

ARTIFICIAL NEURAL NETWORK APPLICATION FOR CASCADING FAILURE MITIGATION IN RENEWABLE POWER GENERATION PLANTS

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Abstract: The lack of adequate fault detection and mitigation strategy has resulted to constant fault cascade on the power generation plants which has led to power plant shutdown and black outs, causing bottlenecks to the economic development of nations. The paper centered on the utilization of artificial intelligent models for the detection and mitigation of machine and inverter faults in the hydro and photovoltaic power plant that was operational in Kaiji power plant and Kaduna Solar power plant, Northern Nigeria. The artificial intelligent models utilized were artificial neural network (ANN) and Fuzzy Logic. The mathematical model for the generation plant was generated and represented in SIMULINK with current signal, voltage signal and speed being the parameters utilized for the measurement of the conditions in the gas plant. From the results presented, it was seen that the current signal, voltage signal and speed, For the fault occurrence in Hydro power plant, Fuzzy logic had 5.998mins, ANN mitigated fault time is 13.4992mins. For the fault occurrence in solar PV system, Fuzzy logic had 5.9988mins mitigation time, ANN mitigated fault for 13.2697 mins. The ANN model had better fault mitigation time.

Keywords: Hydro plant, Solar plant (PV), faults, ANN, Fuzzy, Detection, Mitigation.

1. INTRODUCTION

The concept of power system networks involves the generation, transmission and distribution systems. The generation systems involve the generation of electricity using several sources of power which are considered as conventional and renewable sources (Lin and Wu, 2019). The conventional sources were majorly Gas plant generating stations, thermal plant power generating stations that houses both synchronous and asynchronous machines. The renewable sources are hydro power plants, solar photovoltaic cells and wind turbines.

In the Nigerian power generation systems, hydro-power generation plants, gas plant and thermal plants are majorly the generation plants in use and the transmission voltage ratings are 330kV, 132kV and 33kV systems. Each of the voltage ratings has respective transmission station and substations where the voltage rating was stepped down. The essence of utilizing transmission system was to ensure that the power flow travels longer distances to the end users to be reduced to a distribution voltage.

There are several faults that occurs in the generation plants. The faults were short circuit faults, wear and tear within and at the external part of the machine, lack of synchronism of the generation plants and lack of frequency control and many other faults occurs on the generation plants. If there is no system that could detect the fault, it could cascade into other parts of the generating machine resulting to a total damage to the generator plant (Lazzaretti et al, 2020). Hence, it became

imperative to utilize, a system model to obtain the fault occurrence and the type of fault that occurs and possibly implement the mitigation of the fault for the plant to be tolerate of the fault to aid in proper planning for the operation and maintenance of the generation plants.

The artificial intelligent models have been known to be the best model for the detection of faults in the generating plants, identification of the type of fault that occurs in the generating plants and a mitigation system to the faults that occurs in the generating plants.

Several studies have examined the different methods for the detection and diagnostics of faults in the generation plants. Khalid et al (2023) analyzed the three most used fault detection and diagnostics (FDD) methods for the identification of faults in the thermal power. The FDD methods reviewed were model based, data based and statistical based methods and found that data-based methods were the in identification of faults in thermal plants. Sethu et al (2023) carried out a review on the impact of artificial intelligent models on the safety of generation plants and possible avoidance of human errors in the operation and maintenance of the generation plants. Navid et al (2021) examined the different fault detection and identification methods on the distribution network backed with the integration of the grid integrated photovoltaic systems. The major faults considered faults that emanates from the wide spread of the solar system panels. The fault detection diagnostics models studied were artificial intelligence models, electrical parameters and thermography. Nsaif et al, (2021) carried out a review on the different models that was utilized in the detection of faults on generation plants utilized as a distributed generation and integrated into the distribution network. And furthermore, the author proposed various protection strategy that could mitigate the occurrence of the fault.

Hence, artificial neural networks (ANN) and Fuzzy Logic (FL) were utilized for the detection of fault, identification of the type of fault and mitigation of fault in the renewable generation plant that is operational in the Nigerian power system network. The plant modeling was done in SIMULINK and the ANN and Fuzzy models were introduced for fault identification, classification and mitigation strategy. The outcome of the implementation of fault detection, classification and mitigation would determine the performance of ANN in the power system generation operational process.

2. METHODS

The procedure utilized in this paper was outlined and presented in the flow diagram presented in figure 3.

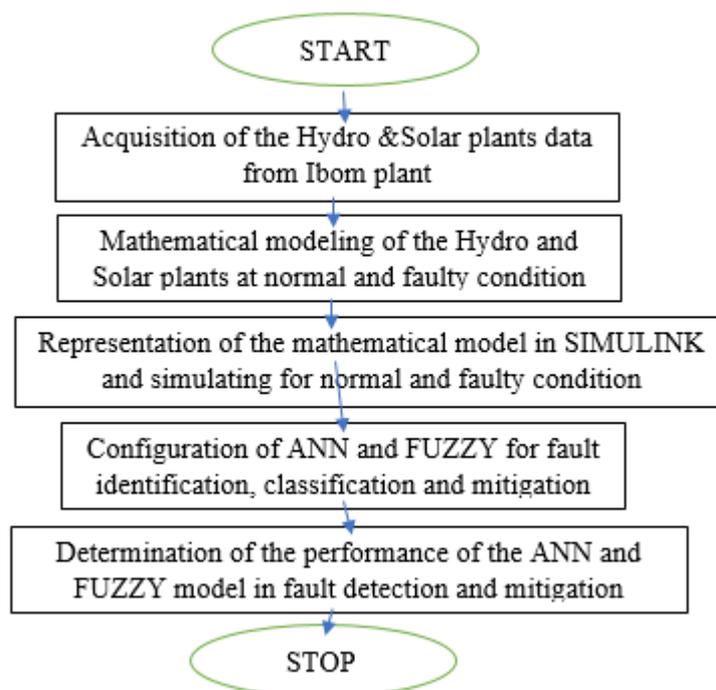


Figure 1; Procedure for the methodology

The data of the Hydro power plant obtained from Kaiji Power plant was presented in table 1.

Table 1; data for the hydro plant

Parameters	Values
Voltage (kV)	15
Speed (rpm)	103
Inertia	33
Velocity of water fall (m/s)	5380
Power rating (MW)	250
Stator resistance (Ohms)	0.0533
Rotor resistance (Ohms)	0.10072
Water flow rate at initial loading level (m ³ /s)	15,000
Net hydraulic head (m)	250
Center line length (m)	80
Gravitational acceleration (m/s ²)	10
Penstock Cross sectional Area	190

Table 2; Data for the solar system generation (Kaduna plant 2023)

Parameters	Values
Voltage (kV)	24
Inverter rating (KVA)	1200
Number of panels	150
Sun irradiance	1050
Power rating (MW)	25
Ideality factor	1.5
Open circuit voltage (V)	0.6
Short circuit current (A)	3.8
Band gap energy (kJ)	1.116
Electron charge (C)	1.6e-19
Reference temperature on the panel (K)	298.16

1. Healthy and Faulty Condition modeling of Hydro-electric Generation system with SIMULINK implementation

For the modeling of the healthy hydroelectric plant, the water column time constant was shown in equation 3.23.

$$T_c = \frac{lq}{g_{va}AH} \tag{1}$$

Where T_c represents the water column time constant, l represents the center line of the penstock, q represents the water flow rate, g_{va} represents the gravitational acceleration, A represents the cross-sectional area of the penstock and H represents the hydraulic head.

