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Non-Technical Power Loss Reduction and Transients Stability: Optimal Placement of Reclosers

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***Abstract*---Rarely do power distribution system, nowadays operates without a novel protection device to manage transients caused by electricity theft. Reliability requirements had been previously the subject, considered by researchers using reclosers to manage transients. However, Non-technical power loss and its cost reduction has not been sufficiently addressed to enhance high quality power supply. Consequently, consumers have always paid more on system losses. To safeguard on this menace, optimal reclosing, ENS.COST, firefly algorithm based has been discussed in this work. The results and analysis of proposed method had a forty three percent (43%) cost reduction on energy not served (ENS) during transient. Radial distribution system employed to analyze this can be replaced by a closed network for further work together with another novel optimization method other than Firefly algorithm for validation**.

***Index Terms*---Loss Reduction; Non-Technical; Optimal Placement; Recloser; Stability Transients**

I. INTRODUCTION

A. Research Background

Notably, power consumers and Industries struggle with frequent power failures [1]. Reviewed work showed that numerous power consumers suffer the loss, particularly developing countries such as Kenya. Similarly, republic of Congo had experienced massive losses on its distribution system and this had been due to lack of metering facilities, theft and fraud acts by non-genuine consumers among others [1]-[2]. Basically, power system stability has always proved to be very expensive, if not well managed and controlled. In power distribution system with limited information on transients, adaptive reclosing strategy was employed to restore system stability [3]. Basing on such experiences, a modern microprocessor-based relay and recloser controls was used to record oscillator performance of distribution line during faults [4]. This was meant to enable operators know the real cause of fault and then design fuse saving scheme and high-speed sensitivity at the expense of securing the system during inrush. Another development employed a multi-objective for the combination of “electricity levels” and “reliability in communication channels” and formulations to optimally place reclosers using genetic algorithm GA [5]. The former objective was on investment costs of recloser as latter was for reliability. Other works came up with a modelled MATLAB-SIMULINK simulation using the principle of adaptive reclosing technique (ART) [3]. A solid-state power controller (SSPC) to replace conventional electromechanical circuit breaker in power distribution was modeled to distribute power and protect it against various loads effects [6]. This technique had the following merits: Improved stabilized transients; the implementation of reclosing scheme was more advanced than the traditional; Web based implementation was possible due to less mathematical calculations. Ordinarily, a flow chart with Monte Carlo convergence was developed to randomly manage the faults [7]. Hitherto, the operation of recloser and settings depended on historical data of transients [7]-[8]. The model was capable of offering (kVA *t) energy held on the line caused by instantaneous faults. Drastic measures showed that, four ways of placement of reclosers for optimal operation can be developed [12]. This work categorized methods applied as follows: Ant colony algorithm, Enhanced network Genetic algorithm without dominated sorting, sectionalized schemes with network loop automation, and CENS-cost of anergy not served savings at the power point.

B. Contributions

This research enhanced ability of recloser reaction time and provided optimal location. The study realized controlled power distribution system, accomplishing balance amid transient deficiencies. There was a realization of energy saving during recloser operation.

C. Paper Organization

This paper is organized into a number of sub-topics including; research background, literature review, problem statement and formulation, research methodology, results, results analysis and conclusions/recommendation.

II. LITERATURE REVIEW

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A. Review of Related Work

Ahmed R Adly, et al. (2017) [3], significantly presented a transient stability enhancement by employing adaptive recloser technique. The modeled method eventually decreased oscillations of the system under study. This method could only work within some limited information and the authors predicted its practicability for real power system. The advantages of this method were: enhanced transient stability and adaptive controller that could automate reclosing strategy. This was meant to reduce fluctuations in generator load angle and zero down to the exact reclosing time.

Renaldo Strydom et al. (2019)[12], highlighted four ways of placement of reclosers for optimal operation. In his work he categorized methods applied as follows: Ant colony algorithm, Enhanced network Genetic algorithm without dominated sorting, sectionalized schemes with network loop automation, and CENS-cost of anergy not seved savingsat the power point. However the aurthors on recloser placement in relation to transients were missed out.

