iin_1	Vout	Iout	%Load	efficiency	% Load Regulation
Volts	Amps	Volts	Amps			
24	0.72	48.503	0.3	10.00%	84.21%	0.08%
24	1.37	48.752	0.6	20.00%	88.96%	0.43%
24	2.02	48.837	0.9	30.00%	90.66%	0.61%
24	2.69	48.838	1.2	40.00%	90.78%	0.61%
24	3.35	48.749	1.5	50.00%	90.95%	0.43%
24	4.01	48.541	1.8	60.00%	90.79%	0.00%

Table 4-2. Efficiency Measurement over the range of load from with two sources

Vin_1	Iin_1	Vin_2	Iin_2	Vout	Iout	%Load	efficiency	% Load Regulation
Volts	Amps	Volts	Amps	Volts	Amps			
24	0.27	24	0.44	48.477	0.3	10.00%	85.35%	0.16%
24	0.56	24	0.78	48.679	0.6	20.00%	90.82%	0.58%
24	0.88	24	1.1	48.791	0.9	30.00%	92.41%	0.81%
24	1.11	24	1.52	48.865	1.2	40.00%	92.90%	0.96%
24	1.57	24	1.73	48.834	1.5	50.00%	92.49%	0.90%
24	1.92	24	2.03	48.735	1.8	60.00%	92.53%	0.69%
24	2.21	24	2.4	48.615	2.1	70.00%	92.27%	0.44%
24	2.58	24	2.71	48.6	2.4	80.00%	91.87%	0.41%
24	2.96	24	3.01	48.543	2.7	90.00%	91.48%	0.30%
24	3.31	24	3.34	48.4	3	100.00%	90.98%	0.00%

Table 4-3. Efficiency Measurement over the range of load from with three sources

Vin_1	Iin_1	Vin_2	Iin_2	Vin_3	Iin_3	Vout	Iout	%Load	efficiency	% Load Regulation
Volt	Amps	Volt	Amps	Volt	Amps	Volt	Amps			
24	0.17	24	0.15	24	0.401	48.535	0.3	10.0%	84.15%	0.07%
24	0.35	24	0.32	24	0.673	48.686	0.6	20.0%	90.63%	0.38%
24	0.55	24	0.51	24	0.922	48.83	0.9	30.0%	92.39%	0.67%
24	0.77	24	0.7	24	1.152	48.826	1.2	40.0%	93.11%	0.67%
24	1	24	0.89	24	1.375	48.782	1.5	50.0%	93.38%	0.58%
24	1.23	24	1.09	24	1.591	48.711	1.8	60.0%	93.41%	0.43%
24	1.47	24	1.29	24	1.804	48.624	2.1	70.0%	93.22%	0.25%
24	1.71	24	1.5	24	2.016	48.6	2.4	80.0%	93.00%	0.20%
24	1.96	24	1.72	24	2.24	48.569	2.7	90.0%	92.30%	0.14%
24	2.21	24	1.94	24	2.415	48.503	3	100.0%	92.35%	0.00%

Table 4-4. Overall Performance of MISO Converter at Max Load with Three Inputs

Max Iout	3 Amps
Vout @ Max Iout	48.5 Volts
Max Output Power	145.5 Watts
Max % Load Regulation	0.67%
% Line Regulation (20-28 Volts)	0.69%
% Efficiency at Max Load	92.35%
Maximum Load Output Voltage Ripple	0.88 Volts

In Tables 4-1, 4-2 and 4-3, the MISO converter was tested by running just one source, two sources and three sources. The I_in is the average current input from the DC power supplies simulating the renewable energy sources. The V_in is set to be 24.0 Volts. Moreover, the Vout and Iout correspond to the voltage and current supplied to the DC house.

