

Review Article

Reliability analysis of protective relays in a transmission network

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ABSTRACT

High-voltage transmission lines are vital assets to electric utility as these lines transmit electricity generated by power stations to various areas throughout the nation. When exposed to the environments, transmission lines are susceptible to various types of failures such as lightning strikes, flora, and fauna encroachments. Fault on transmission lines can cause total blackout, and hence, fault clearing system is provided to minimize the effect of faults to the power system. The commonly used protection device to curb this problem is the use of protective relays. Failure of protection device may reduce the reliability of power system protection that will affect the total performance of the power system. Hence, the need to carry out analysis on the reliability of protective relays to determine if these relays carry out their function as at when required is envisaged. In this research, 4 years (2013–2016) forced outage data of the relays in Ogorode 330kv transmission network are considered. Several indices are calculated for evaluating the reliability of the relays. Mathematical models were developed through the writing of codes in the MATLAB 2015 environment for different scenarios, and the generated models were used to predict how reliable the performance of the relays will be in the future. The obtained results show that the relays in the network have a debugging failure rate and as such they are mostly affected by random external events.

Keywords: Failure, Ogorode, Protection, Relay, Reliability, Transmission

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INTRODUCTION

Adequate power supply is essential for a country's development,^[1] and this involves capital intensive activities demanding huge resources of both funds and capacity. In Nigeria, an economy just shedding off the effects of recession and with the resultant effects of cash paucity, the need for generation, transmission, and distribution of power through a more efficient means cannot be overemphasized, to address the power problem. One attractive prospect to the challenges of the power sector, among others, is the use appropriate maintenance technique to increase the efficiency of power system.^[2] Knowing full well that the inadequacy of it could intensify energy poverty.^[3] According to the International Energy Agency IEA, approximately 1.3 billion people live without electricity, which constitutes 18% of the global population. Till date, about 1.3 billion –1.6 billion people

in the world of which many of whom live in isolated areas do not have electricity, clean water, good education, primary health care, and other basic services; the effect of which to a large extent depends on access to electricity.^[4,5] At the present time, the major energy demands are met by conventional energy resources like coal, natural gas, crude oil, etc. which are fast depleting, finite and are threatening the future energy demands. More so, the emission of greenhouse gases is caused by the combustion of fuels which enhances environmental problems.^[6] Furthermore, the fossil fuel combustion is raising concerns about the climate change and other health hazards. When electricity delivered is strongly dependent on centralized energy systems which operate mostly on fossil fuels, it attributes to high costs of delivery, for establishing transmission and distribution grids that can penetrate remote regions.^[7] According to Anderson and Agarwal,^[8] the authors designed a reliability block diagram for a protection system in

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a substation and concluded that redundancy plays an important factor in determining the availability of the system.

The power transmission system is a highly sensitive and safety critical domain. Faults such as switching surges and short circuits cannot only damage the sophisticated and expensive components, like transmission lines or transformers, but could also lead to catastrophic consequences like the 2005 Moscow power blackout.^[9] This is the same in Nigeria, but due to poor database management, facts are not properly documented. To protect the power transmission systems and their components, it has now become customary to associate a protective relay with every safety critical component of a power transmission system. The Sapele Work Centre Transmission was founded on January 17, 1992. The work center consists of three substations; these are Sapele 330kv Transmission station, Amukpe 132/33kv Substation, and Effurun 132/33kv sub-station. The work center is responsible for the maintenance and operation of transmission network including supply of bulk power to the following states: Delta State and Edo State. The single line diagram of the network is shown in Figure 1. Hence, this research work is aimed at carrying out analysis on the relays in Ogorode transmission station, Delta State, Nigeria, to determine how reliable it is using historical failure data.

