Solar Coupled Switched Mode Power Supply

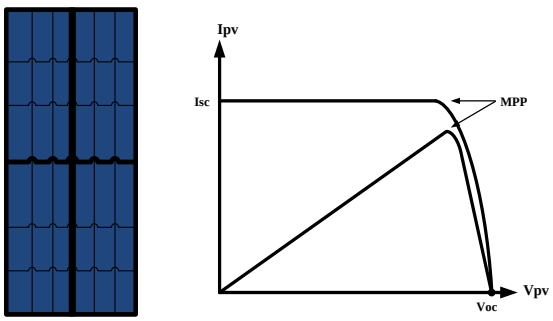
Rashmi Kale
Department of Electrical Engineering
Fr. C. Rodrigues Institute of Technology
Vashi, India

***Abstract*— In remote locations, difficulties are faced during testing and maintenance of electronic circuits. This problem is aggravated due to limitations in obtaining regulated power supply using conventional energy. It leads to search a sustained energy alternative. Among all renewable energy sources, solar energy is abundantly available. This paper highlights the utilization of solar energy in regulated power supplies. Flyback converter facilitates in getting multiple output ports with limited energy storage components.**

***Keywords*— Insolation , isolation, flyback, portable solar, SMPS etc.**

I. INTRODUCTION

Electrical energy demand is continuously increasing. There is always imbalance between demand and supply. Conventional energy sources are limited. Energy balance between demand and supply is possible with use of renewable energy source. Solar energy is abundantly available on the earth's surface. So preferred renewable energy is solar energy. Solar insolation is non-uniform. Solar intensity varies from tropical to polar regions. Output of solar photovoltaic is electrical and acts as a current source. In order to use the available solar energy as a regulated power supply, an optimized selection should be done. There is difference in time period of energy generation and its requirement based on applications. There has to be a means of power storage element to fulfill the load demand.



(a) (b)

Fig. 1: Solar PV panel and its characteristics

Fig.1 (a) shows solar photovoltaic panel in which solar insolation falling on the panel is converted into electrical energy using photo-electric energy conversion. The electrical equivalent of solar photovoltaic is a constant current source at a particular solar insolation. Fig.1 (b) shows solar photovoltaic characteristics as a current source.

Presently linear power supply is used for routine testing and maintenance of circuits. It works on electric grid. It has limitations due to linear mode of operation and bulky circuit. This is one of the major limitations to the portability. There should be an alternative to existing linear power supply. Power supplies are mainly of two types viz. linear and switched mode power supply. Switched mode power supply is based on On-Off switching operating region. Processing circuits are different for both the above mentioned methods. Linear power supply works in the active region of switch whereas switched mode works in cut off and saturation region. Conventional linear power supply has rectifier to convert ac power into pulsating dc power. To smoothen this pulsating dc, a cascaded filter is connected which is followed by regulator as shown in fig.2.

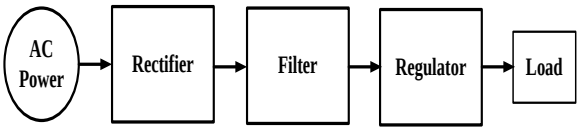


Fig.2: Stages of conventional power supply

Due to multiple cascading stages above method becomes bulky and has more losses. Thus it has low efficiency. This leads to advantages of switched mode power supply over linear power supply are as follows:

1. Due to high switching frequency, energy storage element size reduces which reduces the effective size of device.
2. Input is solar photovoltaic power which is a dc source. It results in the elimination of rectifier circuit.
3. It is a very compact circuit. This can be easily connected to solar panel.
4. As size of components is smaller, it is completely light in weight and portable too.
5. It works in switch mode so on state losses are minimized.
6. The effective total losses are less compared to conventional power supply.

7. Low losses lead to improvement in efficiency.
8. System up gradation can be done easily.

Usage of solar based switch mode power over other switch mode power supply are due to its ecofriendly nature. It is abundantly available on the earth surface. Life span of solar panel is more and has low maintenance.

The dc-dc converter forms the major part of power supply. It decides mainly the size and stability of the complete power supply. Flyback topology [1,2] has added feature where transformer acts as inductor and has unidirectional BH curve operation. It is a second order converter which can have multiple outputs. The only limitation of flyback converter is its restricted power handling capacity.

