A Highly Efficient Low Ripple PMS for EECU with Advance Interleaved DC DC Converter for Turbo Shaft Engine Applications.

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***Abstract*— Any Engine Electronic Control Unit(EECU) present inside the aircraft, should have its own dedicated power supply. In this paper the EECU under consideration is in HAL(Hindustan Aeronautics Limited). Normally the EECU is powered by aircraft DC bus, once the engine reaches self sustained speed the EECU will be powered by its own supply. It mainly consists of engine driven 3-phase alternator, 3-phase rectifier, buck-boost converter. Here the line regulation and load regulation is achieved by using buck-boost converter. It can achieve step up and step down easily and have been widely used in many application because of the simple topology, easy control etc., In this paper, the analysis and modeling of interleaved buck-boost converter with PID controller is discussed. Now-a-days, buck-boost power converter is widely used in many applications and power capability demands. The applications of buck-boost power converter may be in electric vehicles, photovoltaic (PV) system, uninterrupted power supplies (UPS), and fuel cell power system. Converters are controlled by interleaved switching signals, which have the same switching frequency but shifted in phase. By paralleling the converters, the input current can be shared among the inductors so that high reliability and efficient in power electronic system can be obtained and ripples also reduced, the converter performance can be improved. The control circuit of this converter is controlled by using the PID controller. The simulation of interleaved buck-boost converter results with PID controller has been presented in detail.**

***Keywords—* EECU, Aircraft DC bus, Buck-Boost Converter, Line regulation, Load regulation, Interleaved Buck Boost Converter, PID Controller.**

I. INTRODUCTION

Hindustan Turbo Shaft Engine (HTSC-1200) for Helicopter is an In-house project initiated by Hindustan Aeronautics Ltd to replace Indo-French co-developed Shakti engines for LUH, LCH and ALH Series of Indigenous Helicopters developed by HAL in India.

Every aircraft need a good control on mainly (a) Engine Temperature, (b) Engine Pressure, (c) Engine RPM, (d) Fuel Flow etc.Under Our observation these constraints are monitored and controlled by a control unit called EECU, which is designed to remove as far as possible work load from the pilot still allowing him to control the engine. And this EECU require a regulated DC power supply of 28(±1)V. Earlier power supply for the EECU was given by the regulated power supply(28V DC bus powerd by a battery), and at the time of flight the battery system may get damage or battery has to be check and rcharge regularly.

In our design we are removing these complication by regenerating the power by the use of a small generator coupled to gears which in turn directly connected to engine shaft.

Fig. 1. . Engine Electronic Control Unit

The design i.e., Power Management System include a Generator, Rectifier, Advance Interleaved DC-DC converter and filters.

EECU modulates the fuel flow in to the engine to keep the engine and hence the aircraft in a safe running condition. It is designed to remove as far as possible, work load from the pilot still allowing him to control the engine. Therefore it is important to manage the stable power supply to the EECU, this is done by using the buck boost converter design proposed in this paper.

II. BLOCK DIAGRAM

The fig.2 Represents the power flow to the EECU in the both ways i.e., from the Aircraft Bus at the starting stage and from PMS after the engine attains its self sustainable speed.

At the start, the EECU gets supply from the aircraft bus. The alternator in the engine is coupled to the shaft which converts rotational energy to electric energy. The electric energy generated (28V constant DC) is supplied back to the EECU.

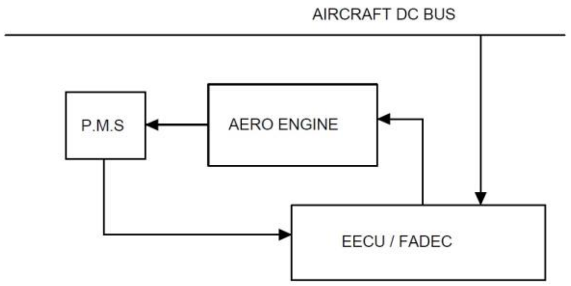

Fig. 2. . Simple Architecture Representing Power Flow To EECU.

