International Journal of Science Academic Research
Vol. 05, Issue 08, pp.8075-8081, August, 2024
Available online at http://www.scienceijsar.com
ISSN: 2582-6425

Research Article

IMPROVING THE PROTECTION OF NEW HAVEN - NKALAGU 132KV TRANSMISSION NETWORK USING A GENETIC TRAINED ADAPTIVE RELAY SCHEME

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Received 12th June 2024; **Accepted** 14th July 2024; **Published online** 30th August 2024

Abstract

Power transmission systems are heavily invested in hence the need for superb protection schemes to be incorporated into them. Electrical unbalance or fault conditions can damage equipment and personnel, thus super protection schemes are necessary. Existing protection schemes have failed to isolate faults quickly and reduce power system false trips. The government and power supply firms have spent more money due to unjustified damage to power system components caused by such protective schemes. In severe circumstances, poor/existing protective schemes have caused fire outbreaks that destroyed lives and property. Existing protection schemes also cause false tripping, which cause power outages when there is actually no fault occurring in the system. This research investigated how the protection of a power transmission line could be improved upon using a genetic trained adaptive relay scheme. The test network used for carrying out the research is the New Haven-Nkalagu 132KV transmission line. The research objectives for carrying out the research was accomplished in seven major steps. Load flow analysis was carried out on the Nigerian 330KV 48 bus power system and hence the New Haven-Nkalagu 132kV transmission network was extracted. Thereafter, a model of the New Haven Nkalagu 132KV transmission network was developed alongside its existing protection relay scheme using the Matlab/Simulink environment. An adaptive system was developed for controlling the over current relay scheme in the network. A genetic algorithm was developed and used to train the adaptive relay scheme in for optimizing its performance. The over current relay and its genetic trained adaptive controller was integrated to the test network and hence simulated in order to evaluate the performance of the adaptive relay scheme. The results of the research indicated a 26.43% reduction in tripping times of both relays with the genetic trained adaptive relay scheme integrated. The results also indicated a 41.78% increase in CTS value of both relays with the genetic trained adaptive controller integrated. It was therefore concluded that the genetic trained adaptive relay scheme is capable of improving the protection of power transmission networks.

Keywords: CTS, TDS, ts, Relay, Adaptive, CTR.

INTRODUCTION

Power system protection is a fascinating and critical field of study. A protection scheme in a power system is designed to continuously monitor the system to ensure the continuity of electrical supply with minimal damage to life, equipment, and property. Designing effective protective schemes requires a deep understanding of the fault characteristics of individual power system elements and comprehensive knowledge of the tripping characteristics of various protective relays (Glover *et al.,* 2012; Blackburn & Domin, 2014). In recent decades, there has been rapid growth in power grids worldwide, resulting in the installation of numerous new transmission and distribution lines. This expansion has brought about significant challenges in maintaining system stability and reliability (Horowitz & Phadke, 2014). Additionally, the introduction of new marketing concepts such as deregulation has heightened the need for a reliable and uninterrupted supply of electric power to end users who are increasingly sensitive to power outages (Kundur, 1994). The complexity of modern power systems necessitates advanced protection strategies to handle diverse and dynamic conditions. This includes the integration of renewable energy sources, which introduce variability and uncertainty into the grid (Bollen & Hassan, 2011). Furthermore, the advent of smart grid technologies has revolutionized power system protection by enhancing real-time monitoring, fault detection, and adaptive protection measures (Phadke & Thorp, 2008).

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Effective power system protection not only ensures the safety and reliability of the power supply but also contributes to the economic efficiency of power system operations. By minimizing disruptions and damage, protection schemes help maintain the stability of the grid and reduce repair and maintenance costs (CIGRÉ, 2010). In turn, this supports the overall sustainability and resilience of the power infrastructure (IEEE Power & Energy Society, 2016). The development and implementation of protection schemes involve a multidisciplinary approach, incorporating electrical engineering principles, computer science, and data analytics. Advanced protection technologies such as digital relays, phasor measurement units (PMUs), and wide-area monitoring systems (WAMS) play a crucial role in enhancing the protection and control of modern power systems (Haldar, 2019). In conclusion, power system protection is essential for maintaining the integrity, stability, and reliability of electrical power systems. As the power grid continues to evolve, the importance of robust protection schemes will only increase, necessitating ongoing research and innovation in this field (Elmore, 2004).