The power output of the hydro electric generator was shown in equation 3.24.

$$P_{HE} = \frac{1-T_cq}{1+\frac{T_cq}{2}} g_{va} \tag{2}$$

Where P_{HE} represents the power output of the generator at normal condition.

The speed of the hydraulic generator at healthy condition was shown in equation 3.25.

$$\omega_{HE} = \frac{P_{HE}q}{2\pi} \tag{3}$$

Where ω_{HE} represents the speed of the hydro electric generator.

The current signal from the hydro electric generator at normal condition was shown in equation 3.26.

$$I_{HE} = \frac{P_{HE}}{V_{rtg}} \sin(\omega_{HE}) \tag{4}$$

Where I_{HE} represents the current signal from the hydro electric system.

The voltage signal for the healthy condition of the hydroelectric plant was shown in equation 5.

$$V_{HE} = \frac{P_{HE}}{I_{HE}} \log lq^{0.42} \tag{5}$$

Where V_{HE} represents the voltage of the healthy hydro electric generator.

The SIMULINK representation of the hydro-electric models at healthy condition as shown in Figure 2.

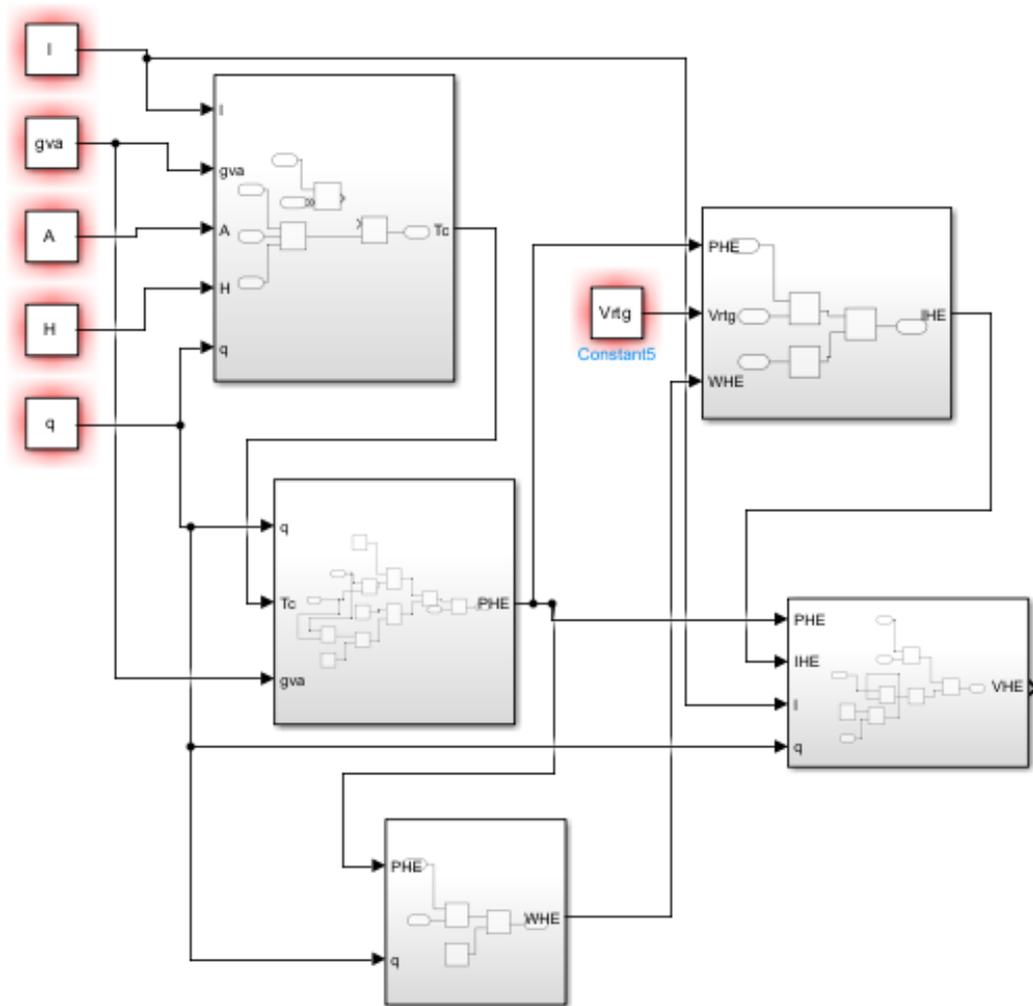


Figure 2; SIMULINK model of the hydro electric generator at healthy condition

The speed, current signal and voltage signal with the occurrence of fault in the hydro electric generator was shown in equation 6, equation 7 and equation 8 respectively.

$$\omega_{HEF} = \frac{\omega_{HE}}{q} \sin(g_{va}) l \tag{6}$$

$$I_{HEF} = \frac{P_{HE} \sin(\omega_{EHF})q}{V_{EH} l^3} \tag{7}$$

$$V_{HEF} = \frac{P_{HE}}{I_{HEF}} \log l^{0.04} q^{0.42} \tag{8}$$

Where ω_{HEF} , I_{HEF} and V_{HEF} represents speed, current and voltage signal of the faulted hydro electric plant.

The SIMULINK representation of the hydro-electric models at faulty condition was shown in figure 3.

