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Optimization and Reduction of Losses in 330kv Power Systems for Efficient and Optimal Operation

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Abstract: ***This study was undertaken to mitigate against the loss of electrical power in transformers within the 330kv transmission system in Nigeria using Fuzzy logic technique. The objectives included to utilise Newton-Raphson's technique to perform a load flow analysis to determine line losses, bus voltages, and load angles, and to use a Fuzzy Inference System to determine the points suitable for capacitor placement in order to reduce reactive power losses on the process and increase voltage profile, thereby improving the power system's stability and efficiency. Using the MATLAB toolbox, Newton- Raphson's power flow software was run to yield p.u nodal voltages ranging from 0.8890 to 1.0564, total real power line losses (0.09438 p.u), and total reactive power line losses. The power loss index is assessed and normalized in the range [0, 1] using power loss reduction. These indices, along with the magnitude of the p.u nodal voltage, were fed into the Fuzzy Inference System to produce the Capacitor Suitability Index (CSI). The obtained CSIs vary from additional to 0.897. Most nodes are influenced by the strength of the CSIs. for capacitor establishment. Tentatively, most elevated upsides of CSIs are picked for capacitor establishment. Therefore, 3 transports (3, 8, and 10) with CSI upsides of 0.680, 0.750, and 0.897 separately, are picked. Capacitor sizes of 50MVar, 85MVar, and 60MVar (got from Index Based Method) are introduced on the buses. Voltage profile improved by 3.74%, 3.27%, and 3.33% individually, while absolute genuine power loss in the framework reduced by 17.55% and all out receptive influence infusion to the system diminished by 8.70% separately. By the installation of capacitors at strategic areas in a transmission framework we were able to achieve a more stable network, reliable service delivery and a record of minimal technical losses.***
Keywords: ***Power System, Efficient and Optimal Operation,***

I. INTRODUCTION

The number of blackouts in a given locality each year means that the efficiency of power supply even as customer disappointment with power service is often connected to significant degree of blackouts (Amadi & Okafor, 2015; World Bank, 2009). Since the more the quantity of outages, the less productive the power framework, it follows that given higher framework losses (specialized and non-specialized), there would be more blackouts demonstrating the failure of the framework. Specialized losses are because of the idea of the parts being used in the organization, commercial losses allude to energy not charged for, and collection losses mean energy charged however not paid for. At the point when the appropriation organizations were privatized as a component of the power area change process by the Nigeria government, the exchanges expected some specific loss levels. After the resource hand-over, in any case, obviously the losses were a lot higher than had been assessed. In 2014, ~46% of energy was lost through specialized (12%), business (6%), and assortment losses (28%) (Nigerian Power Baseline Report, 2015). Throughout the long term, researchers and scientists have ascribed blackouts to: Weak framework and obsolete power stations, hardware over-burdening, insufficient remuneration gear on the framework, climate and tree related elements, defacing, helpless upkeep culture, and so forth (Amadi & Okafor, 2015; Udoh, 2014; Samuel et al., 2012; Lave et al., 2005).

Electrical power is a fundamental prerequisite for the advancement of any country, financially or economically. Envision a country without power, life would be exhausting. Along these lines, accessibility of this electric power achieves a positive change in all viewpoint which calls for venture. It is of good advantages to restore the electric power frameworks to expand usefulness in ventures, agriculture, increasing the expectation of individuals' vocation, in light of the fact that there is a satisfactory inventory of electrical energy. There is an association between the way of life of individuals and the current power supply in a country (Akpojedje et al., 2016). The interest for this fundamental utility is directly proportional to populace size. As the populace size expands the interest likewise increments bringing about a comparing expansion in the weight of existing transmission frameworks.

Since the discovery of electricity in the 18th century and its eventual realization in the 19th century, the need for reliable, cheap, and affordable electricity is still continuously sought through the complete structure of the electric power system (Komolafe et al., 2003).

In Nigeria, the power sector experience significant difficulties, ranging from the inability of the transmission companies to adequately deal with the reactive power stream issue, to inadequate power generation resulting to low voltage profile and load shedding activity; and when operating transmission network past its limit could result to voltage collapse. Since the demand for power keeps on growing consistently whereas the growth of power generating and transmission has been terribly hindered because of insufficient assets, numerous uncompleted transmission line projects, poor network setup, over-burdening of in-service transformers, and unremitting defacement of the transmission networks in the different districts of the country. The networks are related with inadequate power dispatch and under-available generation capacity, poor power network, insufficient or complete shortfall of reserve.

As of now, numerous electrical energy companies in various nations are encountering exceptionally high losses. Research show that around 9% of the entire power generated is squandered as losses at the transmission level in Nigeria (Robinson, 1994). Essentially, voltage drops or potentially over-voltages are every now and again experienced by TCN in transmitting power. With dynamic power losses decrease and voltage profile improvement as goals, the ideal capacitor position issue intends to decide the ideal capacitor locations and capacitor sizes in the transmission networks. Proficient techniques are needed to decide the best location and sizes. Thus, this study examines ways to lessen these losses and further improve voltage profile, shunt capacitor banks are introduced on transmission sub-stations.

II. LITERATURE REVIEW

The Nigerian power system network, similar to any remaining power system, waves about the whole nation and it is one of the biggest interconnections of a unique system in existence. Regardless of how cautiously the system is planned, losses are present. Electric power losses are wasteful energy brought about by external factors or internal factors, and energy dissipated in the system (World Bank, 2009).

They include losses as a result of resistance, atmospheric conditions, burglary, miscalculations, and so on and losses incurred between sources of supply to load centers (or consumers) (World Bank, 2009). Loss minimization and evaluation is exceptionally imperative in every single human undertaking. In power system, it can prompt more economic activity of the system. Assuming we realize how the losses happen, we can find ways to restrict and limit the losses. Therefore, this will prompt viable and effective activity of the system. Subsequently, the current power generation and transmission can be adequately utilized without wanting to construct new installations and simultaneously save cost of losses.

