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Load Rejection Effects Analysis on Synchronous Generators with ANN

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ABSTRACT : *The increase in load demand has caused the transmission power system to be highly stressed leading to the occurrence of faults in the transmission and generation systems. In this paper, the emphasis was to detect and classify the faults in a synchronous machine installed in Akwa Ibom State in southern part of Nigerian. The data from the station was obtained and utilized in the generation of the plant model for the determination of temperature and speed of the plant at normal and faulted condition. The modeling and simulation were carried out in SIMULINK. The outcome of the simulation should that the temperature would be at maximum at the occurrence of wear and tear with plant speed at maximum at the occurrence of lack of plant synchronism. The detection and identification of the generator conditions was done with ANN. The outcome showed that the maximum error deviation was 10% which proved that ANN was efficient and should be utilized for prompt conditions detection.*

KEYWORDS: *synchronous machine, fault detection and identification, artificial intelligent, modeling, simulation, ANN.*

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I. INTRODUCTION

One of the most crucial pieces of equipment in the power networks that provide consumers with electricity is the synchronous generator (SG). Although synchronous generators are incredibly dependable devices, malfunctions are inevitable and have the potential to stop the electrical power supply [1]. Numerous protective strategies have been put out thus far to improve the power system reliability since the synchronization of generators is a crucial component of power systems. Redundancy, or adding another synchronous generator as a backup unit, enhances reliability, but at the expense of increasing the power generation system's weight, volume, and cost. Therefore, a suitable strategy makes use of a sensitive and precise fault detection technique to find the flaws at an early stage. The most common type of defect in big synchronous generators is the stator-winding fault, with the rotor-winding fault coming in second [2].

Large alternating current networks that run at a constant frequency of 50 Hz (or 60 Hz) rely entirely on synchronous generators, also known as alternators, to supply them with electrical energy. The frequency of the generator changes when the applied load exceeds the maximum load that the generator is capable of handling, and because synchronous generators are highly demanding and an essential part of the power system, precise parameter modeling is required. However, there is still debate regarding the best approaches for precisely estimating the characteristics of synchronous generators. A novel approach to synchronous generator parameter estimation was presented in [3], overcoming some of the drawbacks of earlier suggested methods by a number of authors. It used load rejection test data for both the round rotor synchronous generator and the salient pole in both the direct (d-axis) by which flux is produced in the field winding and the quadrature axes (q-axis) by which torque is produced. Simulink was used in [4] to simulate the effects of field voltage variation on the d-axis utilizing the results of a load rejection test at constant field voltage and again with a field voltage with transient variation.

Since the SG cannot function correctly after such an experiment, creating a true fault on it and analyzing its behavior is mostly damaging and expensive. Furthermore, a genuine flaw may be harmful and result in issues. Since of this, modeling is crucial to the examination of SGs since it lowers expenses and risks [5].

The Synchronous Generator cannot function correctly after such an experiment; thus, it is usually harmful and expensive to create a true malfunction and analyze its behavior. Furthermore, a genuine defect may pose a risk or result in issues. Because of this, modeling helps to reduce costs and hazards in the SGs analysis [6].

In this paper, the major essence was to utilize an artificial intelligent model for the identification of faults in the synchronous machine installed in Ibom Power plant in southern part of the Nigerian 132kV transmission network. The data from the pant were obtained when the plant was at normal condition, load rejection, lack of frequency control, lank of synchronism and the occurrence of wear and tear. The major parameters measured for the modeling were temperature and the speed at each faulty condition. The model utilized for the detection of the faults was artificial neural network.

A new method was developed in [7,8] to estimate the parameters of synchronous generators using load rejection test data for both round rotor synchronous generators and salient poles in both quadrature axes (q-axis) and direct (d-axis) where torque is produced and flux is produced in the field winding. This method overcome some of the drawbacks of earlier approaches that were suggested by multiple authors. Simulation of the effects of field voltage variation on d-axis using load rejection test result at constant field voltage and again with a field voltage with transient variation was done using Simulink in [9].