THEORY OF WORK

Added to the above-mentioned issues the Nigeria power system is made more complex by insufficient generation, aged equipment and general poor network infrastructure. This situation continue to make the Nigerian grid network overstretched and prone to various types of faults. These faults have increased frequency and duration of outages thereby impacting negatively on both commercial and domestic consumer. Uncontrolled fault situation can also introduce severe instabilities in the network. There is strong need to equip the Nigeria grid network with an adaptive protection scheme that will control the incessant disturbance / faults that have characterized the network. This can achieve by equipping the protection scheme with an intelligent relay. This research therefore deals with the improvement of the protection of the New-Haven-Nkalagu 132kV network using genetic trained adaptive relay scheme. Any abnormal flow of current in power systems components is called a fault in the power system (Yadav and Thoke, 2011). These faults cannot be completely avoided since a portion of these faults also occur due to natural reasons which are way beyond the control of mankind.

MATERIALS AND METHODS

Load flow Analysis on the Nigerian 330KV 48 bus Power System

The Model of the Nigerian 330KV 48 bus Power system was developed using its single line diagram (Figure 1). The New Haven – Nkalagu 132 KV transmission network was also incorporated into the model to enable the extraction of its load flow values. Modeling of the Nigerian 330KV 48-bus power system derived from the bus and transmission line data, comprising of 16 PV generators for load flow studies, 59 transmission lines and 32 load buses was achieved using PSAT software in MATLAB. The bus data and transmission line input data of the Nigerian power system network were picked from (Nkan, Okpo, & Okoro, 2021). Load flow was performed on the developed psat model. Figure 2 shows the extracted New Haven – Nkalagu 132KV power transmission network. Only the load flow results of the extracted New Haven – Nkalagu 132KV power transmission network was used in realizing the rest of this thesis research objectives.

Model of the extracted New Haven-Nkalagu 132KV line with its existing protection relay scheme in Simulink/ Matlab

The New Haven – Nkalagu 132KV power transmission network is exposed to short circuits between phases or from phase to ground. Transmission and distribution lines protection problem concern's to the

$$I_2 = \frac{L_2}{\sqrt{3}\times V} \tag{2}$$

Where,
I_1 = *Current at Nkalagu Bus*
I_2 = *Current at New Haven Bus*
V = *Source voltage as per load flow*
L_1 = *load flow power at Nkalagu Bus*
L_2 = *load flow power at New Haven Bus*

The currents flowing through the sections under normal operating condition is calculated as,

$$I_{21} = I_1 \tag{3}$$

$$I_S = I_{21} + I_2 \tag{4}$$

Where,
I_{21} = *current flowing from nw Haven bus to Nkalagu bus*
I_S = *load flow current flowing into New Haven bus*

The relay currents are given by:

