AIRCRAFT ELECTRICAL POWER SYSTEMS AND NONLINEAR DYNAMIC LOADS SIMULATION USING MATLAB

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ABSTRACT

Aircraft has become more dependent on uninterrupted electric power. The latest turbo fan engines, fly by wire flight control systems has increased the need of electrical power in civil aviation. In the similar lines the need to accommodate latest Electronic Warfare equipment has increased the requirement of electrical power in military aviation. Looking forward the future of military aviation with Unmanned Arial Vehicles (UAVs) where the aircraft is completely dependent on electrical power, the requirement of power generation, controlled power Distribution and utilization will certainly play a vital role. To meet the needs as discussed above there are two suggested options.

I. *Increase the electrical power generation of aircraft.*

II. *Effective utilization of available electrical power.*

Increasing the electrical power generation of aircraft will lead to increased fuel consumption which may limit the total flight, weight of aircraft, operating cost of aircraft in civil aviation. In military aircrafts increasing the electrical power generation of aircraft will limit the total mission time. Also the increased power generation is not suggested in terms of environmental considerations. Though there are so many disagreements in the increased aircraft power generation, the total power generation capability of aircraft is keep growing with generations.

Other way around the effective utilization of available electrical power of aircraft is the best way to opt to get benefited. Every aircraft is loaded with electrical power generation systems, power control systems and distributing systems. Controlled utilization of electrical power based on the requirement will eliminate the wastage of electrical power which intern allows the designer to accommodate more aircraft systems onboard.

This paper discusses about the aircraft power generation systems, power control, distribution systems and various electrical loads on aircraft in brief. A simulation also carried out in MATLAB to illustrate the various loads on aircraft and their power source utilization details. The simulation also brings out the relative power consumption details of the electrical loads based on their operating conditions.

Keywords: ***Electric Power, Power Generation, Power Distribution, Electrical Loads, Power Consumption***

I. INTRODUCTION

The conventional aircraft utilizes a combination of hydraulic, electric, pneumatic and mechanical power transfer systems. Increasing use of electric power is seen as the direction of technological opportunity for advanced aircraft power systems based on rapidly evolving technology advancements in power electronics, fault-tolerant electrical power distribution systems and electric driven primary flight control actuator systems.

The latest concepts in aviation industry like More Electric Aircraft (MEA), Unmanned Aerial Vehicle (UAV) implies increasing use of electrical power to drive aircraft subsystems that in the conventional aircraft, have been driven by a combination of mechanical, hydraulic and pneumatic systems. Electrical power consumption in modern aviation is also increasing due to less overall weight of the aircraft, lower maintenance costs, higher reliability and better performance with electrical systems.

The future aircraft power system will employ multi-voltage level hybrid DC and AC systems. Thus, aircraft electrical distribution systems will be mainly in the form of multi-converter power systems.

The electrical system of modern aircraft is a mixed voltages system which consists of the four types of voltage: 405VAC (variable frequency), 200VAC, 28VDC and 270VDC.

II. AIRCRAFT ELECTRIC POWER GENERATION SYSTEMS

Aircraft electrical power system often consists of two or more engine-driven-generators generally it will be combination of Permanent magnet generators (PMGs) & Variable Frequency Generators (VFGs) to supply the AC loads throughout the aircraft. All aircraft systems needs AC and DC power altogether. The DC power comes from rectification of the AC power using transformer rectifier units (TRUs). The constant-speed drive (CSD) generating system found onboard many aircrafts is comprised of a three-stage regulated synchronous generator, the output frequency of which is maintained constant by means of a hydro-mechanical CSD connecting it to the engine via a gearbox. A reduction in the weight of the system is brought about by a combination of the drive and the generator integrated into a single unit, thereby providing the integrated drive generator (IDG). However, continuing developments in power electronics and microprocessor technology have led to the DC-link variable-speed constant-frequency (VSCF) generating system, becoming a viable alternative to the CSD and IDG systems.

