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ONLINE DIAGNOSTICS AND DATA CAPTURING ON A BRUSHLESS DC GENERATOR

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ABSTRACT

In an existing aircraft landing system, the generator is used for driving the electrical systems, whereas brushless DC generator (BLDC) is used as an auxiliary generator in case of failure in the main generator. In order to improve the performance of a brushless DC generator various parameters such as voltage, current, temperature, torque, lube oil flow, lube oil temperature, lube oil pressure are measured. Previously these parameters were measured by Data Acquisition System (DAS) with minimum sampling rate. The output voltage was fluctuating and was not maintained at 28V. In the proposed system the parameters to be measured are sensed using various sensors and the same is acquired into the system through Data Acquisition System with increased sampling rate and LabVIEW software. At various speeds, the operation of the system under no load and loaded conditions is checked and if there is any deviation from the set values, corresponding control action is taken. The output voltage is maintained constant at 28 V, which was difficult in the existing system.

Keywords: brushless DC generator, data acquisition system, LabVIEW.

INTRODUCTION

Each and every component in an aircraft plays a vital role. It is very important to test, experiment and analyze all of them. The generator, which is also an important component to be tested, diagnosed and its performance has to be characterized. While testing, various parameters are measured. Also, the mechanical failure in the system like meshing of the gear teeth, imbalances in rotating parts, friction, insufficient lubrication system and excess heat generation. By monitoring the above mentioned parameters, these problems can be diagnosed. They can be monitored and analyzed by using the LabVIEW [10].

A single value or set of values at a point in time or space is called a sample. Sampling is the reduction of continuous signal into a discrete signal. The maximum frequency component of the signal of interest usually determines the sampling rate. The highest frequency component of the signal of interest is 10times higher than the sampling rate [1]. The data from the DAQ device is sent into the memory (RAM) of the computer, firstly and then the data is read from the buffer which is then given to software memory in chunks. The acquired data is transferred into the software which is performed with DAQmx. Continuous Samples or Finite Samples is sample modes which can be set, based on this channels have different effects and this is implemented in DAQmx Timing VI for a task in LabVIEW.nFor Finite Samples, the Samples per Channel determine the exact number of samples to acquire before the task completes. For Continuous Samples, the Samples per Channel is used to determine the size of the buffer. It indicates how often a sample is taken. The number of samples sets the buffer size. When we configure the DAQmx Read VI, we are essentially configuring the second transfer from the buffer to the software memory.Buffer size is given by the number of samples. The software memory is configured along with configuration of DAQmx Read VI. It should be noted that the DAQmx Read VI waits until a chunk of data at least that big exists in the buffer before it places the data into the software from the buffer for processing. Therefore, if the sampling rate is not fast enough to create a chunk of this size in the time allotted by the timeout, the VI will throw a timeout error [7]. To prevent this, increase the timeout or reduce the Number of Samples per Channel. Decreasing the timeout delays the process. So, the sample rate can be increased. A band limited signal can be successfully reconstructed or recovered from its sampled version only if the sampling frequency is greater than twice the maximum frequency of the signal. The minimum rate at which the signal should be sampled to recover it from its sampled version is called Nyquist rate.

$$f_s > 2 * f_m \quad (1)$$

where,

f_s = sampling frequency
f_m= maximum frequency of the input signal

A combination of a real-time controller, reconfigurable IO Modules (RIO), FPGA module and an Ethernet expansion chassis forms the CompactRIO controller. They include a microprocessor for implementing control algorithms and support a wide range of clock frequencies. Input and Output modules are hot swappable, i.e., they can be connected or disconnected even when the unit is powered up. To implement high-performance data processing on reconfigurable fabric, the FPGA Module may be used. When data is streaming in from connected I/O Modules, data processing may be performed. The module is powered by a Xilinx Virtex high-performance FPGA. The FPGA can be programmed separately and is connected to the real-time controller using an internal PCI bus. CompactRIO systems are often considered as an industrial control unit, where a small

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form factor and ruggedness are important. For supervisory purposes and for displaying logged data, CompactRIO systems can also be connected to a host PC. PXI is designed for measurement and automation applications that require high-performance and a rugged industrial form-factor. We can select the modules from a number of vendors and integrate them into a single PXI system. PXI Express also allows us to use hybrid slots, compatible with both PXI and PXI Express modules.