A. *Technical Losses*

These are losses that happen normally and comprise essentially of dissipated power in system components, for example, transmission and distribution lines, transformers and measurement systems (Gupta, 2008). Technical losses in power system are brought about by the physical properties of the components of the power system. The clearest model is the power distributed in transmission lines and transformers because of internal electrical resistance. Technical losses are normally happening losses (brought about by activity internal to the power system) and comprise essentially of power dissipated in electrical system component, for example, transmission lines, power transformers, measuring system, and so on technical losses are feasible to compute and control, given the power system being referred to comprises of known amounts of loads (World Bank. 2009). Technical losses happen during transmission and distribution and include substation, transformer, and line related losses.

B. *Non-Technical Losses*

Non-technical losses, then again, are brought about by activities external to the power system or are brought about by burdens and condition that the technical losses calculation neglected to consider (World Bank, 2009). Non-Technical losses are harder to measure on the grounds that these losses are frequently unaccounted for by the system operators and subsequently have no recorded data. Non-Technical Losses happen because of robbery, metering mistakes and unmetered energy. Paradoxically, relate primarily to power theft in some structure. Power theft is energy conveyed to clients that isn't estimated by the energy meter for the client. This can occur because of meter altering or by-passing the meter. Losses due to metering errors are characterized as the difference between the amount of energy actually conveyed through the meters and amount registered by the meters.

C. Fuzzy Logic Technique

Fundamentally, Fuzzy Logic (FL) is a multi-esteemed rationale that permits intermediate qualities to be characterized between ordinary assessments like valid/bogus, yes/no, high/low, and so forth (Zadeh, 1965). Thoughts like rather tall or extremely quick can be figured numerically and handled by PCs to apply a more human-like perspective in the programming of PCs (Zadeh, 1984). Fuzzy logic idea is similar to human beings feeling or inference process. Dissimilar to old style control technique, which is a point-to-point control, fuzzy logic control is a range-to-point or range-to-range control. The result of a fuzzy controller is gotten from fuzzifications of the two data sources and results utilizing the related enrollment capacities. A fresh info will be changed over to the various individuals from the related enrollment capacities dependent on its worth. Starting here of view, the result of a fuzzy logic controller depends on its participations of the diverse enrollment capacities, which can be considered as a scope of sources of info (Zadeh, 1984). Fuzzy Logic has arisen as a beneficial apparatus for the controlling and directing of system and complex modern cycles, just as for family and amusement gadgets, including other master systems (Zadeh, 1965). Fuzzy ideas and fuzzy logic are so frequently used in our normal life that no one even focuses on them. For example, to respond to certain inquiries in specific reviews, most time one could reply with 'Not Very Satisfied' or 'Very Satisfied', which are likewise fuzzy or vague replies.

D. Power Flow Analysis

Load flow analysis is the most significant and fundamental way to deal with research issues in power system operating and planning (Tinney & Hart, 1962). In light of a predetermined generating state and transmission network structure, load flow analysis addresses the consistent operating state with node voltages and branch power flow in the power system. Load flow analysis can give a fair consistent operating condition of the power system, disregarding system transient cycles. Consequently, the mathematic model of load flow problem is a non-linear algebraic equation system without differential equations. Power system dynamic analysis explores system steadiness under some given disturbances. Its mathematic model incorporates differential equations (Tinney & Hart, 1962). It ought to be brought up that dynamic analysis is based on on load flow investigation and the calculation of load flow analysis is likewise the base for dynamic analysis techniques. Consequently, knowledge of the hypothesis and calculations of load flow analysis is crucial for understanding the philosophy of modern power system analysis. Utilizing computerized PCs to work out load flow began from the mid-1950s. From that point forward, an assortment of techniques has been utilized in load flow computation.

E. Newton-Raphson's Load Flow Method

Load flow studies are utilized to guarantee that electrical power transfer from generators to purchasers through the grid system is steady, efficient and economical. Load flow analysis frames a fundamental essential for power system studies. Impressive exploration has as of now been completed in the improvement of PC programs for load flow analysis of enormous power system.

Ordinary procedures for tackling of the load flow problems are iterative, utilizing the Newton-Raphson or the Gauss-Seidel techniques. The Newton-Raphson strategy is generally utilized for settling non-linear equations. It changes the original non-linear problem into a succession of linear problems whose solution approach the solution of the first problem (Andreich *et al*., 1968). The Newton-Raphson's power flow method is the most vigorous power flow algorithm utilized by and by. Notwithstanding, one downside to its utilization is the way that the terms in the Jacobian matrix should be re-calculated after each iteration, and afterward the whole set of linear equations should likewise be resolved after each iteration (Andreich *et al*., 1968).

F. Bus Classification

A bus is a node at which one or many lines, one or many loads and generators are connected (Tinney, 1972). In a power system every node or bus is related with 4 quantities, for example, magnitude of voltage, phase angle of voltage, active or true power and reactive power. In load flow problem, two out of these 4 quantities are indicated and remaining 2 are required to be determined through the solution of the equation. Contingent upon the quantities that have been indicated, the buses are characterized into 3 classifications. For load flow studies it is expected that the loads are steady and they are characterized by their real and reactive power consumption. The principle objective of the load flow is to observe the voltage magnitude of each bus and its angles when the powers generated and loads are pre-specified (Stagg & El Abiad, 1999).