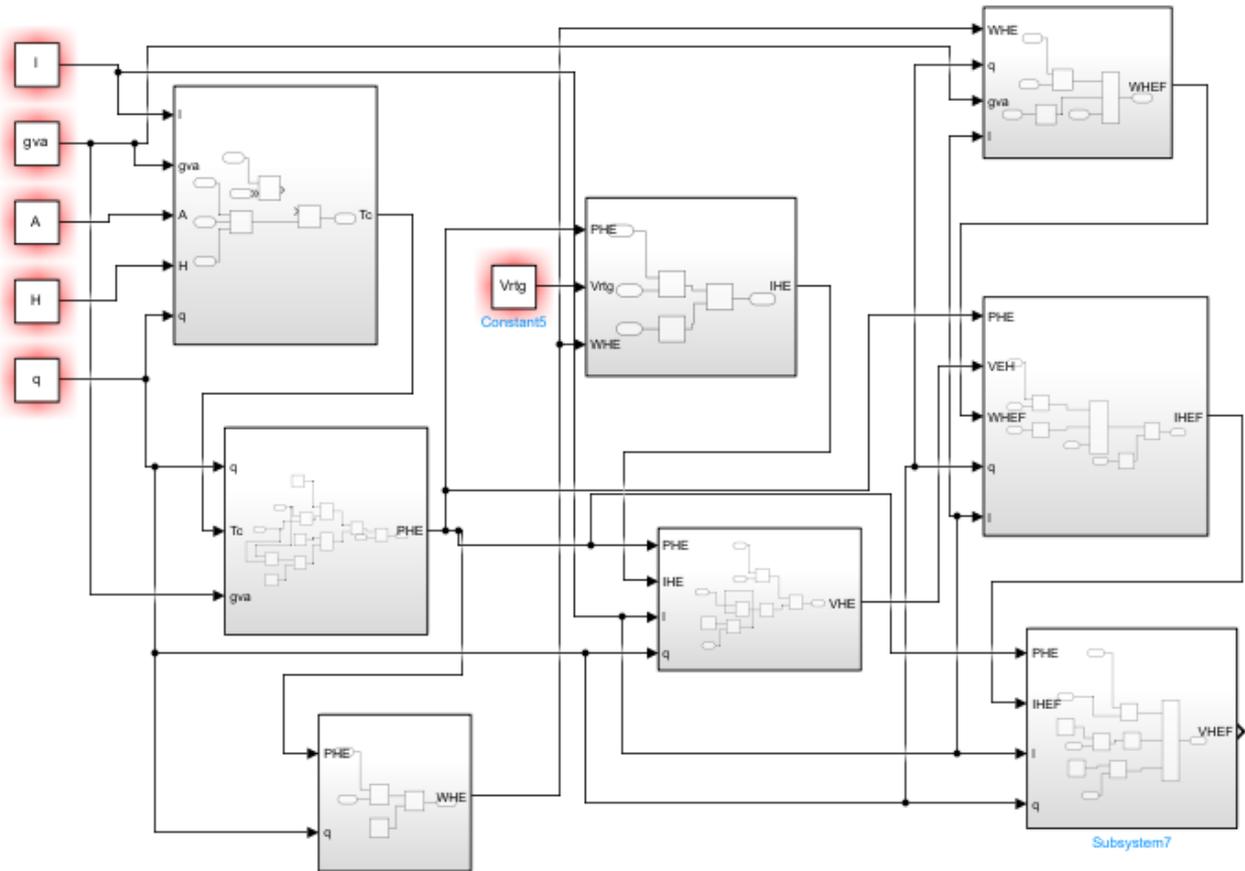


Figure 3; SIMULINK model of the hydro electric generator at faulty condition

2 Healthy and Faulty Condition modeling of solar Generation system with SIMULINK implementation

The model for the diode current and the photocurrent of the solar system generation was shown in equation 3.31 and equation 3.32.

$$I_{do} = AT_{ref} + P_{ar} \exp(Q_e^{0.0002}) \tag{2.1}$$

$$I_{pho} = \frac{I_{do}}{T_{ref}} N_p \sin(V_{oci}) \tag{2.2}$$

Where I_{do} represents the diode current of the power system network with solar energy source, I_{pho} represents the photocurrent from the solar system, A represents the ideality factor, T_{ref} represents the reference temperature incidence on the panel, P_{ar} represents the power rating of the solar system design, Q_e represents the single electron charge on the solar system panels, N_p represents the number of panels utilized and V_{oci} represents the open circuit current on the solar system.

The output power generated from the panels was shown in equation 2.3.

$$P_{op} = \left(\frac{P_{ar}}{(I_{do} + I_{pho})^{0.3}} \right) \sin(V_{ar} + V_{oci}) \tag{2.3}$$

Where P_{op} represents the output power from the solar generation system and V_{ar} represents the voltage rating of the solar system.

The output voltage and current from the solar system at healthy condition in equation 3.34 and equation 3.35.

$$V_{op} = \frac{P_{ar}}{P_{op}} + (V_{ar} + V_{oci}) \frac{I_{do}}{I_{pho}} \tag{2.4}$$

$$I_{op} = \sin\left(\frac{P_{op}}{V_{op}} + \frac{P_{ar}}{V_{ar}}\right) \tag{2.5}$$

Where V_{op} and I_{op} represents the output voltage and output current from the solar power system respectively.

The SIMULINK model of the solar system at healthy condition was shown in figure 4.