In Table 4-4, maximum output power is calculated by using (4-1)

$$P_{max} = V_{out\,full\,load} * I_{out\,full\,load} \qquad\qquad (4\text{-}1)$$

Efficiency is calculated by using (4-2)

$$Efficiency = \frac{Vout*Iout}{V_{in1}*I_{in1}+V_{in2}*I_{in2}+V_{in3}*I_{in3}} 100\% \qquad\qquad (4\text{-}2)$$

Load Regulation is calculated by using (4-3)

$$\% \, Load \, Regulation = \frac{V_O - V_{Ofull\,load}}{V_{O\,full\,load}} 100\% \qquad\qquad (4\text{-}3)$$

Line Regulation is calculated by using (4-4)

$$\% \, Line \, Regulation = \frac{V_O@V_{in\,max} - V_O@V_{in\,min}}{V_O@V_{in}=24} \, 100\% \qquad\qquad (4\text{-}4)$$

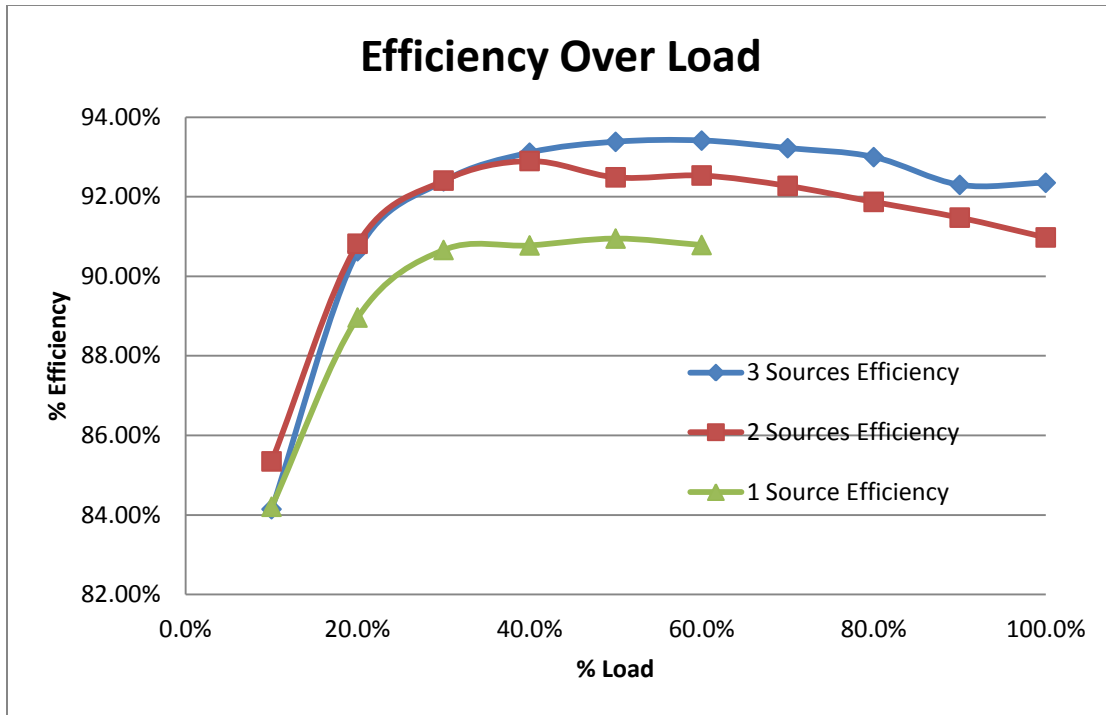Output Power and Efficiency data are plotted in Figure 4-6 and 4-7.