Wei Liu et al. (2006) [13] modeled solid-state power controller (SSPC) to replace conventional electromechanical circuit breaker in power distribution. The system was able to distribute power and protect it against various loads. The model was capable of offering current squared time protection (I^2t) caused by instantaneous faults. However, his work did not employ artificial intelligence to solve the problem.

B. Theoretical Background

In this situation, to prevent the damage to three-phase loads, it was desirable to use a recloser with single- phase tripping and three phase lockouts. Whereas enhancing loops schemes would require replacing one feeder with two parallel ones to increase reliability. Adapting feeder design: altering feeder paths and cross-section would increase feeder impedance and lower voltage sag. Overcurrent protection would be adopted easily by adopting the first five actions. Faults that normally occur along the power lines were classified as temporary or permanent. The former type could self-clear and power interruption would be restored at least in one to four times and the latter would require line crew work.

III. PROBLEM STATEMENT AND FORMULATION

No doubt, electrical power supply has become a necessity in every sector of economy together with domestic use. Eventually new connections are increasing progressively and will not be able to stop any time soon especially in developing countries. Meantime, more alarming state of power supply is the cause of frequent power failures that culminates to interruption of industrial processes and power supply to domestic use. Research on the causes have shed light on electricity theft which had become a menace because of short circuit transients it causes to the distribution lines. According to research conducted [1], as power consumers increased, new installation emerged and power theft also increased in a similar magnitude. In the recent time non-technical power loss reduction and related research work are stagnant only on improving the reliability concept of power supply and quality. More power producers may opt to close their supply to vulnerable areas with frequent power theft cases. Following this, Kenya Power and Lighting Company (KPLC) brought down their transformers in Kibera area due illegal connections, according to Kenya News Agency (KNA) 24th August, 2019. In this research work, specifically, the study conducted, looked at the non-technical loss reduction techniques and employed the reclosing cycle model (RCM) applicable to transient condition to formulate the problem. An Artificial intelligent technique (Firefly Algorithm) correspondingly, was employed to provide Optimal reclosing to minimize the power loss cost.

The problem formulation is based on [7]

$$W_{ENS} = \text{Min}\,[\sum_{r=1}^{n} \mathrm{P_r\,T_r C_r}] \qquad (1)$$

Where $W_{ENS} = Energy\ not\ served$, $\mathrm{P_r}$, $\mathrm{T_r}$and $\mathrm{C_r}$ are utility power, power recovery time and energy cost for load in that order, r = recovery time during brief failure. The total electricity consumption for a given distribution system in a given power outage is given in (2). In the protection of power-system equipment, kVA value is sometimes defined as let-through energy.

$$E_h = \sum_{i=1}^{9} kVA_i * t_r = P * t \qquad (2)$$

Where $\mathrm{E_h}$ = Un-served Energy in kWA, P = power supplied by the system at time t_r in seconds of the recloser operation and r = recovery time. Using reclosing philosophy of (3)

$$ENS = kVA * t_1 + 0.11kVA * t_2 + 0.06kVA * t_3 \qquad (3)$$

where, I = Fault current, $t_{1,} t_2\ and\ t_3$ = reclosing times at various intervals.

This study seeks to minimize the overall objective function for cost savings formulated in (4)

$$Min\ f(x) = d_i t_1 + 0.11 d_i t_2 + 0.06 d_i t_3 \qquad (4)$$

$$\text{Where } d_i = D_j F_k L_m R(t) C C_r \qquad (5)$$

The overall objective is subject to the following constraints:

$0.5 \le t_r \le 45.9$;

$75 \le D_j \le 400$;

$0 \le F_k \le 1$;

$\mathrm{R(t)} \ge R_0$;

ENSmin ≤ENS≤ ENSmax

Where *CENS* = Cost of Energy not served due to reclosing to protect feeder line and electricity apparatus,

$\mathrm{D_i}$ = Demand upstream up to 9-zones, F_k=Failure rate per line length, Lm=line length downstream, t_r= Reclosing time for three shots to clear Fault, *C*=costs of a recloser (including

maintenance and operation) over the whole review Period, C_r = Energy outage cost per kW. R(t) =Failure rates
Therefore, Savings on Energy not supplied was based on the location of radial network considered the following equation. Setting vector parameters: time, distance, current and power and equate them as: x_1= Standard sensing time per km in seconds as given in recloser settings, x_2 = Line length downstream of i km, x_3 = Line length Upstream in kilometers. Fault sensing time per km along the feeder =2seconds/km
Note 15 and 30 seconds are waiting time for faults to clear.