National Flight Test Centre is the directorate of ADA dealing with flight testing of LCA. All the flight test and aircraft instrumentation related activities are planned, co-ordinated and executed by NFTC which is headed by a Test Pilot from the Indian Air Force. NFTC has Indian Air Force and Indian Navy test pilots and flight test engineers along with the scientists and engineers for instrumentation who are professionally carrying out the flight testing of the LCA.

Table-1 shows the specifications of the Brushless DC Generator. The specification is applied to the military aircraft for its efficient operation.

EXISTING SYSTEM

Table-1. Specifications of Brushless DC Generator.

Parameters	Range
Voltage	28 V DC
Current	250 A
Temperature	120^{o}C
Surface Temperature	180^{o}C
Torque	200 N.m
Lube Oil Flow	30 lpm
Lube Oil Pressure	2 bar

Table-2. Comparison of DAQ cards for existing system and proposed system.

Existing system				Proposed system			
DAQ cards	No. of channels	Resolution	Type	DAQ cards	No. of channels	Resolution	Type
NI 9209	16 Channels	16 Bit	Analog Input Module	NI 9205	32 Single Channel	16 Bit	Analog Input Module
NI 9263	4 Channels	16 Bit	Analog Output Module	NI 9265	4 Channel	16 Bit	Analog Output module
NI 9219	4 Channels	24 Bit	Analog Input Module	NI 9218	2 Channel	24 Bit	Analog Input Module
NI 9217	4 Channels	24 Bit	Analog Input Module	NI 9216	32 Channel	16 Bit	Analog Input Module
NI 9211	4 Channels	24 Bit	Analog Input Module	NI 9213	16 Channel	24 Bit	Analog Input Module

The parameters in the brushless DC generator which acts as auxiliary generator in case of failure of the main generator was measured by Data Acquisition System (DAS) with minimum sampling rate. From Table-2 and Table-3, the limitations of DAQ cards are,

a) Programming latency is high.
b) When multifunction DAQ cards are used, the sampling rate is reduced.
c) No controllers were used.
d) Output voltage was fluctuating.

PROPOSED SYSTEM

The parameters to be measured are acquired into the system through Data Acquisition System with increased sampling rate and LabVIEW software. From Table-2, the advantages are,

a) When the advanced controllers are used, the bandwidth is increased.
b) The modular I/O cards reduce the hardware and increase the sampling rate.
c) Increased number of channels.
d) Output Voltage was constant at 28V.

Table-3. Comparison of DAQ cards with sampling rate for existing and proposed system.

Existing system			Proposed system		
DAQ Cards	**Measurement**	**Sampling rate**	**DAQ Cards**	**Measurement**	**Sampling rate**
NI 9209	Input Voltage	500 S / s	NI 9205	Input Voltage	250 kS / s
NI 9263	Output Voltage	100 kS / s	NI 9265	Output Voltage	400 kS / s
NI 9219	Pressure	100 S / s	NI 9218	Pressure	51.2 kS / s
NI 9217	Temperature (RTD)	400 S / s	NI 9216	Temperature (RTD)	250 kS / s
NI 9211	Oil Temperature (Thermocouple)	14 S/ s	NI9213	Oil Temperature (Thermocouple)	75 S / s

The Table-3 shows the DAQ cards with minimum sampling rate in existing system which increases the processing time. The proposed system reduces the processing time due to increase in the sampling rate.

