ISSN: 2321-8169
052– 056

Aircraft Power System: Peculiarities and Simulation

Shri Krishan
M Tech Scholar, Department of Electrical Engineering
Shri Ramdeobaba College of Engineering and Management
Nagpur, India
E-mail: shrinnn@gmail.com

S.V. Umredkar
Asst. Professor, Department of Electrical Engineering
Shri Ramdeobaba College of Engineering and Management
Nagpur, India
Email: sheetal.umredkar@gmail.com

Abstract—The operation of any aircraft depends upon the reliability of electrical power supply system. As aircraft has to operate for longer periods without any maintenance, equipments are required to have very high MTBF (Mean Time Between Failures) and low MTTR (Mean Time to Repair) for trouble free operation. The weight and space constraints are the main binding factors to design aircraft power supply system. Equipments are required to have failure rate of the order of 10^{-7} for military aircraft and 10^{-9} for commercial aircraft. This stringent requirement imposes several considerations which are to be clearly understood by the personnel involved in the field of aviation. The aspects like Smooth operation of all flying control at all time, flying aircraft as programmed, reliability for longer periods with little maintenance, extremes of vibration and acceleration because of various phases of flight, widely varying operating conditions, normal, abnormal and emergency operations. Aircraft typically utilizes 208 V Three Phase 400 Hz, 115 V Single Phase 400 Hz, 36 V Three Phase 400 Hz, 28 Volt DC and 270 Volt DC. The power supply system operates at 400 Hz. The detailed aspects will be brought out in the paper supported with simulation of various consumers (loads) for clear appreciation of the complexities of the system. This will open and initiate interest in scientific community for further research in aviation field.

***Keywords**- Aviation, Aircraft,Mean Time Between Failure(MTBF), Mean Time To Repair(MTTR)*

*****

I. INTRODUCTION

The reliable operation of the Aircraft depends upon the state of power supply. As Aircraft has to operate for longer periods without any maintenance, the equipments are required to have very high MTBF (Mean Time Between Failures) and low MTTR (Mean Time to Repair). The weight and space constraints are the main binding factors to design an electrical equipments having failure rate of the order of 10^{-7} for military Aircraft and 10^{-9} for commercial Aircraft. Modern day aircraft fly higher, faster and grow larger to meet the requirement. Therefore, in order to meet the demand of longer duration flights (e.g.non-stop flight from New Delhi to New York / Chicago), the services that the power supply has to satisfy also increase in complexity. In civil aircraft, this means more power to the galley units, environmental control and passenger entertainment systems, while increased power demands for actuators, lighting systems, avionics and heating.

II. BASIC AIRCRAFT POWER DISTRIBUTION SYSTEM

The aircraft electric power system often consists of two or more engine-driven generators to supply AC loads throughout the aircraft. While engine driven-generators are singly connected to the distribution buses in some civil aircraft configurations (i.e. each generator is responsible for a specific numbers of buses) almost all American and European air forces use the parallel connection configuration. In this configuration, the main generators bus bars are connected together through Bus-Tie Breaker (BTB). In the event that one generator should fail it is automatically isolated from its respective busbar and all busbar loads are then taken over by the operative generator. Should both generators fail however, non essential loads can no longer be supplied, but the batteries will automatically supply power to the essential services and keep them operating for a predetermined period depending on load requirements and battery state of charge [1].

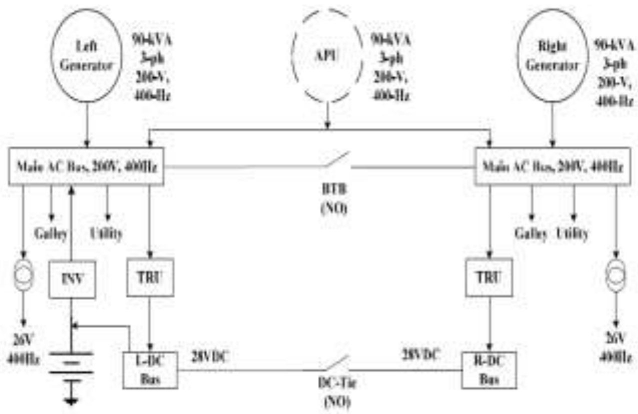

Fig.1. Basic Circuit of Aircraft Power Distribution System

A. *Peculiarities of Aircraft Power Supply*

The aircraft power supply system is peculiar in the sense that it has stringent requirement and has no corrective / preventive measures when aircraft is airborne. The Aircraft power supply is critical as compared to the land based power supply because of following:-

