International Journal of
Science and Engineering Investigations
vol. 8, issue 88, May 2019
Received on May 6, 2019
ISSN: 2251-8843

Optimal Autorecloser Settings for Improved Relaying on the Alaoji-Onitsha Transmission Line

Akwarandu Ikechukwu[1], Udofia Kufre[2], Okon Smart Essang[3]
[1,2,3]Department of Electrical/Electronic and Computer Engineering, University of Uyo, Uyo, Nigeria
([1]akwaranduikechukwu49@gmail.com, [2]kmudofia@uniuyo.edu.ng, [3]okonessang@gmx.com)

Abstract-This paper presents optimal autorecloser (AR) settings for improved relaying on Alaoji-Onitsha transmission network in the southeastern part of Nigeria. Transmission lines are known to have elevated power carrying capacities usually over long distances, making them prone to lightning faults and flashovers. Given the duration of such faults, using appropriate protection devices such as relays, fuses and circuit breakers (CBs) help to cut-off supply and prevent damage to the line equipment. However, use of AR not only protect the line equipment, but also increase the efficiency of the network as it restores the system to full function when the fault has cleared or lock out the network in case of permanent fault on the network to prevent further damage. Alaoji-Onisha transmission network is a medium length network spanning 138 km on 132 kV capacity with its primary source from Afam generating station Rivers State. The proposed modifications on the line comprises two AR setups at the beginning (Alaoji) and the midpoint of the line (around Akwakuma). Single- and three-phase configurations were modelled and tested under different conditions using PSCAD and Simulink MATLAB. Results obtained highlighted single-phase faults to be the predominant fault and three-phase fault to be redundant because of its rare nature. Transient faults in the test model of Alaoji-Onitsha line was successfully cleared within 5000 ms while faults that outlasted the duration of reclosing attempts (beyond 10000 ms are permanent faults) induced a lockout sequence as expected.

Keywords*- Autorecloser, Relays,Transmission Line*

I. INTRODUCTION

Automatic circuit reclosers (ACRs) are a class of switchgear designed for use on overhead electricity networks to detect and interrupt momentary faults. Also known as reclosers or autoreclosers, ACRs are essentially High Voltage (HV) rated CBs with integrated current and voltage sensors and a protection relay, optimized for use as an overhead network protection asset Robert (1997). Recloser are mostly used in conjunction with other protection devices such as sectionalizers where the interconnection of networks is prevalent. There are two main types of ACRs: Medium Voltage (MV) and HV ACRs; in terms of phase, single and three phase ACRs exist; based on interrupters, oil interrupted and vacuum interrupted ACRs are common; classifying them based on control signal, hydraulic and electronically controlled ACRs are predominant; in terms of method of insulation, oil, air and epoxy insulated ACRs exist. For the case study, an epoxy electronically controlled vacuum interrupted single/three phase recloser is proposed given the peculiarity of the line to the region.

II. REVIEW OF RELATED WORKS

Several authors have put forward a number of settings for ARs mainly based on area of application and required condition of operation. Lange and Oens (2007) proposed a protective system which employs two relays in one unit as primary and backup circuit. Their objective was to design a system which provides continuity to the main bus and continued protection to the main feeder in the event of a relay being taken out of service or feeder fault occurs. Rojewski *et al*., (2009) focused on selected problems of protective relaying for distribution networks with distributed generation by exploring the effect of high distributed generation penetration on protective device coordination. The author suggested an adaptive protection scheme as a solution to the problems identified. A comparative analysis of distribution reliability improvements that can be achieved by using various outdoor distribution devices was presented by Goodin *et al*., The authors did a general analysis of ARs as applicable to distribution networks. Tan (2010) analysed certain embedded protections and other relaying needed with more emphasis on digital relays adding that the expected benefits of microprocessor protection have largely been realized. The author stated that unlike manual relays, digital relays have the ability to detect a failure within itself and remove it from service before an incorrect operation occurs which is a huge advantage of the digital relays.