Military aircraft electrical system

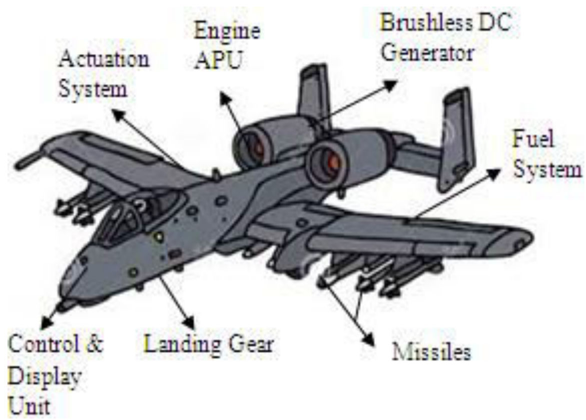

Figure-1. Military aircraft electrical system.

Figure-1 shows the location of BLDC generator in a military aircraft electrical system. The turbine produces mechanical energy which is supplied to a main generator. The main generator converts this mechanical energy into electrical energy. It is used for supplying power to the entire electrical system of the aircraft using the distribution buses. An aircraft electrical system consists of a primary bus and a secondary bus for the distribution of electrical energy. There is a Generator Control Unit (GCU) to control the output from the main generator and to distribute them. It makes use of a Transformer Rectifier Unit (TRU) to supply power to different AC and DC loads [5].

Block diagram of DC generator test rig

From the Figure-2, Prime Mover used here is an AC Asynchronous Induction Motor. It converts electrical energy into mechanical energy. The output is in terms of rotational motion of speed 3500 rpm. It is coupled to a Speed Increaser Gear Box (Step up Gear Box) of ratio 1:5. Output of the gear box is connected to a Torque sensor to measure the input torque of the generator. High speed coupling is used to couple the torque sensor and spindle housing. Generator is fixed in the spindle housing.

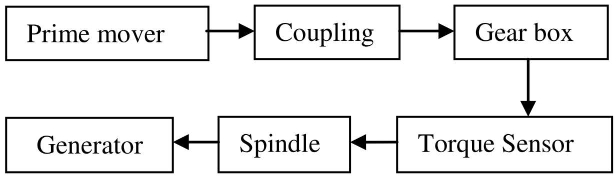

Figure-2. Block diagram of generator test rig.

The Figure-3 shows the BLDC generator test rig in real time process. Lubricating system is used for the lubrication of gear box. Cooling system is used to cool the generator. Generator is driven by the driving motor and loaded by an Electronic Load Bank (resistive load bank).

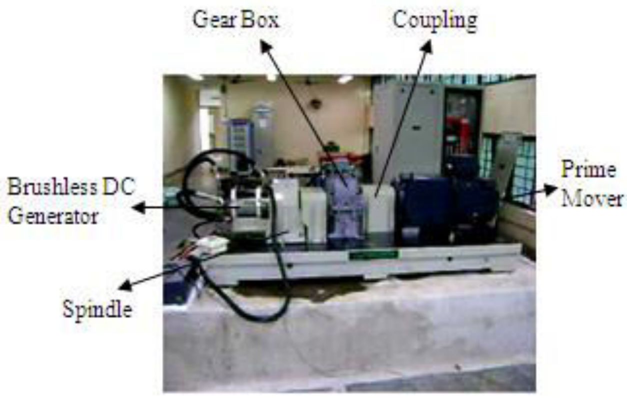

Figure-3. Brushless DC generator test rig in real time process.

Brushless DC generator vs DC generator with brushes

- Brushed type generators wear out over time of usage and brushes need to be replaced at a certain intervals too include any damage caused by pitting or scaring. This happens in Figure-4b). Brushless generators produce a cleaner voltage sine-wave form than the brush types.
- Brushless type generators use an additional VCR (voltage controller regulator) circuit that maintains a constant level with less ripples. This can be visualized in Figure-4a).