METHODOLOGY

The method used in this research work is solely dependent on the data obtained from the company log books to calculate the

parameters needed for the relay reliability analysis. Operational data for 4 years (2013–2016) comprising forced outage reports on relays, the date, name of the sub-regions/work centers, name of the substation, transmission lines nomenclature, voltage level, relay tripping indication, cause of the outage, time out, outage duration (h), last load recorded (MW), and energy loss (MWhr) per each outage were collated in addition to personal visit to the control room to see how these data are taking and recorded by operators in the events of failure. The indices of reliability have been calculated using equations 1–6^[10] to determine, among others, the level of reliability as well the failure rate of protective relay in the station. Thereafter, codes were written in the MATLAB environment to generate and validate the mathematical model of the reliability and failure rate of the relay. Eventually, the generated model was used to predict the behavior of the relay in the future. In this research, protective relays are assumed to be non-repairable. This assumption was derived from discussion with protection personnel in Ogorode Transmission Company, which concluded that protective relays are normally replaced with a new one once failed:

$$MTBF = \frac{\sum_{i=1}^n ROH_i}{\sum_{i=1}^n RF_i} \tag{1}$$

$$FR = \frac{\sum_{i=1}^n RF_i}{\sum_{i=1}^n ROH_i - DT_i} \tag{2}$$

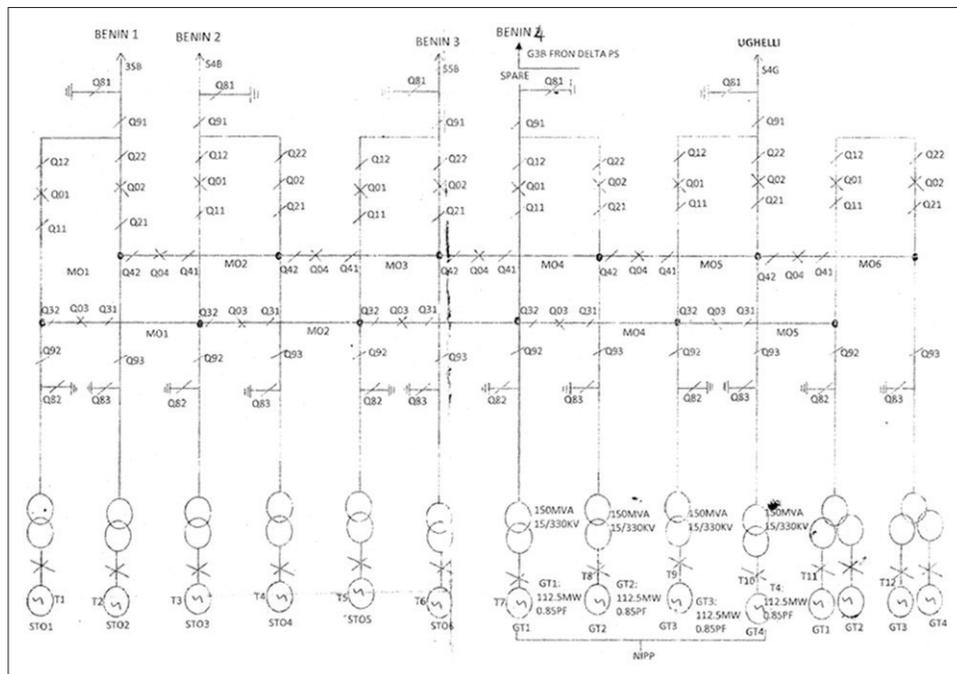


Figure 1: Single line diagram of 330kV ogorode transmission station

$$MTTF = \frac{\sum_{i=1}^n ROH_i - DT_i}{\sum_{i=1}^n RF_i} \quad (3)$$

$$MTTR = \frac{\sum_{i=1}^n ROH_i}{\sum_{i=1}^n RF_i} - \frac{\sum_{i=1}^n ROH_i - DT_i}{\sum_{i=1}^n RF_i} \quad (4)$$

$$REL = \frac{\sum_{i=1}^n ROH_i}{\sum_{i=1}^n ROH_i - \sum_{i=1}^n RF_i} \quad (5)$$

$$A = \frac{MTBF}{MTBF + MTTF} \quad (6)$$

$$\%ANF = \frac{\sum_{i=1}^n NF_i}{\sum_{i=1}^n TNF_i} \times \frac{100}{1} \quad (7)$$

Where
 ROH = relay operating hour
 RF = Relay failure
 DT = Downtime
 NF = Average number of failures in the study period
 TNF = The total number of failure in the study period
 % ANF = Average number of failure in percentages.

