Load flow analysis of 132KV Transmission System Using Artificial Bee Colony Algorithm

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Abstract: In the Nigerian Power Sector (Lagos Zone), the deregulation exercise and constant rise in Load demand has led to the need for planning, controlling and expanding of the power system network which is important and it's done with power flow studies on existing network to determine some unknown network parameters with the assumptions that the system is in steady state. In this work, ABC simulates the intelligent foraging behaviour, of a honeybee swarm and it is used for optimizing a large set of numerical test functions and the results produced by the three variants of the ABC namely, ABC_normal, ABC_global best and ABC_matlab fitness evaluation controlled. They are investigated to ascertain which is best or which of these technique are potential candidates used for load flow analysis of power system network? Simulations were conducted using the MATLAB programming language considering primarily the bus voltage, line losses and phase angle for the 35bus, 132kV Nigerian sub-transmission power system network, Lagos Zone. The results of simulations revealed that the voltages and angles solved by the ABC_normal and ABC_gbest techniques are closely correlated i.e. not significantly different from zero, with a p-value of about 0.3033 and 0.2029 respectively with the Pearson T-test; and on the other hand, there exists no correlation between the ABC_normal and ABC_mfe_controlled technique corresponding to a significant distance from zero. The ABC_gbest also fared better giving the least cost or power mismatch after 15,000 iterations of the load flow simulation.

Keywords: Artificial Intelligence, Artificial Bee Colony, Load Flow Analysis, Employed Bees.
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1. Introduction

Artificial intelligence is defined as the science and engineering of making intelligent machines where intelligent-seeming behavior can emerge from complex systems. AI is also the study of Intelligent Agents, where an intelligent agent is a system that perceives its environment and then takes actions to take full advantage of its chances of success. Load Flow Analysis (LFA) is an important step which helps us to plan ahead in the solution and improvement of power network. Traditional methods (e.g. NR and GS techniques) are frequently used. However, these traditional methods experience slow convergence issues and the local optimality issue. Thus, there are needs for alternative LFA techniques like some modern nature-inspired meta-heuristic algorithms which include **Cuckoo Search Algorithm (CSA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), as well as Artificial Bee Colony (ABC).** The ABC has been recently shown to have some delayed convergence and local optimality issues**.** Investigating the impact of variants of the ABC in the LFA and also determine the line flows and losses of a typical power system network in Nigeria.

The objectives of this work is to develop a standard swarm intelligence model based on the Artificial Bee Colony (ABC) to determine the voltage magnitude, phase angle of load buses, the real and reactive power flows in the transmission line. Also, to apply the tool developed above in load flow studies of a power system network to investigate the effect of variants of the ABC on the performance of the load flow of a power system network with respect to the standard model. The research bothers on the 132kV Nigerian power system network in steady state. Network data will be obtained from field survey of the power station in the Ikeja West 132kv transmission station. The result and inference of this work is significant for the modification and control of the 35bus network with poor lines performance to enhance the efficiency and load ability of the network for future purposes using artificial bee colony algorithm.

2. Literature Review and Theory of the Research

Load flow analysis cannot be left out in power system analysis and design; rather it is an essential study that needs to be carried out to evaluate the steady operating condition of the system under normal condition as regards system parameters such as, voltages, the real and reactive power and losses, transformer tap settings and other line parameters [5]. Numerical methods of solution have been employed over the years despite its challenges and limitations. Among the various numerical methods of solution employed for load flow analysis (LFA), Newton-Raphson (NR) method of solution have been widely adopted by various scholars as the best numerical computational technique for load flow solution due its fast convergence level and fewer number of iterations. But the NR method of solution is also associated with computational challenges when it comes to heavy loaded systems, as it does not converge due to the high ratio of resistance to reactance (R/X) and the singularity of the Jacobian matrix [6]. Nevertheless, AI techniques as a solution method to load flow problems have attracted a lot of attention and research in recent time [11].