Figure 4-6: Efficiency of the MISO Converter over Varied Load
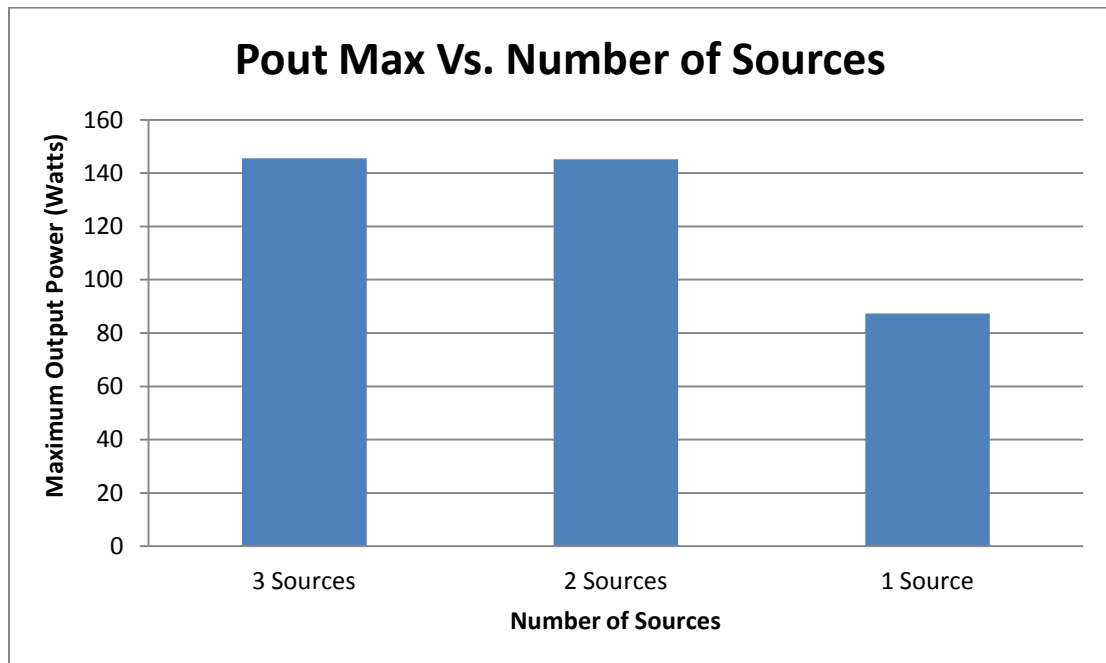

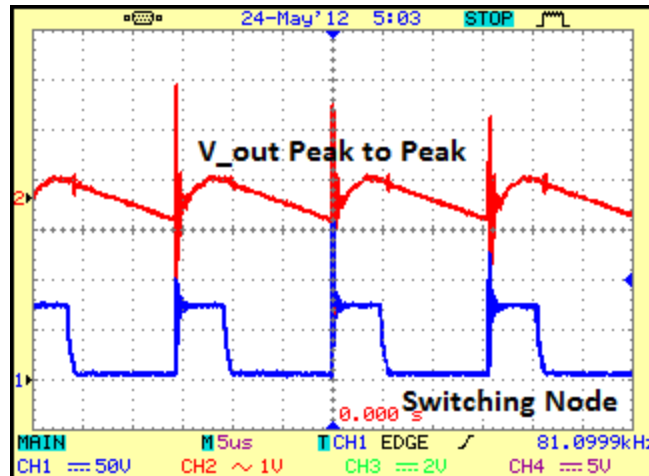**Figure 4-7: Maximum Output Power based on Number of Sources used**

Figure 4-8: Output Voltage Peak to Peak Ripple when MISO converter powered by 3 sources at

maximum load

Table 4-4 shows that the proposed MISO converter successfully interfaces the three independent sources to a stable single output. When MISO is supplied by three sources, it can output 145.5 Watts to the load. Output voltage ripple for this case is captured in Figure 4-8 which yields the highest for all cases. The maximum output load regulation is 0.67% and efficiency at maximum load is 92.35%, which are both within the specified level. However, at lower loads, the MISO converter needs a minimum load of about 330mA; otherwise the output voltage will keep rising.