III. AIRCRAFT ELECTRIC POWER CONTROL AND DISTRIBUTION SYSTEMS

There are various electrical power control systems available on aircraft which contains Bus Power Control Unit (BPCU), Over Voltage Protection Unit (OPU) and Generator Control Unit (GCU) etc., The modern aircraft electrical power control systems are highly automated such that it contains continuous load requirement feedback systems, load operation monitoring systems and Built In Test Equipment (BIT) etc.,

The VSCF electrical system is more flexible compared to the CSD/IDG systems since its components can be distributed throughout the aircraft, in contrast to the CSD/IDG mechanical system in which they must inevitably be located close to the engine. The figure-1 below demonstrates the improvements in aircraft electrical power distribution

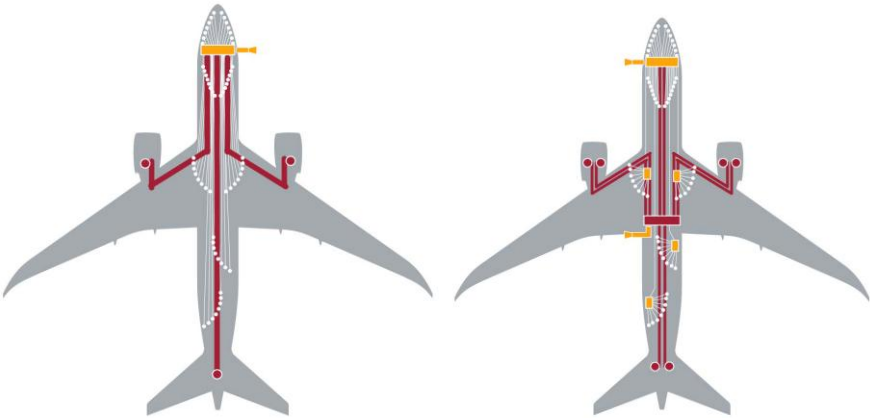

Figure-1: Improvements in Aircraft Electrical Power Distribution Systems [5]
Left: Aircraft with traditional power distribution system, Right: Aircraft with improved power distribution system

IV. AIRCRAFT ELECTRIC LOADS

Aircraft electrical loads vary based on the utilization. Civil aviation will majorly have control systems, actuating mechanisms, Cabin Air Conditioning and Temperature Control Systems (CACTCS) etc., Whereas, a Military aircraft will contain Electronic Warfare Equipment, Cooling Systems etc., which may consume most of the available power. So, air craft power generation and proper distribution is a challenge in modern aviation industry.

V. ELECTRICAL LOAD ANALYSIS USING MATLAB

Analysing the total power available on aircraft to that of total power usage of aircraft is very much helpful as it gives flexibility to the designer to accommodate more systems on board. Also the effective utilization of aircraft power i.e., utilizing power for a particular system only where it is required is most important to preserve the electrical power for other better usage.

The aircraft electrical power utilization analysis has been divided in to two parts

I. AC load analysis
II. DC load analysis

We have developed a MATLAB Graphical User Interface (GUI) to ease the Power Utilization Analysis of the Aircraft. All the calculations in this MATLAB GUI will follow MIL-STD 7016F. Figure-2 shown below represents the flow chart of MATLAB simulation.