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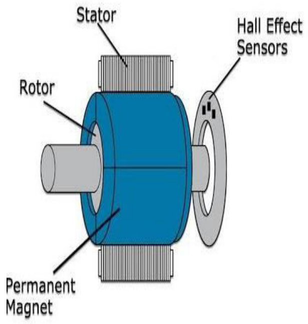

Figure-4 a). Brushless DC Generator

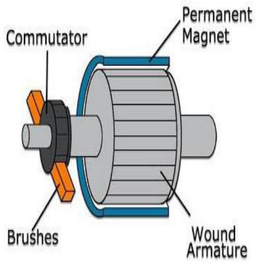

Figure-4 b). DC Generator with brushes

Brushless DC (BLDC) generator

A Brushless DC Generator has a magnetically controlled commutation system instead of a brush based mechanical commutation system. It provides a direct current without the use of slip rings or brushes which reduces the maintenance cost. Brushless DC generators have important advantages when compared to Brushed DC Generators [8]. They have better torque-speed characteristics. Their efficiency and dynamic response are. They are very small in size.

The Figure-5 shows the schematic of a Brushless DC Generator. In order to energize the field, DC excitation must be applied to the generator field coils. The excitation current is supplied from a brushless exciter mounted to the generator shaft. The brushless exciter is an AC exciter which uses full wave rectifier for dc output. During each engine start the generator set field is activated and gives voltage to the exciter stator. This action starts the voltage to energize the generator field. When the field current is controlled, the generator output is also controlled. This is accomplished by regulating the exciter field coil voltage. A solid-state type voltage regulator regulates the exciter field coil voltage. The parts of the BLDC Schematic are as follows:

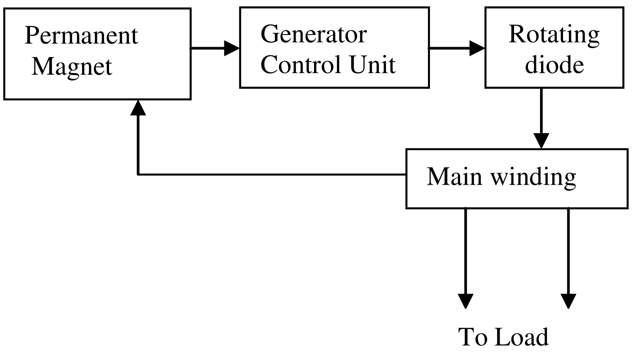

Figure-5. Schematic of brushless DC generator

Brushless exciter

In a stationary field, a three-phase AC winding and rotating rectifier assembly is present in armature of brushless exciter. The stationary exciter field assembly is mounted on the main generator frame. The bearing end of the generator rotor shaft is slided over by the rotating rectified assembly. Bolts and washers secure it to an adapter hub shrunk on the generator shaft.

Rotating rectifier bridge

There are rectifying diodes mounted on a brass heat sink. The heat sink is then mounted on an insulating ring. The entire assembly bolts to the adapter on the generator shaft. Along with the exciter armature, the rotating rectifier assembly will rotate.This does not require any sliding contacts placed between the exciter output and the alternator field.

Exciter field

The exciter field is made up of laminated segments of high carbon steel on the high frequency exciter. To make up the field poles, they are fitted together. Within the slots of the field poles, the field coils are placed.

Exciter field coil voltage source

The voltage from a phase to neutral line of the generator output is rectified to produce the field coil DC voltage, or other appropriate terminal to provide the needed voltage reference. One of the integral parts of the static regulator is the rectifier bridge.It senses a variation in the generator output is sensed by the static regulator. Current flow in the exciter field coil circuit is automatically regulated to increase or decrease the exciter field strength. To adjust the regulator sensing circuit, an externally adjustable rheostat compatible with the regulator is used.
The emf equation is given by,

$$E_{ph} = 4.44 f \Phi N K_w \quad (2)$$

$$K_w = K_b * K_p \quad (3)$$

where,

E_{ph} = RMSemf per phase
f = Frequency (Hertz)
Φ = Flux per pole (Wb)
N = Number of turns in series
K_b = Breadth factor
K_p = Pitch factor
K_w = Winding factor

Data acquisition

The process of sampling of real world physical conditions and converting the resulting samples into digital numeric values that can be processed by a computer is called Data Acquisition. A data acquisition and data acquisition system typically involves the process of conversion of analog waveforms into digital values [2]. The sensors are the major components in the data acquisition system that converts physical parameters into electrical signals. The components are shown in Figure-6.