II. STAGES OF POWER SUPPLY

Block diagram of proposed solar panel attached power supply is shown in fig.3. It has two major modules namely power electronic converter and control circuit. The converted photo voltaic power is processed through dc-dc converter and used to supply load and battery.

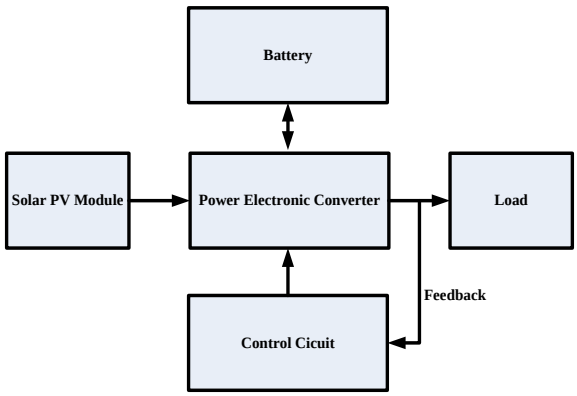


Fig. 3: Block diagram of solar panel attached regulated power supply

Automation is the indivisible part of each and every control circuit. Transducer acts as an indicator of output. Output is feedback to control circuit through transducer. Control circuit can be at remote location which is under supervisory control. In order to have routine testing or maintenance, independently powered portable power supply is required.

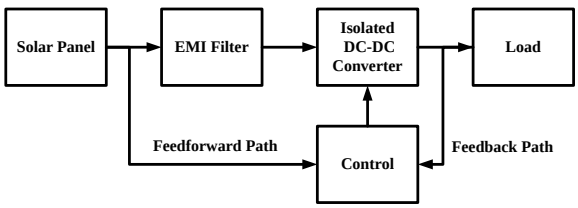


Fig.4 : Stages of switched mode power supply

Solar based switched mode power supply has isolated dc-dc converter which is controlled using either feed forward or feedback path and has an EMI filter to reduce noise interference. This is shown in the block diagram in fig.4. A solar panel which generates optimum power of 36W is selected. Solar energy is available in day time. The availability of source and load requirement can be matched with battery.

III. PERFORMANCE OF POWER CIRCUIT

Consider solar panels with rating 36W. The dc output of solar panel can be boosted using a flyback converter. It is an isolated unidirectional magnetization topology. This converter is used for medium power application. Here transformer is used as an inductor.

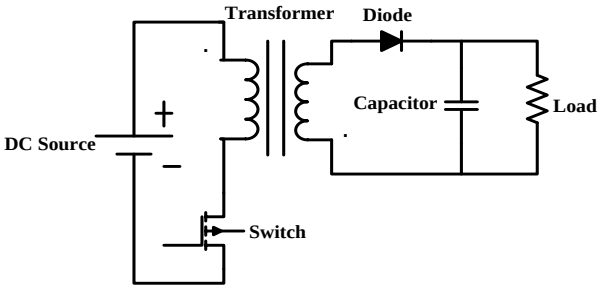


Fig. 5: Power circuit of switch mode power supply -Flyback converter

The power circuit of proposed power supply with isolated topology with single output as shown in fig5. Multiple output ports can be obtained based on requirements as given in fig.6.

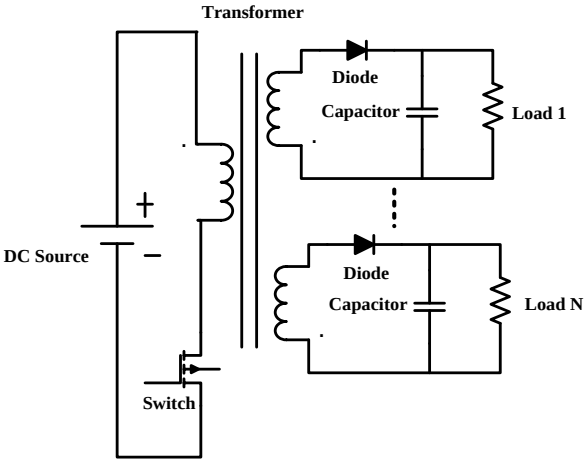


Fig. 6: Power circuit of switch mode power supply - Flyback converter based on number of outputs

Working of flyback converter is analyzed for switch on and switch off states. Fig.7 (a) is when controlled switch is on and diode is off. In this case transformer primary acts as an inductor and capacitor acts as an energy source to the load.