3. Methods of Swarm Intelligence for Load Flow Problem

The algorithmic concepts of the Cuckoo-Search (CK), Particle Swarm Optimization (PSO), Differential Evolution (DE) and Artificial Bee Colony (ABC) algorithms have been analyzed. The numerical optimization problem solving successes of the mentioned algorithms have also been compared statistically by testing different benchmark functions [6]. Empirical results reveal that the problem solving success of the CK algorithm is close to the DE algorithm. The required *function-evaluation number* for acquiring global minimizer by the ABC algorithm is generally smaller than the comparison algorithms [4]. The performances of the CK and PSO algorithms are statistically closer to the performance of the DE algorithm. The ABC algorithms supply more robust and precise results than the PSO and DE algorithms [9].

3.1 General Features of Intelligent Swarms

There are different kinds of swarms, of which it is not possible to call all of them intelligent or their intelligence level could vary from swarm to swarm. Self-organization is a key feature of a swarm system which results to collective behaviour by means of local interactions. The three phases of ABC are: EMPLOYED BEES; they exploit food source and share information to the onlooker bees. ONLOOKER BEES; they evaluate food source based on the employed waggle dance. SCOUT BEES: they abandon the food source and then look for other food sources.ABC Algorithm finds near–optimal solutions to the difficult optimization problems.

4. Mathematical Model and Fundamental Equations of Load Flow Analysis on an Nbus System

Consider an n-bus system comprising of voltages, angles, admittances and line (MW and MVAR) flows between pairs of buses indexed at say i, k; then the real and reactive power may be represented as

$$P_i = V_i * V_k * \mathrm{Y}_{i,k} * \cos(\delta_k - \delta_i) \qquad (3.1)$$

$$Q_i = V_i * V_k * \mathrm{Y}_{i,k} * \sin(\delta_k - \delta_i) \qquad (3.2)$$

Where,
V_i = voltage at the i^th bus

V_k = voltage at the k^th bus

$\mathrm{Y}_{i,k}$ = the admittance between bus i and bus k.

δ_k , δ_i bus i, k angles

Note that when the bus generates electrical power, it is termed a generator bus otherwise it is a load-bus; a slack bus is also often necessary to accommodate (suck-up) the excess power flows.

The line flows may further be expressed as changes in the computed real bus/or generator powers with respect to pre-specified real bus/or generator values and is expressed as:

$$\Delta P_i = \left| P_i^{sp} - P_i^{cal} \right| \qquad (3.3)$$

Where,

P_i^{sp} = the specified real bus powers at power exchange sequence i, and

P_i^{cal} = the computed real bus powers at power exchange sequence i, using eqn.3.1

Similarly, the reactive power changes may be expressed as:

$$\Delta Q_i = \left| Q_i^{sp} - Q_i^{cal} \right| \qquad (3.4)$$

Where,

Q_i^{sp} = the specified reactive bus powers at power exchange sequence i, and

Q_i^{cal} = the computed reactive bus powers at power exchange sequence i, using eqn.3.2

Typically, the admittances, line power demand and generations are given while the bus voltages and angles are obtained by making an initial guess and solving using a load-flow program. The net power balance is then expressed as the sum over all bus power sequence exchanges as:

$$\Delta P_{net} = \sum_i^n \Delta P_i \qquad (3.5)$$

And,

$$\Delta Q_{net} = \sum_i^n \Delta Q_i \qquad (3.6)$$

4.1 Tuning ABC Parameters for Optimal Load Flow

The ABC parameters are constrained parameters i.e. there is a typical (limited) range of values that give optimum performance. In order to perform load flow optimization with the ABC, a fitness function has to be defined for the LFA problem.

This is obtained from eqns. (3.5) and (3.6) and is expressed as:

$$f_{obj} = \Delta P_{net} + \Delta Q_{net} \quad (3.7)$$

Values of f_{obj} must be close to zero or attain very small values including convergence after a setting number of trial observations have been made.