The MATLAB 2015 program was employed in generating the codes subsequently, mathematical models of the relays reliability were developed. The reliability of the relay was modeled as a polynomial function through the use of curve fit tool program in the MATLAB environment based on data collected. The resulting expression under running of the codes is given in equation 8.

$$R_{(x)} = a_1x^3 + b_1x^2 + c_1x + d_1 \quad (8)$$

Where;
 R = Reliability
 X = Time
 $a_1 = -0.02833$
 $b_1 = 0.225$

$$c_1 = -0.5467$$

$$d_1 = 1.32.$$

Similarly, the MATLAB program shown in Appendix B is employed in generating the mathematical model of the failure rate of the relay. The failure rate of the relay is also modeled as a polynomial function of degree three. This also is achieved through the use of curve fitting tool program in MATLAB as contained in Appendix B. This is done to obtain a general expression that models the behavior of the relay failure rate based on the collected data.

The resulting equation on running the codes contained in Appendix B is given in equation 9.

$$FR_{(x)} = a_2x^3 + b_2x^2 + c_2x + d_2 \quad (9)$$

Where
 FR = Failure rate
 x = Time
 $a_2 = -0.022$
 $b_2 = 0.2275$
 $c_2 = -0.7575$
 $d_2 = 0.8740.$

The monthly reliability of the relay for the year 2017 is predicted using its mathematical model which is achieved

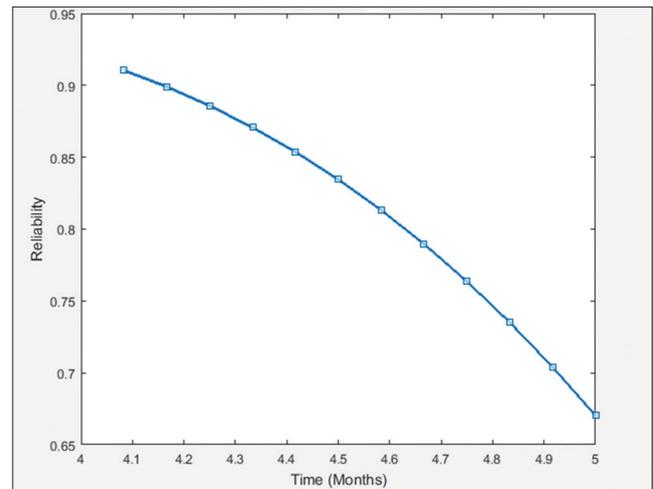


Figure 2: Plot of predicted reliability with time 2017

Table 1: Reliability indices for relay

Year	OUTG	DT	UPT	MTTF	MTBF	FRT	AVAIL	RELI	%ANF
2013	38	259.77	7804.23	31.04	1081.54	0.322	0.97	0.97	12.54
2014	53	748.03	7315.97	10.78	352.09	0.093	0.90	0.91	36.10
2015	63	446.93	7617.07	18.04	613.55	0.055	0.94	0.94	21.57
2016	52	617.43	7446.57	13.06	434	0.076	0.92	0.92	29.80

through simulation of its Simulink model with the appropriate input values. Table 1 shows the predicted values of the reliability for January–December 2017 [Table 2 and Figure 2].

The monthly failure rate of the relay for the year of 2017 was also predicted using the obtained mathematical model which is achieved through the writing of codes in the MATLAB environment as shown in Appendix B. Table 3 shows the predicted values of the failure rate for the month of January–December 2017.

In many cases, computed data are plagued with errors, and the generated or fitted equation may be taken to be a better representation of the actual relationship between the dependent and independent variables than the collected data. To test the validity and accuracy of a given fitted

Table 2: Predicted monthly reliability of relays for 2017

Monthly reliability prediction for 2017		
Month	Time	Predicted values
January	49/12	0.9104
February	25/6	0.8990
March	17/4	0.8858
April	13/3	0.8707
May	53/12	0.8537
June	9/2	0.8345
July	55/12	0.8132
August	14/3	0.7896
September	19/4	0.7636
October	29/6	0.7351
November	59/12	0.7040
December	5	0.6703

Table 3: Predicted monthly failure rate for 2017

Monthly failure rate prediction for 2017		
Month	Time	Predicted values
January	49/12	0.0763
February	25/6	0.0760
March	17/4	0.0750
April	13/3	0.0733
May	53/12	0.0708
June	9/2	0.0674
July	55/12	0.0630
August	14/3	0.0576
September	19/4	0.0511
October	29/6	0.0433
November	59/12	0.0343
December	5	0.0240

equation, the following can be carried out to getting an estimate of the error of the fit. The first areas of interest we can use to look at how good the fit is are the residuals. Suppose that we are fitting a function $f(x)$ to a set of collected data t_i . The sum of the squares of the residuals is given as follows:

$$A = \sum_{i=1}^N [f(x_i) - t_i]^2 \tag{10}$$

Now let the collected data have a mean or average value given by \bar{t}_i . The sum of the squares of the deviation of the collected data from the mean is:

$$S = \sum_{i=1}^N (t_i - \bar{t}_i)^2 \tag{11}$$

The r-squared value is then computed as follows:

$$r^2 = 1 - \frac{A}{S} \tag{12}$$

If $r^2 = 1$, then the function would be a perfect fit to the collected data. Hence, the closer r^2 is to 1, the better the fit.

