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SPACECRAFT POWER SYSTEMS USING THE FLYBACK CONVERTERS

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Abstract: The paper presents harvesting of solar energy by the charge controller techniques to charge the battery bank at a particular voltage during the daylight by the Flyback converter to utilize this power at spacecraft power systems during the orbital night or when the load demand exceeds the solar cell or array ability. All bits and pieces are monitored and controlled by the Flyback power supply unit or converters as light weight, high power density, compact size, least cost, low profile, low volume, tight regulations, good design, high reliability and high efficiency.

Keywords: Spacecraft power supply systems, Solar power, Designs, thermal limits,failure rate and Results.

1. INTRODUCTION

The un-interrupted power supply in space is solar energy and free of fees and infinite wherewithal. Hence, solar panels are tied up to harvest solar energy into electrical energy exclusively. When a spacecraft is in silhouette or eclipse, solar panels stop energy generation. Hence, to comprise chaotically infinite reserve of energy, a fragment of electrical energy is stored during sunny time which is utilized during eclipse [1]. Thus, the power necessities of the majority of the aircrafts, are met by the personification of solar cells or panels using fastidious dimension and hermitically preserved the battery bank, which confirmed it's secure in is performance and far above the ground reliability. Whereas, on the sunny surface of the earth, the solar panels energize the power loads as well as recharge the battery bank, which will take over and power to loads during the orbital eclipse [2].

The significant battery bank and solar array structure blocks of a emblematic spacecraft power system is to be placed at explicit position at which the different power circuit connection may result the robustness of the power supply unit. In any sort of spacecraft power system, the outputs of the solar cell array and storage batteries are to be adapted so as to go with supplies of the various subsystems [3]. The battery bank has to be charged from the solar cell or array during the orbital day at 48V through the Flyback converters and discharged to arrange power during the orbital night or when the load demands goes beyond the solar cell array aptitude. All these purposes are not performed with the aid of the power conditioning and control unit of the Flyback converters [4-5].

Nomenclature 1

CFD = Computational fluid dynamics

C_{oss} = Drain to source parasitic capacitance of the MOSFET

C_d = Junction capacitance of the Flyback diode

D = Duty cycle of the converter

E_P = Initial stored energy by the Coupled Inductor

E_S = Stored energy during on time by the Coupled Inductor

FIT = Failure Rate Unit in Time
f_s = Switching frequency of the converter
L_e = Primary leakage inductance
L_{se} = Secondary leakage inductance of the coupled inductor
L_p = Primary inductance of the Flyback Transformer
I_P = Primary peak current of the coupled inductor
I_V = Valley current of the DCM of operation
I_{AV} = Average current of the converter
N_1 = Primary turns of the coupled inductor
N_2 = Secondary turns of the Flyback transformer
N = Turns ratio of the transformer
P_0 = Power output of the converter
R = Summation on time resistance of MOSFET & Primary winding resistance of the coupled inductor
R_1 = Load resistance of the converter
t_{on} = On time of the power switch
t_{off} = Off time of the power switch
T = Time period of the gate pulse
V_p = Primary voltage of the coupled inductor
V_s = Secondary voltage of the Flyback transformer
V_{DS} = Maximum turn off voltage across the power switch
V_1 = Input voltage of the converter (Solar Panel)
V_O = Output voltage of the converter
η = Efficiency of the converter

Nomenclature 2: For the Block Diagram

BB = Battery bank
CRS = Communication and data recording system
FC-1 = Flyback converter 1
FC-2 = Flyback converter-2
FC-3 = Flyback converter-3
FCSR = Flyback converter as shunt Regulator
FCCR = Flyback converter as charging system
FCDS = Flyback converter as charging system
SA = Solar Array
TTC = Telecomm –Telemetry communication system
AOCS = Altitude and orbital control system
ALOE = All others equipment loads

2. SKETCH OF A SPACE CRAFT POWER SYSTEM

Fig. 1 depicts the spacecraft power system as non- dissipative regulated bus at which a common control unit drives the power stage of shunt, charge and discharge condition of the Flyback converters. The Flyback converter continues the constant bus voltage as a charge controller. When the battery bank is completely charged, the Flyback converter is turned on as a shunt regulator to trickle mode charging the battery bank to keep up the fixed bus voltage. The bus voltage is supplied to payloads directly, whereas through another Flyback converter to the bus loads, explicitly TTC, AOCS, propulsion system. Some of the loads like CRS are supplied from the battery bank through commendable redundant fuses.