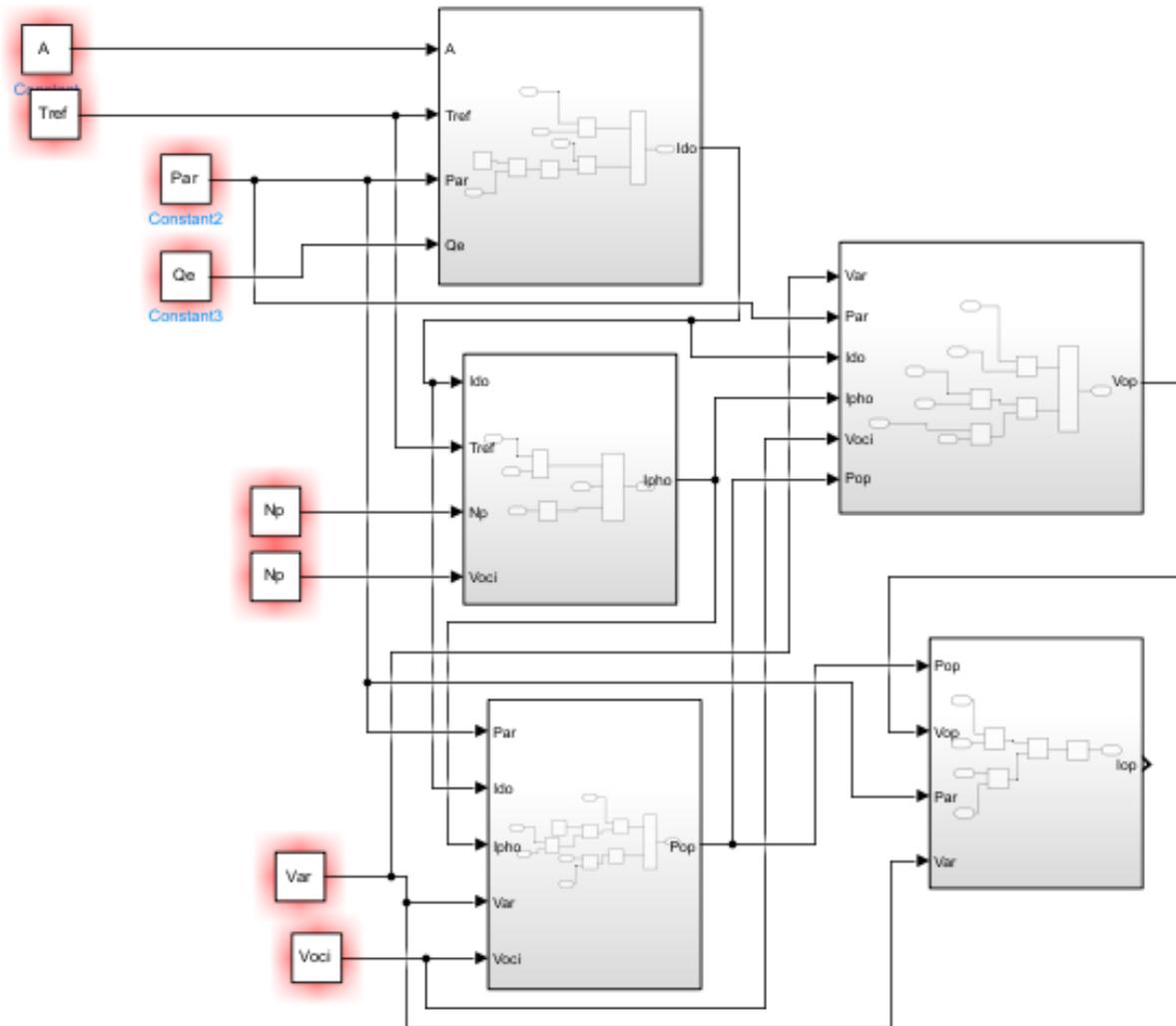


Figure 4; SIMULINK model of the solar system at healthy condition

The voltage and current signal of the solar power system model at faulted condition was shown in equation 2.6 and equation 2.7.

$$V_{fao} = \frac{V_{op}A}{T_{ref}} \sin(N_p^{0.0055}) \tag{2.6}$$

$$I_{fao} = \frac{I_{op}P_{op}}{V_{op}} V_{fao} \tag{2.8}$$

Where V_{fao} and I_{fao} represents the voltage and current signal's fault in the solar power system.

The SIMULINK model of the faulted solar power system network was shown in figure 5.

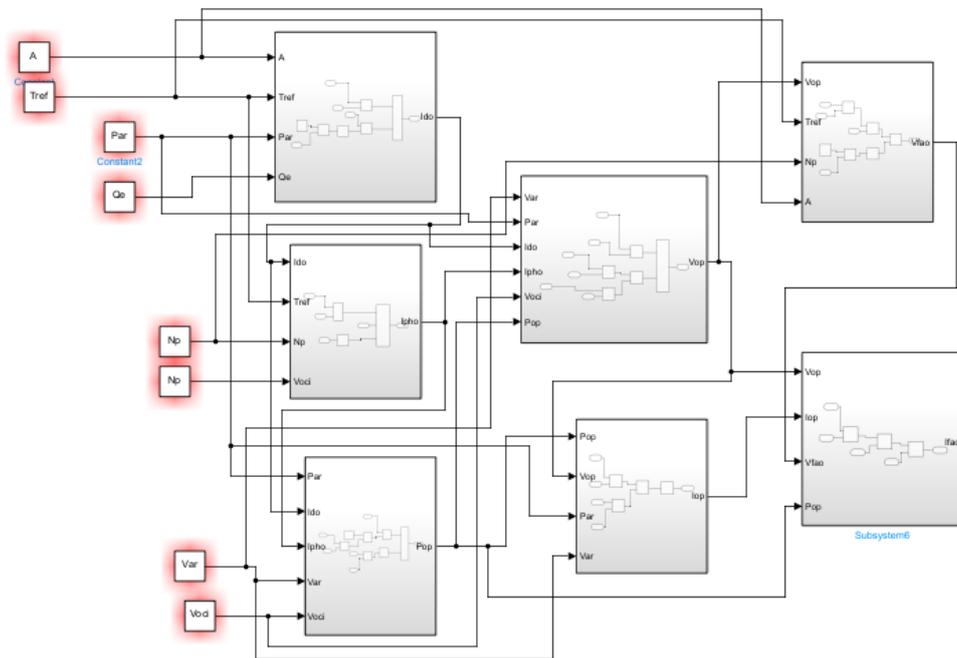
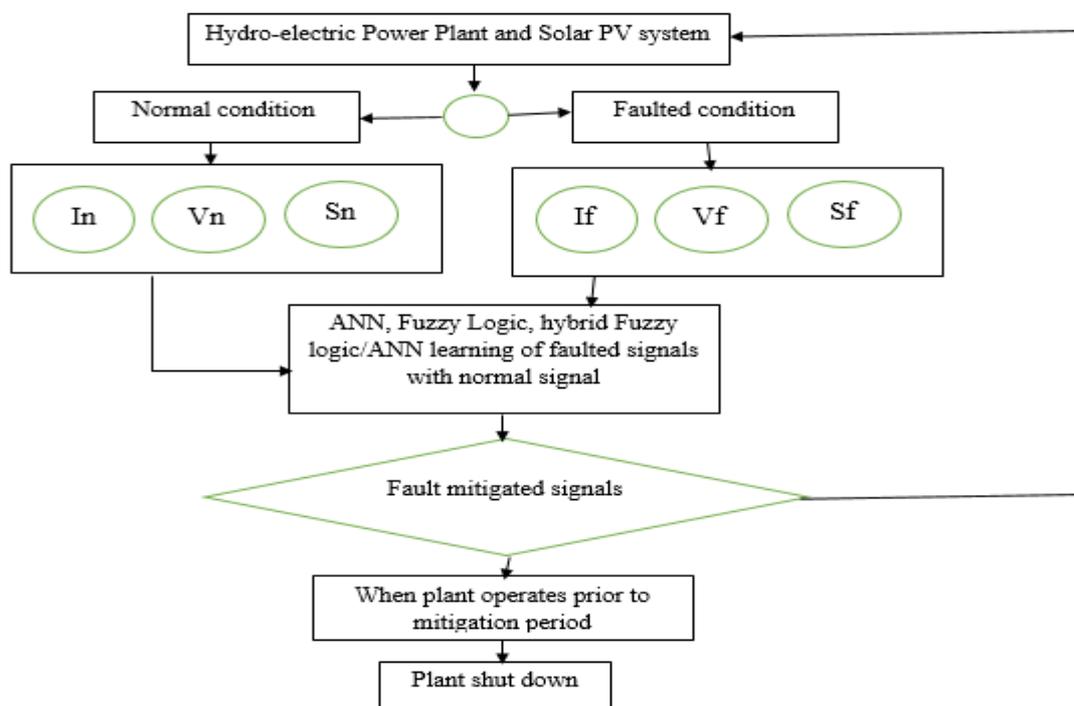


Figure 5; Solar power system model of the faulted solar power system network

Figure 6; block diagram of fault cascade mitigation with intelligent models for hydro-electric and solar PV system

From the previous figures the fault occurrence is seen in the voltage, current signals and the speed. The signals were sent to the AI models together with the power system operation signals at normal condition. The AI utilized the signals at healthy condition in the learning process of the faulted signals which resulted to the generation of the fault mitigated signals which aids in plant operation and prevents abrupt shut down. The process continues until the determined fault mitigation time becomes critical (overwhelmed by the faulted signals) leading to plant shutdown. Once the fault is sent to the AI model, the AI sensors display the type of fault that occurred and starts a countdown on the mitigated period. It is expected that generator maintenance be carried within the period of plant operation during fault occurrence.