- Smooth operation of all flying control at all time.
- Flying aircraft as programmed.
- Reliability for Longer Periods with Little Maintenance.
- Extremes of Vibration and Acceleration during various phases of flight like taxying, cruising, landing etc.
- Widely Varying Operating Conditions.
- Weight and Space Constraints.
- Less MTTR and High MTBF requirement.
- Arcing being Major Safety Hazard.

B. Requirement of Aircraft power Supply

The primary function of an aircraft electrical system is to generate, regulate and distribute electrical power throughout the aircraft. It is used for operation of following services:-

- Aircraft Flight Instruments.
- Passenger Services.
- Engine System.
- Hydraulic System.
- Radio System.
- Navigation System.
- Radar System.
- Weapon System (for military aircraft)
- Aircraft Lighting System.

Essential power is that the aircraft needs to be able to continue safe operation. Passenger services power is the power that is used for cabin lighting, operation of entertainment systems and preparation of food.

C. Types of Aircraft power Supply

Aircraft electrical components operate on many different voltages both AC and DC. However, most of the aircraft systems use 115 volts AC at 400 Hz or 28 volts DC.26 volts AC is also used in some aircraft for lighting purposes. DC power is generally provided by "self - exciting" generators containing electromagnetic, where the power is generated by a commutator which regulates the output voltage of 28 volts DC. AC power, normally at a phase voltage of 115 V, is generated by an alternator, generally in a three-phase system and at a frequency of 400 Hz[2].

III. Elements of Aircraft electrical systems

An aircraft electrical system is mainly composed of power Sources, power distribution systems, electrical loads and components including control devices, conversion devices protection devices.

1) Direct Current (DC) Power Sources:-

a) DC Generators:- DC Generator serves as the primary source of DC Power and converts mechanical energy into electrical energy.

b) Batteries:- Battery converts chemical energy into electrical energy and stores electricity (DC). The primary function is to supply power for short term DC loads when generator or ground power is not available (for example: internal starting of aircraft aero-engine), flight critical loads during emergency conditions (for example, flight instruments, radio communication equipments etc). The batteries that are used in the aircraft are of Lead-acid and Nickel-cadmium type. In Lead Acid Batteries, the Sulphuric Acid is used as electrolyte. The fully charged Lead Acid batteries will have specific gravity of 1.275 to 1.300. Lead Acid batteries gives 2.0 volts per cell whereas Ni-cd Batteries use KOH (Potassium Hydroxide) as electrolyte and gives 1.2 volts per cell[2].

2) Alternating Current (AC) Power Sources:-AC Generators are used for generating AC Power (Typically, 22 KVA, Three Phase, 400 Hz). Inverters are also used when AC generators are not available as back-up[2].

IV. Bonding and shielding

The Aircraft can become highly charged with static electricity while in flight. If aircraft is improperly bonded, all metals will not have same amount of static charges. A difference in potential exists between various metal surfaces. The resistance between insulated metal surfaces also causes radio interference. If lightening strikes an aircraft, a good conducting patch for heavy current is necessary to minimize severe arcing and sparks. When metal parts of an aircraft are connected together to complete an electrical unit, it is called as bonding. Bonding connections are made of screws, nuts, washers, clamps and bonding jumpers. Bonding is a flexible metal strap (metal wire) which has good electrical connection and which has resistance approximately that which would exists, if the two connected parts were integral. Bonding reduces radio interference caused by atmospheric discharge in the aircraft exterior. It prevents the static discharges from electrically isolated parts, units or elements that would interfere with radio reception or even start the fire. Bonding provides path of low resistance for the grounding of electrical equipment to the metallic structure of the aero plane. Bonding supplies a means of equalizing the electrical potential of the aero plane with electrical potential of the earth on landing and maintaining these potential in balance until the aircraft again takes off.