A synchronous machine, sometimes referred to as a synchronous generator or motor, is an electrical device that runs continuously at a speed determined by the frequency of the grid to which it is attached. In addition to being extensively utilized for transportation and industrial power, synchronous generators are also essential for preserving the stability and dependability of electrical grids. Using brushes and slip rings fixed on the synchronous machine's rotating shaft, a direct current must be sent to the rotor's field circuit in a synchronous generator. The rotor of a synchronous motor rotates at the speed of the rotating field, which is provided by the machine's balanced three-phase stator magnetic field [10]. Synchronous motors transform electrical energy into mechanical energy.

The synchronous generator is a multipurpose electromechanical energy conversion tool that may be used for many drive applications as well as the generation of electricity. When an engineering team worked on the invention's early development in the last decades of the 1800s, it was discovered [11]. Although the synchronous machine actually originated in the 1880s, it has been around for more than a century [12]. Built in 1887, the first three-phase synchronous generator produced roughly 2.8 kW at 960 revolutions per minute (rev/min), or 32 cycles per second, which is now known as hertz (Hz).

Any unusual event that interferes with the regular flow of electricity in an electrical power system and may cause equipment damage or power outages is referred to as a fault. During operation, transmission networks, machinery, and equipment frequently encounter a variety of defects that cause system instability and serious damage to power system components. Fault events in the power system network are caused by a number of variables, including aging assets, extreme weather conditions including strong winds, falling trees, lightning strikes, and many more. Electrical power system defects can be divided into two main categories: symmetrical faults and asymmetrical faults. Short circuit, open circuit, and ground faults are examples of these types of faults [13].

When electrical components, such as transformers, generators, transmission lines, and distribution equipment, are exposed to currents or power levels above their rated capability, overloading effects take place in the power system. Serious repercussions from these overloaded effects may include system instability, equipment damage, and safety hazards [14].

Electrical components, including transformers, distribution equipment, transmission lines, and generators, can experience overloading effects in a power system when their rated capacity is exceeded by currents or power levels. In addition to posing a risk to safety, these overloading effects can cause system instability and damage to equipment [15].

In order to enhance the durability of the turbine blade, novel methodologies were deployed in [16]. The study focused on identifying fatigue-prone regions during loading using finite element method (FEM). The outcome of the study showed that stress distribution in the blade body is well suited for operational loads. In order to have a proper understanding of the mechanism of turbine blade damage and identification of areas with high stress levels, computational analysis with excess of rotational speed was done in [18, 34]. Turbine blades primarily composed of Nickel based super alloys that plays a high role in the conversion process of high temperature and high-pressure gas into mechanical work. The study carried out in [20], offers a comprehensive review on the historical developments, fundamental characteristics, the impacts of operational parameters and atmospheric conditions, modelling and simulations, and innovative approaches such as evaporative coolers, heat exchangers, and absorption chillers. The impacts on basic operational features of gas turbine cycle with power willing capacity of 100MW was carried out in [19, 21, 35], the study deployed EES software-based calculation code in conformity with the Tunisian electricity and gas standard. The study outcome showed that elevated ambient temperature results to increase in TPZ and NOx emissions coupled with reduced cycle efficiency and

UHC emissions. The study concludes that the cycle efficiency and NOx emissions rise in tandem with increased pressure ratios. The research conducted in [22, 23, 31, 32], investigates on the performance of two gas turbine engines, GT1 and GT2, operating in same location, with GTI utilizing both online and offline water washing optimization, while GT2 relies solely on offline water washing. The result show that GT1, with online washing exhibits improved compressor efficiency, overall turbine efficiency and lower fuel consumption compared to GT2. The study in [24, 37], investigates two blades' samples to ascertain the cause of fracture, the both samples exhibited significant superficial heat damage. Diffusion coating was considered a viable solution for blade protection, the approach delayed cracking in the first stage blades. Damage to the thermal barrier coating led to overheating, accelerating the creep and rafting of the precipitates. The study in [25, 36] introduces a time-frequency analysis approach utilizing two variations of the Wigner-Ville distribution to effectively identify and characterize common power quality disturbances in Nigeria, specifically voltage sag and swell, with promising results for potential application in the classification of power quality disturbances in electrical power smart grids. Successful utilization of the Windowed Wigner-Ville Distribution (WWVD) and Filtered Wigner-Ville Distribution (FWVD) for precise analysis of voltage sag and swell power quality disturbances, with the FWVD outperforming WWVD by providing more closely concentrated energy along the frequency axis, while also noting a relationship between voltage amplitude and energy concentration, suggesting potential applications for feature extraction and classification in identifying specific power quality disturbances [26, 33].