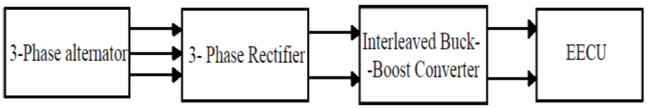

Fig. 3. PMS (Power System Management)

The fig.3 shows the block diagram of the power management system. The generated three phase supply is given to the Rectifier which converts AC to variable and unregulated DC.

By using Interleaved Buck Boost converter the variable and unregulated DC Power is converted into 28V constant regulated DC power which fed back to the EECU.

III. INTERLEAVED BUCK BOOST CONVERETER

Interleaving also called as multi phasing is a technique which is useful for reducing the size of filter component . In a interleaved circuit there will more than one power switch. The phase difference for two switches is 180º. Interleaving technique is a strategic interconnection of multiple switching cells that will increase the effective pulse frequency by synchronizing several smaller sources and operating them with relative phase shift . Interleaved method is used in order to improve converter performance in the aspects of efficiency, size, and conducted electromagnetic emission. Interleaved also has benefits such as high power capability, modularity, and improved reliability. But, having interleaved may cost on additional inductors, power switching devices, and output rectifiers. When the size of inductor increases, the power loss in a magnetic component will decrease although both the low power loss and small volume are required. In the power electronic, application of interleaving technique can be found back to early days especially in high power application.

The voltage and current stress can easily go beyond the range that power device can handle in high power application. One solution to this problem is by connecting multiple power devices in parallel or in series. But, instead of paralleling power devices, it is better to parallel the power converters. By paralleling the power converters, the interleaving technique will comes naturally. Interleaving can cancel the harmonics, increase the efficiency, better thermal performance and the high power density can be obtained. Paralleling of converter power stages is a well known technique that is often used in high-power applications to achieve the desired output power with smaller size power transformers and inductor.

In addition to physically distributing the magnetic and their power losses and thermal stresses, paralleling also distributes power losses and thermal stresses of the semiconductors due to a smaller power processed through the individual paralleled power stages.

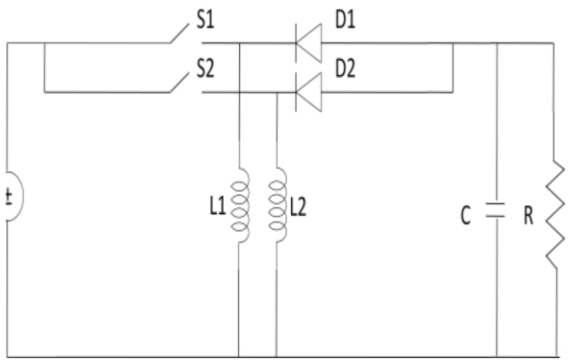

Fig. 4. Interleaved Buck Boost Converter

IV. CLOSED LOOP SYSTEM

A. PWM switching strategy and dc voltage control

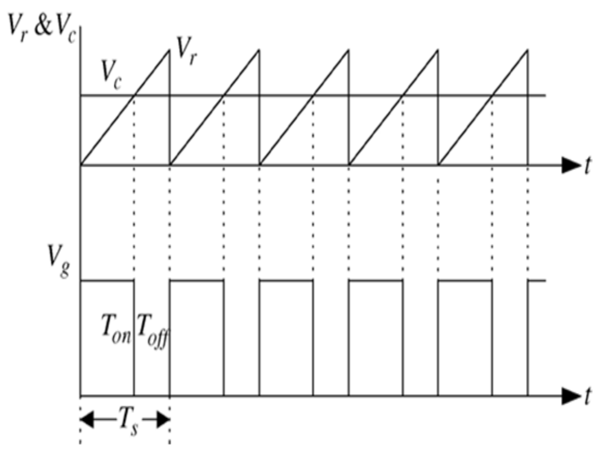

Fig.5. Diagram representing generation of PWM waveforms using reference voltage and ramp wave.

The generation of the MOSFET driving signal is accomplished by comparing a dc reference signal, having a variable amplitude V_c, with a saw-tooth carrier wave, having a fixed amplitude V_r and frequency fs, known as the switching frequency. The ratio between V_c and V_r is called the duty cycle, D $=V_c/V_r$, which is defined as the ratio of the on time ton to the total switching period $t_s = t_{on} + t_{off}$. The average output voltage is varied by changing through the variable V_c to control the duty cycle D.