1) *Load Bus (P-Q Bus):* A bus where there is just load connected and no generation exists is known as a load bus [16]. At this bus, real and reactive load demand 25 and 65 are drawn from the supply. The demand is for the most part estimated or predicted as in load forecast or metered and estimated from instruments. Regularly, the reactive power is determined from real power demand with an assumed power factor. A load bus is additionally called a P-Q bus. Since the load demands 25 and 65 are known values at this bus. The other two obscure quantities at a load bus are voltage magnitude and its phase angle at the bus.

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In a power balance equation 25and 65 are treated as negative quantities since generated powers 27 and 67 are assumed positive (Stagg & El Abiad, 1999).

2) *Voltage Controlled Bus or Generator Bus (P-V Bus):* A voltage-controlled bus is any bus in the system where the voltage magnitude can be controlled. The real power developed by a synchronous generator can be varied by changing the prime mover input. This thus changes the machine rotor axis position regarding a synchronously rotating or reference axis or a reference bus. As such, the phase angle of the rotor δ is straightforwardly related with the real power.
3) *Slack Bus:* In an network, as power flows from the generators to loads through transmission lines power losses happens because of the losses in the line conductors. These losses when included, we get the power balance relations (Momoh, 2009). The voltage magnitude is indicated at this bus. Further, the voltage phase angle δ is additionally fixed at this bus. For the most part, it is indicated as 0° so all voltage phase angles are measured with respect to voltage at this bus.

III. METHODOLOGY

The materials used in this study include generation data of TCN 330 KV transmission system. Also, in this study, a 10-bus transmission system is taken as the model as shown in figure 1.

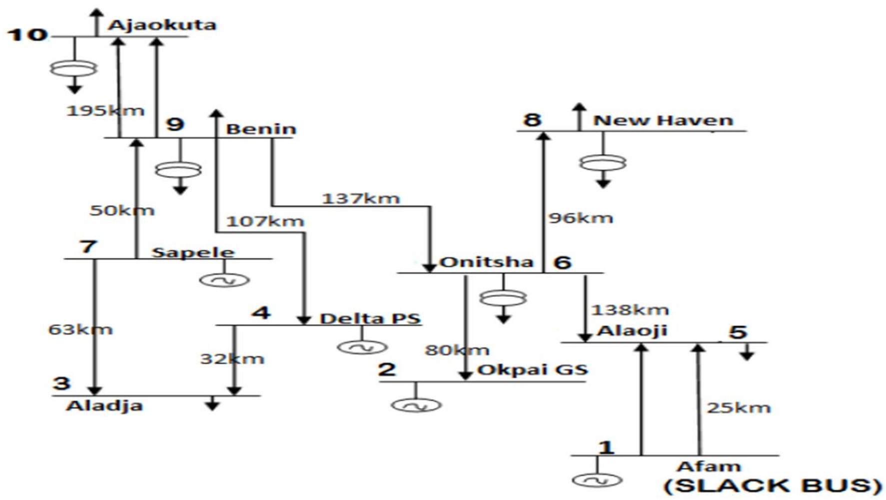

Figure 1: Schematic of Single line diagram of the 10-Bus Transmission Network Model

The bus system (which cut across 2 of the 8 TCN locales), is painstakingly picked as a contextual analysis for this work. As shown in Figure 1, the network is a 10-bus, 10-transmission line system. There are four (4) generator (P-V) buses namely; Bus 1-Afam (Slack bus), Bus 2-Okpai GS, Bus 4-Delta PS, and Bus 7-Sapele. The remaining six (6) buses, namely; Bus 3-Aladja, Bus 5-Alaoji, Bus 6-Onitsha, Bus 8-New Haven, Bus 9-Benin, and Bus 10-Ajaokuta are load (P-Q) buses. The transmission lines running across the network are all 330KV voltage level, with their lengths clearly indicated. So, it is a simple model network. The system's line & bus data is shown below in table 3.2 and table 3.3 respectively. It is also important to note that the total distance of the chosen transmission network is 923km.

A. *Optimal Capacitor Placement Approach*

The overall capacitor arrangement problem is defined as an optimization problem to determine the number and location of capacitors, the types (fixed or switched), and size of capacitors to be introduced and the control scheme for the capacitors at the buses of the transmission network. At the point when capacitors are placed power loss is decreased and likewise energy loss is minimized. To decide the location and size of capacitors to be introduced, a load flow program was executed on MATLAB. This gives the location of bus generally reasonable for capacitor installation. In this work, shunt (switched) capacitors are utilized at suitable buses.

B. *Fuzzy Logic Technique and Shunt Capacitor Placement in Power Loss Reduction*

Power Loss Index and Capacitor Suitability Index range fluctuates from 0 to 1, while p.u nodal voltage range differs from 0.9 to 1.1. Five membership functions are chosen for PLI and CSI.

They are Low, Low-Medium, Medium, High-Medium, and High. All the five membership functions are triangular. Additionally, five membership functions are likewise chosen for Voltage. They incorporate Low, Low-Normal, Normal, High-Normal, and High. These membership functions are trapezoidal and triangular. Crisp sets permit just full membership or no membership by any means, while fuzzy sets permit partial membership as found in the membership functions of PLI/CSI and Voltage going from 0 to 1, and 0.9 to 1.1 individually.

C. General Algorithm of Fuzzy Logic Implementation Using Capacitor Placement Method

In this venture, there are essentially three (3) steps used to carry out the proposed strategies. These are; **Stage 1:** Load flow solution for the first 10-bus system utilizing Newton-Raphson's iterative methodology is needed to get the real and reactive power losses, voltage magnitudes and angles, and so on. Load flow solutions are likewise needed to get the power loss decrease by compensating the absolute reactive load at each node of the model system. The loss reduction indices are linearly normalized into a [0, 1] range with the biggest record having a worth of 1 and the littlest one having a worth of 0. **Stage 2:** Calculation of power loss reduction indices. The power loss reduction indices alongside the p.u. nodal voltages acquired in step 1 are the inputs to the Fuzzy Inference System (FIS), to assess Capacitor Suitability Indices (CSIs). **Stage 3:** The values of the CSIs decide the nodes more reasonable for capacitor situation (installation). Having distinguished the nodes (buses) and number of capacitors to be introduced, the sizes of the capacitors are then determined utilizing Index Based Method. At last, an improvement in voltage and decrease in total real and reactive power losses is assessed.