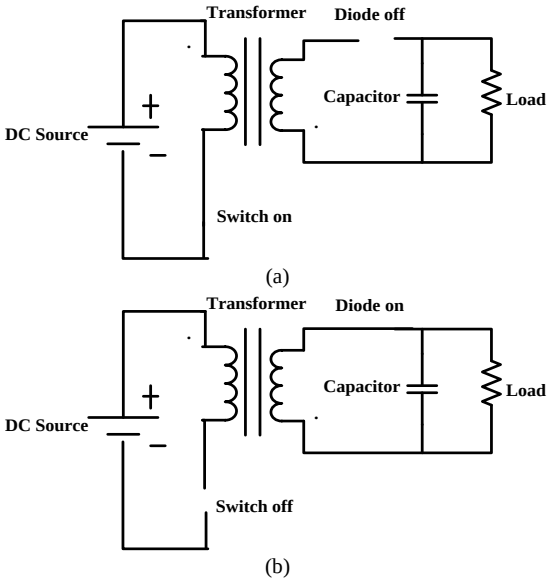


Fig. 7: Working of Flyback converter under switch on and off condition

During switch off state, diode is forward biased. This gives a discharge path to transformer secondary as shown in fig. (7b) and thus load and capacitor gain power.

IV. MATHEMATICAL MODEL OF POWER CIRCUIT

Mathematical model is used to analyze the stability of power circuit. Flyback converter is selected power circuit. It is a second order isolated converter. Its mode of operation is nonlinear. Since it is nonlinear in nature, approximate averaging method is used for mathematical modeling. Universal governing equation is modified state space equation and is as follows:

$$\dot{x} = Ax + Bu + Ed \quad (1)$$

$$y = Cx + Du \quad (2)$$

Where x : state vector matrix
u: input matrix
y:output matrix
A:state coefficient matrix
B:input coefficient matrix
C:source to output matrix
D:feedforward coefficient matrix
E:matrix for nonlinearity approximation
d:duty cycle

Considering the internal resistance r_L and internal series resistance r_C, the values of state space matrices are as follows:

Calculated state coefficient matrix,

$$A = \begin{bmatrix} \frac{-r_L}{L} & 0 \\ 0 & \frac{r_C C - R(1-d)}{r_C C(R + r_C)C} \end{bmatrix}$$

Calculated input coefficient matrix,

$$B = \begin{bmatrix} \frac{d}{L} \\ 0 \end{bmatrix}$$

Calculated source to output matrix,

$$C = \begin{bmatrix} r_L (1-d) & 1 \end{bmatrix}$$

The steady state voltage transfer is given by equation (3)

$$\frac{V_o}{V_d} = -CA^{-1}B = d(1-d) \quad (3)$$

The transfer function which is the ratio of output voltage to duty cycle for power stage is calculated by allowed variations in duty cycle to permissible changes in output voltage. This differs for different operating output voltage and its corresponding frequency. This model proves stability of power circuit.

V. DESIGN

Consider a solar panel with open circuit voltage 20V and maximum power of 36W which has terminal voltage of 18V. This solar photovoltaic dc power is given to flyback converter to maintain stable output. The expected output is 60V, 36W. For stable operation preferred maximum duty cycle is 0.45 to 0.5. Mode of operation is continuous conduction mode.

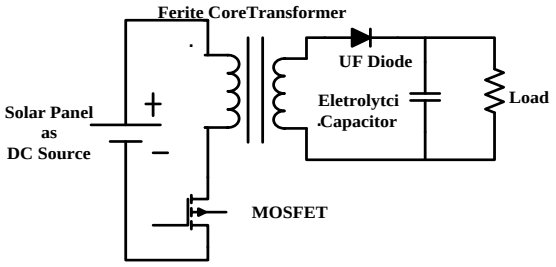


Fig. 8: Flyback converter of SMPS

To minimize size of power supply, size of energy storage elements should be as small as possible. This goal can be achieved by using high switching frequency. Adoption of high frequency such as 50 kHz reduces overall size of the device. Fig.8 shows detailed circuit of flyback converter.

Step1: Calculation of Transformer
Transformer required output voltage is 60V.