The fig4. shows a saw-tooth wave (V_r) having a amplitude of $2V_P$ having a frequency as career frequency (50kHz in our design). And, a reference signal (V_c) with a variable amplitude produced by the compensator after processing the actual output and required output(28V). The ratio between V_c and V_r gives the required duty cycle for PWM.

B. Closed loop flow

The closed loop control system for the Interleaved Buck converter with PID controller feedback. The ultimate aim in designing the controller is to minimize the error between V_0 and V_{ref}, the important functional blocks that are evident are: PID Controller, PWM(Pulse Width Modulation) and dc-dc converter. The PID Controller acts as a compensator and generates the control signal by compensating the error signal (V_e).PWM block is for the generation of driver signal obtained from the compensator. The error (V_e) between the output voltage (V_0) and reference voltage (V_{ref}) is processed by the compensator block with PID Controller algorithm to generate control signal shown in fig.6.

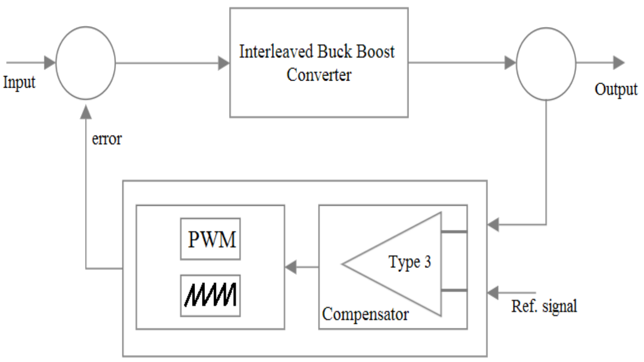

Fig.6. closed loop flow

V. CALCULATIONS

A. Specification of the Power Stage

1. $V_{inmin} = 20V$
2. $V_{inmax} = 48V$
3. $V_{out} = 28V$
4. $I_{out} = 5V$
5. $Estimated\ Efficiency\ (\eta) = 90\%$
6. $Ripple\ Voltage\ (\Delta V) = 1\%\ of\ V_{out}$
7. F_{sw}= 50Khz

B. Design Calculation:

DUTY CYCLE

$$D_{min} = \frac{V_{out}}{(V_{inmax} + V_{out})}$$
=36%

$$D_{max} = \frac{V_{out}}{(V_{inmin} + V_{out})}$$
=58%

C. Inductor Selection:

$$L = \frac{(\eta \times V_{in}{}^2 \times V_{out}{}^2)}{(\Delta I \times F_{sw} \times P_{out}(V_{in} + V_{out}) \times (V_{out} + \eta \times V_{in})}$$

$when\ V_{in} = 20V,$
$L = 12.7\mu H$
$when\ V_{in} = 48V,$
$L = 28\mu H$

Where, η = Efficiency = 90%
ΔI = Ripple Current =
30% of $I_{out} = 1.5A$
And,
Taking Standard value - $25\mu H$.

D. Output Capacitor Selection:

$$C = \frac{(D_{min} \times V_{out})}{(F_{sw} \times R_{load} \times \Delta V)}$$

$$C = \frac{(0.36 \times 28)}{(50 \times 10^3 \times 5.6 \times 0.28)}$$
=128μF

Where, $\Delta V = Ripple\ Voltage =$
$1\%\ of\ V_{out} = 280mV$
And,
Taking Standard value - 100μF.

E. Openloop Transfer Function of buck boost:

$$\frac{V_o}{V_{EA}} = \frac{V_{out}}{V_P \times D(1-D)} \times \frac{\left(\frac{1-S}{\omega_{RHZ}}\right)}{1 + \frac{S}{Q \times \omega_0} + \left(\frac{S}{\omega_0}\right)^2}$$

Where, $\omega_{RHZ} = \frac{(1-D)^2}{D} \times \frac{R_L}{L}$

$$\omega_0 = \frac{(1-D)}{\sqrt{LC_0}}$$

$$Q = (1-D) \times R_L \times \sqrt{\frac{C_0}{L}}$$

Every terms are calculated and tabulated in the below table .