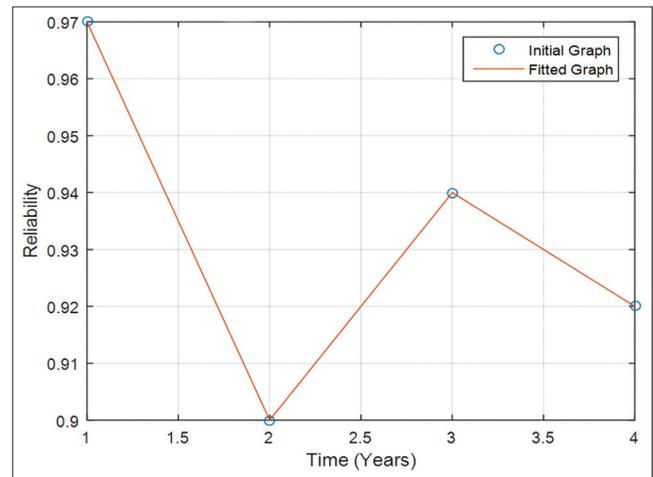


Figure 3: Fitted plot of the reliability with time

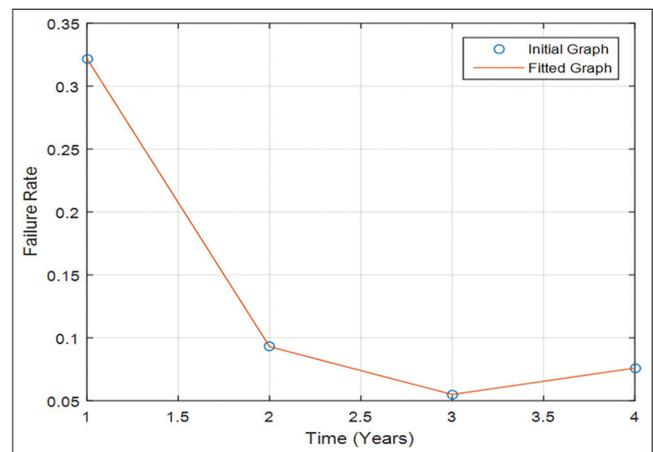


Figure 4: Fitted plot of failure rate with time

Table 4: Comparison of computed and fitted values of the relay reliability

Time (years)	Reliability	
	Computed values	Fitted values
1	0.97	0.96997
2	0.90	0.89996
3	0.94	0.93999
4	0.92	0.92008

Table 5: Comparison of computed and fitted values of the relay failure rate

Time (years)	Failure rate	
	Computed values	Fitted values
1	0.322	0.322
2	0.093	0.093
3	0.055	0.055
4	0.076	0.076

The above model validation computation can be done through the use of MATLAB codes. The MATLAB codes for the computation of r^2 value for reliability and failure rate of the relay are given in Appendix C and D [Figure 3].

RESULTS AND DISCUSSION

The monthly failure rate of the relay for the year of 2017 is predicted using the generated mathematical model. Tables 2 and 3 show the predicted values of the relay reliability and failure rate, respectively, for January–December 2017. It is obvious from the results in Tables 4 and 5 that the models generated are well fitted for the collected data. Furthermore, it can be seen from Figure 4 that the rate of failure of the relay decreases with time and this is an indication that the relay is mostly affected by random external event.

CONCLUSION

According to the property of relay protection system, this research uses the historical forced tripping of the breakers to analyze the MATLAB which was used for the analysis of the relay reliability. The developed model validation and computation are done through the use of MATLAB codes. The mathematical model developed is used to predict the reliability and failure rate of relays in 2017, this is to test its accuracy, and hence, this method provides alternative to other methods used for the same purpose.

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