$$x_2 = \sum_{i=1}^{9} \boldsymbol{L_i} \quad (6)$$

$$x_3 = \sum_{i=1}^{9} \boldsymbol{L_j} \quad (7)$$

$$L_i = 5.6\ ,7.4, 10.4, 13.2\ ,16.7, 19.9, 22.5\ ,24.5\ ,26.1 \quad (8)$$

$$L_j = 26.1, 25.4.22.5\ ,19.9\ .16.7\ ,13.2, 10.4, 7.4\ ,5.6 \quad (9)$$

If g_1 = Fault location time and x_1=2 sec/km fault detection time per km along the feeder. Switching time for the feeder is given by:

$$g_1 = \frac{x_2}{x_2 + x_3} x_1 \quad (10)$$

Switching time for the feeder line after fault is given by

$$g_2 = g_1 + 15s \quad (11)$$

Fault clearing time of the feeder is given by:

$$g_3 = g_2 + 30s \quad (12)$$

Energy not supplied due to outage based on demand is given by:

$$g_4 = \sum_{I=1}^{9} 1.17 g_1\, D_i \quad (13)$$

Energy outage cost per kW is given by*:*

$$C_r = \$\frac{1}{kVA} \quad (1)$$

Failure rate of the Zonal line per kVA

$$g_5 = 0.008D \quad (11)$$

D = demand downstream
Operational and Maintenance expense of the protective device is given by:

$$g_6 = \$\frac{0.008}{kWA} \quad (13)$$

Savings on the cost of Energy not used in given as

$$\text{CENS} = \min\left(C_r * \sum (g_1 g_2 g_3 g_4 g_5 g_6)\right) \quad (14)$$

Subject to Constraints:
$0.5 \le x_1 \le 45$: 80≤ D ≤ 1800;0 ≤g_5 ≤ 1 and 1 ≤ x_3 ≤26

IV. METHODOLOGY

Along with problem formulation, the planned Firefly algorithm is employed to minimize energy not supplied during reclosing operation as in (2). The objective of the methodology is to limit the blackout cost that comes about due to recloser mitigation process [9]. Ideal setting of a recloser includes parameters with arbitrary nature, such as, faulted area and fault type (transient or permanent). To reclose vulnerabilities, the firefly technique, a computational calculation depended on rehearsed irregular examination to acquire numerical outcomes that are utilized in the planned strategy [13].

A. Pseudo code for classical firefly (FA) algorithm

The code for FA is as follows:
Step 1: Initiate algorithm
Step 2: Develop initial population using equation $X_{j,i} = X_{j.i}^{L} + rand\ (X_{j,i}^{U} + X_{j,i}^{L})$
(where j = 1,2...n, i=1,2...N and N is the number of decision variables)
Step 3: Calculate objective function $f(\text{X}), \text{X} = (x_1\ , \dots x_N)^T$
Step 4: Define parameters for the algorithm (γ - light absorption coefficient, α - randomization parameter and β - attractiveness)
While (Iter < max_Iteration)
for j=1: n all n firefly
for k=1: j all n firefly
Light intensity I_a at x_a is decided by f (x_a)
if (Ia < I_b)
Step 5: Shift firefly a towards the direction of firefly b (shift towards brighter one)
Attractiveness varies according to distance $d_{a,b}$ via exp [-$\gamma d_{a,b}^2$]
Step 6: Create and calculate new solutions and update light intensity
end for k loop
end for j loop
Step 7: Put limits for equality and inequality constraints violations
Step 8: Rate the fireflies, and find the best currently available
end while
Step 9: Post results
Step 10: Display the highest light intensity firefly among all the fireflies, which is the optimum solution
Step 11: Plot the light intensity versus time/iterations