$$i_{21} = \frac{I_{21}}{(C.T.R)_1} \tag{5}$$

$$i_S = \frac{I_S}{(C.T.R)_2} \tag{6}$$

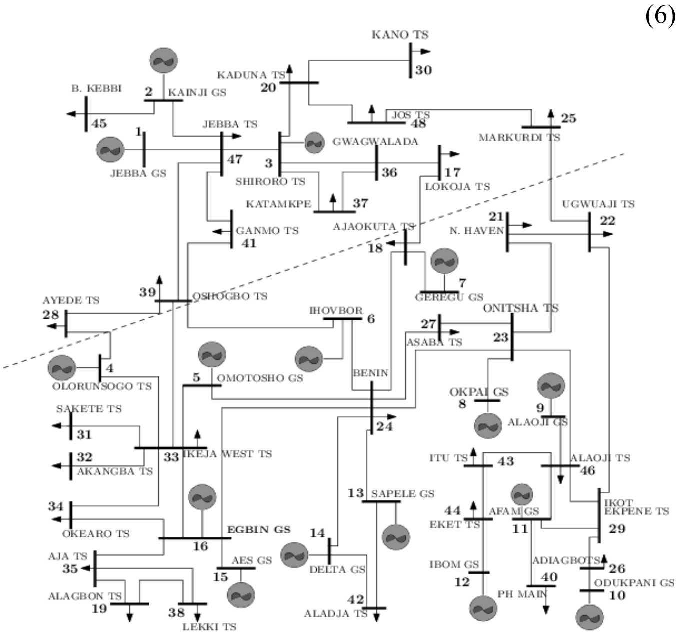

Figure 1. Single Line Diagram of the Nigerian 330KV 48 Bus Power System

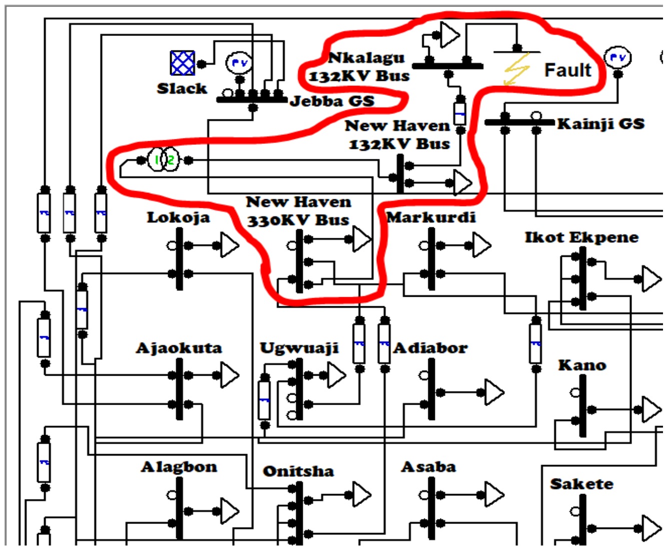

Figure 2. Extracted New Haven-Nkalagu 132KV Transmission Network

fault current range, effect of load, directionality, and system configuration impact. From the extracted model, the load currents are calculated as:

$$I_1 = \frac{L_1}{\sqrt{3}\times V} \tag{1}$$

$$I_2 = \frac{L_2}{\sqrt{3}\times V} \tag{2}$$

Where,
$I_1 = Current\ at\ Nkalagu\ Bus$
$I_2 = Current\ at\ New\ Haven\ Bus$
$V = Source\ voltage\ as\ per\ load\ flow$
$L_1 = load\ flow\ power\ at\ Nkalagu\ Bus$
$L_2 = load\ flow\ power\ at\ New\ Haven\ Bus$

The currents flowing through the sections under normal operating condition is calculated as,

$$I_{21} = I_1 \quad (3)$$
$$I_S = I_{21} + I_2 \quad (4)$$

Where,
$I_{21} = current\ flowing\ from\ nw\ Haven\ bus\ to\ Nkalagu\ bus$
$I_S = load\ flow\ current\ flowing\ into\ New\ Haven\ bus$

The relay currents are given by:

$$i_{21} = \frac{I_{21}}{(C.T.R)_1} \quad (5)$$

$$i_S = \frac{I_S}{(C.T.R)_2} \quad (6)$$

Where,
$(C.T.R)_1 = current\ transformer\ ratio\ for\ relay\ at\ Nkalagu$
$(C.T.R)_2 = current\ transformer\ ratio\ for\ relay\ at\ New\ Haven$

The Current Tap Settings (C.T.S) or pick up current is obtained in such a manner that the relay does not trip under normal current. For this type of relay (C07), the current tap settings available are: 4, 5, 6, 7, 8, 10, 12 and 12.

The Time Dail Settings (T.D.S) for coordinating the relays at New Haven and Nkalagu are calculated as:

$$i_{SC1} = \frac{I_{SC1}}{(C.T.R)_1} \quad (7)$$

Where,
$i_{SC1} = short\ circuit\ current\ of\ relay\ 1$
$I_{SC1} = short\ circuit\ current\ flowing\ into\ Nkalagu$

Expressing equation 7 as a multiple of the pickup current or C.T.S value yields,

$$\frac{i_{SC1}}{(C.T.S)_1} = R_1(ratio) \quad (8)$$

Choosing the lowest time dail setting for relay 1 for fastest action,

$$(T.D.S)_1 = \frac{1}{2} \quad (9)$$

Pairing $(T.D.S)_1$ and R_1 and comparing it with the relay characteristic curve of C07, the operating time of relay at Nkalagu is gotten as,

$$Operating\ time\ of\ Nkalagu\ relay = T_1$$

To set the relay at New Haven responding to a fault at Nkalagu, a 0.1 second is allowed in practice for breaker operation and an error margin of 0.3 second in addition to T_1, Thus