4.2 Cross-Section of Nigerian 132KV Power Transmission Network (Lagos Zone)

In this research paper, the Ikeja West 132kv transmission network was investigated and a special attention was paid to the Egbin - Ikeja West line (since EGBIN delivers the highest quantum of power to the station). The Ikeja West 132kv transmission station is considered strategic and unique to the Nigerian national grid. The station has seven (7) incoming 330kV lines, two (2) 330kV outgoing lines and fourteen (14) 132kV outgoing lines to step down transmission stations in the network.

The transmission station consists of four (4) 150MVA step-down transformer (resulting in a total station capacity of 600MVA or 480MW) for stepping the incoming 330kV to 132kV. The transformer has nomenclatures given as; T1A, T1B, T2A and T2B. Two (2) 75MX reactors R1 and R2 are connected to the 330kV bus-bar for voltage stability. Two earthing transformers (GT1A and GT2A) are attached to the transformers, and GT1A is connected to the tertiary of T1A while GT2A is connected to the tertiary of T2A.

The generators are assumed to be operating at 80% of their maximum installed capacity with the highest being the EGBIN thermal station which will be assumed as the power swing bus for the Load flow Analysis. The information for the accurate representation of this test system was obtained through an authorized data gathering from the Transmission Company of Nigeria Substation.

Typical values of machine parameters such as steady state and dynamic data that could not be obtained from TCN (Transmission Company of Nigeria) was implemented for simulation in this research work. Lagos has one of the Largest 132kv Transmission Network in Nigeria. The Lagos metropolitan Transmission network has the following line voltage levels: 330kv/132kv/33kV/11kV/240v.

4.3 Analysis of ABC Variants and Its Application for Load Flow Computation

ABC Variants are ABC_Normal, ABC_Gbest and ABC_mfe_controlled. In this work, the performance of ABC_Gbest was compared with ABC_normal and ABC_mfe controlled optimization algorithms. Although there are several improved versions of GA, DE and PSO in the literature. In the Analysis, we used the same population number and the maximum evaluation number for all problems although it is a known fact that these control parameters affect the performance of algorithms significantly.

However, in most comparative studies these parameter values of (1.5, 0.4*10, and 0) are varied with respect to the dimension of the problems or to their other characteristics. The reason is that we assumed the users of an algorithm do not know much about the recommended values of these parameters for their problems to be optimized.

While ABC_normal and ABC_mfe controlled employ crossover operators to produce new or candidate solutions from the present ones, ABC_Gbest does not. ABC_Gbest produces the candidate solution from its parent by a simple operation based on taking the difference of randomly determined parts of the parent and a randomly chosen solution from the population. However, in ABC the best solution discovered so far is not always held in the population since it might be replaced with a randomly produced solution by a scout. Therefore, it might not contribute to the production of trial solutions.

The ABC optimization is applied to obtain the bus voltage magnitude ( ) and voltage phase angle (δ) by minimize the value of objective function, which gives as:

$min\ (x),\ x = (x1,2,. . .,xi\ ,\ \dots\ ,\ xn-1,\ xn)$ (3.8)
This objective function constrained by the inequalities lower bound (Lb) and upper bound (Ub). $Lb \le xi \le Ub$

The voltage magnitude and voltage phase angle are limited in range 0.5≤Vi ≤1.05 and -5≤δi ≤5.

The objective function (F) that designed to determine the load flow problem by using ABC algorithm is:

$$F=\sqrt{\sum \Delta Pi2 + \Delta Qi2} \quad (3.9)$$

Where; i =1, 2, 3… number of bus bars.

The optimization process will continue until the best fitness value is reached. This mismatch power is close to zero the whole application of ABC algorithm approach in load flow computation is as shown in Figure 3.2.