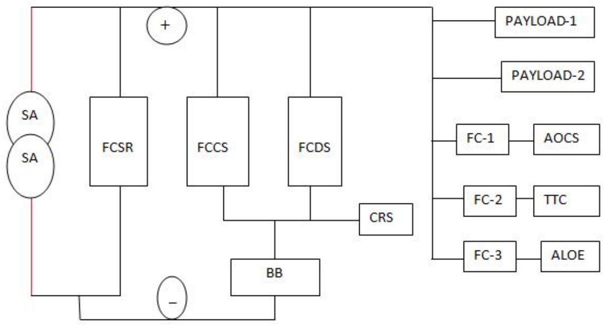

Fig.1. Block diagram of a typical spacecraft power system

3. DESIGN SPECIFICATIONS OF THE CONVERTER

- The following block diagram as shown in Fig. 2. is supportive to optimize the design parameters of the Flyback converter due to contemplations of topologies selection, dimension of the magnetic, parallel techniques for high power density light weight, efficiency achievement, thermal management, ZV-ZCS (zero voltage–zero current switching) soft switching techniques using high switching frequency, lowest EMI generation, high efficiency, compact volume for high power density and low profile flyback power supply by overcoming the following drawbacks as mentioned point wise.
- Low power applications at communication cells or supply
- Huge leakage loss of the coupled inductor for high switching frequency converter's operations and huge switching loss at high frequency switching operation
- Higher voltage and current stress across the main switch at high frequency along with hard switching operations
- High EMI &RFI (Radio Frequency Interference)
- Higher rectifier diode losses of the converter
- Higher conduction losses of main switch of the converter
- Poor circuit efficiency of the Flyback converter
- Unstable at continuous conduction mode (CCM) of magnetic flux operation
- Dilemmas of voltage mode control for better regulations

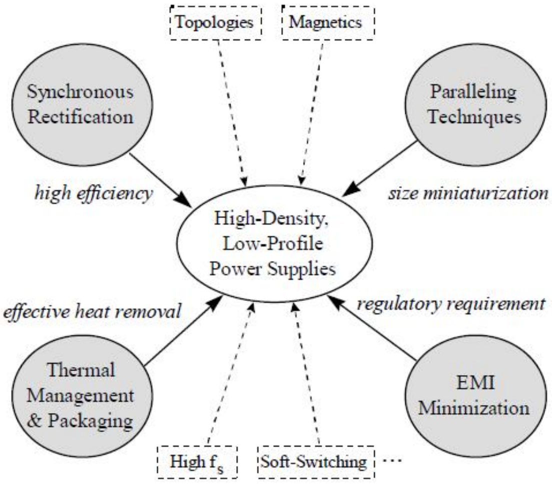

Fig. *2*. Block diagram for optimization of the flyback converter

The following design parameters are obtained by conventional design aspects for Input Voltage = 90V-270V (DC), Output power = 240W, Output Voltage = 48V, Switching frequency = 70 KHz, Primary turns, N_1= 35, Turns ratio =5.32. Magnetizing inductance L_m= 0.19mH, Output capacitance = 2000 μF, Rating of MOSFET 640V & 20A. Rating of UFR Diode 400V & 20A for the SMPS.

4. ENERGY TRANSFER OF FLYBACK SMPS UNDER DCM & CCM

When the flyback switch (M1) is on, the primary inductance is stored up the energy. When the main switch (M1) of the converter is off, the stored energy flies to load under discontinuous mode (DCM) or in a continuous mode of operation (CCM) as per flowing Fig. 3 and Fig. 4 shown below.