$$T_2 = T_1 + 0.1 + 0.3 \quad (10)$$

The short circuit for a fault at Nkalagu as a multiple of the C.T.S at New Haven is,

$$\frac{i_{SC1}}{(C.T.S)_2} = R_2 \quad (11)$$

Then from the characteristics for T_2 seconds operating time and R_2 ratio, then,

$$(T.D.S)_2 = TimeDailSettingsatNewHaven \quad (12)$$

IEEE Standard Inverse Definite Minimum Time (IDMT) Calculation

According to the Institute of Electrical and Electronic Engineers, the tripping time of a relay can be calculated using the formula:

$$t_s = \frac{(T.D.S)}{7}\left(\left(\frac{A}{\left({}^{I_F}/_{I_S}\right)^P} - 1\right) + B\right) \quad (13)$$

Where,
$t_s = Tripping\ time\ of\ the\ relay$
$(T.D.S) = Time\ Dail\ Setting\ of\ the\ Relay$
A = Curve constant of the relay
B = Curve constant of the relay
$I_F = fault\ current\ of\ the\ relay$
$I_S = current\ setting\ of\ the\ relay\ (C.T.S)$

The IEEE formula for calculating the tripping current of the relay in terms of the time settings multiplier is given by,

$$t_s = 0.143 \times (T.S.M) \times \left(\left(\frac{A}{\left({}^{I_F}/_{I_S}\right)^P} - 1\right) + B\right) \quad (14)$$

Where,
$(T.S.M) = Time\ Settings\ Multiplier\ of\ the\ relay$

From equation 12, the current time settings at the different substations can be derived.

$$\frac{7 \times t_s}{T.D.S} = \left(\left(\frac{A}{\left(\frac{i_{SC}}{I_S}\right)^P} - 1\right) + B\right)$$

$$\frac{7 \times t_s}{T.D.S} - B = \frac{A}{\left(\frac{i_{SC}}{I_S}\right)^P} - 1$$

$$\frac{7 \times t_s}{T.D.S} - B + 1 = \frac{A}{\left(\frac{i_{SC}}{I_S}\right)^P}$$

$$\left(\frac{i_{SC}}{I_S}\right)^P = \frac{A}{\left[\frac{7 \times t_s}{T.D.S} - B + 1\right]}$$

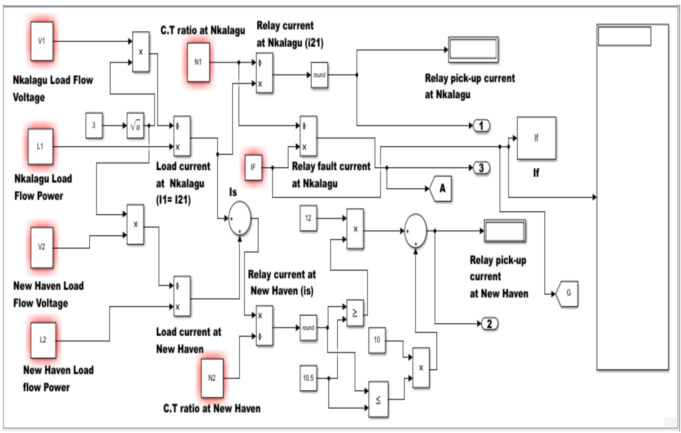

Figure 3a. New Haven-Nkalagu Line Protection Model (Stage A)

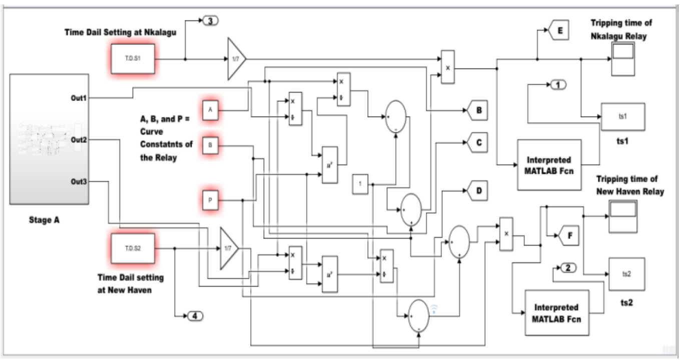

Figure 3b. New Haven-Nkalagu Line Protection Model (Stage B)