D. Newton-Raphson Load Flow Analysis

Newton-Raphson's strategy is an iterative technique which approximates the sets of nonlinear simultaneous equations to a set of linear simultaneous equations utilizing Taylor's series expansion and the terms are limited to first approximation.

$$P_i = V_i \sum_{j=1}^{N} V_j (G_{ij} cos\delta_{ij} + \beta_{ij} \sin \delta_{ij} \quad (1)$$

$$Q_i = V_i \sum_{j=1}^{N} V_j (G_{ij} sin\delta_{ij} - \beta_{ij} \cos \delta_{ij} \quad (2)$$

$i = 1.N$

Where

Vi, Vj: Voltage magnitude at bus i and j

δI, δj: Bus voltage angles at bus i and j

Pi: Real power injection at bus i

Qi: Reactive power injection at bus i

Gij + βij: Entry (i, j) of the admittance matrix

E. Load Flow Problem Formulation

The load flow problem is formulated as a set of non-linear algebraic equations, regularly addressed by equations (1) and (2) and a set of inequality relationship to consider operating limits like reactive power injections/voltage magnitude at generation buses. The issue feasibility is ensured by the traditional bus classification: Slack/reference bus (V-δ), voltage-controlled/regulated buses (P-V) and load buses (P-Q). Load flow as a rule characterizes a solitary bus for example reference bus, which plays a double function: it gives the phase reference angle, and since the transmission losses are known ahead of time, this bus is utilized to adjust generation losses and load. Consider an electrical power system containing nL buses, nPV generation buses and one reference bus. The vector of state variables for example voltage magnitude and phase angles dictated by the load flow formulation is given by:

$$x = [V^T, \delta^T] \quad (3)$$

Where

δ= (n_L, n_{PV}) Vector of phase angles

V= n_L Vector of voltage magnitudes

F. Calculation of Loss Reduction and Power Loss Indices

By compensating the reactive load at each bus, considering each bus, and conducting load flow computation, the real power loss decrease at each bus is acquired. The Power Loss Index ith transport PLI(i) is the variable which is given to fuzzy expert system to distinguish reasonable locations for the capacitors.

Control Loss Index (*PLI*) value for i^{th} node (bus) can be gotten using equation (4).

$$PLI(i) = \frac{(X(i) - Y)}{Z - Y} \quad (4)$$

G. Use of Fuzzy Expert System to Identify Buses for Capacitor Location

The power loss indices and bus voltages are utilized as the inputs to the fuzzy expert system, which decides the bus(s) generally appropriate for capacitor placement. The power loss index range differs from 0 to 1, the voltage range varies from 0.9 to 1.1 and the result [Capacitor Suitability Index (CSI)] range varies from 0 to 1. These factors are portrayed by five membership elements of high, high-medium/ordinary, medium/typical, low-medium/typical and low. The membership elements of power loss indices and CSI are triangular in shape. The voltage is combination of triangular and trapezoidal membership functions. These are graphically displayed in Figures 2, 3 and 4 individually. Tests show that nodes with the most elevated CSI are generally appropriate for capacitor placement. In this work, nodes with CSI of 0.6 or above are picked for capacitor placement.

H. Procedure to Calculate Capacitor Size Using Index Based Method

Subsequent to knowing the ideal locations to put the capacitor, the size of the capacitor can be determined by utilizing record-based technique (Tinney, 1972).

$$Index[i] = \frac{Vi}{V_{base}} + \left(\frac{I_q[k]}{I_{p[k]}}\right) + (\frac{Q_{effectiveload,i}}{Q_{total}} \quad (5)$$

Where
Vi =Voltage at ith bus.
Ip[k], Iq[k[=Real and reactive component of current in kth branch.
Qeffective load,i=Total reactive load beyonf ith bus (counting Q load at ith bus)
Qtotal=Total reactive load of the given transmission system

$$Capacitor\ size[i] = Index[i]\ x\ Q\ load[i] \quad (6)$$

Where
Q load[i]= Local reactive load at ith bus.
Subsequent to assessing the size of capacitors to be introduced, an improvement of voltage profile of the framework is recorded. Essentially, total real and reactive power losses are diminished and recorded.

I. Data Source

Table 1. Line Data of the 10-Bus System

S/N	LINES	LENGTH(KM)	IMPEDANCE (Z p. u)	ADMITTANCE (Y p. u)	SHUNT (y/2 p. u)
1	Benin-Ajaokuta	195	0.007+j0.056	1.429-j12.180	0.745
2	Benin-Delta PS	107	0.0022+j0.019	6.013-j51.935	0.239
3	Benin-Onitsha	137	0.0049+j0.0416	2.80-j33.771	0.521
4	Sapele-Benin	50	0.0018+j0.0139	3.194-j17.555	0.208
5	Sapele-Aladja	63	0.0023+j0.019	5.284-j51.913	0.239
6	Delta PS-Aladja	32	0.0011+j0.0088	13.995-j1.119	0.171
7	Onitsha-Okpai GS	80	0.009+j0.007	59.230-j53.846	0.104
8	Onitsha-Alaoji	138	0.0049+j0.0419	2.754-j33.553	0.524
9	Onitsha-N. Haven	96	0.0034+j0.00292	3.935-j3.379	0.355
10	Afam-Alaoji	25	0.009+j0.007	59.230-j53.846	0.104