III. PROPOSED AR MODEL AND SETTINGS

Alaoji-Onitsha transmission line (138 km) is the backbone of Transmission Company of Nigeria (TCN) Network that connects major areas in and around Onitsha metropolis (Izuegbunam *et al*., 2012; Katende and Okafor, 2004). The supply on the line is majorly from the Afam thermal power plant of 969.6 MW capacity hence the base admittance of the line is derived as follows:

$$I_{base}=\frac{S_{base}}{V_{base}\times\sqrt{3}} \quad (1)$$

S_{base} = apparent power = 969.6 MW = 969.6×10^6 W

V_{base} = line voltage = 132 kV = 132×10^3 V

Therefore, $I_{base}=\frac{969.6\times10^6}{132\times10^3\times\sqrt{3}}$=4.249kA=424.900 A

Base impedance, $Z_{base}=\frac{V_{base}}{I_{base}}=\frac{132\times10^3}{4249}$=31.125 Ω

Base admittance, $Y_{base}=\frac{1}{Z_{base}}=\frac{1}{31.125}$=0.0321 Ω^{-1}

S =31.1 mS

The measured voltage on the line at Alaoji station was 130 kV while the nominal voltage capacity of the line is 132 kV. Thus, the per unit value of the line is:

$$V(p.u)=\frac{\text{measured voltage}}{\text{nominal voltage}} \tag{2}$$

$$=\frac{130\times10^3}{132\times10^3}=0.98 \text{ p.u.}$$

For typical recloser, trip time (tt) after fault detection is computed using the IEEE standard inverse time characteristic equation given thus (using field data from TCN):

$$tt_{fc}=\frac{\frac{K_d}{\tau_s}}{\left(\left(\frac{I}{I_p}\right)^p-1\right)}TDS \tag{3}$$

where tt_{fc} is the trip time, K_d: drag magnet damping factor = 0.32, τ_s: Initial spring torque = 1.2 kNm, I: normal current = 4.249 kA, P: constant exponent = 0.15, TDS: time dial setting = 55, I_p: relay pick up current = 42 A.

Equation (3) is further compressed into Equation (4):

$$tt_{fc}=\frac{A}{M^p-1}TDS \tag{4}$$

$$A=\frac{K_d}{\tau_s}=\frac{0.32}{1.2\times10^3}=2.67\times10^{-4}$$

$$M=\frac{I}{I_p}=\frac{4.249\times10^3}{42}=100$$

Hence, $tt_{fc}=\frac{2.67\times10^{-4}}{(100)^{0.15}-1}\times55$ = 0.0148 s =14.8 ms

However, using IEC 60255 standard electromechanical relay equation (Equation 5) to compute the trip time of the relay outside fast curve for four current time characteristics gave similar value as the IEEE standard.

$$t=\frac{K}{\left(\left(\frac{I}{I_s}\right)^\alpha-1\right)}\times TMS \tag{5}$$

where t = trip time in (s), I = fault (actual) current secondary CT current (A), I_s = relay pick-up current and TMS = time multiplier setting.

This simply means that on the Alaoji-Onitsha transmission line, fault-incidence to fault-detection takes approximately 15 ms (for fast curve) under normal operating current of 4200A. After the trip action has taken place, ARs have to reset to anticipate the next reclosing action. The reset time is computed using Equation (6).

$$t_{rst}=\frac{t_r}{M^2-1} \tag{6}$$

where t_r = K which is a constant describing the operating characteristics of the AR modelled. For extremely inverse condition $t_r = 80$ thus:

$$t_{rst}=\frac{80}{100^2-1}=8.0008\times10^{-3}=8.0 \text{ ms}$$

In line with the protective relaying theory and application, minimum Dead Time, T adopted for power transmission network as given by (2013) as in Equation (7);

$$T = 10.5 + kV / 34.5 \text{ cycles} \tag{7}$$

Hence, for 132 kV transmission line the minimum dead time for fast curve reclosing attempt is evaluated thus:

$$T=10.5+\left(\frac{132}{34.5}\right)=14.33 \text{ cycles}$$

Using a conversion factor of 1 cycle = 0.01667

$S = 16.67\ ms$

T = 14.33×16.67 = 0.023888 seconds = 238.88 ms.