1) Transformer core is calculated using area product method. Based on calculations, selected transformer core is EE core of E42/21/9
With area product, Ap=2.739x10-4mm^2
Cross sectional area, Ac=107mm^2
Window area, Aw=256mm^2

Fast reverse recovery voltage is obtained using ultrafast diode with nanosecond recovery time. Diode ratings are as follows:
Diode current, I_{diode}=1.8A
Diode voltage, V_{diode}=123V Designed parameters are matched with available ratings and are tabulated in table 1.

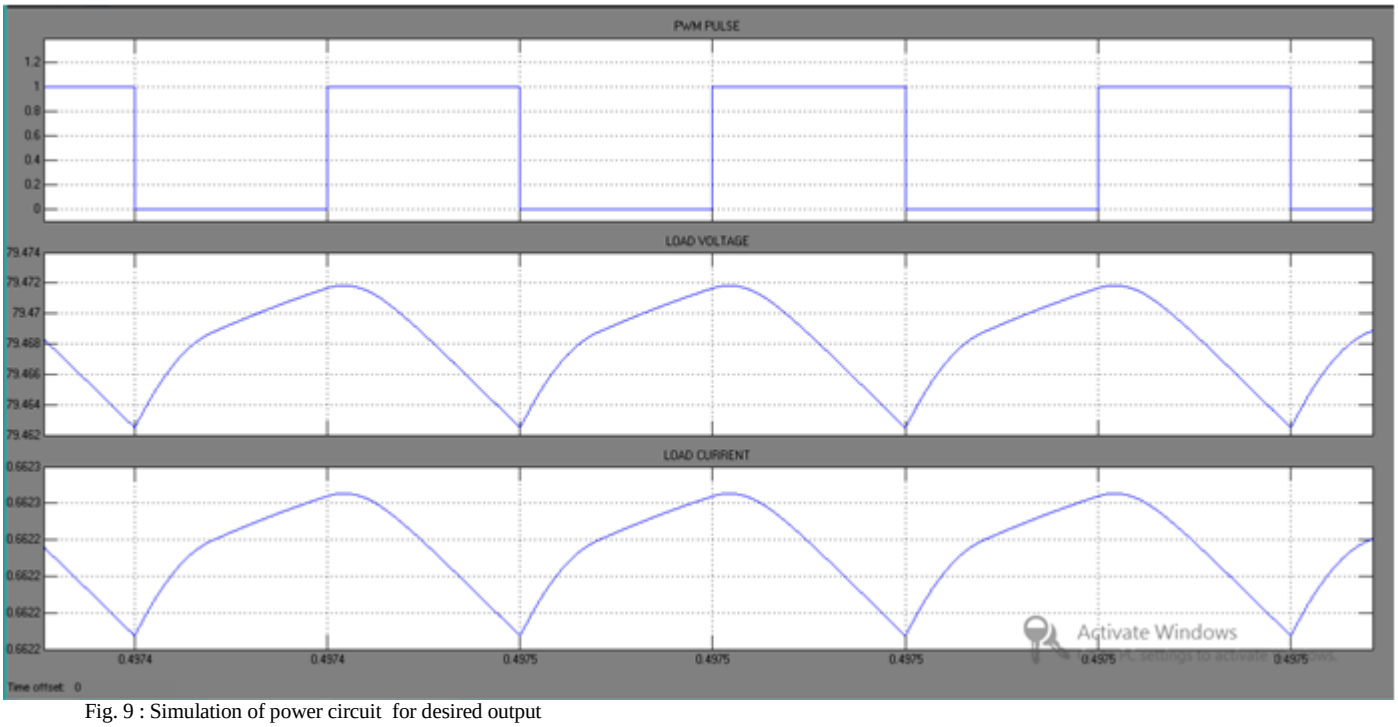


Fig. 9 : Simulation of power circuit for desired output

2) Number of turns are found using cross sectional area and window area.
N1=5turns
N2=21turns
3) Air gap length l_g decided which 0.006mm is.