Source: National Control Centre, Oyigbo

Table 2: Bus Data of the 10-Bus System

		GENERATION				LOAD				
Bus No	Bus Name	P(MW)	Q(MVar)	P(p.u)	Q(p.u)	P(MW)	Q(MVar)	P(p.u)	Q(p.u)	Remarks
1	Afam	NS	NS	---	---	--	--	--	--	PV
2	Okpai GS	220.00	112.70	2.20	1.127	--	--	--	--	PV BUS
3	Aladja	--	--	--	--	47.99	24.59	0.4799	0.2459	LOAD BUS
4	Delta PS	55.00	28.16	0.55	0.2816	--	--	--	--	PV BUS
5	Alaoji	--	--	--	--	163.95	83.98	1.6395	0.8398	LOAD BUS
6	Onitsha	--	--	--	--	130.51	66.86	1.3051	0.6686	LOAD BUS
7	Sapele	75.00	38.42	0.75	0.3842	--	--	--	--	PV BUS
8	N. Haven	--	--	--	--	113.05	57.91	1.1305	0.5791	LOAD BUS
9	Benin	--	--	--	--	160.56	82.24	1.6056	0.8224	LOAD BUS
10	Ajaokuta	--	--	--	--	63.22	32.38	0.6322	0.3238	LOAD BUS

NS-Not Specified (Source: National Control Centre, Oyigbo)

IV. RESULTS & DISCUSSIONS

A. Newton-Raphson's Load Flow Analysis Result

The results (power injection, generation and load) for the 10 buses obtained from simulation using MATLAB Toolbox is given in table 4.1. As shown in table 3, Bus 1 (slack), bus 2, bus 4, and bus 7 are the only generation buses in the 10-bus network. Bus 1 (Afam) generates the highest real power (338.718MW) while bus 4 (Delta PS) generates the least (55MW). Overall real power generation is 688.718MW. Total real power injection is 9.438MW or 0.09438 p. u (on a 100MW base). Total reactive power injections and generations are also shown in table 3. For the 10-bus system, total real and reactive load drawn are 679.280MW and 347.960MW respectively. The p.u nodal voltage magnitudes and angles obtained from the Newton-Raphson's load current study are equally revealed in table 3.

Table 3: Power Flow Result

				INJECTION		GENERATION		LOAD	
Bus No	Bus Name	Voltage (p.u)	Angle (degree)	MW	MVar	MW	MVar	MW	MVar
1	Afam	1.0000	0.0000	338.718	12.815	338.718	12.815	0.000	0.000
2	Okpai GS	1.0500	-3.7025	220.000	-128.543	220.000	-128.543	136.000	84.000
3	Aladja	0.8990	-8.1180	-47.990	-24.590	-0.000	-0.000	47.990	24.590
4	Delta PS	1.0500	-7.9922	55.000	-97.354	55.000	-97.354	0.000	0.000
5	Alaoji	0.9750	-1.2259	-163.950	-83.980	0.000	0.000	163.950	83.980
6	Onitsha	1.0392	-5.0645	-130.510	-66.860	0.000	0.000	130.510	66.860
7	Sapele	1.0500	-7.8910	75.000	-111.894	75.000	-111.894	0.000	0.000
8	New-	0.9530	-5.2043	-113.050	-57.910	-0.000	-0.000	113.050	57.910
9	Benin	1.0564	-8.3221	-160.560	-82.240	0.000	-0.000	160.560	82.240
10	Ajaokuta	0.9278	-10.2920	-63.220	-32.380	-0.000	-0.000	63.220	32.380
TOTAL				9.438	-672.937	688.718	-324.977	679.280	347.960

As seen in table 3, there is instability in the voltages of the system as one of the values (Bus 3-Aladja) is outside the voltage constraint of $0.9 \leq 8 \geq 1.1$ p.u. A number of factors could cause this low voltage; these include:

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1) High load demand on the bus.
2) High reactive power generation in the network
3) High transmission line reactance, etc.

It is paramount to note that base value of energy is 330KV.

Similarly, the result of the line flows and the accompanying losses (real and reactive) for the ten (10) transmission lines are presented in table 4.

Table 4: Line flow and Power Losses

From	To	P	Q	From	To	P	Q	Line Losses	
Bus	Bu	MW	MVar	Bus	Bu	MW	MVar	Real (p.u)	Reactive (p.u)
7	9	52.876	-55.331	9	7	-52.780	56.070	0.00096	0.00738
9	4	-29.068	39.316	4	9	29.115	-38.909	0.00047	0.00407
9	6	-142.351	64.729	6	9	143.424	-55.614	0.01074	0.09115
6	8	113.468	20.243	8	6	-113.050	-19.884	0.00418	0.00359
4	3	25.885	-13.243	3	4	-25.877	13.310	0.00008	0.00067
6	2	-214.930	121.020	2	6	220.000	-117.077	0.05070	0.03943
6	5	-172.473	9.926	5	6	173.827	1.652	0.01354	0.11579
7	3	22.124	-7.281	3	7	-22.113	7.375	0.00011	0.00093
1	5	338.718	24.281	5	1	-337.777	-16.959	0.00941	0.07322
9	10	63.638	-51.170	10	9	-63.220	54.516	0.00418	0.03346
TOTAL LOSS								0.09438	0.36970

Absolute real and reactive power losses are 0.09438 and 0.36970 p.u individually. Highest real power loss of 0.05070 p.u is seen on line 6-2 (Onitsha-Okpai GS) while the highest reactive power loss of 0.11579 p.u is on line 6-5 (Onitsha-Alaoji).

B. Loss Reduction and Loss Reduction Index

By compensating the reactive load at each bus, considering one bus at a time, and conducting load flow calculation, the real power loss reduction at each bus is obtained and shown in table 5.