However, to account for the anticipated stress placed on the other protection devices installed on the line such as fuses as a result of the reclosing action, a delay constant, Q, alongside sensitivity constant, y, are introduced into Equation (7) to give Equation (8):

$$T=10.5+\frac{kV}{34.5}\text{cycles}+Q^y \tag{8}$$

The values of Q and y have a direct relationship with the age of protection equipment on the line, the older the installed equipment, the higher the values of the constants and vice versa. Aside age factor, since the voltage considered is in the mid-range of transmission line capacity, introducing the delay and sensitivity constants makes for a more efficient tripping. Table II shows the characteristic values of constants Q and y.

The implemented system block is similar to the one presented by Mandar et al., (2012) with certain fast curve modifications and with different computed and simulated network parameters having signal source, RMS block, gain, time-current characteristics and the output block consisting of the signal processing unit, relay and scopes.

IV. RESULTS

From the values computed using different equation presented before now along with operating parameters gotten from the company managing the transmission network, a simulation model was developed on MATLAB Simulink and PSCAD. The single pole tripping technique was modelled in Simulink MATLAB and three-phase tripping was implemented in PSCAD. The results of the entire model are presented subsequently. Several other selected fault currents were used to ascertain the tripping time of the line under fault condition as presented in Table I. The computation was done using a MATLAB program

TABLE I. THEORETICAL AND SIMULATION VALUES OF RECLOSING TIME FOR GIVEN VALUES OF CURRENT

Current (A)	Theoretical data (Reclosing time in seconds)	Simulation data (Reclosing time in seconds)
4288	0.0148	0.0148
4318	0.0148	0.0147
4398	0.0147	0.0147
44488	0.0146	0.0146
4548	0.0146	0.0145
4648	00.145	0.0144
4808	0.0143	0.0143
5048	0.0140	0.0139
5898	0.0141	0.0137
6898	0.0134	0.0132
7898	0.0127	0.0126
9340	0.0117	0.0115
10200	0.0115	0.0111
15000	0.0104	0.0090

TABLE II. VALUES OF CONSTANTS Q AND Y

Characteristic	Q	Y	T(ms)
Standard inverse	1.5	20.9	5029
Very inverse	2.0	13.2	9,649
Extremely inverse	3.0	6	968
Long-time inverse	1.8	16.3	14,725

The single-phase autorecloser switchgear was then implemented using MATLAB Simulink, and results obtained are given in Fig.1 and Fig.2.

The occurrence of fault after 80 ms on a single-phase was detected and the faulted phase was taken out of service after 95 ms for a duration of 430 ms before reclose action was initiated and completed at 439 ms as seen from Fig. 1. The arc created due to the fault lead to a surge in arc resistance of the affected phase with a corresponding decline in the phase current as illustrated in Fig. 2.

Also simulated single phase autorecloser output on PSCAD are as presented. Using only data from TCN, settings of the model were adjusted and a transient fault was built into the system to ascertain the response of the system to fault. The result obtained is presented in Fig. 3. From the Fig. 3, two reclosing actions were attempted but the arc created was not extinguished completely. The dead time used for this model in Fig. 1 was derived from Equation (7). Adjustments were then made in line with computed values while the dead time computed from Equation (8) and presented in Table II was used for implementing the new settings on Fig. 4.

From Fig. 4, a three-phase autorecloser was simulated in PSCAD and ran for 500 ms with a built-in transient fault. As observed from the figures, the fault occurred on the line at 270 ms and lasted for 400 ms before it was cleared successfully during the fast cycle. The spike in the current magnitude was as a result of the fault which occurred simultaneously on the three phases. Because of the severity of most three phase faults, extra shunt reactors were placed at the end of each phase to douse the arc behaviour that results from reclosing action.