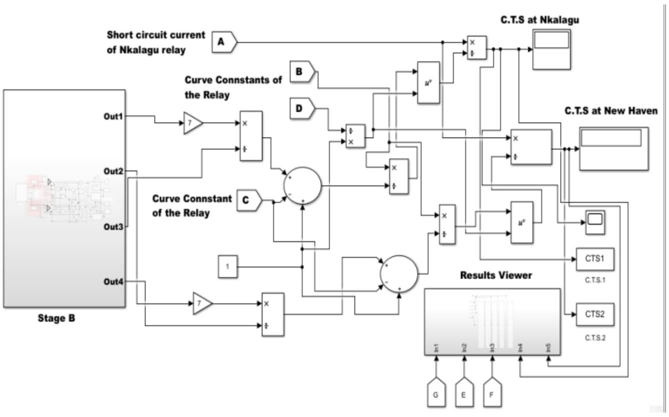

Figure 3c. New Haven-Nkalagu Line Protection Model (Stage C)

$$\frac{i_{SC}}{I_S} = \left(\frac{A}{\left[\frac{7 \times t_s}{T.D.S} - B + 1\right]}\right)^{\frac{1}{P}}$$

Hence,

$$I_S = \frac{i_{SC}}{\left(\frac{A}{\left[\frac{7\times t_S}{T.D.S} - B + 1\right]}\right)^{\frac{1}{P}}} \qquad (15)$$

Figures 3a to 3c shows the New Haven – Nkalagu line protection Simulink model.

Development of the adaptive system that will control the over-current relay

The adaptive system that will control the over-current relay was developed from the equation for calculating the tripping time of the relay. Then by replacing the short circuit current i_{SC} of the relay with the ratio of fault current of the line I_{SC} to the turns ratio N of the current transformer, an adaptive system was developed. At this stage, no optimization is carried out but the adaptive equations to be used as the objective function for optimization was developed. Hence from

$$t_s = \frac{(T.D.S)}{7}\left(\left(\frac{A}{\left({}^{I_F}/_{I_S}\right)^P} - 1\right) + B\right)$$

Recall that

$$i_F = \frac{I_{SC}}{N}, I_S = C.T.S$$

And 1/7 = 0.143, then,

$$t_s = 0.143 \times T.D.S.\times\left(\left(\frac{A}{\left({}^{I_{SC}}/_{N\times C.T.S}\right)^P} - 1\right) + B\right) \qquad (16)$$

Inserting the values of A, B and P into equation 3.19 and using the experimental values of C.T.S for Nkalagu and New Haven relays at a fault current of 3000 amps, then the equation can be written as:

$$t_{s1} = 0.143 \times T.D.S.\times\left(\left(\frac{19.61}{\left({}^{3000}/_{N \times 8.6466}\right)^2} - 1\right) + B\right)$$

Or,

$$t_{s1} = 0.143 \times T.D.S.\times\left(\left(\frac{19.61}{\left({}^{346.96}/_{N}\right)^2} - 1\right) + B\right) \text{(for Nkalagu relay)} \qquad (17)$$

Similarly

$$t_{s2} = 0.143 \times T.D.S.\times\left(\left(\frac{19.61}{\left({}^{225.13}/_{N}\right)^2} - 1\right) + B\right) \text{(for New Haven relay)} \qquad (18)$$

Both equations 17 and 18 was optimized so as minimize the overall operating time of the relay while in turn maximizing the relay pick up current in order to enhance the speed of operation of the relay, reduce false trips and improve the overall protection of the New Haven – Nkalagu 132 KV line. Thus the optimization of both equations was done using genetic algorithm. After optimizing equations 3.20 and 3.21 using a preset value, then optimization results was adapted into the model in form of combination ratios so as to control the tripping times and C.T.S values of both relays at New Haven and Nkalagu during varying fault current levels in the transmission network.