Table 5: Bus Power Loss Reduction

BUS NO	REAL POWER LOSS REDUCTION (p.u)
1	0.08497
2	0.04368
3	0.09419
4	0.09383
5	0.07143
6	0.01522
7	0.09331
8	0.09020
9	0.07803
10	0.09020

Using equation (4) and table 6, Power Loss Index (PLI) value for i^{th} node (bus) is obtained.

The result is shown in table 6. Detail of calculations is shown in the Appendix.

Table 6: Bus Power Loss Indices

BUS NO	POWER LOSS INDEX(PLI)
1	0.88325
2	0.36039
3	1.00000
4	0.99544
5	0.71178
6	0.00000
7	0.98886
8	0.94947
9	0.94947
10	0.79536

The loss reduction indices are linearly normalized into a [0, 1] range with the largest index (bus 3) having a value of 1 and the smallest one (bus 6) having a value of 0.

C. *Voltage Stability and Capacitor Suitability Index*

For deciding the suitability of a specific bus for capacitor installation at a specific bus, sets of multiple antecedent fuzzy rules have been set up and five membership elements of high, high-medium/ordinary, medium/typical, low-medium/typical and low are gotten. For instance, In case PLI is Low and Voltage is Very-Low, then, at that point, appropriateness Index is Medium. In case PLI is Low-Medium and Voltage is Low, then suitability Index is Medium. In case PLI is High-Medium and Voltage is Low-Normal, then suitability Index is High-Medium. In case PLI is High and Voltage is High, then suitability Index is Low-Medium. The rules are summed up in the fuzzy decision matrix in Table 6. In the current work, 30 rules are structured. The membership functions of Power Loss Indices and Capacitor Suitability Indices are triangular and similar in shape as displayed in Figure 2. The voltage is blend of triangular and trapezoidal membership functions. This is graphically displayed in Figures 3.

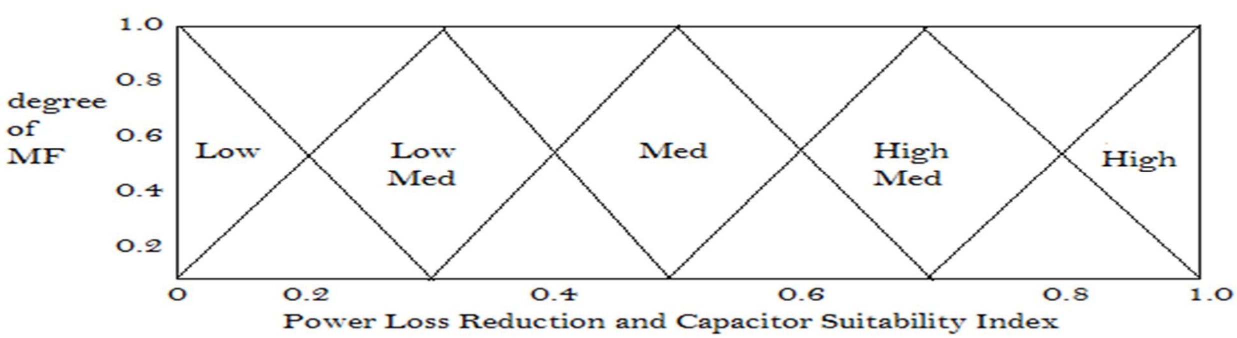

Figure 2: Power Loss Reduction and Capacitor Placement Suitability Index

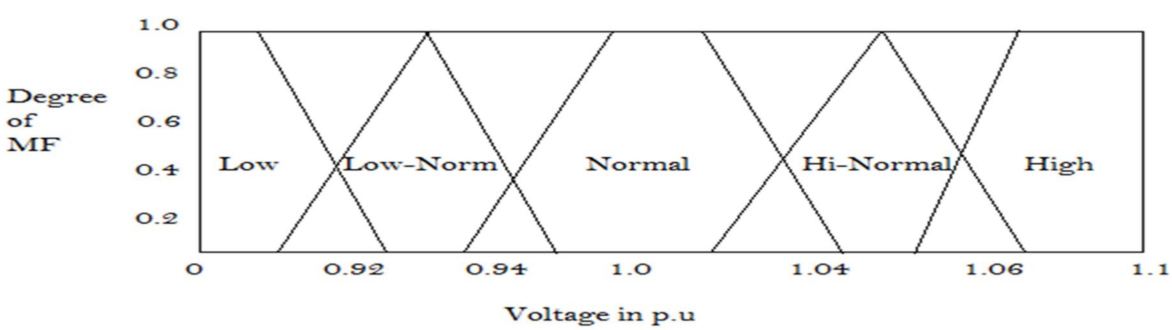

Figure 3: Voltage Membership Function

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By using Power Loss Reduction Index (PLRI) and Voltage Index (VI) as inputs to the fuzzy system, the result obtained from fuzzy implementation is shown in table 7. It displays the input variables (Voltage Index, and Power Loss Reduction Index), and output variable (CapacitorPlacement Sensitivity Index (CPSI)). Meanwhile, figure 4.4 is an aggregate of fuzzy rule viewer for the inputs and output variable. By selecting relevant values of PLRI, and VI, the output CPSI is displayed. Having noted earlier that experiment shows that buses with high CPSI are chosen for capacitor placement. It is observed from table 7 that three (3) buses; bus 3, bus 8 and bus 10 has CPSI values 0.680, 0.750 and 0.897 respectively, which is above 0.6 threshold defined earlier. Thus, these three buses are the optimal locations for installing capacitors.