Step2: Calculation of Capacitor
Tolerable output voltage variation is + 1% of output voltage which leads to selection of capacitor rating.
Capacitance, C=0.9µF
Voltage across capacitor, V_c= 150V

Step3: Selection of switch with RC snubber
Power MOSFET is selected using switching frequency and power requirement. Calculated switch values are for switch selection are as follows:
Switch voltage, V_{sw}= 34.28V,
Switch current, I_{sw}=3.513A,
RC snubber provides protection for switch.
Calculated values for snubber are as follows:
Snubber resistor, R_s=100Ω
Snubber capacitor, C_s=34.7nF

Step4: Selection of Diode

TABLE I. LIST OF COMPONENTS WITH THEIR SPECIFICATIONS

Serial No.	Components	Specifications
1	Solar Panel	20V,36W Max
2	Transformer	EE core, E 24/21/9
3	Switch	120V,4A MOSFET
4	Diode	2A,200V UF diode
5	Capacitor	1µF,220V
6	Battery	2A-Hr Rechargeable

VI. SIMULATION

For feasibility, regulated power supply is simulated using designed parameters. PWM pulse is fed to gate terminal of MOSFET as shown in waveform 9A. Transformer with opposite coupling acts as an inductor. It stores energy when the switch is on and dissipates energy when the switch is off. When the switch is off, diode conducts and supplies power to the load. The capacitor

filters out the ripples in diode current. The capacitor filter provides regulated current and voltage. Waveforms 9b and 9c represent the regulated voltage and current respectively. Simulation result shows that it matches the desired output.

VII. CONCLUSION

In remote locations, difficulties which were faced during testing and maintenance of electronic circuits are overcome by the use solar coupled switched mode power supply. Adoption of solar energy has proved to be a viable solution. This paper proves successful usage of solar energy even at remote locations. Flyback converter plays a significant role. It has provided multiple output ports with limited energy storage elements.

This paper established that solar coupled switched mode power supply is one of the best methods even in the absence supply from electric grid. It is a very useful tool and it can be easily upgraded for applications like emergency lighting etc.

REFERENCE

[1]T. H. Chen, W. L. Lin,C. M. Liaw, Member, National Tsing Hua University Taiwan , "Dynamic Modeling and Controller Design of Flyback Converter. " IEEE transactions on aerospace and electronic systems vol. 35, no. 4 October 1999, Pg.no.1230-1239.

[2]Ned Mohan, Tore M.Undeland, William P.Robbins,"Power Electronics Converter Applications and Design",Wiley Publication,reprint2009.

[3]Warren E. Dixon, Darren M. Dawson, , B. T. Costic, and Marcio S. de Queiroz, ,"A MATLAB-Based Control Systems Laboratory Experience for Undergraduate Students: Toward Standardization and Shared Resources ."IEEE transactions on education, vol. 45, no. 3, august 2002,Pg.no.218-226

[4]Tatsuya Kikuchi, Shuichi Fukuda, , Akinobu Fukuzaki, Keizo Nagaoka,Kenji Tanaka, Takashi Kenjo, and Dale A. Harris," DVTS - Based Remote Laboratory Across the Pacific Over the Gigabit Network." IEEE transactions on education, vol. 47, no. 1, february 2004, Pg.no.26-32.

[5]Y. Jaganmohan Reddy, Y. V. Pavan Kumar, K. Padma Raju, and Anilkumar Ramsesh,"Retrofitted Hybrid Power System Design With Renewable Energy Sources for Buildings." IEEE transactions on smart grid, vol. 3, no. 4, december 2012,Pg.no.2174-2187.

[6]Benjamin Kroposki, , Pankaj K. Sen and Keith Malmedal, "Optimum Sizing and Placement of Distributed and Renewable Energy Sources in Electric Power Distribution Systems."IEEE transactions on industry applications, vol. 49, no. 6, november/december 2013,Pg.no. 2741-2752
.
[7]Chen Zhao, Xiaogao Xie, Hanjing Dong, and Shirong Liu, "Improved Synchronous Rectifier Driving Strategy for Primary-Side Regulated (PSR) Flyback Converter in Light-Load Mode." IEEE transactions on power electronics, vol. 29, no. 12, december 2014,Pg.no.6506-6511

[8]Wu Chen, Member, IEEE, Xiaogang Wu, Liangzhong Yao, Senior Member, IEEE, Wei Jiang, and Renjie Hu," A Step-up Resonant Converter for Grid-Connected Renewable Energy Sources." IEEE Transactions on Power Electronics,

[9]Regan Zane and Dragan Maksimovi´c," Nonlinear-Carrier Control for High-Power-Factor Rectifiers Based on Up–Down Switching Converters." IEEE transactions on power electronics, vol. 13, no. 2, march 1998,213.