3. Results of the Hydroelectric System at Healthy Condition

The voltage of the hydro-electric system at healthy condition was shown in figure 4.23.

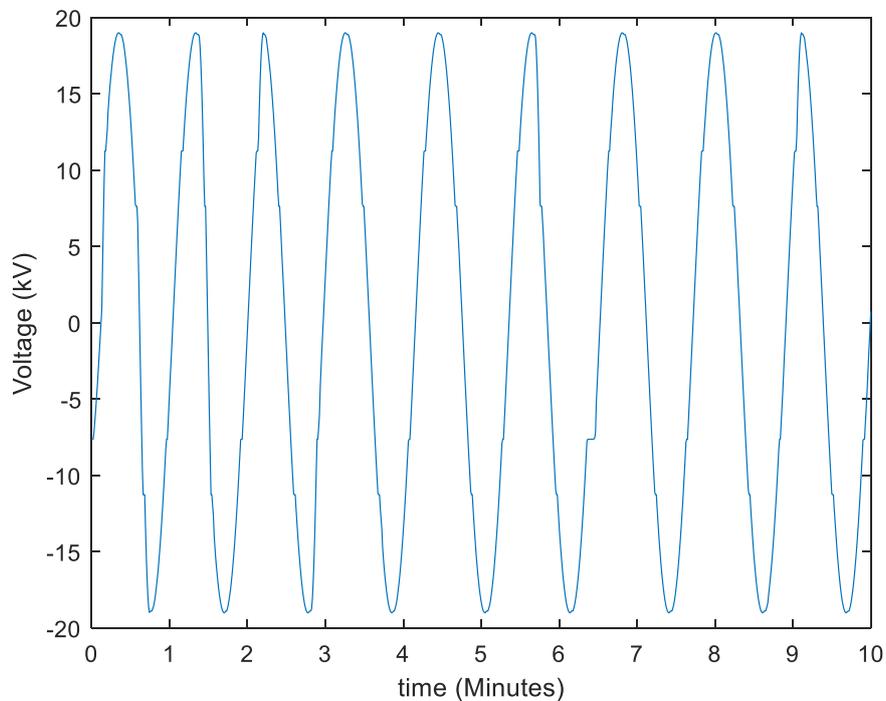


Figure 6; Voltage signal of the machine at Healthy condition

The figure showed the operation of the voltage signal at normal condition in the synchronous plant. It was observed that the plant operated at 19kV which was the plant rating which implied that the generation plant operated at normal condition.

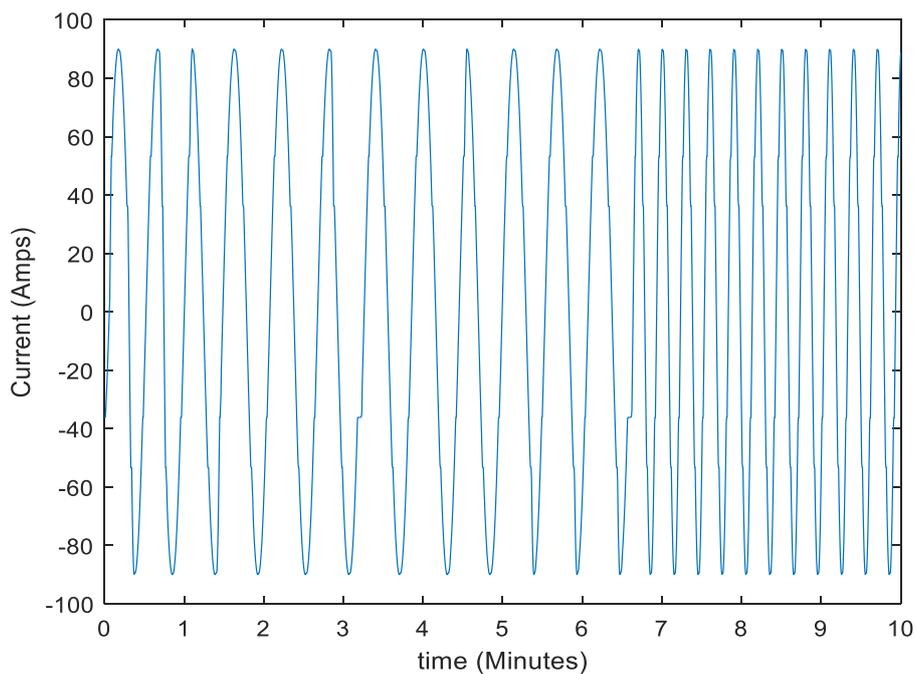


Figure 7; healthy current signal of the system at normal condition

From the current signal presented in the figure, it was observed that the maximum current was 85amps which was the slightly higher than the expected current generation of the plant which implied that the system operated at healthy condition and was devoid of fault occurrence.

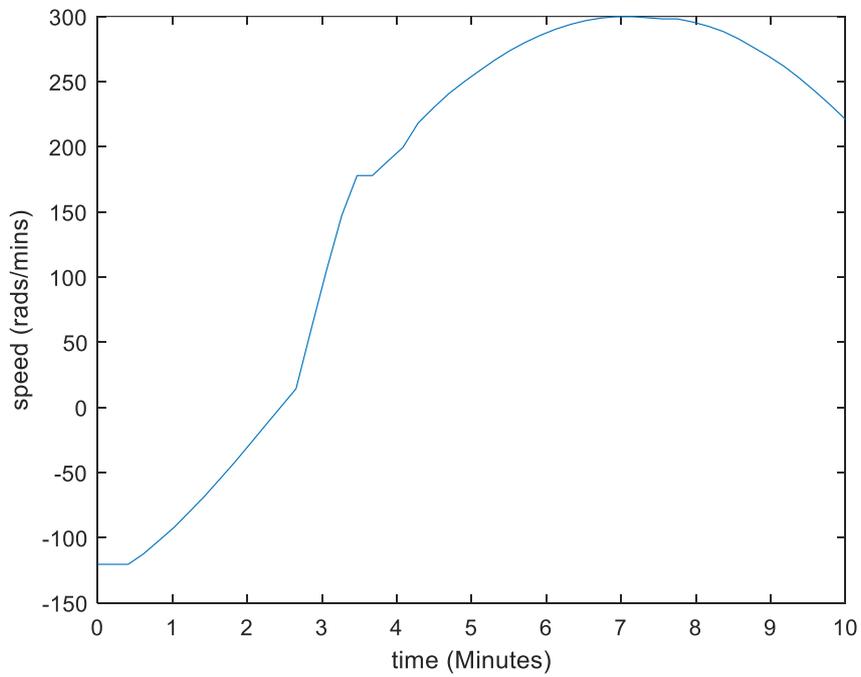


Figure 8; speed of the system at normal condition

The speed of the plant as shown in the figure 8. It showed that within the period of monitoring the system, the speed of the plant increased and saturated at 3000 rpm with a slight drop. The outcome indicates that the system operated at a healthy condition.