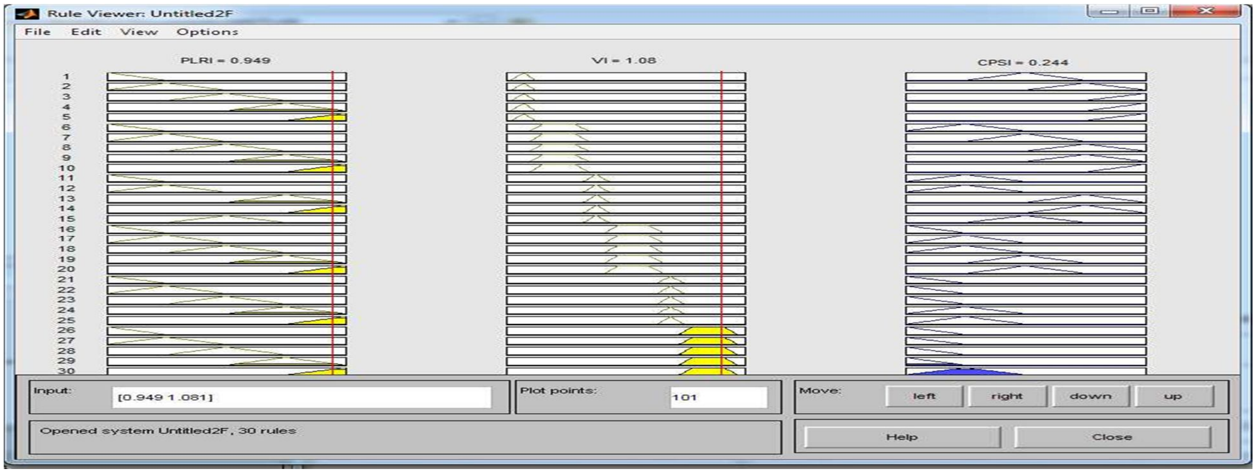
Table 7: Fuzzy Logic Result

Bus No	Voltage Index (VI)	Power Loss Reduction	Capacitor Placement Suitability Index
1	1.0000	0.88325	0.500
2	1.0500	0.36039	0.250
3	08890	1.00000	0.680
4	1.0500	0.99544	0.500
5	0.9750	0.71178	0.542
6	1.0392	0.00000	0.080
7	1.0500	0.98886	0.500
8	0.9530	0.94947	0.750
9	1.0800	0.94947	0.244
10	0.9278	0.79536	0.897

Tale 8: Decision Matrix for Determining Optimal Capacitor Location

AND		Voltage Sensitivity Index (VI)					
		V- Low	Low	Lo- Normal	Normal	Hi- Normal	High
PL RI	Low	Med	Lo-Med	Lo-Med	Low	Low	Low
	Lo-Med	Hi- Med	Med	Lo-Med	Lo-Med	Low	Low
	Med	High	Hi-Med	Med	Lo-Med	Low	Low
	Hi-Med	High	Hi-Med	Hi-Med	Med	Lo-Med	Low
	High	High	High	Hi-Med	Med	Lo-Med	Lo-Med

PLRI: Power Loss Reduction Index



Using the Index Based Method defined in equations (3.5) and (3.6), sizes of the capacitors are calculated and shown in table 9.

Table 9: Optimal Buses and Capacitor Sizes

Bus No	Capacitor Sizes (MVar)
3	51.268
8	83.129
10	57.963

However, for the above sizes, the nearest practical capacitor sizes available are 50MVar, 85MVar and 60MVar respectively. Thus, capacitor sizes of 50MVar, 85MVar, and 60MVar are installed on buses 3, 8 and 10 respectively.

These installed capacitors absorb reactive power from the system which helps charge the capacitors. When needed, the power system's shunt capacitors generate reactive power to increase power factor and voltage profile, consequently increasing system capacity and lowering total power losses. Table 4.8 shows the overall improvement recorded as a result of installation of the capacitors.

Table 8: Optimal capacitor size allocation, voltage improvement and loss reduction for the 10-bus System

<table>
<tr><td>Bus No</td><td>Without Capacitor
Voltage (p.u)</td><td colspan="2">With Capacitor
Voltage (p.u)</td><td colspan="2">Improvement
Voltage (p.u)</td><td>Capacitor Sizes
Q (MVar)</td></tr>
<tr><td>3</td><td>0.8990</td><td colspan="2">0.9326</td><td colspan="2">0.0336</td><td>50</td></tr>
<tr><td>8</td><td>0.9530</td><td colspan="2">0.9739</td><td colspan="2">0.0312</td><td>85</td></tr>
<tr><td>10</td><td>0.9278</td><td colspan="2">0.9526</td><td colspan="2">0.0309</td><td>60</td></tr>
<tr><td colspan="6">Total Size of Capacitor</td><td>195</td></tr>
<tr><td colspan="2">Without Capacitor</td><td colspan="2">With Capacitor</td><td colspan="3">Improvement</td></tr>
<tr><td>P_{loss} (MW)</td><td>Total Q (Injection) (MVar)</td><td>P_{loss} (MW)</td><td>Total Q (Injection) (MVar)</td><td>P_{loss} (MW)</td><td colspan="2">Q (MVar)</td></tr>
<tr><td>9.438</td><td>672.937</td><td>7.156</td><td>614.358</td><td>2.282</td><td colspan="2">58.579</td></tr>
</table>

As seen in the table, an improvement of 0.0336 (3.74%), 0.0312 (3.27%) and 0.0309 (3.33%) was recorded in the voltage profile of buses 3, 8 and 10 respectively. Similarly, the 10-bus system's total actual power loss is reduced by 2.282MW (17.55 percent), and the total reactive power injection into the network is reduced by 58.579MVar (8.70%); as a result of installation of a capacitor with a combined capacity of 195MVar on the three optimal buses.