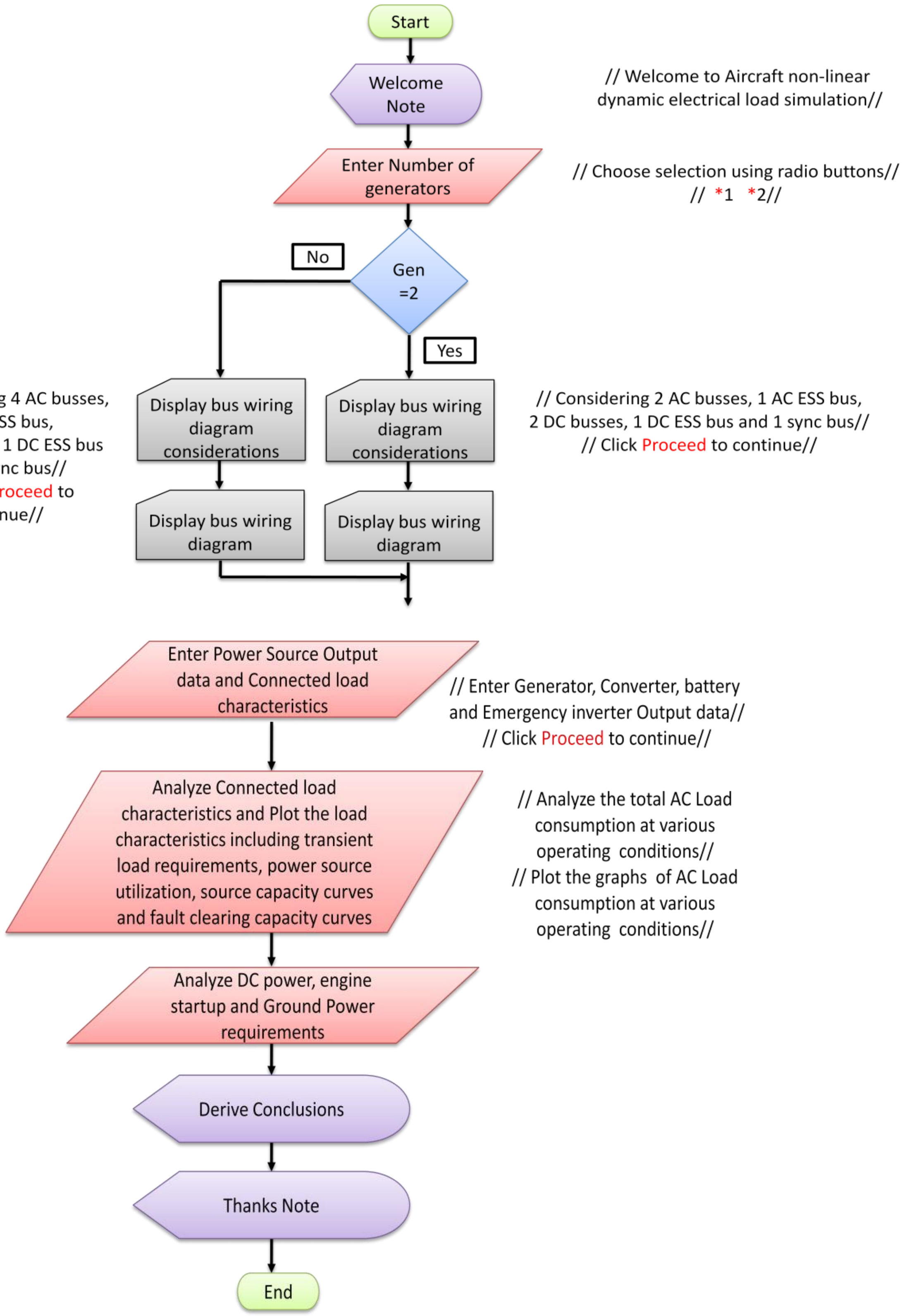

Figure-2: Flow chart of MATLAB simulation.

5.1 Calculations

The basic input for the simulation is number of generators in the aircraft, based on this user input the aircraft bus wiring method will be auto selected by the simulation. Further to that Generator data, Converter data, Battery

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data and Emergency inverter data will be fed to the simulator. Here to simplify the architecture we have considered AC single phase stand alone calculation. As specified in MIL-E-7016F the total flight conditions are divided in to seven stages.

$$\text{Total AC power consumption in specific flight condition (KVA)} = \sum_{i=1}^{n} \frac{\mathbf{Ni\ Pi\ Gi}}{\mathbf{1000}}$$

Where Ni = No. of Systems

Pi= Power consumption of the System (VA)

Gi=working Condition of system in specific flight operating condition

(Gi=0 if system is off, Gi=1 if system is on)

$$\text{Total DC power consumption in specific flight condition (KW)} = \sum_{i=1}^{n} \frac{\mathbf{Ni\ Vi\ Ai\ Gi}}{\mathbf{1000}}$$

Where Ni = No. of Systems

Vi= DC voltage (Vdc)

Ai=Current consumption (Amps)

Gi=working Condition of system in specific flight operating condition

(Gi=0 if system is off, Gi=1 if system is on)

5.2 The Load Simulator

As discussed above the simulation has been done in MATLAB. Below figure 3-7 will illustrate the input windows of GUI and figure 8-11 will illustrate the output windows of GUI. (Since the GUI windows are self explanatory no specific explanation has been given.)