For this reason, aircraft are equipped with ground wire fastened to the metallic part of the aircraft. When aircraft lands, this wire drags on the ground, discharges static electricity. On some aircraft, wheel tyres which will conduct electricity, are used instead of ground wire. Shielding is the covering applied to the wiring and equipment to eliminate interference with radio reception and grounded at the frequent intervals.

V. Analysis of Requirement of 400 Hz Power Supply

Aircraft electrical power system operates at 400 Hz instead of conventional 50 Hz / 60 Hz. Because of this, equipments will be smaller, lighter and efficient. As space is at premium and weight is main constraints, 115 volts 400 Hz offers many advantages. The explanation for utilization of 400 Hz Frequency is as follows:-

- Flux linkage is inversely proportional to speed.
- Speed is proportional to frequency.
- Flux linkage is inversely proportional frequency (f).
- $\Phi = V/f$ (at constant voltage) .
- $f \propto 1/\Phi$.
- Increase in frequency causes decrease in flux (Φ).
- Hence, size of core reduces resulting into reduction in requirement of core material. Equipment becomes smaller in size and lighter in weight which in turn will contribute towards higher efficiency.
- Cost Economisation.

$$f = \frac{NP}{120}$$

where

EMF = Electro-motive force in volts.

Φ = flux in Weber.
T = Number of coils per phase.
f = frequency in Hertz (Hz).
N= Rotor Speed (RPM).
P= Number of Poles.

Now let us analyse, $f = \frac{NP}{120}$

Imagine that N (RPM) increases which results in proportional increase in Frequency (f)
For 400 Hz

F = $f = \frac{24000 \times 2}{120}$ (similar results can be obtained by using RPM = 12000 and Number of Poles = 4 OR 6000 RPM and 8 Poles). These values can be interchanged but Number of poles are increased. Hence, in EMF equation, if frequency is higher, accordingly T or Phi can be reduced in proportion to create same amount of Voltage. That translates to lesser weight with reduced armature and stator size. Since, we have good source of high rotational speed in the aircraft, we can keep frequency (f) high, and reduce number of coils and keep the size of stator down (lesser magnetic field and lesser flux considering each pole being a heavy piece of iron).

$$EMF = 4.44\phi Tf$$

However, higher frequencies are very sensitive to voltage drop problems. These drops are resistive and reactive. Resistive losses are function of current flowing through the conductor with respect to length and size of conductor. This is the most important factor to control the power losses regardless of frequency. The short transmission range of higher frequencies is not a factor in most airborne application.

Reactive voltage drops are on the other hand are caused by inductive properties of the conductors (cables and wires).Reactive voltage drops are function of both cable length and AC frequency flowing through the conductor. With higher frequency such as 400 Hz, the reactive drops approximately 7 times greater at 60 Hz.

$$X(at60Hz) = 2\pi fL = 2 \times 3.14 \times 60 \times L$$

$$X(at400Hz) = 2\pi fL = 2 \times 3.14 \times 400 \times L$$

As the frequency is increased, the reactive voltage drop is also increased resulting into higher currents to meet the load demand.

VI. Effect Of Higher Frequency On Losses

Transformer being a static device, the mechanical losses are not experienced by this machine.. Electrical losses are generally considered. Loss in a machine is defined as the difference between input power and output power. When input power is supplied to the primary of a transformer, some portion of that power is used to compensate core losses in the transformer i.e. hysteresis loss in transformer and eddy current loss in transformer core and some portion of the input power is lost as I= I^2R loss and dissipated as heat in the primary and secondary windings, because these windings have some internal resistance. The first one is called as the core loss or iron loss and later is known as ohmic loss or copper loss in transformer. Another loss which occurs in the transformer is called as stray loss owing to stray flux linkage with mechanical structure and winding conductors. The losses that are prevalent in this machine are copper losses, hysteresis losses, eddy current losses, stray losses etc. The effect of higher frequency such as 400 Hz on losses are as brought out in succeeding paragraphs.

Copper Losses

Whenever current is flowing through a conductor, power is dissipated in the form of heat. The amount of power that is dissipated by the conductor is directly proportional to the resistance of the wire, square of the current and the duration of the current through the conductor. Greater the values of the current or the resistance, higher will be the power that will be dissipated. The resistance of the given winding is function of length of the wire and its diameter. Primary and secondary winding of the transformer are made up of low resistance wire in order to reduce these losses and by selecting the proper diameter of the wire. Larger diameter is required for higher current winding and small diameter is required for small current winding.