> "LT3748 recovers output voltage information using the flyback pulse that occurs once the MOSFET turns off and the secondary winding conducts current. In order to regulate the output voltage, the LT3748 delivers a minimum amount of energy even during light load conditions to ensure accurate output voltage information. The minimum delivery of energy creates a minimum load requirement on the output approximately 2% of maximum load. The minimum operating frequency at minimum load is approximately 42 kHz."-[4]

The minimum load requirement of the MISO converter can be calculated for example from one source measurement result of 1.8 Amps at maximum load. The 2% minimum load requirement translates into 360 mA. Therefore, 330 mA load requirement is correct including loss along the energy transferring. However, to keep the efficiency high, another flyback circuit to drive two fans is connected at the output. This extra flyback circuit serves as the minimum load of the MISO converter and also as the cooling system driver required by the MISO converter. This extra flyback fans driver circuit is shown in Figure 4-9. It is a step down circuit that converts 48 V to 24 V, using LT3748 as the controller. The loads are two fans rated at 24 Volts – 0.3 A. Thus, the two fans will draw a total of 0.6 Amps at 24 Volts, or 0.3 at 48 Volts. To protect the input of the fans driver circuit, 4 12Volts zener diodes are used.
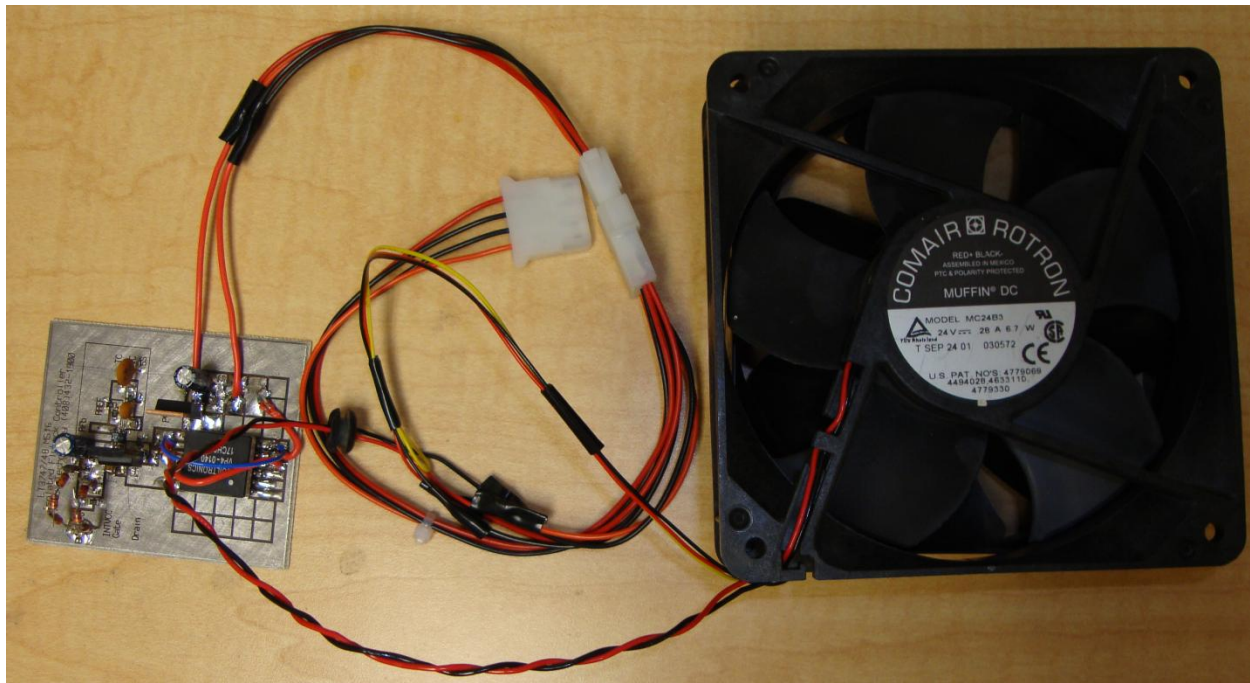

Figure 4-9: Flyback Circuit to drive 2 of 24Volts fan as cooling system and also fulfill minimum load requirement of the MISO converter