Contingency analysis study of the Nigerian power systems network was carried out in [27, 38], the study pointed out that the primary objective of contingency analysis in power systems is to enhance security by identifying and addressing potential overloads and issues that may disrupt system performance during abnormal conditions, using contingency tools to manage, analyze, and report on contingencies and violations; this study employs the Newton-Raphson method for load flow analysis and models the system in ETAP version 12.6, also it revealed significant reduction in branch losses for line 4 and transformer T2A of 156kW and 0.8kW respectively. Highest PI values were recorded from the performance Index (PI) values for Kinkinau and Turuku feeders respectively, the outcome of this study will serve as valuable insights for system operators and expansion planning [28, 29, 30].

II. METHODS

The flow diagram deployed for the procedure of research in this paper was shown in fig. 1.

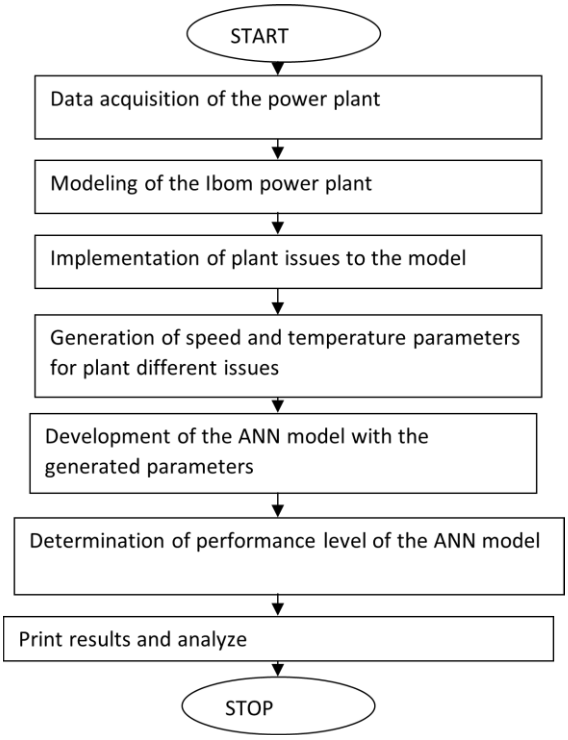

Fig.1: Summary of the Research Procedure

The data obtained from Ibom power plant in Ikot Abasi generation station was shown in table 1.

Table 1: Data utilized for the modeling of the synchronous generator in Ibom power plant

Parameter	Values/ range
Temperature at normal condition	0-99 degrees C
Warning level	>99°C
Abnormal condition	>148°C
Normal speed (rpm)	3000-3300
Frequency at normal condition (Hz)	50
Voltage rating (kV)	15

The Simulink model of the synchronous machine with the speed and temperature parameters was shown in fig. 2.