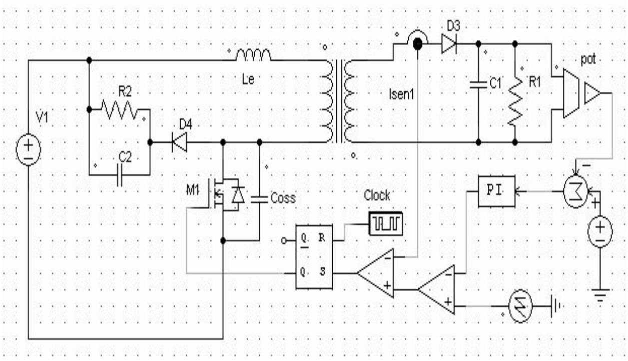

Fig. 3. Basic Flyback Converters with RCD Snubbe

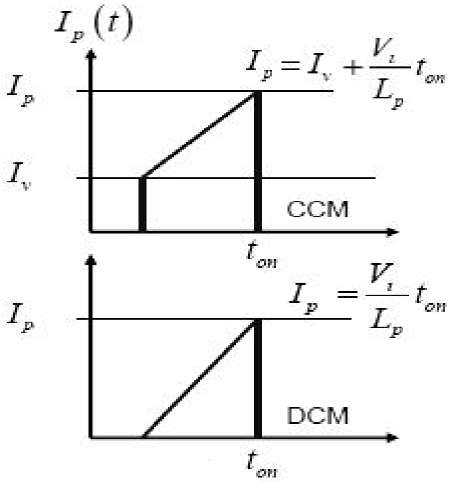

Fig. 4. Current waveforms under CCM and DCM operation

Initial store energy during the on time t_{on} at CCM condition is given as:

$$E_I = \frac{1}{2} L_P I_V^2 \qquad (1)$$

Stored up energy during on time t_{on} given as:

$$E_S = \frac{1}{2} L_P I_P^2 \qquad (2)$$

Energy transfer at this CCM operation written as:

$$E_T = \frac{1}{2} L_P \left(I_P^2 - I_V^2\right) \qquad (3)$$

Effective power transferred by the consideration of switching frequency and efficiency of the converter given as:

$$P_T = \frac{1}{2} L_P \left(I_P^2 - I_V^2\right) f_{sw}\ \eta \qquad (4)$$

The valley current I_V is being zero at the DCM, then the equation (12) reduces as:

$$P_T = \frac{1}{2} L_P \left(I_P^2\right) f_{sw}\ \eta \qquad (5)$$

DC transfer function of the CCM is given as:

$$\frac{V_0}{V_1} = N\left(\frac{t_{on}}{t_{off}}\right) \qquad (6)$$

Duty ratio or cycle is given as:

$$D = \left(\frac{t_{on}}{t_{on} + t_{off}}\right) \qquad (7)$$

For the CCM operation, time period is expressed as:

$$T = \left(t_{on} + t_{off}\right) \qquad (8)$$

and $I_V > 0$

And corresponding switching frequency can be written as:

$$f_{sw} = \frac{1}{T} \qquad (9)$$

The equations (6&7) can be modified in terms of duty ratio written in CCM as:

$$\frac{V_0}{V_1} = N\left(\frac{D}{1-D}\right) \qquad (10)$$

Corresponding DC transfer function under DCM of operation may be expressed as:

$$\frac{V_0}{V_1} = D\left(\sqrt{\left(\frac{R_L}{2 L_P f_{sw}}\right)}\right) \qquad (11)$$

and $T > \left(t_{on} + t_{off}\right)$ & $I_V = 0$ (12)

The volt-second balances as shown in the Fig. 5 and Fig. 6 under the CCM and DCM of operation of the Flyback converter for the time period (T) showing the primary voltage of the converter with respect to time.

