Regional Grid System Design Results for the Nigeria Electric Power System with the Aid of Neplan

By

Yusuf Jibril, Boyi Jimoh and Aminu Muhammad Bashir
Department of Electrical Engineering
Ahmadu Bello University, Zaria

Abstract:

An attempt has been made, though by use of computer programme, Network Planning (NEPLAN), to look at the possibilities of Regional Electric Power Grid System in Nigeria based on the existing electric power system structure. The effects, as in voltages at various main busbars and line losses, were discussed.

1.0. Introduction:

The erratic nature of power supply within Nigeria as a developing economy in recent decades has continued to be a source of national concern. Outages, brown-outs and load-shedding have become prominent characteristics that have led to reduced quality of service of the Power Holding Company of Nigeria plc (PHCN), erstwhile National Electric Power Authority (NEPA). Even if the generating capacity is increased, the line losses, due to long distances between various power stations and load centers, will still be comparatively very high. This is mainly because the Nigeria grid system with a single National Control Center (NCC) in Oshogbo, of today, is a radial one and therefore has a low reliability index among other characteristics.

Due to economical, geographical and environmental constraints, electrical energy is generated in large quantities at plants which are generally insular to load centers. This necessitates an extensive power supply network between the stations and consumer loads. Depending on the voltage level at which electrical power is being transported, this network could be divided into 2: the transmission system and the distribution system. The transmission system of an area is known as a grid and this transfers bulk electrical energy at high voltage level(s); consumers not being supplied enroute [1]. In a country, different grids are interconnected to from regional grids and further interconnection of regional grids (through tie-lines) results in a national grid. Each regional grid comprises of the basic components of a power system (generation plant(s), a transmission network and distribution systems) and thus could operate independently; it is this characteristic that provides the accepted norm for the operation of interconnected regional grids:

1. Each system (control area) should provide enough capacity to carry its expected load at desired frequency with provision for adequate reserve and regulating margin.
2. Each system (control area) should operate in such a way that it will not impose a regulating burden (changes in generation resulting from load changes in an adjacent system) on intermediate systems[2].

Whereas the advantages of adopting a regional grid system are in themselves quite conspicuous, the claim of a possible reduction of technical losses by this arrangement could be verified. Comparism was drawn between the performance of the existing 330KV network and a proposed model under a typical system loading condition; Evaluations are based on the load flow results of four case studies:

Case 1:The existing 330KV network with compensation

Case 2:The existing 330KV network without compensation

Case 3:The proposed model with islands tied

Case 4:The proposed model on island mode

Since electric power networks are non-linear in nature, a mathematical solution to these networks would require the use of any of the established iterative methods. A means would therefore have to be devised to enable digital computer based solutions i.e. the computer using its basic arithmetic and logic operations [3].

Digital computer applications to load flow studies involves the writing of computer programme which processes adequate system data input into the mathematical model of a network under consideration to yield at various points, the values of desired system parameters. In the last six decades, this idea alongside other formulations for power system design and analysis has evolved into a range of well-developed specialized and general-purpose packages (such as Network Planning – NEPLAN). These softwares equip today's power engineer with a tool that guides decision making thus broadening the energy prospects of the modern world. NEPLAN is used for the above-mentioned evaluations i.e. investigate the structural modifications of the existing network.

2.0 Proposed Regional Grid Model

A central issue in the power industry and among alternative power advocates is how best to eliminate the bottlenecks in the transmission grid: by building more long-distance transmission lines or by generating more power in small quantities close to where it is needed [4].

The proposed model is an interconnected regional grid system that would have two obvious benefits: improved reliability of the power supply and reduced electricity costs (as transmission costs would be reduced) [5]

With the proposed model, the present radial national grid system is to be broken down into four regional grid networks as follows:

- NorthWest/Central
- NorthEast
- SouthWest
- SouthEast

3.0. The study tool: NEPLAN:

NEPLAN is a user-friendly planning and information system software package for electrical-gas-and water-networks. In the electrical field, it can be used for network designing and computation of system parameters under normal or fault conditions. This is achieved by the following steps:

- Providing a graphical representation of the network (typically in layers) using symbols.
- Entering data of network elements
- Using libraries (optional)
- Running calculations
- Presenting the results of calculations in a manner adapted to the objective of the analysis [6].