Step 12: end of algorithm

B. Optimal reclosing Flow Chart [7]

Apparently, optimal reclosing flow chart of Fig.1 was used to develop an algorithm to place reclosers along the feeder. The solution procedure: assigned the initial values for the firefly algorithm, followed by setting limits and uploading data for the system. Finally, tuning and running of the algorithm is done to generate output values. The output is responses to the feeder radial system during transient fault. The algorithm was meant to automate the whole system during fault condition. Energy not served was generated as the system iterates to mitigate the disturbance. The optimized algorithm had the ability to perform the simulation with the intention to reduce the expense of reclosing. The tuned algorithm at the end of the process will give the amount of the total cost or expense (fees) alongside the CENS values. The difference between the fees charged at the actual CENS was the actual savings required

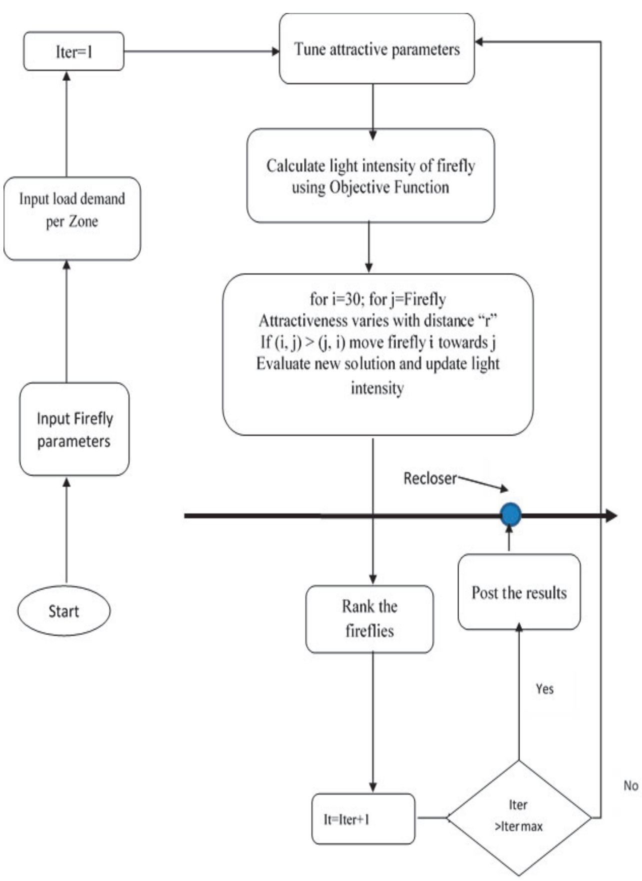

Fig. Optimal reclosing Flow Chart

V. RESULTS

Following the results generated, as illustrated in Table I, input values are in every column. These inputs are found in the radial network of the power system. Zones were separated by different distances between them. Larger span of the a given zone is taken to have less reliability. Fault location time depended on the distance of the zone from the upstream reclosers and that also determines time at which the fault can be cleared. Slightly more time is taken to clear furthest zone such as zone9. In Table I , CENS in zone 8 is less than zone 9 because zone8 has kVA*t and maintenance and operation cost being lower in the network system making saving low.

Table I: Summary results

Zone	1	2	3	4	5	6	7	8	9	
kVA	100	300	315	400	230	110	160	75	90	
Distance Downstream	5.6	7.4	10.4	13.2	16.7	19.9	22.5	24.5	26.1	
Failure Rate (Reliability Level)	0.7143	0.54	0.384	0.303	0.239	0.201	0.177	0.163	0.153	
Maintenance and Operation Cost ($)	25.0	75.0	78.75	100.0	57.0	27.0	40.0	18.7	22.5	
Fault Location Time	0.1767	0.2209	0.2849	0.3359	0.3902	0.4326	0.4630	0.4842	0.5000	
Fault Clearing Time	45.1767	45.2209	45.2849	45.2849	45.3902	45.4326	45.4630	45.4842	45.5000	
Min (CENS ($)	**234137**	**189518**	**125643**	**104778**	**81795**	**71376**	**59705**	**52307**	**54746**	**822339**
									Min (Cost) ($)	**1451400**
									Savings ($)	**629061 =43.3%**

A. Savings for cost of energy not served

Table I illustrates CENS in the downstream**,** where an optimized re-closer upstream automatically acts on fault based (kVA *t) as a protection scheme expressed in equation (2) [12]. The transients are cleared within first or second shot while in permanent fault; line is closed during the third shot. Fig.3 depicts the demand of energy upstream and their cost during the transient. The simulation provides the downstream cost of energy not served (CENS). The downstream shows a lower cost compared to upstream during transient. This agrees with the fact that the upstream loads have higher values of power being transferred per zone. Non-technical power loss reduction is discussed here as adding up all losses which are not technical in nature. Formulating non-technical power loss could only be tackled using equations derived from the energy not served during power failures. Based on the past experiences and major causes of power failures, transients such as power line tapings by humans and interruptions by animals were considered. Savings of this energy loss was the major concern.