Copper Losses = I^2Rt
where I = Current flowing through the conductor in Ampere
R = Resistance of the conductor in Ohm
t =Duration of the current in the conductor in seconds

D = diameter of the wire and ($A = \pi D^2/4$)
R α l
R α1/A
R=ρ l/A
where ρ is the resistivity of the conductor.

Hysteresis Losses

Hysteresis loss depends upon the properties of magnetic material. Each time magnetic field is reversed, a small amount of energy is lost due to hysteresis (lagging of magnetism behind the magnetising force). According to Steinmetz, formula, heat energy due to hysteresis is given by

Wh = $\eta Bmax^{1.6}$ X f Watts
where η = Hysteresis Coefficient
Bmax = Flux Density in Weber/ m^2

The empirical exponent of which varies between 1.4 to 1.6 but often given as 1.6

Therefore, hysteresis losses are directly proportional to operating frequency of power supply. Greater the frequency, higher will be the losses.

Physical Explanation of Hysteresis Loss

The magnetic core of the transformer is made of Cold Rolled Grain Steel (CRGO). Steel is very good ferromagnetic material. This kind of material is very sensitive to be magnetized. That means whenever magnetic flux would pass through it, it will behave like a magnet. Ferromagnetic materials have numbers of domains in their structure. Domains are very small regions in the material structure, where all dipoles are paralleled in the same direction. In other words, domains are like small permanent magnets situated randomly in the material structure in such a manner that net resultant magnetic field of same material is zero. Whenever external magnetic field or mmf is applied to that substance, these randomly directed domains get arranged in parallel to the axis applied mmf. After removal of external mmf, maximum number of domains again come to random positions but some of them still remain in their changed positions. Because of these unchanged domains, substance becomes slightly magnetized permanently. This magnetism is called as Spontaneous Magnetism. To neutralize this magnetism, some opposite mmf is to be applied. The magneto motive force or mmf applied in the transformer core is alternating. Hence, for every cycle due to domain reversal, there will be extra work done. Hence some extra energy will be consumed and this energy is called as Hysteresis Loss of transformer.

Eddy Current Loss

Core of transformer is constructed usually with some kind of ferromagnetic material because of its good conducting properties of magnetic lines of force. Whenever primary winding of transformer is energized by an alternating current source, a fluctuating magnetic field is produced. This magnetic field cuts the conducting core material and induces a voltage into it. The induced voltage causes random currents to flow through core which gets dissipated in the form of heat. These undesirable currents are called as Eddy Currents and the losses are known as eddy current losses. Ferromagnetic materials are good conductor and core made of such a material constitutes like a single short circuited turn through its entire length. Eddy currents therefore circulate within the core in a plane normal to the flux and are responsible for resistive heating of the core.

Eddy Current Loss = $\eta * B^2 max * f^2$

Where η = Hysteresis Coefficient

Bmax = Flux Density in Weber/ m^2

Hence Eddy Current Losses are complex function of Square of Frequency. If frequency is increased, eddy current losses are also increased. However, these losses can be minimized by making core of transformer as laminated and thin laminations of the core will not provide an easy path to the currents.

Hence, at higher frequencies though losses are higher but space and weight being the main constraints in the aircraft , an optimum trade-off is reached to use 400 Hz frequency so that power supply equipments become smaller, lighter in weight and more efficient. Therefore, frequency of 400 Hz is used in the field of aviation.

VII. AIRCRAFT CABLES

The continued safe operation of aircraft beyond expected life depends on the safe and effective transfer of electrical signals between aircraft electrical components. Physical integrity of electrical wire and its insulation needs to be maintained. As aircraft increase in age and cycle time, the wire insulation may be degraded to the point that it is no longer capable of ensuring the safe transfer of electrical current. The factors that cause the wire insulation to degrade include dynamic bending, thermal cycling, vibration, chemical exposure, electrical stress, static stress, temperature, humidity, and airflow.