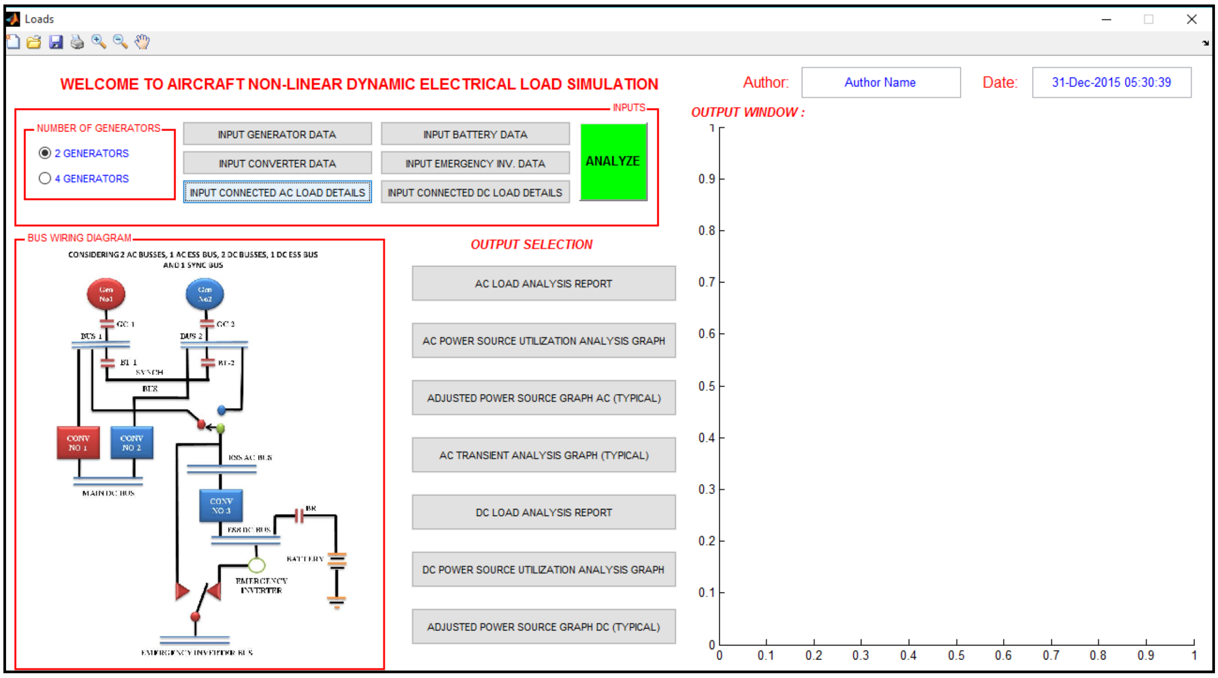

Figure-3: Main window of simulator without Outputs

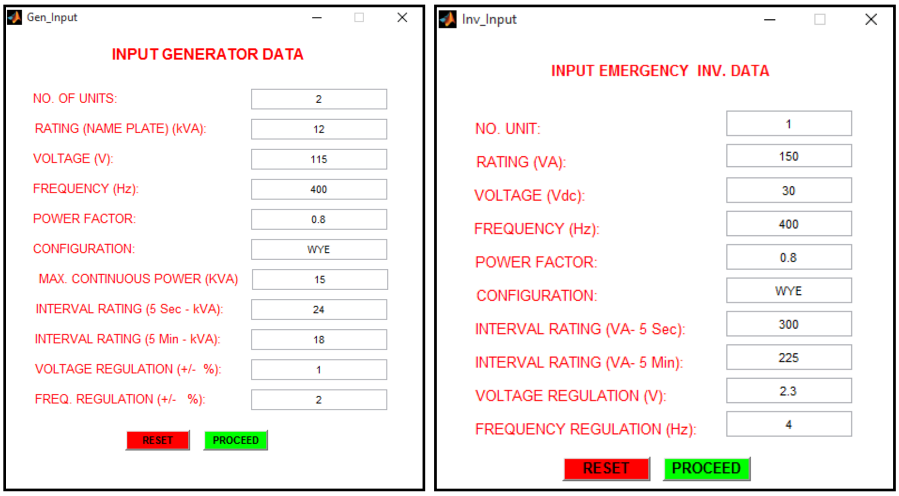

Figure-4: Input windows of Generator and emergency inverter

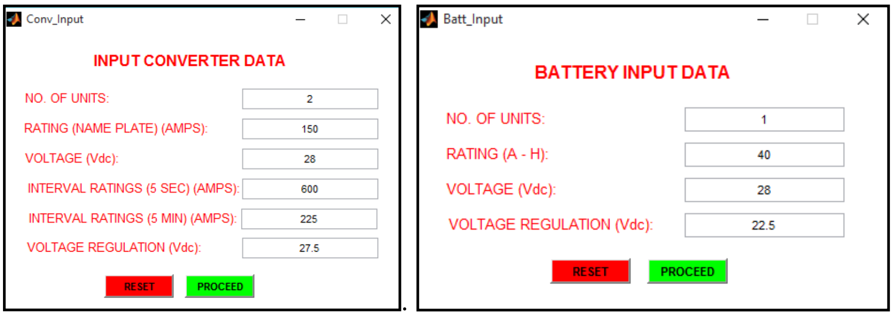

Figure-5: Input windows of Converter and battery

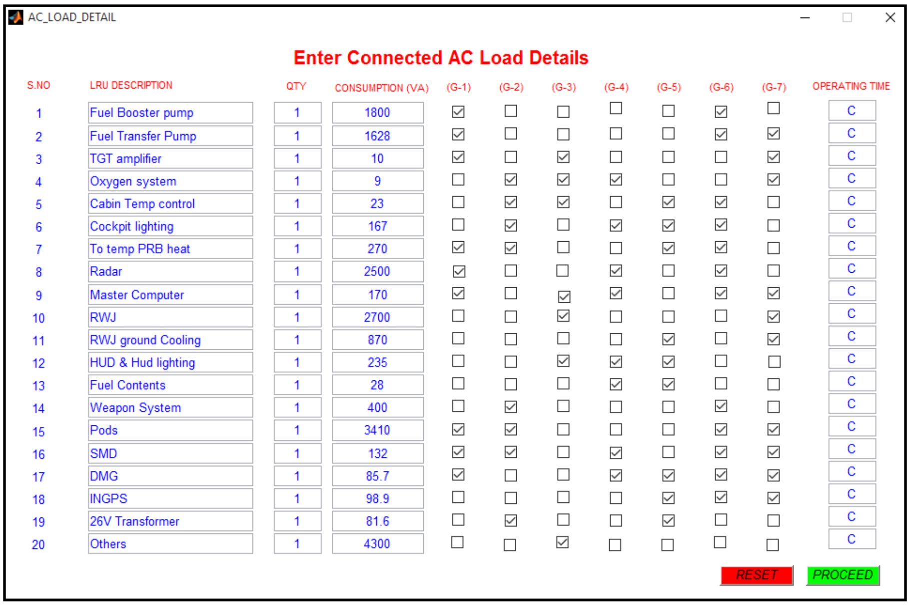

Figure-6: Input windows of AC load details