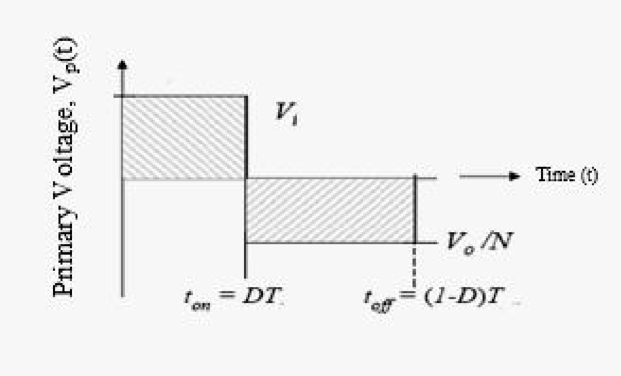

Fig. 5. Volt-Second balances in CCM of the Converter

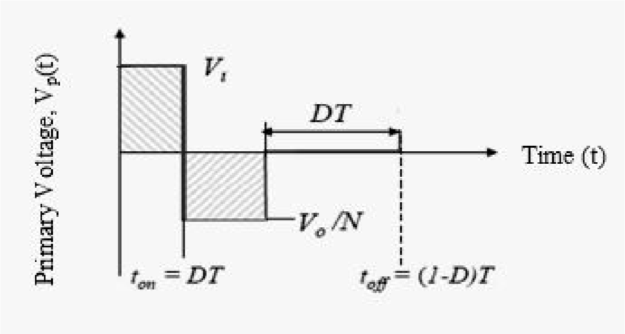

Fig. 6. Volt-Second balances in DCM of the Converter

The valley is very helpful to determine the value of ripple current of the inductor of the converter. Hence, the common expression of the on time of power switch is given as:

$$t_{on} = \frac{L_P(I_P - I_V)}{V_1} \qquad (13)$$

$$t_{off} = T - \frac{L_P(I_P - I_V)}{V_1} \qquad (14)$$

$$I_V = I_P - \frac{(V_o + V_d)}{NL_P} t_{off} \qquad (15)$$

Combining the equation (14) & (15), yields

$$I_V = I_P - \frac{(V_o + V_d)}{NL_P}\left(T - \frac{L_P(I_P - I_V)}{V_1}\right) \qquad (16)$$

$$I_P = I_V + \frac{TV_1(V_o + V_d)}{L_P(V_d + V_o + NV_1)} \qquad (17)$$

Primary inductor (L_p) ripple current is given by

$$\Delta I_{LP} = (I_P - I_V) \qquad (18)$$

$$\Delta I_{LP} = \frac{TV_1(V_o + V_d)}{L_P(V_d + V_o + NV_1)} \qquad (19)$$

The reset voltage of the converter is given as:

$$V_r = \left(\frac{V_o + V_d}{N}\right) \qquad (20)$$

Peak to peak ripple across the inductor is given as:

$$\Delta I_r = \left(\frac{\Delta I_L}{I_{AV}}\right) \qquad (21)$$

If V_{bc} be the minimum bulk voltage of the input filter capacitor of the converter and a huge parameters are involved in the value of the primary inductance is given by as:

$$L_P = \frac{\eta(V_{bc} V_r)^2}{\Delta I_r f_{sw} P_o \{(V_{bc} + V_r)(V_r + \eta V_{bc})\}} \qquad (22)$$

5. ORBITAL CONSIDERATIONS OF SPACECRAFT

The supporting orbital considerations are shown in the Fig. 7. The fraction of time may be defined as in sunlight given as:

$$T_f = \frac{\pi + 2\alpha}{2\pi} \qquad (23)$$

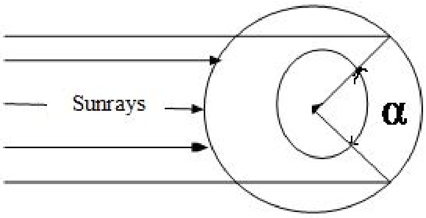

Fig. 7. Orbital considerations

In this condition, the solar array enables to capture enough energy during sunlight to power spacecraft during entire orbit by peak power tracker or direct energy transfer thermal control and bus voltage quality conversion using the flyback converter

6. DIMENSION OF BATTERY BANK & SOLAR PANEL

Choosing the precise solar panel for needs is like choosing a battery bank size. In the same way that a bigger battery will provide more power for longer, a larger solar panel will accumulate more energy in less time.