Table.1. Calculated values tabulation

TERMS	VALUES
V_o	28V
V_P	2V
D	0.58
R_L	5.6Ω
C	1.0×10^{-4}
L	2.50×10^{-5}
ESR	1.20×10^{-1}
ω_{RHZ}	6.81×10^{4}
ω_0	8.40×10^{3}
Q	4.70
F_{ESR}	1.33×10^{4}
Gain	57.4712
$1/\omega_{RHZ}$	1.47×10^{-5}
$1/Q\times\omega_0$	2.53×10^{-5}
$(1/\omega_0)^2$	1.42×10^{-8}

After, all the calculations we have arrived to the open loop transfer function which is,

$$TF = \frac{\left(57.47 \times \left((1 - S) \times 1.47 \times 10^{-5}\right)\right)}{\left(1 + (S \times 2.53 \times 10^{-5}) + (S^2 \times 1.42 \times 10^{-8})\right)}$$

VI. SIMULATION RESULTS

The below plots and graphs are the results we got in the matlab simulation.

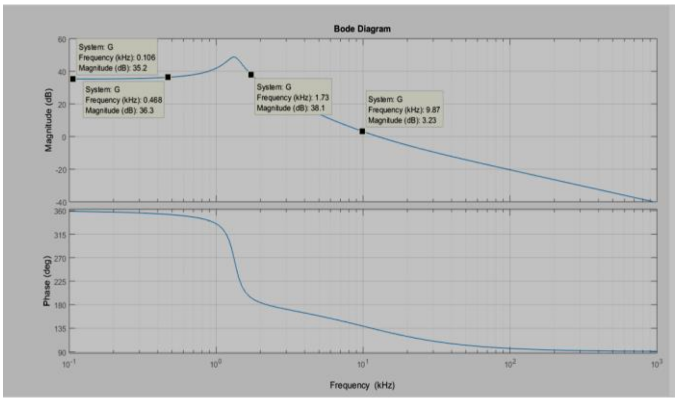

Fig.7. Open loop Bode Plot

Fig.4 is a Bode plot of open loop transfer function of the design. By the observation we can say the system is unstable i.e., the design model can't give a constant output with respect to change in line or load ranges. So for the system stability we decided to use Type 3 Compensator i.e., PID Controller.

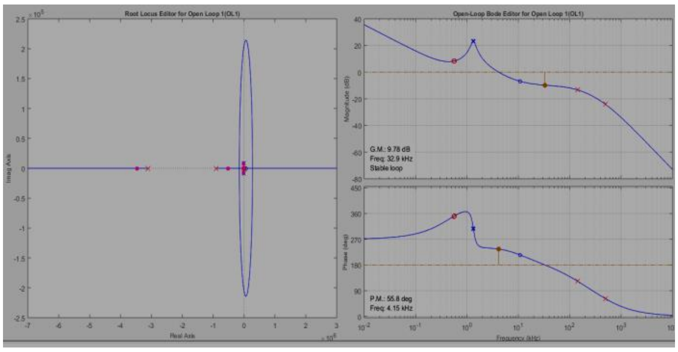

Fig.8. SISO tool plot (control System Designer).

Above plot(fig.5) is a tool called SISO tool or Control system designer by the use of which we can get a unique transfer function of the required Compensator.

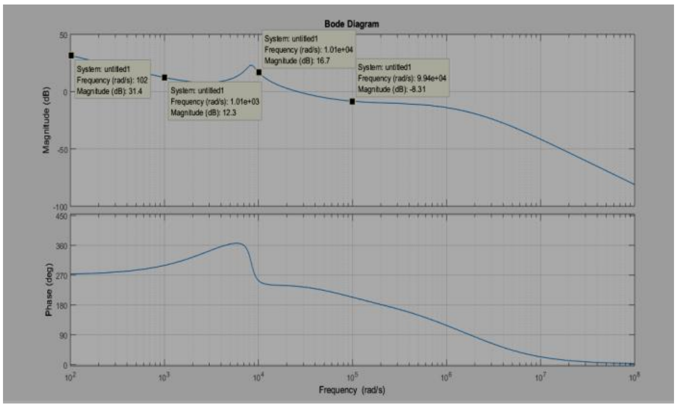

Fig.9. Closed Loop Bode Plot.