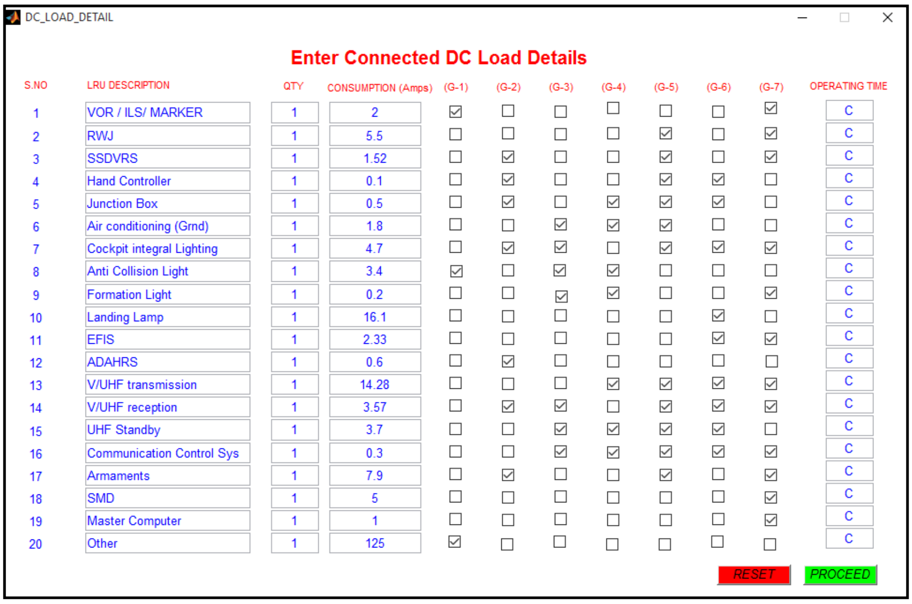

Figure-7: Input windows of DC load details

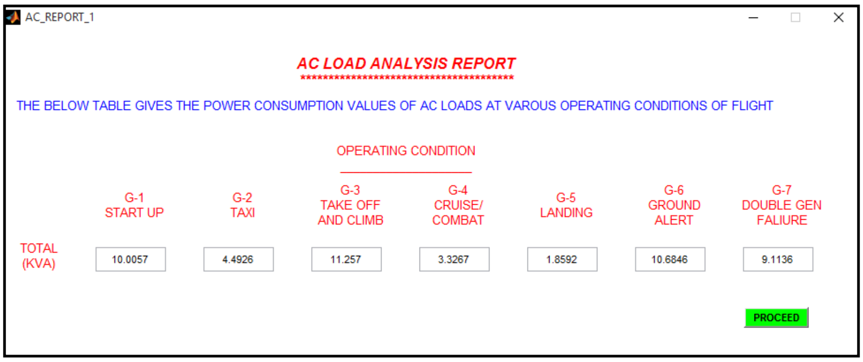

Figure-8: AC load Analysis report

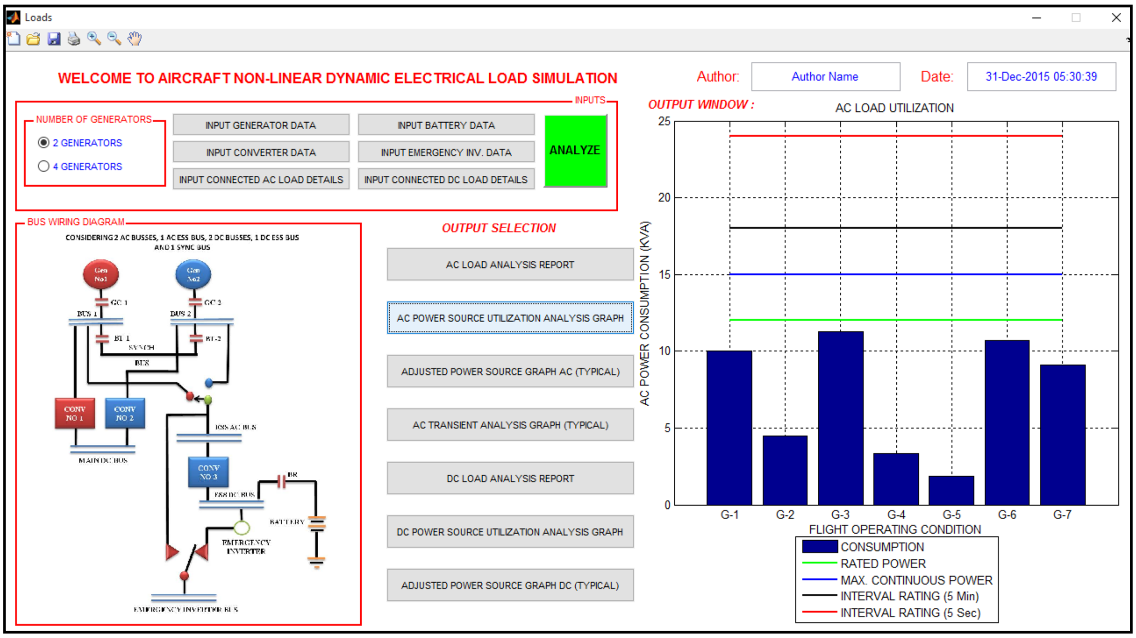

Figure-9: Output window with AC load utilization graph

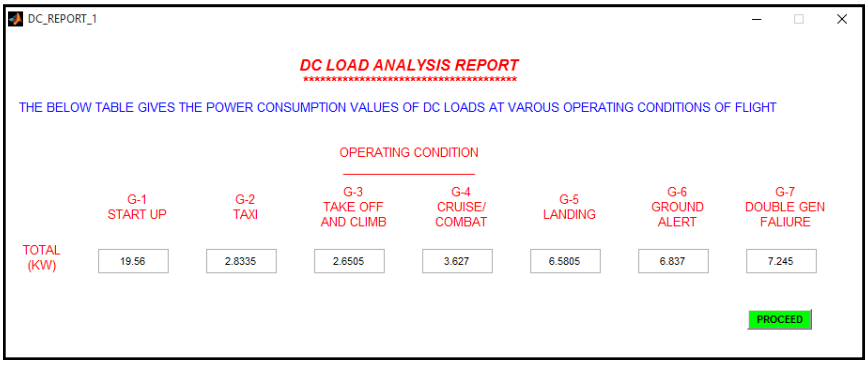

Figure-10: DC load Analysis report

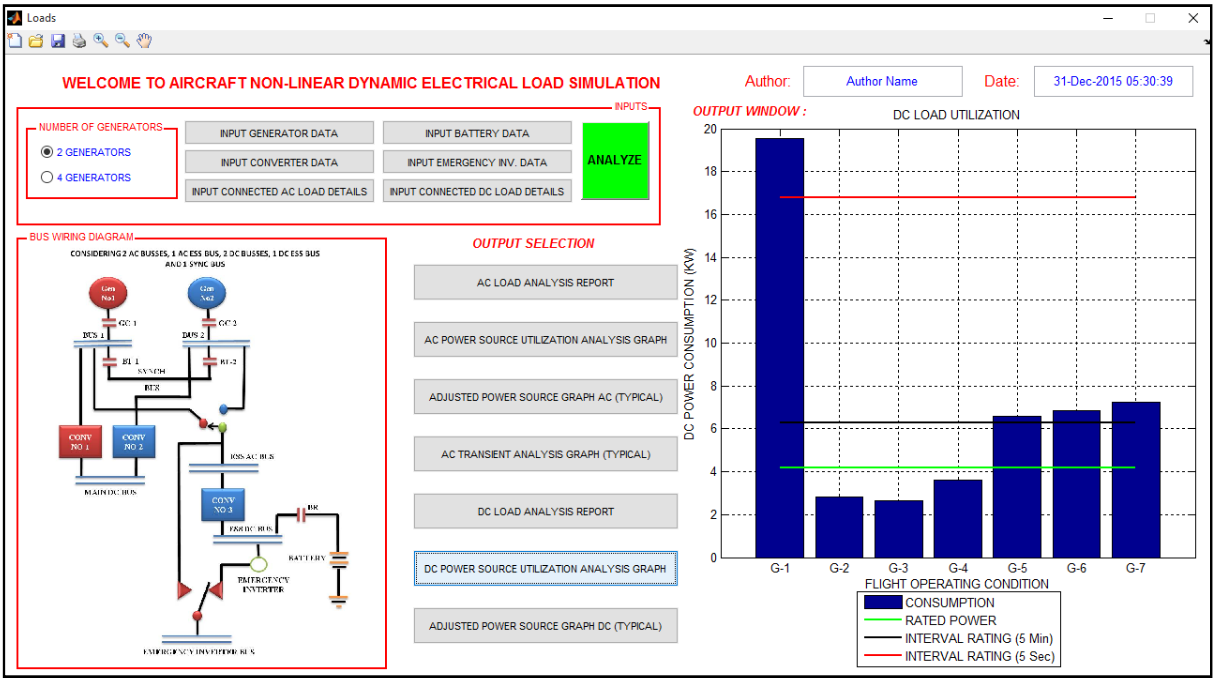

Figure-11: Output window with DC load utilization graph

VI. CONCLUSIONS

As the power requirement increasing rapidly for future aviation, balancing the power generation with power utilization is always mandatory. The simulators as presented above will reduce efforts and avoid human errors. Since these are handy for the designer, there will be better scope for iterative process mainly in military aviation to make configuration flights etc.,

The simulation shown above has got lot of scope for future development. As the Simulator can be made linked with database which will help comparison of various aircraft configurations with power source utilization details will become easy. Also the load transients can be easily simulated with the above simulation approach.

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