V. CONCLUSION

This study has been able to develop a strategy to detect most delicate buses to put capacitors utilizing fuzzy logic and its size is determined utilizing Index Based Method in the picked transmission subsystem. The FES considers loss minimization and voltage profile improvement at the same time while concluding which buses are the best for placement (installation) of capacitor. Hence, a decent trade off of loss reduction, voltage profile improvement is accomplished. In general, improvement in voltage profile and decrease in power losses upgrade system stability and efficiency. The proposed strategy has been tried on a transmission system comprising of ten (10) buses. It was seen that voltage profile of buses 3, 8, and 10 improved by 3.74%, 3.27%, and 3.33% individually. Essentially, complete real power losses decreased by 17.55% while absolute reactive power injection to the network reduced by 8.70%. In the meantime, it is profoundly expected that an expansion of the strategy to the bigger networks of Nigeria's power system will yield a comparative positive outcome.

The case study system, which is a relatively small network of 10 buses, reveals that the proposed approach can yield a significant improvement of voltage profile and reduction in total real power losses, plus reactive power injection to the network. We however recommend that the efficiency of the approach be verified on larger system of Nigeria network with about 31 buses. This may necessitate the use of extra intelligent categorization algorithms in order to reach a high level of accuracy.

REFERENCES

[1] Akpojedje O. F. Onobotsere, E. M. Mormah; C. E. & Onobotsere, E. P. (2016). A comprehensive review of Nigeria electris power transmission issues and rural electrification challenges. International Journal of Engineering Trends and Technology, 31(1), 2016.

[2] Amadi,H. N. & Okafor, E.N.C (2015. The effects of technical and non-technical losses on power outages in Nigeria. International Journal of Scientific and Engineering Research 6:9.

[3] Andreich, R. G. Brown H. E. Happ. H. H. & Person, C. E. (1968). The piecewise solution to the impedance matrix load flow," IEEE Transaction on Power Apparatus and Systems. 2(9), 3.

[4] Arrilaga J., Arnold, C. P. & Harker, B. J. (1999) Computer modeling of electrical power systems. Wiley Publications, New York, 35.

[5] Bolaji A. (2014). The fuzzy systems handbook, Cambridge MA Academic Press, 12.

[6] Gupta, J. B. Kataria, S. K. @ Sons, New Delhi, (2008). A course in power system, 43.

[7] Holmblad. L. P., Ostergaard, J. J. Gupta, M. M. & Sarchexz, E. (1982). Control of cement kiln by fuzzy logic, North Holland, 389.

[8] Komolafe, O. A. Omoigui, M. O. & Momoh, A (2003). Reliability investigation of the Nigeria Electric Power Authority Transmission Network in a Deregulated Environment Industry Applications Conference, 2003; 38th IAS Annual Meetng. Conference Record (1328-1331). Institute of Electrical and Electronics Engineering.

[9] Lave, L., Apt, J., Morgan, G. (2005). Worst case electricity scenarios: The Benefit & Costs of prevention. CREATE Symposium. University of South California.

[10] Mamdani, E. H. & Assilion, S. (1974). An experiment in linguistic synthesis with a Fuzzy Logic Controller. Intl J. Man-Machine Stud 7,1,

[11] Mehta, V. K. & Mehta, R. 92008). Principles of power system, Chand, s and Company Ltd. 4th Revised Edition, 127-128.

[12] Mckhamer, S. F., Elawary, M. E. Soliman, S. A,. Moustafa, M. A. & Mansour, M. (2002). New Heuristic Strategies for Reactive Power Compensation of Radial Distribution Feeders. IEEE Trans. Power Delivery, 17(4), 1128.

[13] Momoh, J. A. (2009), "Electric power system application of optimization", CRC Press, 2nd Edition 43.

[14] Monticelli, A. (1999). State estimation in electric power system: A generalized approach Norwell, M. A: Kluwer, 70.

[15] Nagothu, K. S., Arroju, M. & Maheswarapu, S. (2013). A novel approach to sustainable power system expansion planning with inclusion of renewable energy. 7th international power engineering and optimization conference (PEOCO), (535-539), Langkawi, Malaysia: Institute of Electrical and Electronics Angering

[16] Nigeria Power Baseline Report (2015), Report developed by the advisory power team, office of the Vice President, Federal Government of Nigeria in Conjuction with power Africa.

[17] Nizar, A. H., Dong, Z. Y. & Wang, Y. (2008). Poer utility non-technical loss analysis with extreme learning machine method (2008) IEEE Transactions on Power Systems, 23(3), 946.

[18] Robinson, M. H. (1994). Basics of power systems, Milton publishers ltd, first edition, 10.

[19] Samuel, I., Katende, J. & Ibikunle, F. 92012). Voltage collapse and the Nigerian National Grid, EIE's 2nd Intl' Conf. Comp., Energy, Net. Robotics and Telecom.

[20] Stagg, G. W. & El-Abiad, A. H. (1968). Computer methods in power systems, McGraw Hill, New York, 65.

[21] Stevenson, W. D. Jr., (2003). Elements of Power System analysis, fourth edition, McGraw-Hill International Edition, Singapore, 34.

[22] The World Bank (2009). Reducing Technical and non-technical losses in the power sector. Background paper for the World Bank Group Energy Sector Strategy.

[23] Tinney, W. F. & Hart, C. E. (1967). Power flow solution by Newton's method. IEEE Transactions on Power Apparatus and Systems, 4(3), 23.

[24] Tinney, W. F. (1972). Compensation methods for network solutions by optimal ordered triangular factorization, IEEE Transactions on Power Apparatus and Systems, 91(1), 123-127.

[25] Udoh, B. E. (2014) The causes and effects of electric power outages in the North East zone of Nigeria, using Mubi in Adamawa State as a case study, International Journal of Industrial Electronics and Electrical Engineering. 2.2,