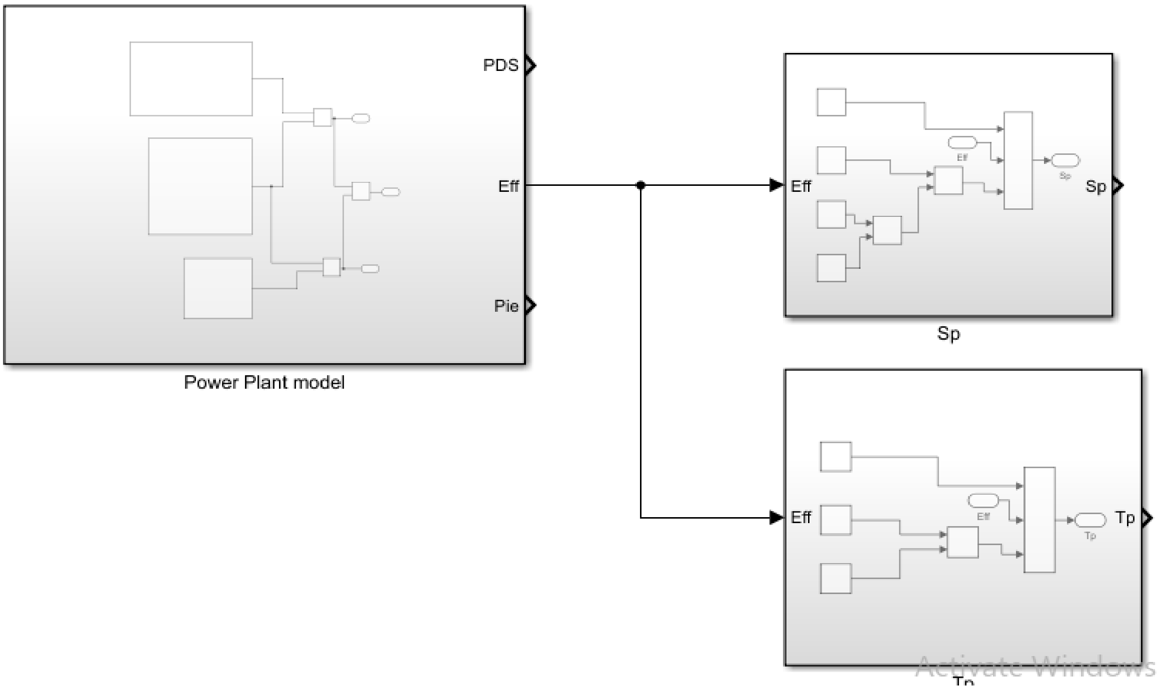

Fig. 2: SIMULINK model of the synchronous generator

The ANN architectural model utilized in the detection of the power plant issues were shown in fig. 3.

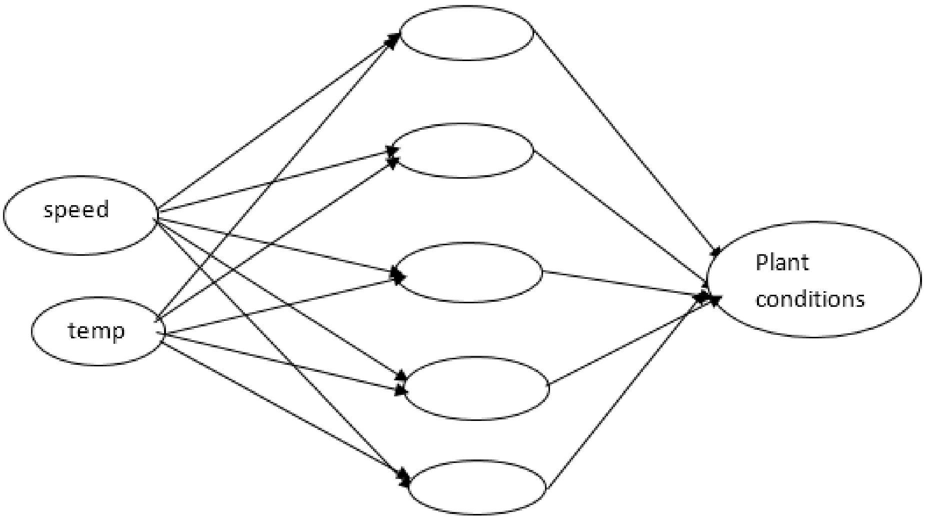

Fig 3: Structure of the ANN model

The architecture of the ANN shown implied that there two input variables which had two input neurons, five hidden neurons and one output variable with one neuron. The input variables to the ANN were speed and temperature at the corresponding plant issues. The output variable was the code for the identification and the detection of the particular plant condition. The codes utilized for each of the plant issues were shown in table 2.