Substation recloser reaction time during faults upstream from this analysis provides a greater power loss savings during transients than reclosers downstream

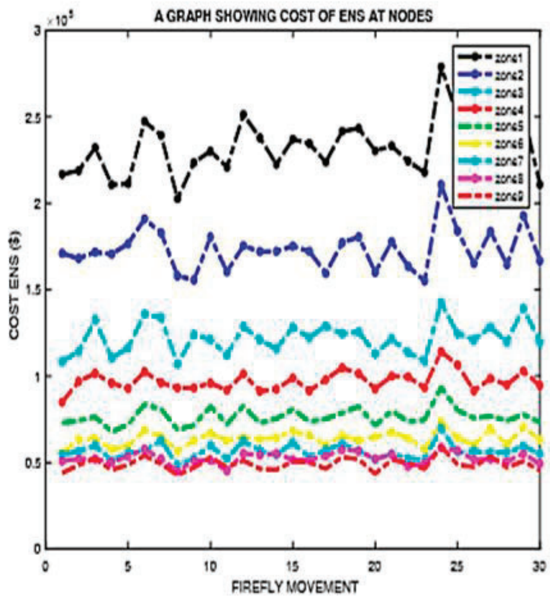

Fig 3: Cost of energy not served

B. 3D Distribution of Recloser Optimisation

Other than generation of CENS curves, the simulation was able to show feeder-reclosing zones with minimum and maximum values respectively. The 3D plots of Figure 4 provided profound solution to the problem. The simulation assigned zone1 higher cost and zone9 least cost respectively, thus provides a significant difference between the zonal costs of energy not served. Based on this analysis it was possible to decide on how to optimally place reclosers.

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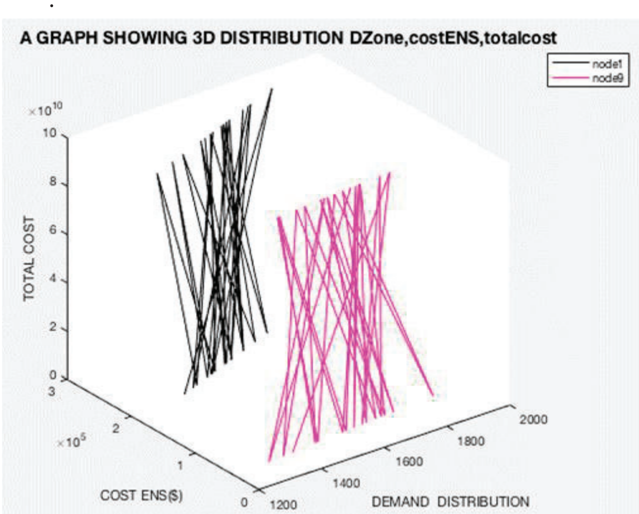

Fig. 4: Distribution of Recloser Optimisation

VI. CONCLUSION

In the final analysis, recloser had similar effect on cost along the feeder and costs were reducing as you move away from the substation. CENS savings can be achieved when the number of zoning is minimized to avoid numerous interruptions. Reclosers would be useful in place of switches and fuses of which the latter leads to long time interruptions and increased CENS Recloser allocation and placement can be achieved satisfactorily through optimal reclosing technique with firefly algorithm simulation. CENS saving was achieved as it was projected. The difference between minimum total cost or fees charged and minimum CENS value was best measure for saving required.

Recloser optimization using FA with hard constraints such as non-radial network topology can be pursued in future. Applicability of FA in cost savings for ENS can be examined using a different meta-heuristic or parameter tuning approach to improve on FA in future

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