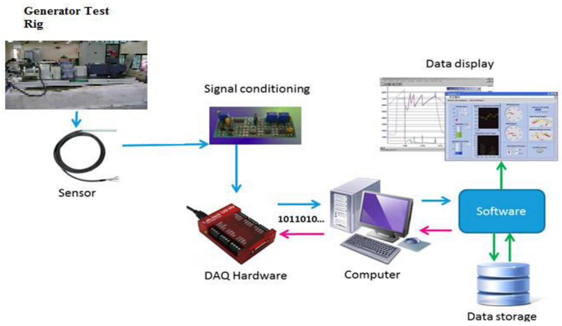

Figure-6. Data acquisition system.

Signal conditioning circuit converts sensor signals into a form that can be converted into digital values. Amplification, filtering, converting, range matching, isolation, linearization, etc. are the processes that come under signal conditioning. Analog to digital converters convert the conditioned sensor signals into digital values.

Software used

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a programming environment. It is a graphical development environment. LabVIEW programs are called virtual instruments (VIs). Built-in functionality for simulation, data acquisition, control of instrument, analysis of measurement and data presentation are provided. The flow of data controls the execution. LabVIEW VI contains three components - front panel, block diagram and the icon and connector pane.

Figure-7. Data acquisition system during testing process.

Using a single compatible software and modular measurement hardware to create user-defined measurement systems is called virtual instrumentation and the systems are called virtual instruments. The basic difference between hardware instrumentation and virtual instrumentation is that software replaces a large amount of hardware [6]. The complex and expensive hardware can be replaced by software. The Figure-7 shows the front panel of the LabVIEW software. It indicates the readings taken during the testing time of the generator under no load conditions.

Controllers used

There are two controllers used. They are CompactRIO based hardware as Test bench controller and PXI based hardware for DAQ purposes.

CRIO Controller

CompactRIO controller consists of a processor and a reconfigurable FPGA. The processor is used for network communication, control, logging of data and processing with the deterministic and reliable NI Linux Real-Time OS [1]. With the user-programmable FPGA, we can implement custom hardware for high-speed control, inline data processing, or complex timing and triggering.

CompactRIO systems include an embedded controller for communication and processing, a reconfigurable chassis housing the user-programmable FPGA, connection and disconnection of I/O modules, and graphical LabVIEW software for rapid real-time, Windows, and FPGA programming. CompactRIO provides multiple types of high-quality measurements all within a single system. Advanced signal processing, frequency analysis, and processing of digital signals can be easily performed using them. Examples are fast Fourier transform (FFT), time-frequency analysis, sound and vibration, wavelet analysis, curve fitting, and control design and simulation.

PXI for DAQ

One of the several modular electronic instrumentation platforms in current use is PCI eXtensions for Instrumentation (PXI). These serve as a basis for building electronic test equipment, automation systems, and modular laboratory instruments. For measurement and automation applications that require high-performance and a rugged industrial form-factor, PXI can be used [3]. We can select the modules from a number of vendors and integrate them into a single PXI system. Industry-standard computer buses acts as a base for PXI and permits flexibility in building equipment. To manage the system, modules are fitted with custom software. PXI express is and adaption of PCI Express to the PXI form factor, developed in 2005. There is an increase in the available system data to about GB/s in each direction [4]. Hybrid slots are compatible with both PXI and PXI Express modules. When these are used, the output voltage is maintained constant at 28V.

Table-4. Gear box readings.

Parameters	Values	Units
Gear box lube oil flow	10.79	lpm
Gear box lube oil pressure	0.02	bar
Temperature	34.73	degree Celsius
Oil reservoir temperature	31.77	degree Celsius

Table-4 shows the Step up gear box readings which was monitored during the testing process.

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RESULTS AND DISCUSSIONS

Table-5. Comparison of output readings between existing and proposed system.