V.   Conclusion and Further Work

This project entails the design and construction of the second version of the Multiple Input Single Output converter. The proposed converter aims to improve the previous design. As explained in this report, the proposed flyback-based MISO converter is able to increase the output power as compared to the previous design. More specifically, the output power level of the proposed MISO converter is almost doubled its predecessor. However, 150 Watts is still below the required power level for a DC House which is expected to consume about 600 Watts. This issue may be overcome by paralleling the proposed MISO converters. Another issue encountered were noise and voltage spike at the sense resistor node which further disturbs the function of "or diode" configuration. This makes the proposed MISO loses the ability to make each of the connected sources independent from one another.

This flyback MISO converter has fulfilled the basic requirements set for the DC House MISO converter. There are still rooms for improvements. One example would be making the input source completely independent from one another. The Y configuration can be employed for controllers that use the current sense method such as LT3748. However, due to the high peak current from three different sources at the same time, the noise disturbs the sensing capability of the controller. Reducing the noise created by the high peak current may help solve the problem. Another simple approach is to use three different values of current sense resistors. For example, if the first source uses 30 mOhms, the second source uses 20 mOhms, and the third source uses 15 mOhms. By doing so, only the highest voltage built up by highest the sense resistor will go through the "or diode" configuration and sensed by the sense pin. If the first source is turned off, the second source's sense resistor will take over the regulation scheme.

Boundary Conduction mode works perfectly to achieve high efficiency of the MISO converter. Boundary mode introduces the zero current switching at the turn on scheme, reduces the switching loss.

Another way to reduce switching loss when using boundary mode is to increase the primary side magnetizing inductance of the transformer. By increasing the inductance, it will reduce the operating frequency which leads to less switching loss and less AC loss inside the transformer since skin effect and proximity effect are functions of frequency.

The proposed MISO flyback converter has achieved full isolation required by the DC house project. This was made possible by the primary current sensing function. While this is the most economical method, it does have a drawback. There are other options to provide isolation such as tertiary windings and opto-coupler.

The proposed MISO converter was found to be sensitive towards short circuit on its primary side windings. If one of the sources gets shorted to ground, the controller will not be able to regulate the output voltage of the MISO converter. Adding a switch between each renewable energy source to its primary winding will add one layer of protection to short circuit condition. If one source gets shorted to ground then the switch is turned off, hence isolating the shorted source from its primary winding.

In conclusion, this project demonstrates the ability of the proposed MISO converter to accept several different sources and then convert the power into one single output as required by the DC House.

Bibliography

[1] Public Broadcasting Service, "Tesla Life and Legacy – War of the Currents"

http://www.pbs.org/tesla/ll/ll_warcur.html

[2] Microwaves101, "Skin Depth" http://www.microwaves101.com/encyclopedia/skindepth.cfm

[3] Wong, Taffy Chi Kin. "Multiple Input Single Output DC-DC Converter for the DC House Project".

October 2011.

[4] Linear Technology. "100 Volts Flyback Controller Datasheet"

http://cds.linear.com/docs/Datasheet/3748fa.pdf

APPENDIX A

The following information is specification data for transformer ferrite core PQ4040

(mm)	Nominal:	Tol. min.:	Tol. max.:
A	41.5	-0.9	+ 0.9
B	19.9	-0.15	+ 0.15
2B	39.8	-0.3	+ 0.3
C	28.0	-0.6	+ 0.6
D	14.75	-0.2	+ 0.2
2D	29.5	-0.4	+ 0.4
E	37.0	-0.6	+ 0.6
F	14.9	-0.3	+ 0.3
G	29.0	-1.0	+ 1.0
H	6.25	-0.2	+ 0.2
J	15.0	0.0	+ 1.0