With the optimized results of the C.T ratios and T.D.S values of Nkalgu and New Haven relays being:

$$C.T.R1_{optimized}, C.T.R2_{optimized}, (T.D.S1)_{optimized}\ and (T.D.S2)_{optimized}$$

respectively, then the adaptive ratios for the model will be given by:

$$AdaptiveC.Tratio(Nkalagu) = \frac{C.TraioatNkalagu}{C.T.R1_{optimized}} \qquad (19)$$

$$AdaptiveC.Tratio(NewHaven) = \frac{C.TraioatNewHaven}{C.T.R2_{optimized}} \qquad (20)$$

$$AdaptiveT.D.Sratio(Nkalagu) = \frac{T.D.SatNkalagu}{(T.D.S1)_{optimized}} \quad (21)$$

$$AdaptiveT.D.Sratio(NewHaven) = \frac{T.D.SatNewHaven}{(T.D.S2)_{optimized}} \quad (22)$$

Development of a genetic algorithm for optimizing the performance of the adaptive relay scheme

In equations 17 and 18, T.D.S for both Nkalagu and New Haven will be designated as x(1) while the turns ratio/C.T. ratio (N) will be designated as x(2), thus

$$T.D.S_1 = x(1)$$
$$T.D.S_2 = x(1)$$

And

$$N = x(2)$$

Thus the optimization problem model therefore becomes:

$$t_{s1} = 0.143 \times x(1) \times \left(\left(\frac{19.61}{\left(346.96/_{x(2)}\right)^2} - 1 \right) + B \right) \text{for Nkalagu relay} \quad (23)$$

Subject to the constraints,

$$0 \le x(1) \le 0.5$$
$$100 < x(2) \le 200$$

$$t_{s2} = 0.143 \times x(1) \times \left(\left(\frac{19.61}{\left(225.13/_{x(2)}\right)^2} - 1 \right) + B \right) \text{for New Haven relay} \quad (24)$$

Subject to the constraints,

$$0 \le x(1) \le 1$$
$$0 < x(2) \le 1000$$

A flowchart for solving the solving the optimization problem of equation 23 and 24 using genetic algorithm was developed. The flowchart contains the steps taking by the genetic algorithm solver in order to find the best values of the turns ratio (N) and the Time Dail Settings (T.D.S) of both Nkalagu and New Haven Relays.

Training of the adaptive relay scheme using genetic algorithm for optimal performance

The training of the developed adaptive relay scheme was done using the Genetic Algorithm (GA) solver app of Matlab. The training was done by first inputting the parameters of table 1 into the GA solver app and clicking on the start button so that the training could start running. The adaptive relay scheme was trained and retrained several times until an indication of good training emerged in the app.

Integration of the impedance relay and its genetic trained adaptive controller to the test network

The integration of the genetic trained adaptive controller was done in two major steps. The first step involved the design of the adaptive interface for the controller. The interface has four adaptive controllers in it. When fault current flows towards the relay, then each adaptive controller chooses its best/optimized settings so as to determine if the relay will operate to trip or remain in operation. The implication of the adaptive controller is that the tripping time of both relays at Nkalagu and New Haven will be minimized relative to the relay pick up current which will be maximized at every fault scenario in the transmission network. By so doing, false trips and damage to equipment resulting from longer presence of fault current in the network will be minimized and thereby improving the overall protection of the network. Figure 4 shows the integrated genetic trained adaptive controller to the test network.

The percentage reduction in tripping times of both relays was calculated using the formula:

$$\%\, reduction\ in\ tripping\ times =$$

$$\left(\frac{(Totalaveragetrippingtimesoftheexistiingmodel) - (totalaveragetrippingtimesoftheimprovedmodel)}{Totalaveragetrippingtimesoftheexistiingmodel} \right) \times 100\% \quad (25)$$

Similarly, the percentage increase in CTS values of both relays are calculated from the formula:

$$\%\, increase\ in\ C.T.S\ value =$$

$$\left(\frac{(TotalaverageC.T.Softheimprovedmodel) - (totalaverageC.T.Softheexistiingmodel)}{TotalaverageC.T.Softheexistiingmodel} \right) \times 100\% \quad (26)$$