An electric power system consists of nodes and elements. Referring to Figure 1 below, the essential concepts to understanding how the NEPLAN environment treats these can be described:

A node is the connection point of 2 or more elements or a location where electrical energy will be produced or consumed (generator, load). It is described by its Name, Nominal system voltage in kV, Zone and area, and Type (main bus bar, bus bar, sleeve, special). The nominal system voltage (U_n) is the line-to-line voltage for which a power system is designated and on which several characteristics of the power system has been referred. This parameter is entered during the node data input.

An element corresponds to a network component such as a line, transformer or electrical machine. In a network, each element could be classified as being active or passive and is mapped topologically by a starting and an ending node. The electrical description of an element is given by its rated current, rated power and rated voltage, it's parameters such as losses and reactances. These are entered with input dialogs. Active elements are network feeders (neighboring networks), asynchronous machines, synchronous machines and power station units. For a load flow calculation, these elements are represented by PQ – nodes or slack nodes; network feeders are usually modeled as slack nodes.

In NEPLAN, switches are used to change the network topology. A switch could be one of two types: a physical switch or logical switch. Physical switches are couplings, circuit breakers (CB's) and disconnect or load switches. Logical switches are fictive switches which are assigned to all elements by the system.

A partial network is an independent network (otherwise referred to as an island); it has no connection to any other network. In NEPLAN, these are created by opening logical or physical switches. A demonstration of this is shown in Figure 2.

3.0. Methodology:

Using a typical system loading profile that cumulates to a value of 3000MW (Appendix II), the load flow results of the respective case studies is determined for analysis; In order to provide for the contingencies (lack of generation) in the NE and NW regions, two assumptions have been incorporated into case 3 and 4:

(i) A fictive 450MVA synchronous generator has been brought on-bars at node GOMBE 3 to service the NE.

(ii) Shiroro and Jebba Hydro stations have been designated to take up the load of the NW in addition to their zonal load.

Other assumptions guiding the enquiry are:

- The effect of transformer tap setting is negligible
- The phase shifting of transformers is negligible
- Transformer losses is negligible
- Load power factor is 0.85
- Voltage regulation is –10% to +10% of nominal value (330KV)
- Performance indicators for analysis are:
    - system voltage profile and
    - line losses

The choice of these indicators was based on:

i. their availability from the computation process

ii. their importance to system stability considerations as well as to providing an economical operation.

4.0. Results and discussions:

4.1. System voltage profile.

With reference to table 1 which is a collation of the system voltage profile under the respective case studies, the following can be inferred:

(i) With the exception of Kano, Kaduna, Jos and Gombe, the bus bar voltage values over the nodes remain relatively the same for cases 1, 2 and 3.

(ii) Based on the statistical tools employed, case 1 provides the best profile with the least range, highest mean and least variance of data. It is closely followed by case 3; the source of disparity being from the nodes mentioned in (i).

(iii) Case 4 has a better profile than 2 in the NE but introduces poorer voltage values at some nodes in the SW; heavy loads are at the ends of a radial island network.

It is important to note the following:

1. An improvement of the voltage profile of the existing network can be effected by reactive power compensation or a variation of generation pattern (which the proposed model achieves); the results in this case being somewhat similar. Subject to economical scrutiny, a good managerial proposition would be to expand generation capacity to meeting a growing demand while still being able to maintain a good profile. A corrective measure of the scenario in the SW under case 4 would be to introduce generation at other nodes.

2. The nodes mentioned in inference (i) are identified as critical points within the system. In particular, the distance between nodes JOS 3 and GOMBE 3 constitutes a major bottleneck to operators as this line serves as the key corridor for power transfer to the NE; under the existing configuration, supply from the National grid is accessible to this region through a single channel.