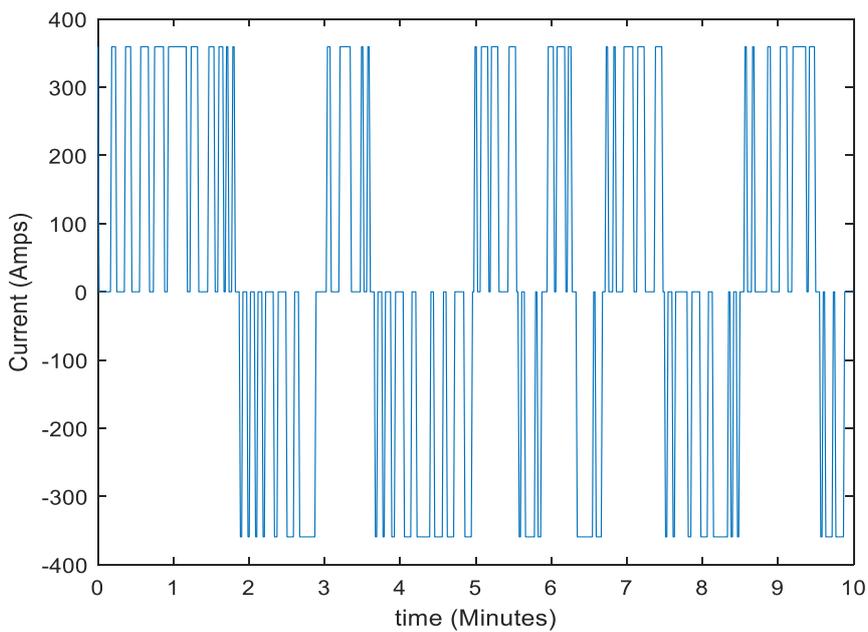


Figure 9, Current signal during the occurrence of Fault in the System

The impact of the occurrence of fault in the hydro-electric system on the current signal was shown in figure 4.26. It can be seen that it resulted to the instability of the current signal of the system. Hence, a detection and mitigation system would limit the spread of the fault to other plant component.

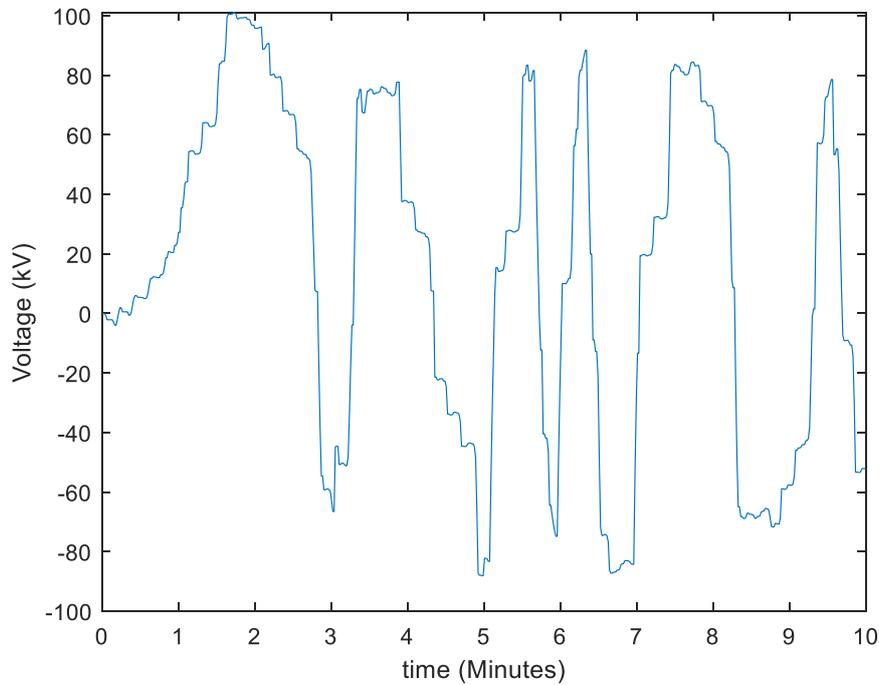


Figure 10, Voltage signal during the occurrence of Fault in the System

The system showed voltage instability within the monitoring period of which continuous occurrence without detection and cascade mitigation would result to system shut down.

The speed of the system at the occurrence of fault was shown in figure 4.28.

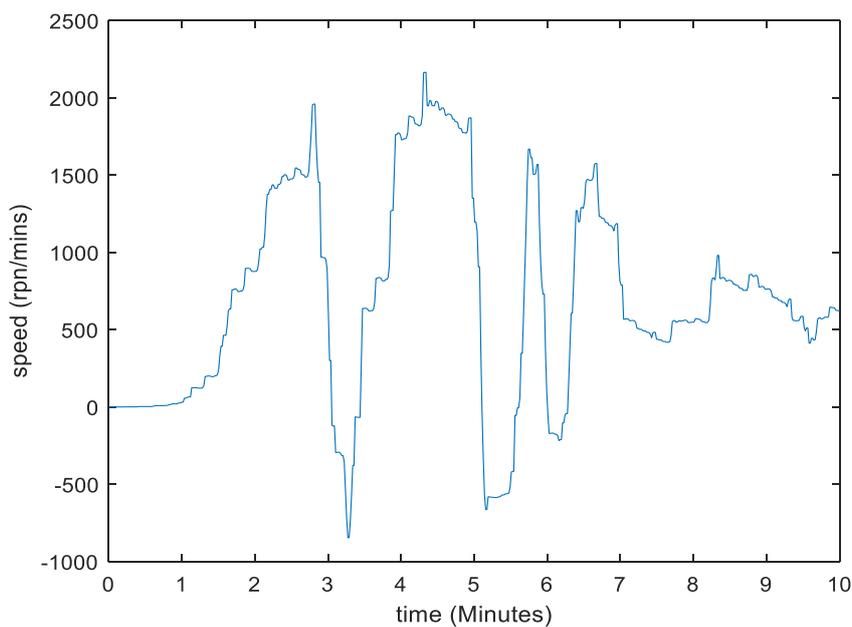


Figure 11, Speed of the system during the occurrence of Fault in the Machine

The impact of fault on the speed of the hydro-electric system resulted to the speed instability as shown. Once the speed of the system becomes unstable, it tends to spread through other components of the plant result to abrupt plant shut down.