Table 2: Code for the identification of the plant conditions

Plant issues/ condition	Code
Normal condition	0
Loss of synchronism	1
Load rejection	2
Lack of frequency control	3
Occurrence of wear and tear	4

Each of the hidden neurons has log sigmoid model shown in equation 1.

$$\log(n) = \frac{1}{1+e^{-n}} \qquad (1)$$

Where n represents the input data to the hidden neurons of the ANN model. Each of the data utilized were subjected to data normalization prior to utilization in the ANN modeling. The data normalization model was shown in equation 2.

$$n_{norm} = \frac{n}{\max(n)} \qquad (2)$$

Where n_{norm} represents the normalized data and n represents the data to be normalized. The Simulink model of the issues with the synchronous machine and the ANN for the detection and classification of the issues was shown in fig. 4.

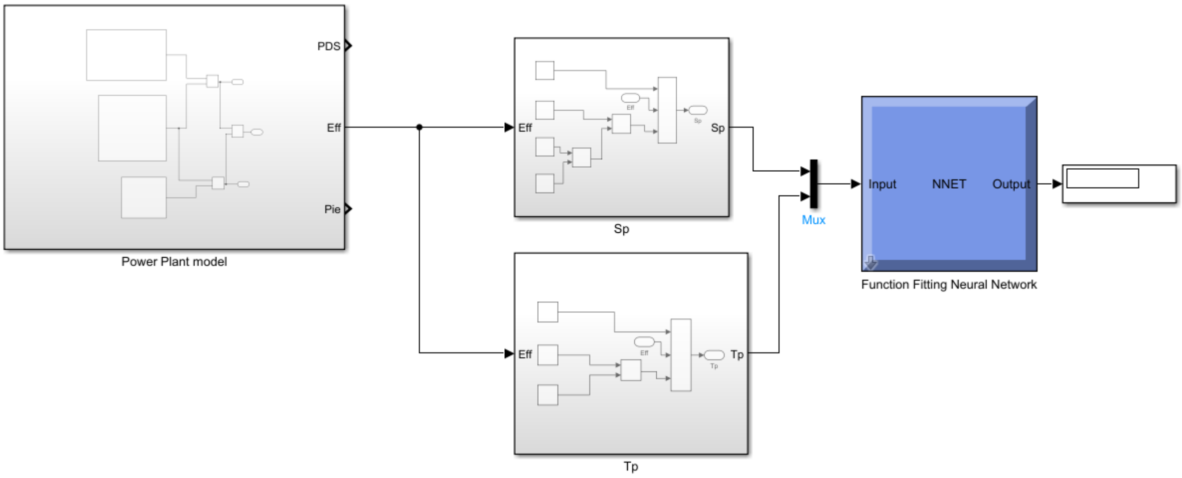

Fig. 4: Ibom power plant model with ANN sensor model

The outcome of the simulation was displayed in the result section

III. RESULTS

The speed of the synchronous plant for each of the fault condition was shown in figure 5.