Fig.5 is again a Bode plot of the design system after adding the feedback path (PID compensator). And we can observe the stability is achieved with almost -20db slope and Phase margin greater than45^0.

The following fig.6,7,8 and fig.9 are under Boost operation.

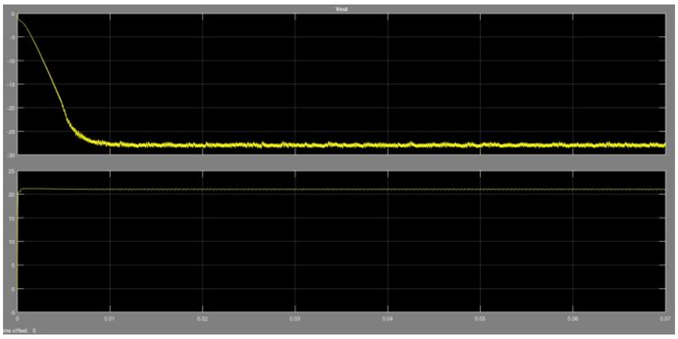

Fig.10. Boost Output Voltage

The above fig is the graph of output voltage at the time of boost operation the input voltage is 21V and after a very short settling period the output we get is constant 28V which was our aim.

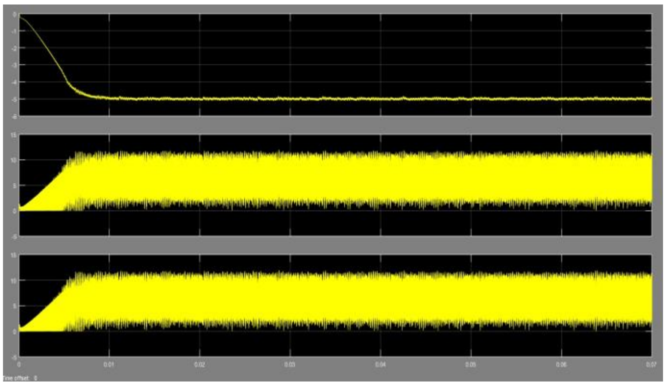

Fig.11. Boost Output Current

Above fig is to show the output current and currents through two Inductors. A current of 5A is obtained in the output side.

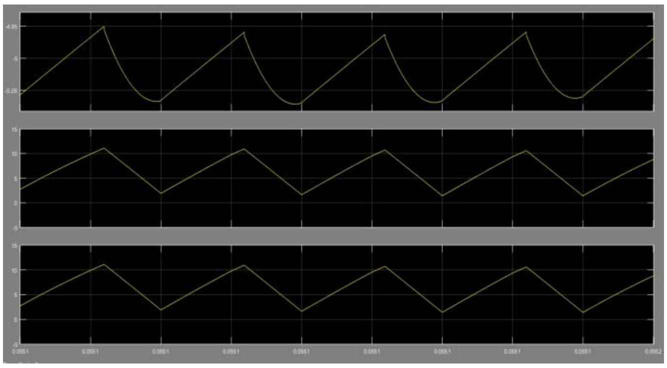

Fig.12. Showing current Ripple at the of boost operation

Fig.8 and Fig.9 are the ripple voltage of current and voltage waveforms and we can observe the ripple is low.

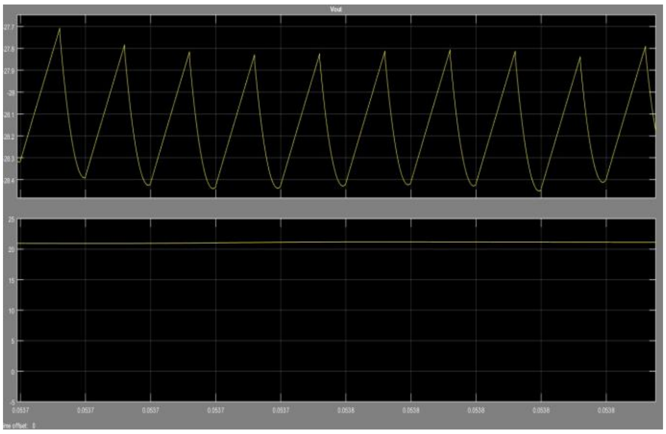

Fig.13. Showing Ripple of Voltage at the time of boost operation.