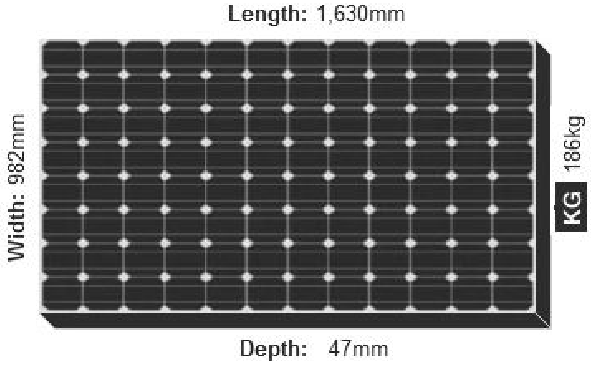

Fig. 8. Dimension of the Solar Panel for 250W power Generation

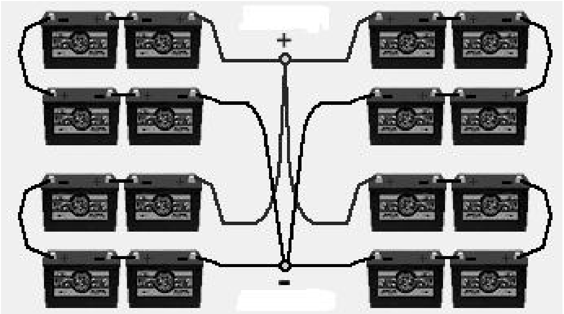

Fig. 9. Size and layout of the battery bank

The right dimension as shown in Fig. 8 of panel will rely on variables such as the power required by the power appliances, the length of time, it wishes for power utilization. It and how much sunshine, it gets a hold at the time of year. There are three criteria to reflect on while choosing a solar array or panel or creating a solar system. The designers necessitate identifying what appliances applicant will be using and how much energy they need, how much energy his system battery can store and which solar panel will stock up energy in the battery bank in line with pattern of use. If one considers the power density of the solar cell as 150 W/m^2 for 250W power and weight about 186 Kgs, the requisite dimension of solar panel will be as per following Fig. 8.

Fig. 9 depicts the groups of 4 batteries in series at 12 volts & 280 AH produce a 48V battery bank at 1120 AH capacity as a huge battery backup power resources which will be used as power sources during dark period and (±) part is to be connected output of the Flyback converter to charge the battery bank during the sunlight.

How much energy will be needed for use of appliances over a period of time is to find out. The power consumption of electrical devices is given in Watts.

To work out the energy use over time, just multiply the power consumption by the hours of use. As for the example, 18W load on for 4 hours, will take 18 x 2 = 36WH from the battery bank. It calls for conversion this to Watt Hours by multiplying the AH (Ampere Hour) figure by the battery voltage (i.e. 12V). For a 17AH, 12V battery the WH (Watt Hours) figure is 17 x 12 = 204WH. This means the battery could supply an 18W load for 15.6 and a half hour, 204W for 1 hour (approximately).

For the solar 250W panel in 4 hours of sunshine, 250 x 4 x 0.85 = 850WH. This is the amount of energy the solar panel is able to supply to the battery bank size.

7. THERMAL LIMIT OF CONVERTER AND HIGH FAILURE RATE

Thermal analysis has been mainly focused on component-level performance in the free-air environment or with estimated boundary conditions Since components behave differently in a high-power-density environment due to thermal coupling with surrounding components, the accuracy and, therefore, the usefulness of the component level thermal characterization are very limited in practical high-power-density systems. In addition, the extrapolation of the thermal-design performance from one converter structure to another is also of a limited value because of the possible lack of packaging similarities, different fluid velocities, and different temperature gradients as shown in the Fig.10.