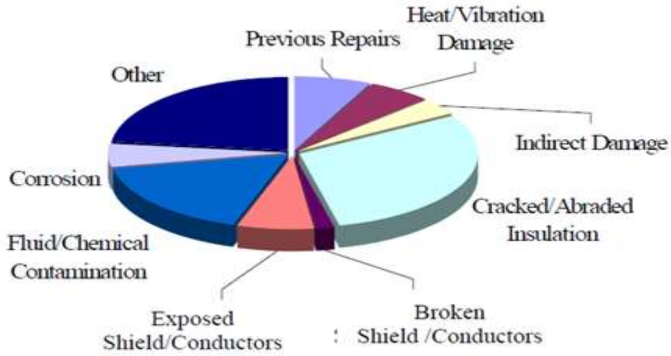

Fig.2. Typical Defects on Aircraft Cable.

VIII. MAINTENANCE ASPECTS OF AIRCRAFT SYSTEM

The operation of Aircraft system depends on higher reliability of mounted equipments. The maintenance philosophy is basically preventive maintenance. The servicing is carried out as per calendar based and hourly based periodicity. To have trouble free operation, higher MTBF and lower MTTR is must.

IX. SIMULATION OF AIRCRAFT POWER SUPPLY

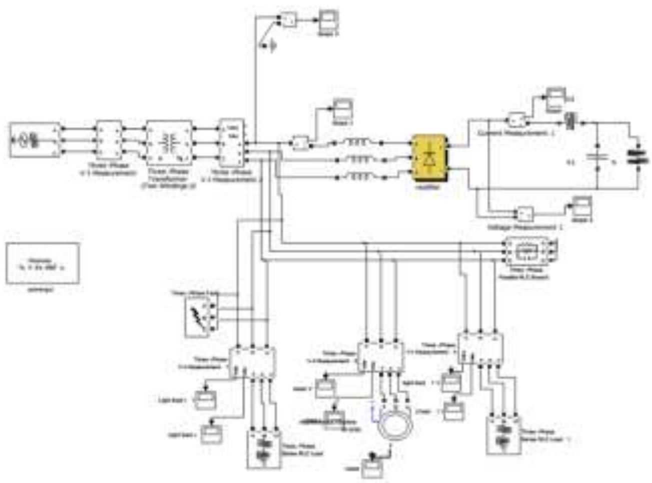

Fig.3. MATLAB/simulink block of Aircraft power supply

ISSN: 2321-8169
052– 056

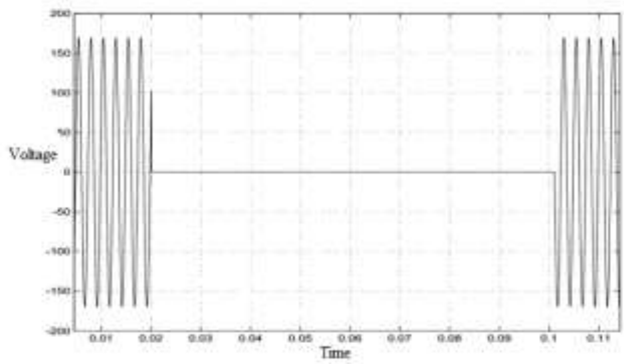

Fig.4. Simulated Waveform of Input Phase Voltage.

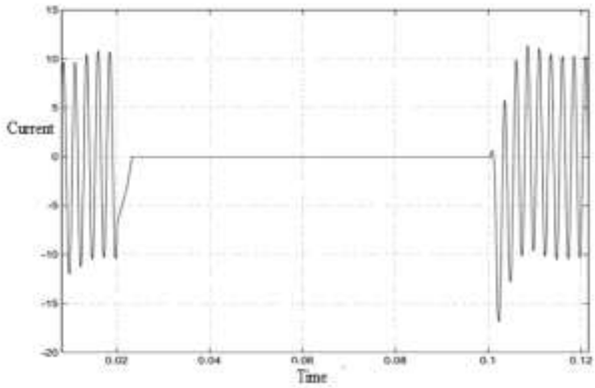

Fig.5. Simulated Waveform of Input Current.