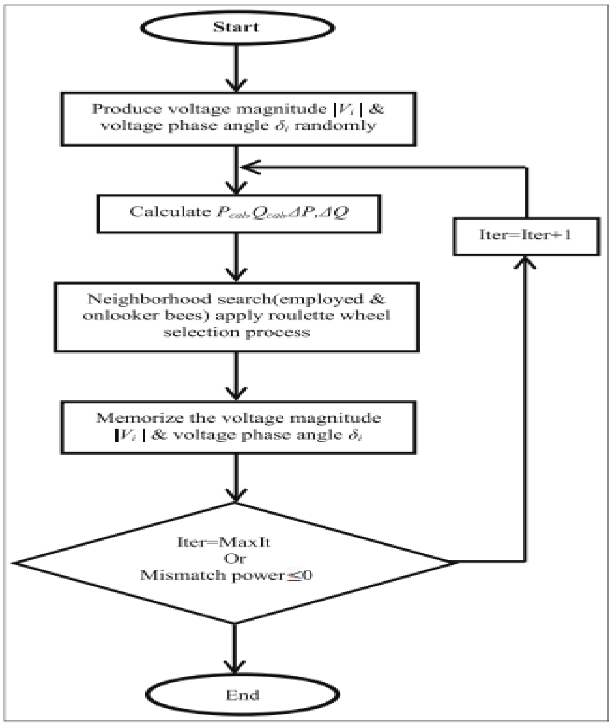

Figure 2.0: Scheme for Optimal Load Flow Using The ABC Swarm Technique.

4.4 Results and Analysis of Results

TABLE I
BUS CODES, LABELS, BUS TYPES, BUS POWER INJECTION (S_{MVA}), REAL AND REACTIVE POWER.

Bus Code	**Label**	**Type of Bus**	**S_{MVA}**	**P (MW)**	**Q (MVAR)**
1	Aja	PQ	120.0000	96.0	72.0
2	Alagbon	PQ	132.0000	105.6	79.2
3	Ikeja West	PQ	600.0000	480.0	360.0
4	Oworonshiki	PQ	90.0000	72.0	54.0
5	Akoka	PQ	85.0000	68.0	51.0
6	Akangba	PQ	660.0000	144.0	108.0
7	Amuwo	PQ	130.0000	104.0	78.0
8	Ojo	PQ	150.0000	120.0	90.0
9	Apapa Road	PQ	75.0000	60.0	45.0
10	Ijora	PQ	135.0000	108.0	81.0
11	Ayede	PQ	150.0000	120.0	90.0
12	Shagamu	PQ	60.0000	48.0	36.0
13	Ijebu Ode	PQ	60.0000	48.0	36.0
14	Ogba	PQ	135.0000	108.0	81.0
15	Papalanto	PQ	60.0000	48.0	36.0
16	Agbara	PQ	150.0000	120.0	90.0
17	Alimosho	PQ	120.0000	96.0	72.0
18	Ejigbo	PQ	90.0000	72.0	54.0
19	Otta	PQ	165.0000	132.0	99.0
20	Egbin GS	Slack	337.5000	270.0	202.5
21	Ikorodu	PQ	180.0000	144.0	108.0
22	Itire	PQ	70.0000	56.0	42.0
23	Isolo	PQ	115.0000	92.0	69.0
24	Illupeju	PQ	105.0000	84.0	63.0
25	Maryland	PQ	120.0000	96.0	72.0
26	Abeokuta	PQ	90.0000	72.0	54.0
27	Jericho	PQ	85.0000	68.0	51.0
28	Alausa	PQ	135.0000	108.0	81.0
29	Osogbo	PQ	522.0000	417.6	313.2
30	Illorin	PQ	105.0000	84.0	63.0
31	Omuaran	PQ	60.0000	48.0	36.0
32	Ife	PQ	60.0000	48.0	36.0
33	Ondo	PQ	60.0000	48.0	36.0
34	Illesa	PQ	80.0000	64.0	48.0
35	Akure	PQ	120.0000	96.0	72.0

5. Results

The results of the proposed approach are presented graphically in Figure 4.1 – Figure 4.3 showing the bus-voltages at ABC_Gbest, the corresponding best fitness and line losses. These values are obtained for a *maxcycle* value of 15000 iterations.