The following fig.10,11,12 and fig.13 are under Boost operation and as explained in boost operation case the buck results also consists Output voltage and Current graphs, graphs showing ripple voltage and current.

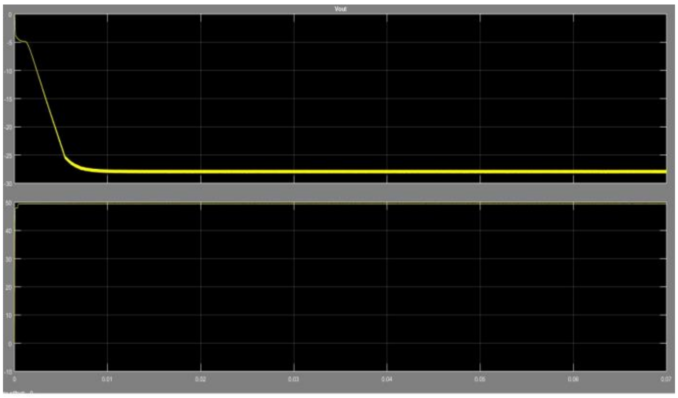

Fig.14. Buck Output Voltage

Fig.15. Buck Output Current

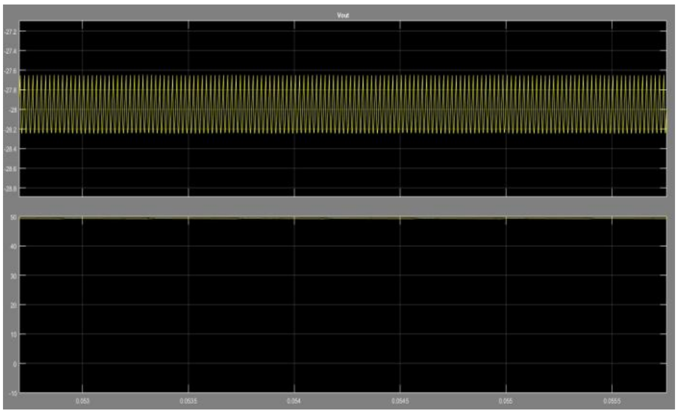

Fig.16. Showing Output Ripple at the time of buck operation

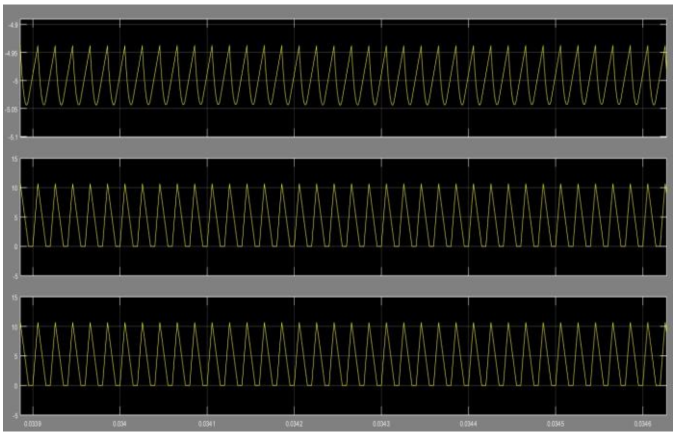

Fig.17. Showing Buck Ripple Current

VII. CONCLUSION AND FUTURE SCOPE.

In this Paper, a new Interleaved Buck-Boost converter has been proposed with PID controller. The simulation results thus obtained using MATLAB Simulink is with the mathematical calculations. The mathematical analysis, simulation study and the experimental study show that the controller thus designed to achieves tight output voltage regulation and good dynamic performances and higher efficiency. It can be conclude that, by using the interleaved Buck-Boost converter, the output voltage ripples can be reduced and efficiency can be improved. Most importantly, the input current has no ripple. By using two switches on the circuit, it can reduce the switching losses because it can alternate the turning on and off between these two switches.

EECU is supplied by Regenerative power without any interruption with proper line regulation and load regulation.

Our design will help HAL in the power management of EECU/FADEC (Engine Electronic Control Unit/Full Authority Digital Engine Control).

In future, the design can be implemented from software to hardware.

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