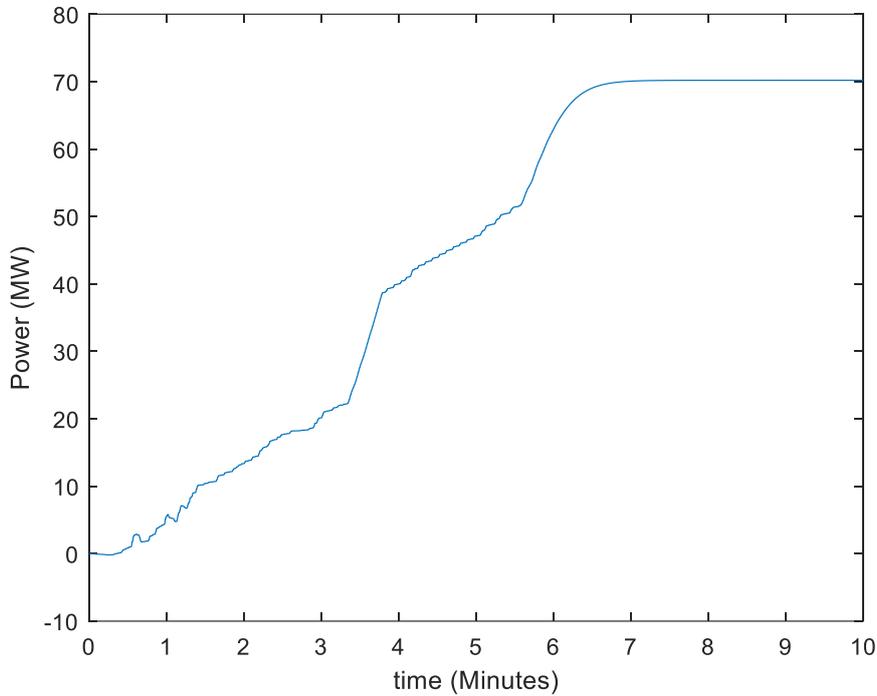


Figure 12; Power of the Solar system

The power of the solar system increased from zero and saturated at 70amps in 7 minutes as shown