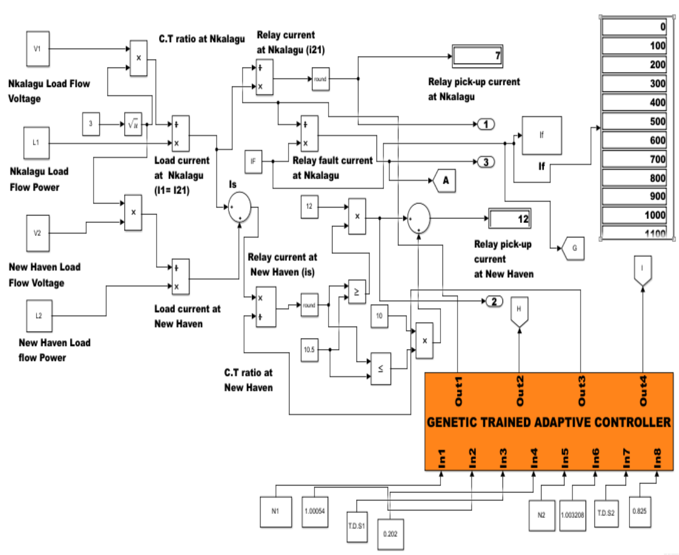

Figure 4. Integration of the Genetic trained Adaptive Controller

RESULTS AND DISCUSSION

In an attempt to validate the developed simulation models, a comparison of the simulated load flow results is made with the experimental results. The average percentage deviation of the simulated values from the experimental values is 0.9838%. This is acceptable in practice since the deviation is not more than five percent. Figures 5 and 6 respectively shows the Nkalagu and New Haven relay tripping times comparison of the existing model and improved model. As can be seen from figure 5 and 6, the total average tripping times of both Nkalagu and New Haven relays for the existing model is 378.8363 seconds while the total average tripping times of both relays for the improved model is 278.7372 seconds. The percentage reduction in tripping times of the New Haven and Nkalagu relay is computed as follows:

$$\% \, reduction \, in \, tripping \, times = \frac{378.8643 - 278.7372}{378.8643} \times 100 = 26.43\%$$

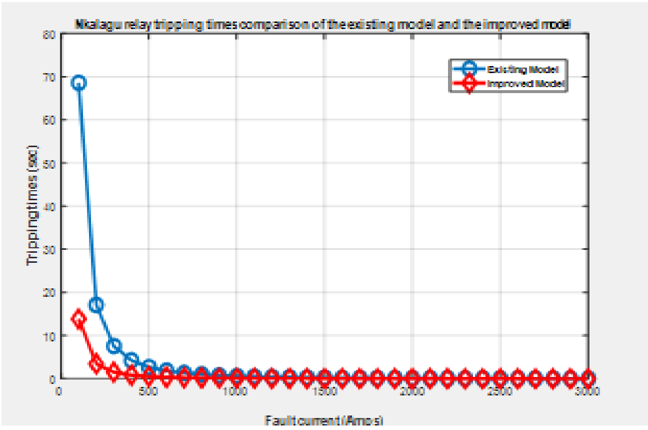

Figure 5. Nkalagu relay tripping times comparison of the existing model and the improved model

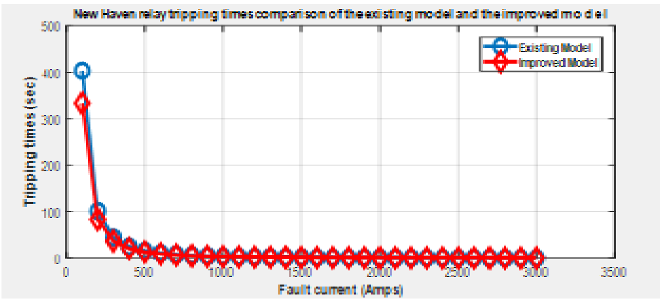

Figure 6. Nkalagu relay tripping times comparison of the existing model and the improved model