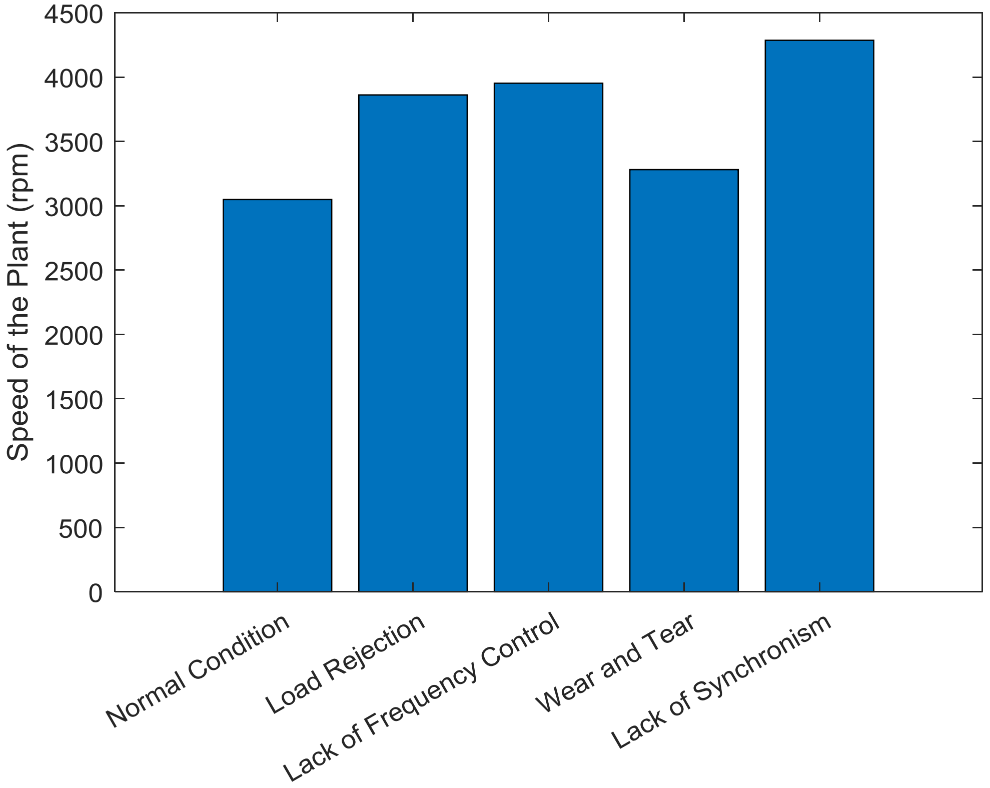

Fig. 5: Speed at different conditions of the plant

Aside from the normal condition, the speed of the plant was above 3000 rpm during the occurrence of the faults. Hence, at normal condition, the speed of the plant should be within 3,000 rpm as shown in fig. 5. The temperature of the synchronous plant for each of the fault condition was shown in fig. 6.

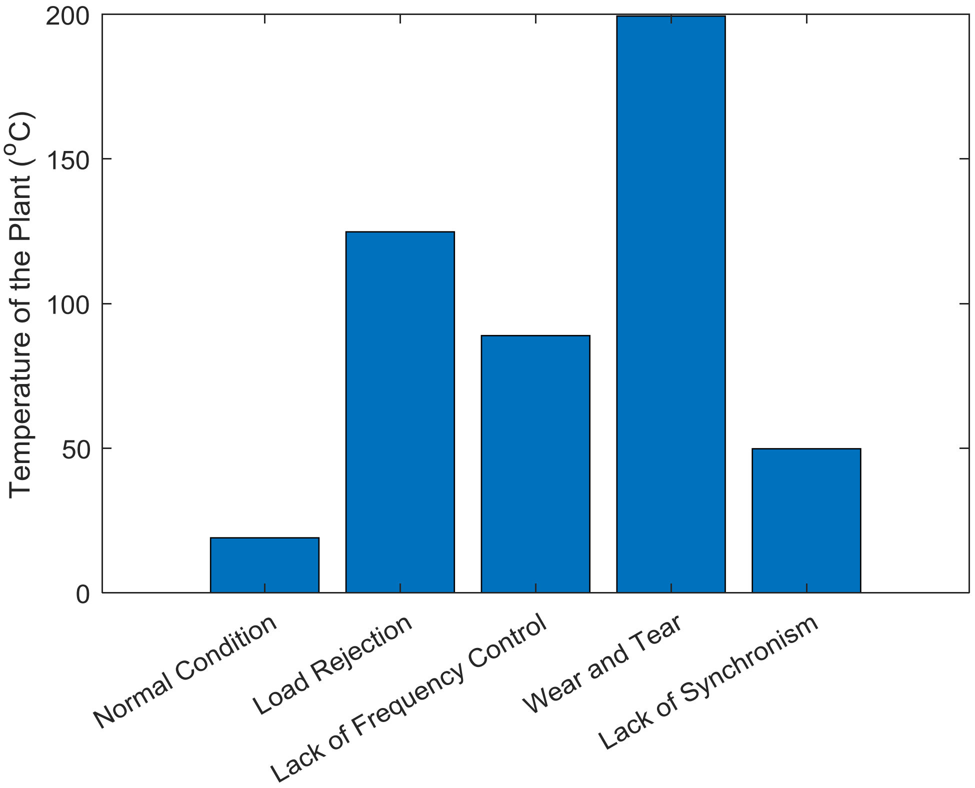

Fig. 6: Temperature at different conditions of the plant

It was seen from figure 6 that the temperature at the occurrence of wear and tear in the synchronous machine had the maximum value of 200°C and followed by the occurrence of load rejection which was 128°C, followed by the occurrence of lack of frequency control in the plant, lack of synchronism and then at normal condition. Hence, for a plant to operate normally, the temperature should be within the value displayed as normal condition in fig. 6. The comparative analysis, actual and ANN predicted fault detection and classification code after simulation was shown in table 3 and fig. 7.