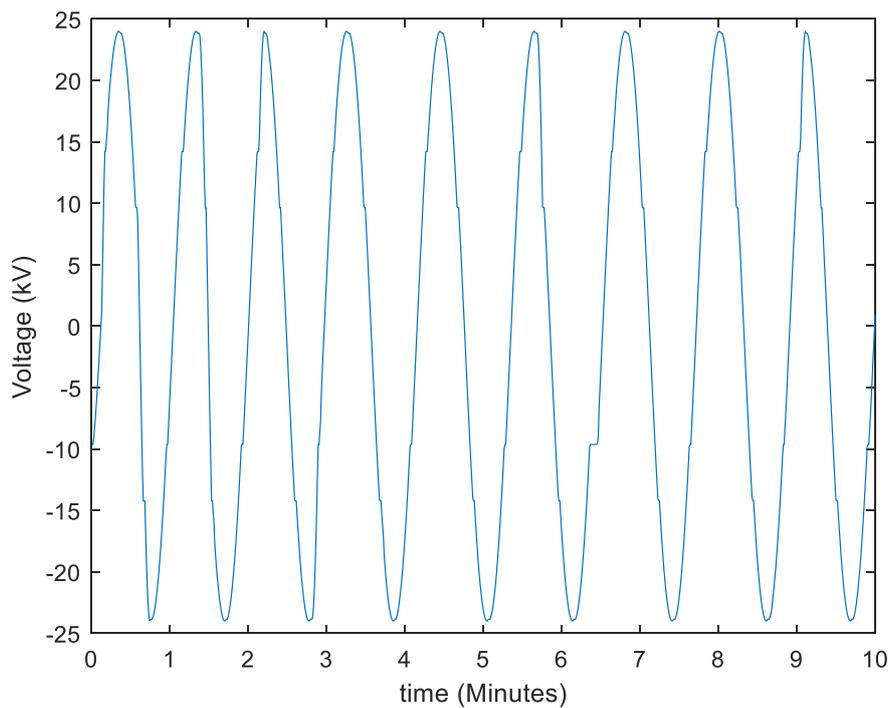


Figure 13; voltage signal at healthy condition of solar system

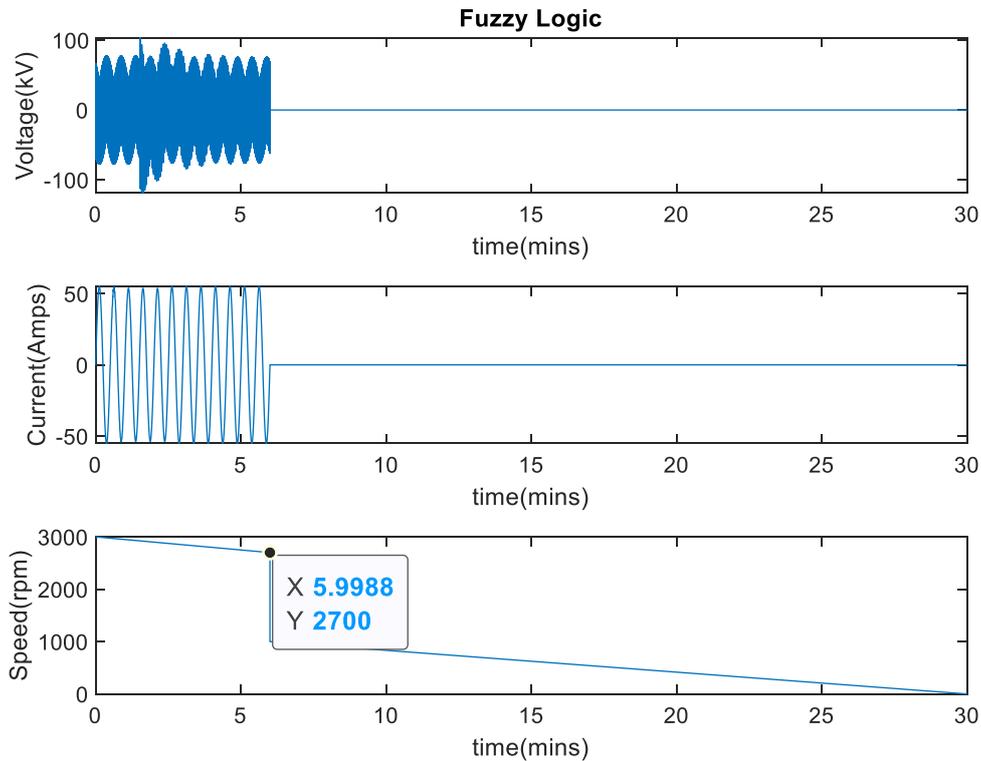


Figure 14; Hydro plant fault mitigation with fuzzy logic

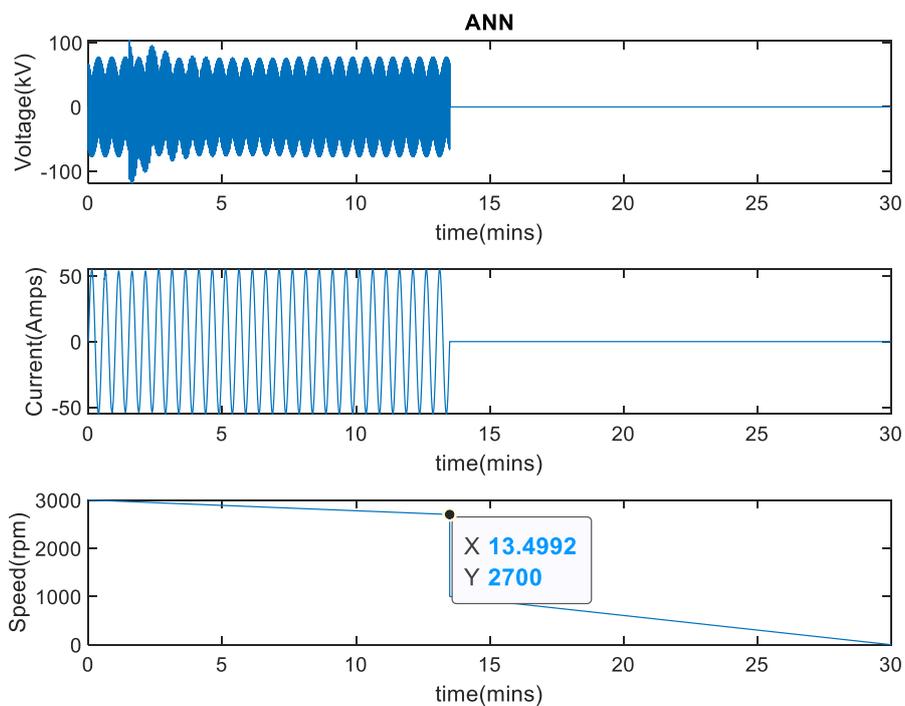


Figure 15; Hydro plant fault mitigation with ANN

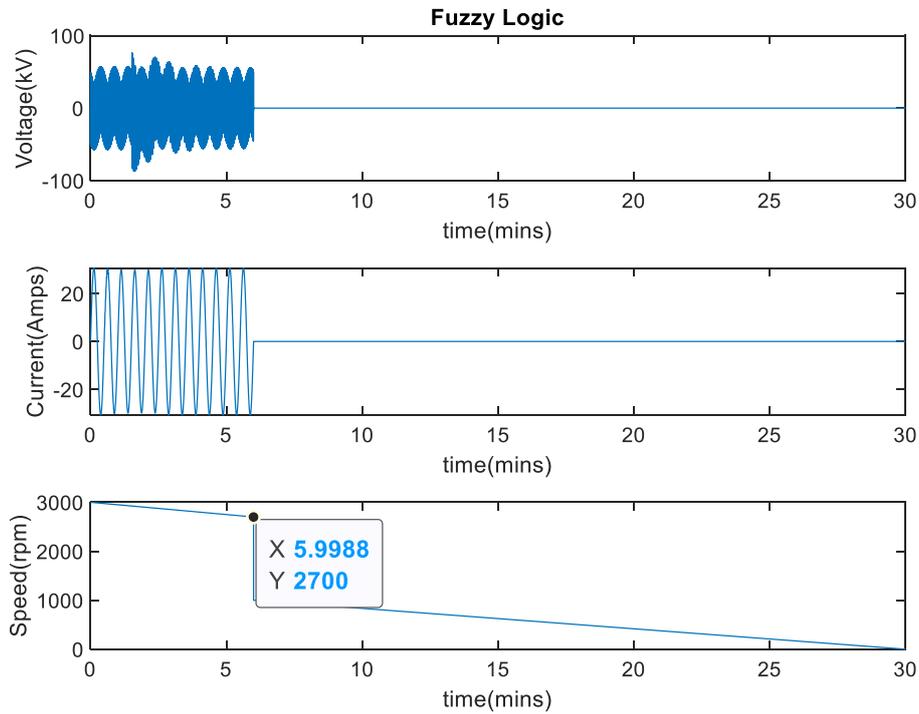


Figure 16; Solar plant fault mitigation with fuzzy logic

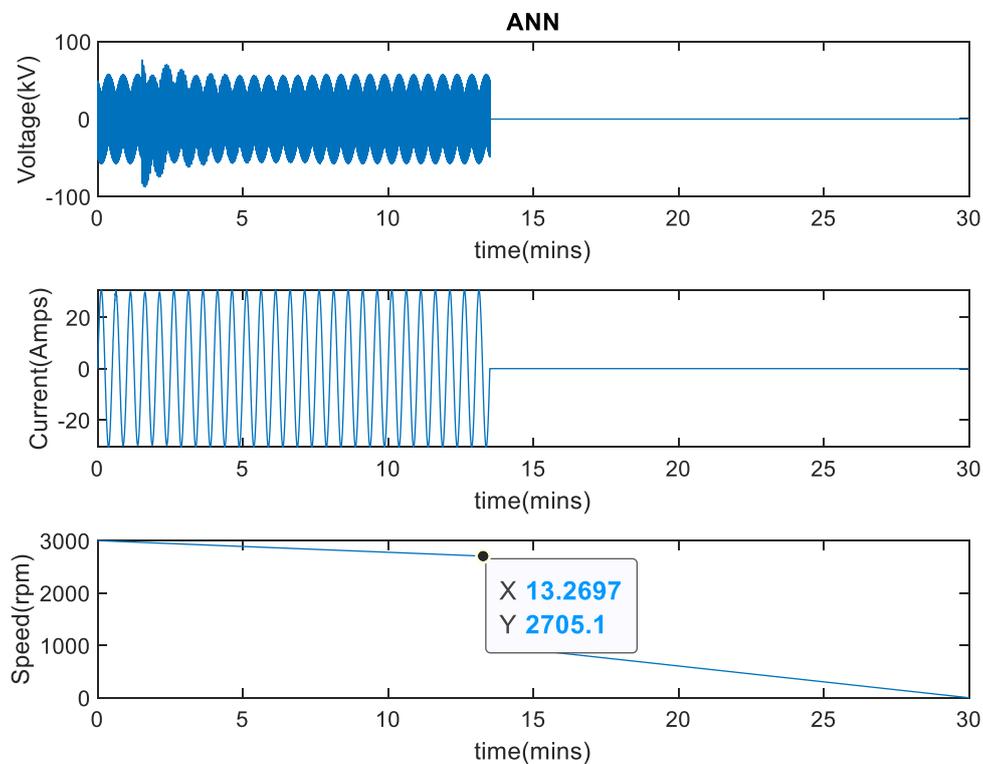


Figure 17; Solar plant fault mitigation with ANN

3. CONCLUSION

The paper was on the utilization of ANN and Fuzzy models for the detection and mitigation of machine and inverter faults in the hydro and PV power plants that was operational in Kaiji Hydro and Kaduna solar power plants. The plants model was done in SIMULINK and the outcome of the speed, current signal and voltage signals from the gas plant model were utilized in the configuration of ANN and Fuzzy for fault detection and mitigation in the power plant. It was found that the current signal, voltage signal and speed output from the ANN detected the faults faster than Fuzzy and it was also observed that ANN prolonged the operation of the plants than Fuzzy model which meant that ANN model had better fault mitigation performance than Fuzzy.

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