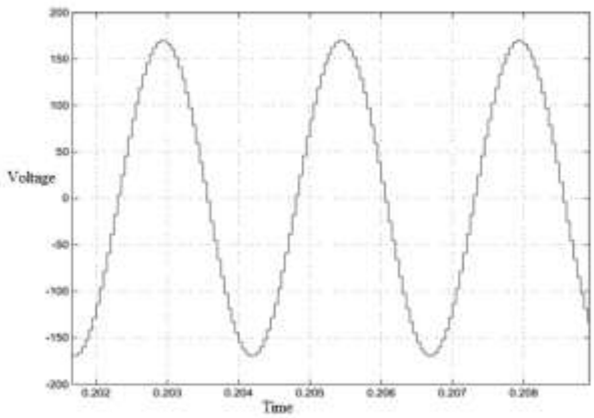

Fig.6. Simulated Waveform of Input Voltage.

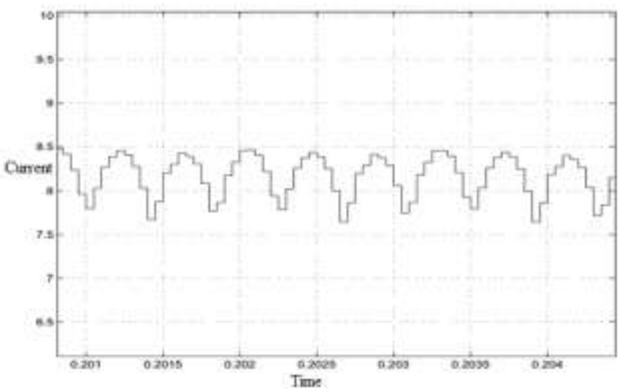

Fig.7. Simulated Waveform of Rectified Current.

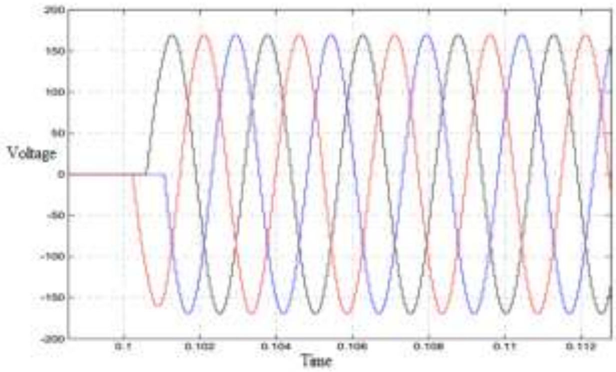

Fig.8. Simulated Waveform of Three Phase RYB Voltage Waveform

X. CONCLUSION

The paper has brought out the importance of aircraft power supply and utilization of higher frequency i.e. 400 Hz. Though the research is on to use higher frequencies for further reduction of size of power equipments but it has its own limitations. The power distribution and its simulation have been demonstrated. This will help in understanding the peculiarities of aircraft system for better appreciation of complexities involved in the field of aviation. The power rating of AC generators have been reflected just to visualize the requirement. Future aircraft may use higher rating and it may reach 1MVA per generator than the present day aircraft which use generally power rating of 90 kVA per generator.

REFERENCES

[1] Reyad Abdel-Fadil, Ahmad Eid, Mazen Abdel-Salam; Electrical Distribution Power Systems of Modern Civil Aircrafts, 2nd International Conference on Energy Systems and Technologies 18 – 21 Feb. 2013, Cairo, Egypt

[2] EHJ Pallet, Aircraft Electrical System (Book)

[3] Dan M. Ionel,Mircea Popescu, Stephen J. Dellinger, T. J. E. Miller, Robert J. Heideman, and Malcolm I. McGilpKellar; On the Variation With Flux and Frequency of the Core Loss Coefficients in Electrical Machines, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 42, NO. 3, MAY/JUNE 2006

[4] Kirby, Jordan, Brett and Del Aml, Ana; Aircraft Electrical Power Systems Prognostics and Health Management, Society of Automotive Engineers Conference,Reno Nevada, November 2004.

[5] Pierchel, J.: Student Thesis: Benefit analysis of the electrical aircraft network based on the A380, Hamburg: Airbus and Helmut-Schmidt Unrsity. 2009.

[6] M.S.Salglimbene, "Reliability analysis techniques: how they relate to aircraft certification", The Omnicon group Ltd.

[7] I.Moir and A.Seabridge,"Aircraft systems; mechanical, electrical and avionics subsystem integration", 3rd Ed, Wiley, 2008, ISBN 978-096902-2.