To analyse the existing settings, failure incidents, MATLAB and PSCAD simulation results provided the basis for determining the most suitable modification for the auto reclosing settings of Alaoji-Onitsha transmission network. The failure analysis using simulated result revealed that most of the transient faults are cleared within a minimum dead time of 239ms.

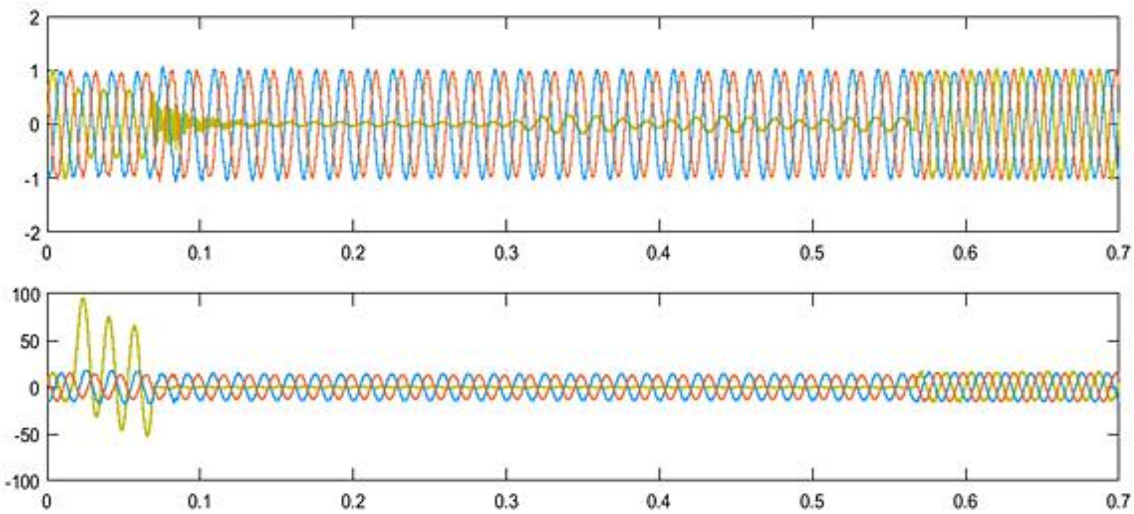

Figure 1. Faulted line voltage and current vs Time (s) during successful reclosing action

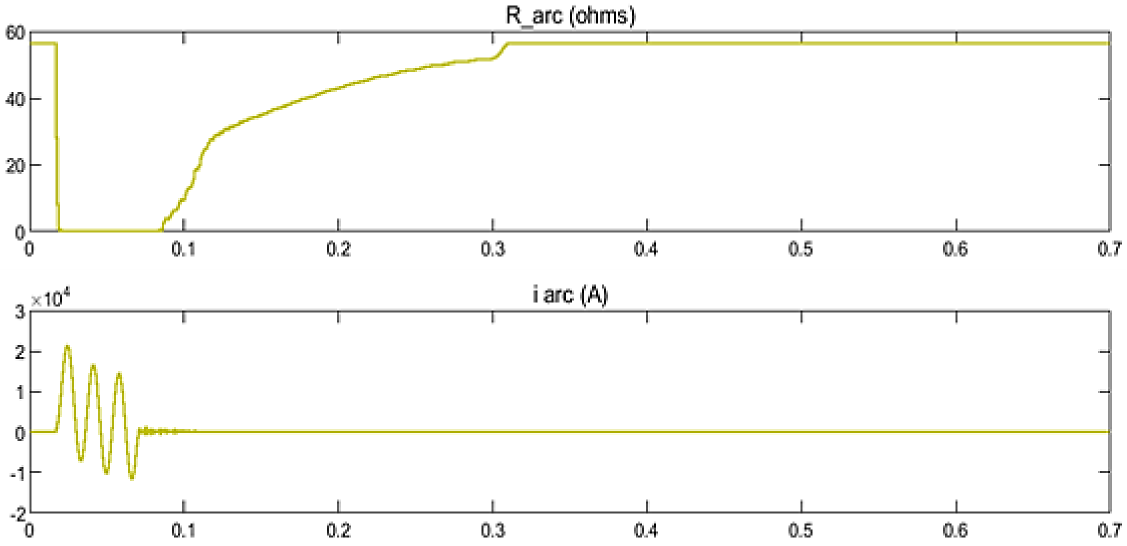

Figure 2. Arc resistance and current against time in seconds.