Table 3: Comparative analysis of classification of issues in Ibom Plant

Plant operating conditions	Actual classification code	ANN predicted classification code
Normal condition	1	0.98
Load rejection	2	2.03
Lack of frequency control	3	2.99
Wear and tear	4	4.06
Lack of synchronism	5	4.9

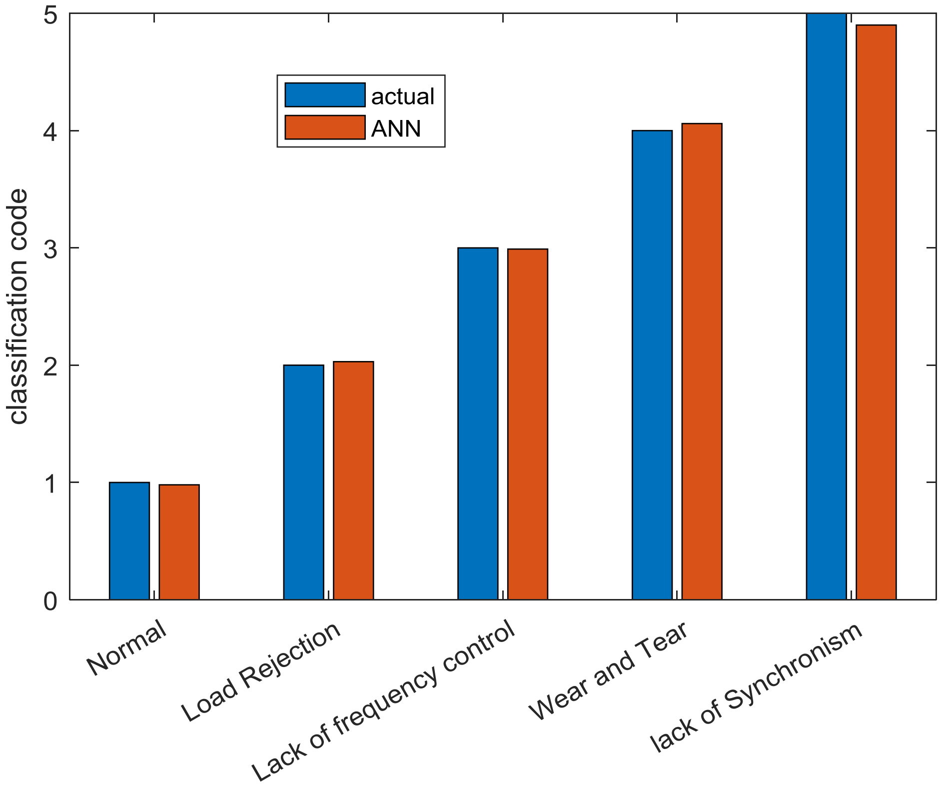

Fig. 7: Comparative analysis of the actual and the ANN classification code

From the figure shown in fig. 7, it was seen that the deviation of the ANN classification prediction with the actual classification was insignificant with the deviation mainly seen in the lack of synchronization which has deviation error of 0.10 (10%).

IV. CONCLUSION

The modeling of the synchronous machine with speed and temperature at occurrence of faults in the machine were carried out in SIMULINK and ANN model was for the detection and identification of the various conditions in the machine with the aid of classification code. From the results obtained, it was seen that the wear and tear had the highest temperature value while the occurrence of lack of synchronism resulted to the highest speed. The maximum error deviation seen was 10% which indicated the ANN ability to detect and classify fault in synchronous machine. However, other intelligent models should be implemented in the detection and identification of the faults and compared to ANN.

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