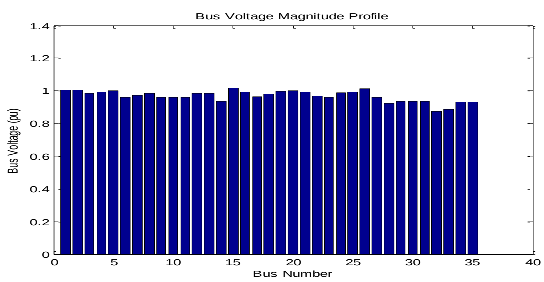

Figure 3.0: ABC_Gbest Bus Voltage Magnitude Profile Chart.

In Figure 4.1, the bus voltage started within the tolerance level of about 1 p.u for bus number 1 and still maintained its tolerance in bus 2 before fluctuating down toward 0.99 p.u at bus 3, although it exceeded 1 p.u in bus 15 which means voltage overstepped its boundaries in the response pattern within the normal tolerance limit.

The result of the Best cost/Iteration for the corresponding ABC-Gbest is presented graphically below.

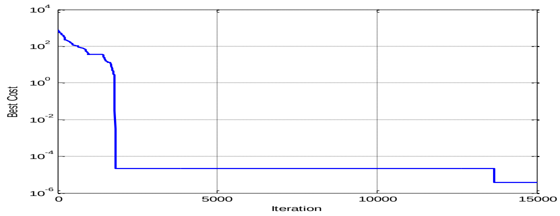

Figure 4.0: ABC_Gbest Best Cost (fitness) and Iteration Graph.

In Figure 4, a total number of cycles or iterations of 2000 is sufficient to ascertain early stability or convergence of the load flow analysis program. Which implies that any number of iterations above 2000 cycles is of little or no effect on the convergence or stability of the LFA till about 14000 iterations? This later had a suboptimal convergence at 14000 iterations. It should be handled with care.

The result of the Line Losses for the corresponding ABC-Gbest is presented graphically below.

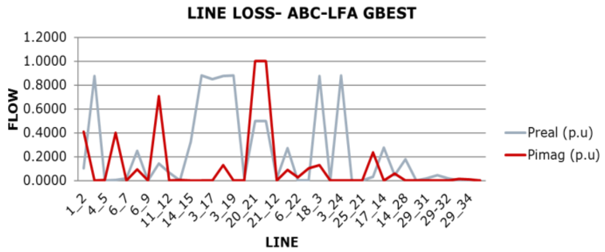

Figure 5.0: Graph Showing ABC_Gbest Line Losses

From figure 5, the load flow results reveals that the transmission lines from 1 to 2, 10 to 6, 3 to 18 and 20 to 21 recorded the highest power losses, this could be as result of distance, overloading of the lines or due to aging of the lines.

TABLE II:
ABC_GBEST LOAD FLOW BUS CODE, LABEL, VOLTAGE (V), BUS ANGLE (D), LOAD BUS REAL POWER (PD), LOAD BUS REACTIVE POWER (QD), GENERATOR BUS REAL POWER (PG) AND GENERATOR BUS REACTIVE POWER (QG).