Generator speed (rpm)	**Excitation**		**Load**	**Existing system** Load		**Proposed system** Load	
	Voltage (V)	**Current** (I)	**Power** (kW)	**Voltage** (V)	**Current** (I)	**Voltage** (V)	**Current** (I)
8000	1.34	0.35	No load	24	No load	28	No load
	1.67	0.41	1	25	30	28	37
	1.9	0.62	2	27	59.8	28	75.2
	2.34	0.8	3	27	108	28	112
	2.93	1.02	4	27	138	28	150
	3.54	1.25	5	28	172	28	180
	4.2	1.41	6	28	200	28	215
	4.5	1.6	7	29	225	28	250

From the Table-5, we infer that for the same excitation voltage and excitation current under various load conditions, the existing and proposed system values are tabulated and compared. Initially when the generator was tested with the speed of 8000rpm, under both loaded and no load conditions, the output voltage was fluctuating and it was difficult to maintain at constant 28V. With the help of proposed system, we are able to achieve the output voltage at a constant of 28V.

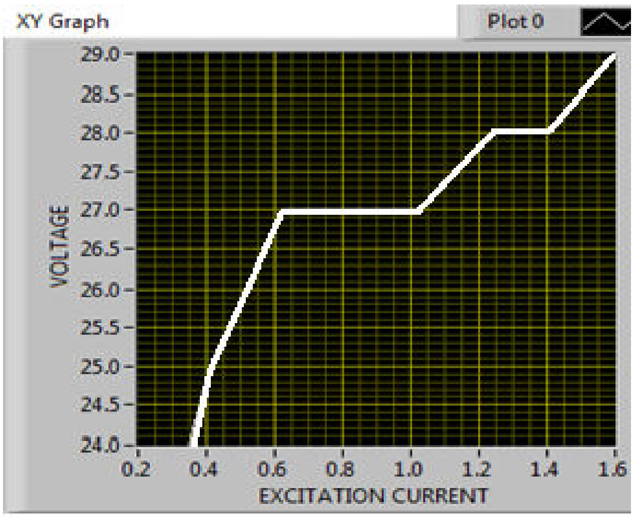

Figure-8. a) Output characteristics of existing system.

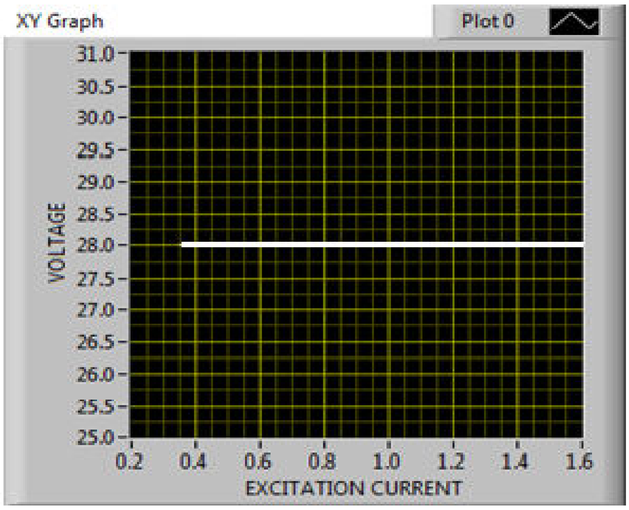

Figure-8. b) Output characteristics of proposed system.

Figure-8 a) shows the output characteristics of existing system, where the output voltage was not linear. Figure-8 b) shows the output characteristics of proposed system, which has obtained a linear curve.

CONCLUSION AND FUTURE WORK

This paper suggests checking and diagnosing the conditions of one of the most important component of an aircraft using a generator test rig under no load and loaded conditions. The proposed system overcomes the disadvantages of the existing system. It is able to maintain a constant DC voltage for varying excitation voltage and current and varying load. When it is operated under different speeds, the ability to withstand loads can be known. If it meets the desired amplitude at the desired speed, the generator is safe. If it deviates from the desired values of speed and amplitude, the generator has to be checked for its endurance. In future scope of this project, a wireless web based data acquisition; data logging and supervisory control system can be implemented. The main advantage of wireless web based data acquisition system is that any authorized person anywhere in the world can access the real time process data with the help of internet. The main concern area of web based data logging and supervisory control system is the security of data and authentication of the user. For security, a firewall can be implemented.

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