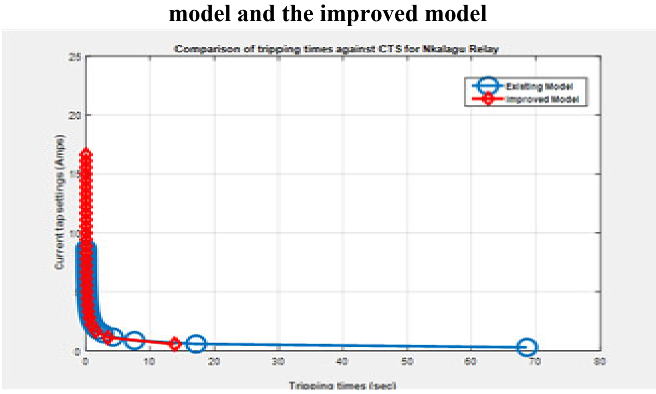

Figure 7. Comparison of tripping times against CTS for Nkalagu Relay

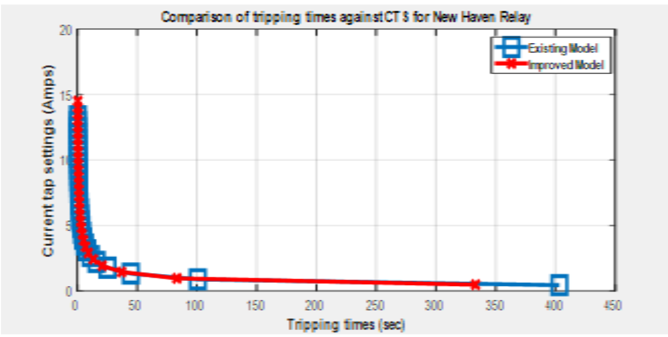

Figure 8. Comparison of tripping times against CTS for New Haven Relay

This result indicates a 26% improvement in relay operation during fault condition in the transmission network. Thus, this will help in providing more secured operating of the power system equipment since any condition that might cause excessive power in the system will be isolated by the relay in the quickest possible time. Incidences of fire outbreaks resulting in loss of lives and properties because of the New Haven – Nkalagu power transmission network being in operation for a longer time during fault conditions have also been minimized.

In related figures the Nkalagu CTS comparison of the existing model and the improved model was shown alongside the New Haven CTS comparison of the existing model and the improved model. A close observation of the figures shows that the CTS values of both relays at Nkalagu and New Haven for the improved model were both maximized when compared to the existing model. The total average CTS for the existing model is 170.2831 A while the total average CTS for the improved model is 241.4302. The percentage increase in CTS values of both relays at Nkalagu and New Haven is therefore calculated as,

$$\% \, increase \, in \, CTS \, values = \frac{241.4302 - 170.2831}{170.2831} \times 100 = 41.78\%$$

This result indicates approximately 42% percent increase in the relays current tap settings for varying fault current in the system. The implication of the CTS increase is that the relay will not have to trip at every instance of current rise in the system and thus minimizing false trips, which causes unnecessarily power outage from the New Haven – Nkalagu 132 KV transmission network. Thus, the results also indicates better relay coordination for the New Haven – Nkalagu 132KV transmission network.

Figure 7 and 8 shows the comparison of the tripping times against CTS graph of the existing mode and improved model. As can be seen from those figures there was an increase in the CTS value of both graphs along the y-axis. There is also a decrease in tripping times of both graphs along the x-axis thus indicating an improved protection of the New Haven Nkalagu 132KV transmission network.

Conclusion

This research work investigated how the protection of New Haven – Nkalagu 132KV power transmission network can be improved upon using a genetic trained adaptive relay scheme. The type of protection scheme considered is the over-current protection and the type of relay standards used is the IEEE very-inverse relay characteristics. The modeling of the transmission network was done using the PSAT Matlab and Simulink environment yielded values, which did not deviate much from the experimental values. Thus the percentage deviation of the simulated values from the experimental values was found to be 0.9838% which was adjudged to be OK in practice since the deviation is not more than five percent. The simulation of the New Haven – Nkalagu 132KV transmission model with its existing protection relay scheme showed that the total average tripping times of both relays at Nkalagu and New Haven is 378.8643 seconds. The CTS values of both relays for the existing protection scheme was found to be 170.831 A. The training and integration of the Nkalagu and New Haven adaptive relay scheme into the test network showed that the total average tripping times of both relays at Nkalagu and New Haven reduced to 278.7372 seconds. Similarly the total average CTS value of both relays with the genetic trained adaptive relay scheme integrated was found to 241.4302 A. These results indicated a 26.43% reduction in tripping times of both relays with the genetic trained adaptive relay scheme integrated. The results also indicated a 41.78% increase in CTS value of both relays with the genetic trained adaptive controller integrated. With these values, there will be an improved relay coordination of the New Haven – Nkalagu 132KV transmission network by ensuring quicker operation of both relays during fault conditions in the transmission network as well as minimized false trips disrupting power availability. With the percentage reduction in tripping times and percentage increase in CTS values of both relays at Nkalagu and New Haven found to be 26.43% and 41.78%respectively, it is therefore concluded that the genetic trained adaptive relay scheme is capable of improving the protection of New Haven – Nkalagu 132Kv transmission network.

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