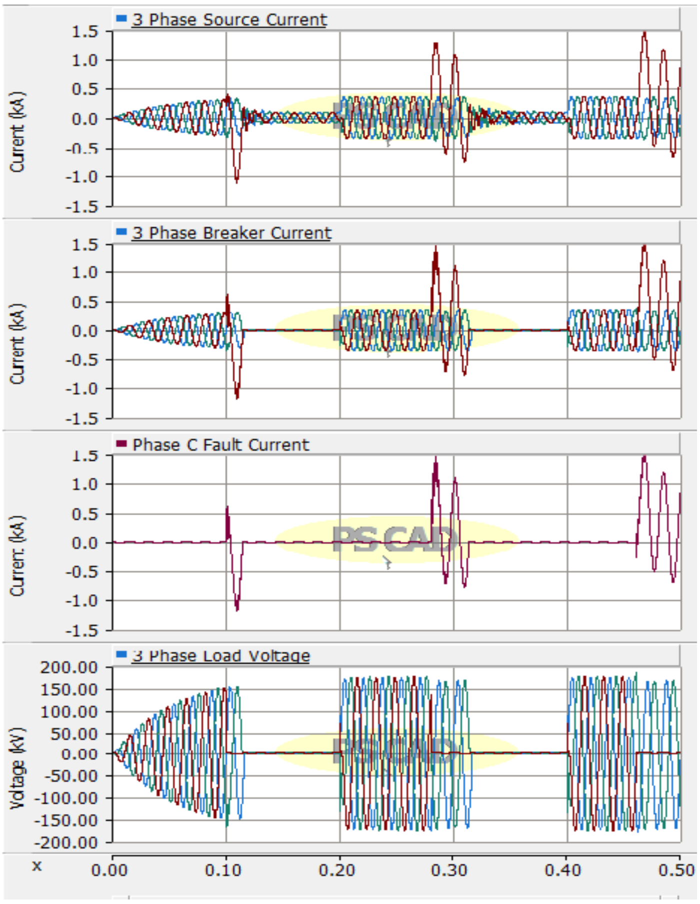

Figure 3. Source current, breaker current, phase fault current and phase load voltage