Bus Code	Label	V (p.u.)	d (p.u.)	Pd(p.u.)	Qd(p.u.)	Pg(p.u.)	Qg(p.u.)
1	Aja	0.8500	0.2461	0.5000	-1.0000	0.0000	0.0000
2	Alagbon	0.8500	0.2290	0.5000	-1.0000	0.0000	0.0000
3	Ikeja West	0.9673	0.3139	0.7523	-0.3142	0.0000	0.0000
4	Oworonshiki	0.9275	0.2597	0.5000	-1.0000	0.0000	0.0000
5	Akoka	0.8971	0.2365	0.5000	-0.7507	0.0000	0.0000
6	Akangba	1.0120	0.3175	0.5001	-1.0000	0.0000	0.0000
7	Amuwo	0.9793	0.3082	0.5000	-1.0000	0.0000	0.0000
8	Ojo	0.9477	0.2980	0.5000	-1.0000	0.0000	0.0000
9	Apapa Road	1.0063	0.3200	0.5000	-1.0000	0.0000	0.0000
10	Ijora	1.0158	0.3182	0.6474	-1.0000	0.0000	0.0000
11	Ayede	0.9629	0.2514	0.5000	-1.0000	0.0000	0.0000
12	Shagamu	0.9789	0.2954	0.4800	-1.0000	0.0000	0.0000
13	Ijebu Ode	0.9856	0.3246	0.4800	-1.0000	0.0000	0.0000
14	Ogba	0.9517	0.3529	0.5000	-1.0000	0.0000	0.0000
15	Papalanto	0.9512	0.3944	0.4800	-0.7453	0.0000	0.0000
16	Agbara	0.9637	0.3161	0.5000	-1.0000	0.0000	0.0000
17	Alimosho	0.9612	0.3346	0.5000	-1.0000	0.0000	0.0000
18	Ejigbo	0.9765	0.3102	0.5000	-1.0000	0.0000	0.0000

19	Otta	0.9599	0.3661	0.5000	-1.0000	0.0000	0.0000
20	Egbin GS	1.0000	0.3448	0.0000	0.0000	2.7000	2.0250
21	Ikorodu	0.9952	0.3402	0.5000	-1.0000	0.0000	0.0000
22	Itire	0.9890	0.3094	0.5000	-1.0000	0.0000	0.0000
23	Isolo	1.0160	0.3221	0.5000	-1.0000	0.0000	0.0000
24	Illupeju	0.9644	0.3204	0.5215	-1.0000	0.0000	0.0000
25	Maryland	0.9801	0.3410	0.5766	-0.9185	0.0000	0.0000
26	Abeokuta	0.9511	0.3871	0.5242	-1.0000	0.0000	0.0000
27	Jericho	0.9498	0.1410	0.5000	-1.0000	0.0000	0.0000
28	Alausa	0.9393	0.3468	0.5000	-1.0000	0.0000	0.0000
29	Osogbo	0.9735	0.2848	0.5000	-1.0000	0.0000	0.0000
30	Illorin	0.9649	0.2928	0.5000	-1.0000	0.0000	0.0000
31	Omuaran	0.9657	0.2857	0.4800	-1.0000	0.0000	0.0000
32	Ife	1.0020	0.2697	0.4800	-1.0000	0.0000	0.0000
33	Ondo	1.0339	0.2568	0.4800	-0.8279	0.0000	0.0000
34	Illesa	0.9744	0.2852	0.5000	-1.0000	0.0000	0.0000
35	Akure	0.9687	0.2908	0.5000	-1.0000	0.0000	0.0000

THE SINGLE LINE DIAGRAM OF THE 132 KV NETWORK IS PRESENTED IN FIGURE 3.1.