Eff. Parameters			
Ae mm^2	Amin mm^2	le mm	Ve mm^3
201.0	175.0	102.0	20500
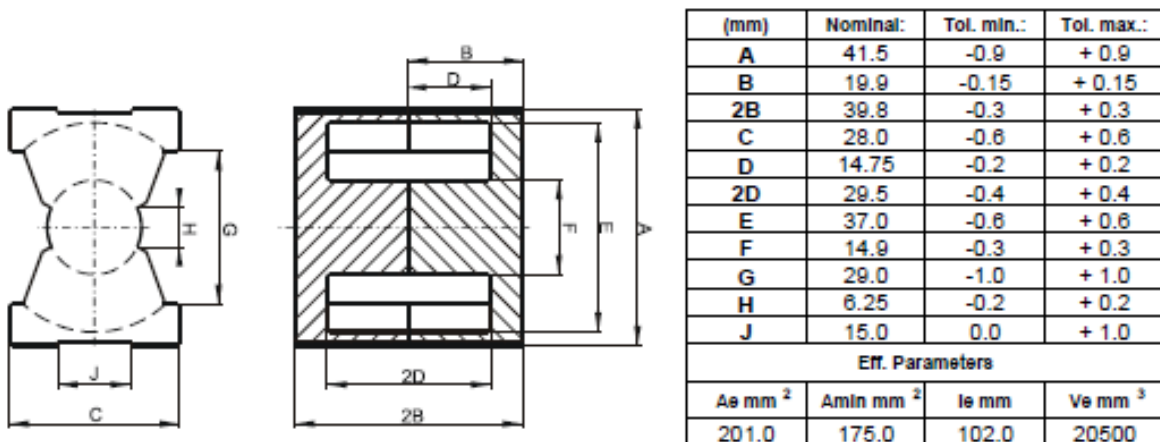
INDUCTANCE

AL value (nH)	Test conditions
Nom: 4267 Min.: 3200	10 kHz, < 0.5 mT, 25 ℃

MARKING

0R44040UG PXXXXX

CORE LOSSES

P$_l$ max	Test conditions
102 mW/cm^3 (2.1 W/set)	100 kHz, 100 mT, 100 ℃
615 mW/cm^3 (12.6 W/set)	100 kHz, 200 mT, 100 ℃

NOTE

Spec. modifications	Previous	Revised
2005-06-22	A=42.37 Max. B=19.99 Max. 2B=39.98 Max. D=14.6 MIN 2D=29.21 Min. Losses: General R material	A=42.4 Max. B=20.05 Max. 2B=40.1 Max. D=14.55 Min. 2D=29.1 Min. Losses: Detail as indicated

APPENDIX B

The following information is specification data for ferrite core R-type materials

Saturation Flux Density - gausses 5,000 (at 15 oersted, 25°C) (500 mT)
Coercive Force - oersted 0.18 (14A/m)
Curie Temperature . . . . 230°C

μᵢ 2,300 ±25%

NOTE: The core loss curves are developed from empirical data. For best results and highest accuracy, use them. The formula on page 3.10 yields a fair approximation and can be useful in computer programs.

PERMEABILITY vs. TEMPERATURE

CORE LOSS vs. FLUX DENSITY

CORE LOSS vs. TEMPERATURE

APPENDIX C

Part Lists used for the Proposed MISO Converter

Parts	Part Number	Manufacturer	Price per Unit	Quantity Ordered	Total
PCB	Custom	Express PCB	$ 33.88	4	$ 135.50
MOSFETs	IPP200N25N3 G-ND	Infineon Technologies	$ 7.62	10	$ 76.17
Schottky	MBR40250TGOS-ND	ON Semiconductor	$ 1.83	10	$ 18.27
Ceramic Capacitor	445-4109-1-ND	TDK Corporation (VA)	$ 5.12	10	$ 51.15
LT3748		Linear Technology	$ -	5	$ -
PQ4040 Core		Mag-Inc	$ -	1	$ -
PQ4040 Bobbin		Mag-Inc	$ -	1	$ -
NPN	FMMT624TA	Mouser	$ -	3	$ -
PNP	FMMT723TA	Mouser	$ -	3	$ -
				Total	$ 281.09