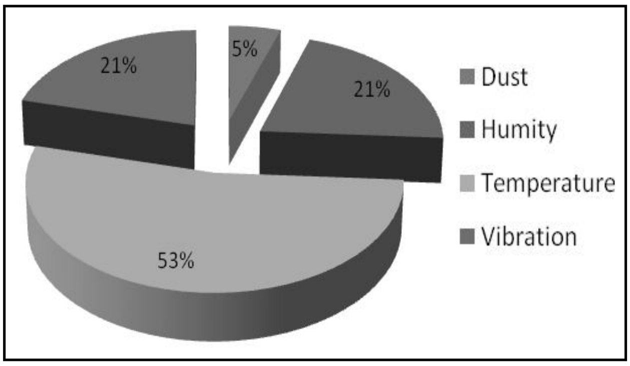

Fig. 10. Breakdown of premature failures of flyback converter

The usual design aspects of the thermal management for high power density external adapters/chargers for portable spacecraft equipment are discussed. As an example, an off-line, 250W Flyback power supply unit is analyzed using computational fluid dynamics (CFD) thermal modeling and simulation with Flotherm. The thermal modeling and simulation are performed for a number of packaging approaches. The Table I, depicts the failure rate unit in time (FIT) against the component of the flyback converter.

Table 1

Components	Quantity	FIT Each	Total FIT
Source Voltage	1	2	2
Coupled Inductor	1	3	3
Resistor	2	50	100
Capacitor	2	200	400
MOSFET	1	300	300
Diode	2	400	800
Total	9		1605

Finally, the practical design guidelines for the high reliability performance are outlined as shown in Table I. Reliability modeling is a faster and more efficient tool than experimental

Cut-and-try processes for improving and optimizing the power management for high-density power converters. EMI emission of switch mode power supplies needs to be suppressed to reduce susceptibility, and more importantly, to reduce the size of filter components for the differential surroundings as shown in Fig. 10 accordingly.

8. RESULTS

The effective power losses of each active and passive component of the converter are computed by simulations to predict the reliability of the spacecraft power systems as shown in the Fig. 11 showing the power losses in watts of each components of the Flyback converter for different input operating voltages.

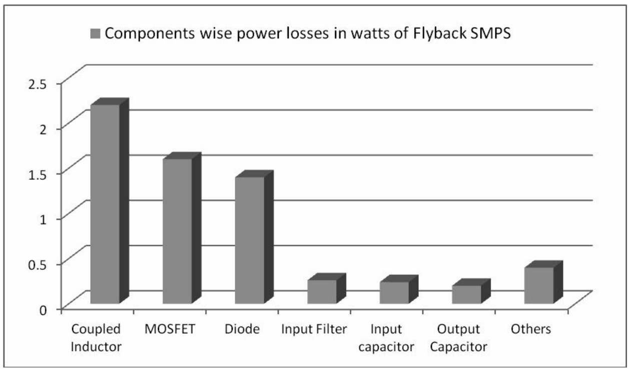

Fig. 11. Component wise power losses in watts of the Flyback SMPS

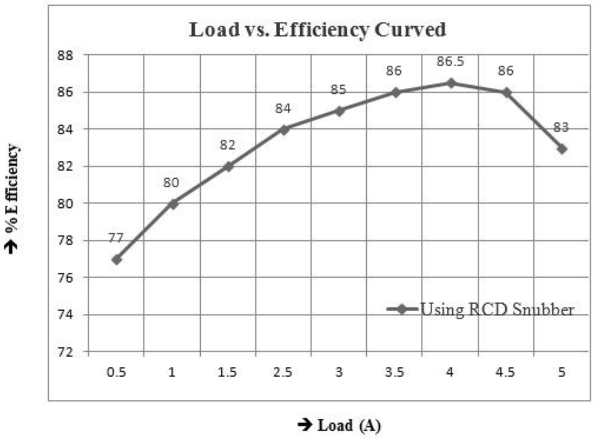

Fig. 12. Input voltage vs. efficiency curved of the Flyback SMPS

In Fig. 12, X-axis and corresponding Y-axis represents the comprehensive efficiency and corresponding input voltage of the Flyback converter respectively in accordance with practical predictions following common nature.

9. CONCLUSIONS

The major design challenges in today's circumstances of the skill, high power density, and power conversion circuits are progressively more allied to the spacecraft power supervision subjects. In this paper, it has been demonstrated that the design optimization of a Flyback converter in a preserved enclosed space can be carry out on a cost effective and time efficient support by utilizing robust analysis software based on the CFD approaches. Using a 250W/48V, DC-DC, spacecraft power supply system as an energy model, the results of the design optimizations gained by CFD based simulations were experimentally recognized due to innovative design and spacecraft applications with respect to referenced papers.

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