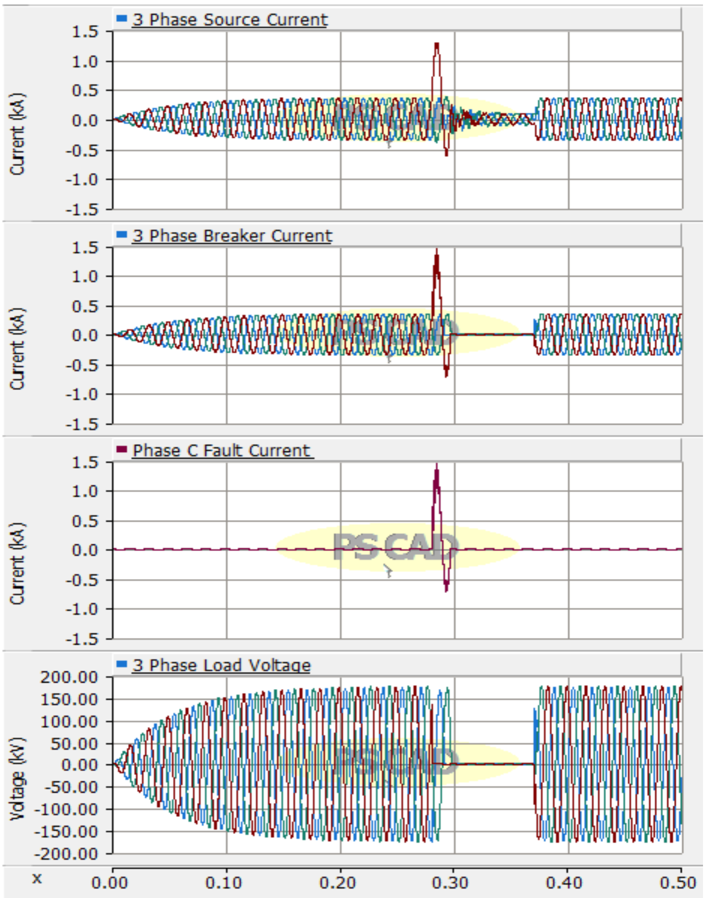

Figure 4. Source current, breaker current, phase fault current and phase

V. CONCLUSION

Optimal autorecloser settings for improved relaying on Alaoji-Onitsha transmission line have been presented. From the results presented, it was observed that the new settings proposed, performed better than the one on the existing line. This was attributed to the aging on protection devices on the line which necessitated the need for an optimal setting to improve the efficiency and stability of the line.

REFERENCES

[1] Robert W. Smeaton (ed) Switchgear and Control Handbook 3rd Ed., McGraw Hill, New York 1997.

[2] B. L. Theraja and A. K. Theraja, "A Textbook of Electrical Technology," 25th Edition. S. Chand & Co Ltd, India, p. 2782, 2008.

[3] J. Machowski, J. W. Bialek and J.R. Bumby, "Power System Dynamics: Stability and Control," 2nd Edition. Chichester, West Sussex, UK: John Wiley & Sons, 2008.

[4] C. Lange and M. Oens, "Improvements in Feeder Protection - Providing a Primary and Backup Relay System Utilizing One Relay per Feeder," DistribuTECH Conference, San Diego, California, pp.1-11, 2007.

[5] W. Rojewski, Z. Styczynski and J. Izykowski, Selected Problesms of Protective Relaying for Distribution Network with Distributed Generation," IEEE Power & Energy Society General Meeting, 1-5, 2009.

[6] R. Goodin, T. Fahey and A. Hansen, "Distribution Relainbility Using Reclosers and Sectionalisers," ASEA Brown Boveri (ABB) Inc. Conference Paper, pp.1-13, 2006.

[7] S. F. Tan, "Development of a Novel Single-Phase Auto-Reclosing Scheme for Distribution Network with Integrated Distributed Generation," PhD. Thesis. Robert Gordon University, Aberdeen, p.208, 2010.

[8] F. Izuegbunam, C. Ubah, and I. Akwukwaegbu, "Dynamic Security Assessment of 330Kv Nigeria Power System," Academic Research International, vol 3, no 1, pp. 456-466, 2012.

[9] J. Katende, and F. N. Okafor, "Automatic Generation Control Performance of the Nigeria Power System after Deregulation," 7th Africon Conference in Africa, Gaborone, Botswana, 2004.

[10] IEEE-SA Standards Board, Power Systems Relay Committee, IEEE standard common format for transient data exchange (COMTRADE) for power systems, IEEE Std C37.111¢-R2005 (Revision of IEEE Std C37.111-1999), 1-56, May, 2013.

[11] P.K. Mandar, S.H. Jangamshetti, R. Ajay, "Modelling of Auto-Recloser for Smart Grid," International Journal of Modern Engineering Research, Vol. 2, Issue. 5, pp-3172-3177, 2012.

[12] PSCAD/EMTDC, EMTDC: Users' Guide. Version 4.6.2.0 for Windows. Manitoba HVDC Research Centre, Canada, 2017.

[13] MATLAB, Matrix Laboratory: User's Guide. Version R2018a Update 3 for Windows. MathWorks Inc., Massachusetts, 187p, 2018.

How to Cite this Article:

Ikechukwu A., Kufre U., Essang O. S. (2019) Optimal Autorecloser Settings for Improved Relaying on the Alaoji-Onitsha Transmission Line. International Journal of Science and Engineering Investigations (IJSEI), 8(88), 44-48. http://www.ijsei.com/papers/ijsei-88819-08.pdf