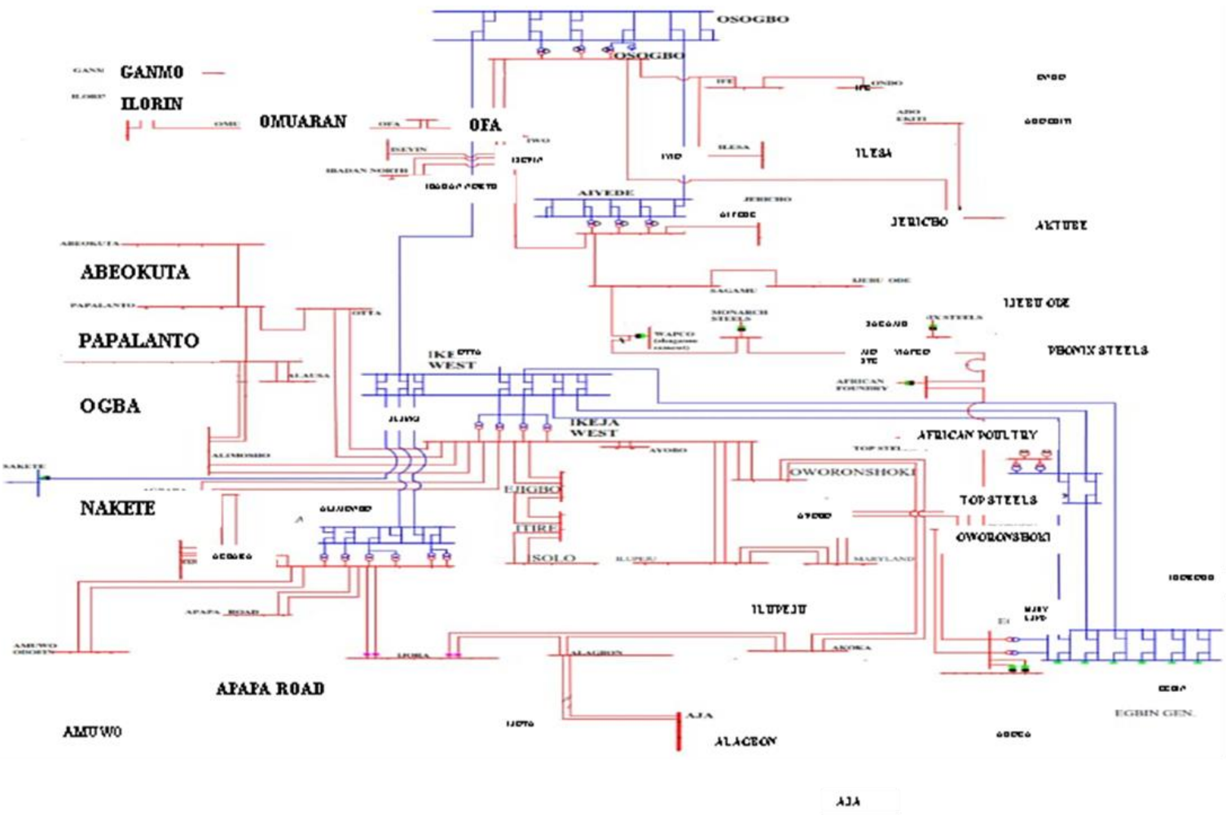

Figure 1.0: Single line diagram of Lagos 132KV transmission network.

6. Conclusion

This study has presented a swarm based approach that can be useful in Load Flow Analysis (LFA) of a power system where the ABC_Gbest fared better than the other ABC techniques giving the least or best cost (power mismatch) and Voltage profile has been found to improve better. The ABC_Gbest LFA simulations gave least fitness or best cost (i.e. power mismatch). This occurred after a little over 14,000 max-cycles. The transmission line from bus 20 to 21 had losses in all the three ABC variants due to overloading, distance and aging of the line. Both the real and reactive power flow can be affected by the change in bus voltage angles and voltage magnitude respectively as lines with the highest amount of real and reactive loss are those connected to buses with lowest voltage angle magnitude respectively.It is recommended that the lines with high power losses be modified to reduce losses and increase performance and efficiency by replacing old lines with lines whose conductors have large cross sectional area by conductor bundling of the old lines and also through the use of unified power flow controllers (upfc). It is known that line length affects the line performance; it is recommended that the line length be stipulated properly in the system to help in the analysis, lines having high power losses, compensated to reduce losses.

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