4.2. Line losses:

Referring to Table 2, the following can be inferred as regarding power flows under the respective case studies:

i. Case 3 has the least active power losses which imply the highest efficiency. Case 4 has the least efficiency

ii. Compared to case 1 and 2, case 3 saves 3.39 MW and 8.39 MW respectively.

iii. The highest reactive power loss is recorded in case 3.

4.3. High reactive power losses

The load flow results indicate very high reactive power losses. This could be explained thus: When operating, transmission lines produce and consume reactive power (Q) such that:

i. The shunt capacitance of the line produces $Q \propto V^2$. Since V is being regulated, the value of Q could be said to be relatively constant:

$Q_{produced} = V^2B, B = \omega C$ ....(4.01)

Where B – shunt susceptance of the line

ii. The series inductance of the line consumes $Q \alpha I^2$. Since I varies from heavy-load periods to light-load periods, the value of Q is variable

$Q_{consumed} = I^2X, X = \omega L$ ......(4.02)

Where X-line series reactance

Now the natural characteristic impedance loading (P_o) of a line is the loading at which

$Q_{produced} = Q_{consumed}$

Equating (4.01) and (4.02)

$V^2B = Z_0 = V/I = \sqrt{(X)}/B = \sqrt{(\omega L)}/\omega L = \sqrt{(L)}/L$

Hence, the natural impedance loading is

$Po = V^2/Z_O$......(4.03)

As a rule of thumb, the natural impedance loading of an overhead 330KV line is about 350 MW. And it is the deviation from this value that gives rise to the requirement for the respective reactive compensation types [7].

Comparing the value of P_o with the loading at the respective load busses on the networks considered, the NEPA network can be regarded to as being light-loaded; by implication, capacitive: From standards V^2B is given for 330KV lines as 38Mvar/100km and thus for the 5300km NEPA transmission network it implies that:

Total line $Q_{produced}$ = (38MVar/100MVar) x 5300km = 2014MVar ...... (4.04)

$Q_{absorbed}$ by the system (generators, loads and line) is not able to offset this value (by a wide margin) hence the large values of losses recorded.

Despite the capacitive nature of the system which suggests room for higher successive loading, this assumption could be misleading because P and Q transmission is dependent on ΔV and $\Delta\delta$ between nodes.

4.4 Performance of case 4

The proposed model operating on island mode (case 4) was found to have the least efficiency. A suggestion as to explaining this poor performance is that some of the partial networks created are radial in nature; The SW which under the existing network had been loaded multi-directionally (from the central, SS and SW zones) had lost this property. However, as more generation plants are introduced at other nodes, this impairment would be corrected.

5.0 Conclusion:

The analysis confirms an improvement in the performance of the existing network given a structural modification as proposed; In both respects, the proposed model (case 3) has a better output than the existing network (case 2). Since dealing with non-linear networks, it would also be safe to speculate that for successive increase in system loading, improvement in performance is likely to become more prominent.

References

1. William D. S. Jr.(1962): "Elements of Power System Analysis", 2nd Edition, Mcgraw-Hill KogaKusha Ltd. pp1-13, 214-224.

2. Gupta, B. R. (1993):"Power System Analysis and Design", 2nd Edition, A. H. Merkr and Co. Ltd. Pgs 1-3, 198-221, 232-248.

3. El Abaid, A. H., Stagg, G. W.(1968): "Computer Methods in Power System Analysis", Mcgraw-Hill Book Company, 1968, pp 258-341.

4. "Regional Grid Reduces Costs" http://findarticles.com/p/articles/mi_go2340/is_200312/ai_n6605550

5. Feder, B. J. (2003), "Redrawing the Electric Power Grid",http://healthandenergy.com/electricpower_grid.htm

6. NEPLAN Users Guide v5, pp1.1-1.9.

7. NEPA (2003): Executive Summary Draft Report, "Reactive Compensation Study", Omega System Tractabel Engineering., pp 6-16.

Figure 1

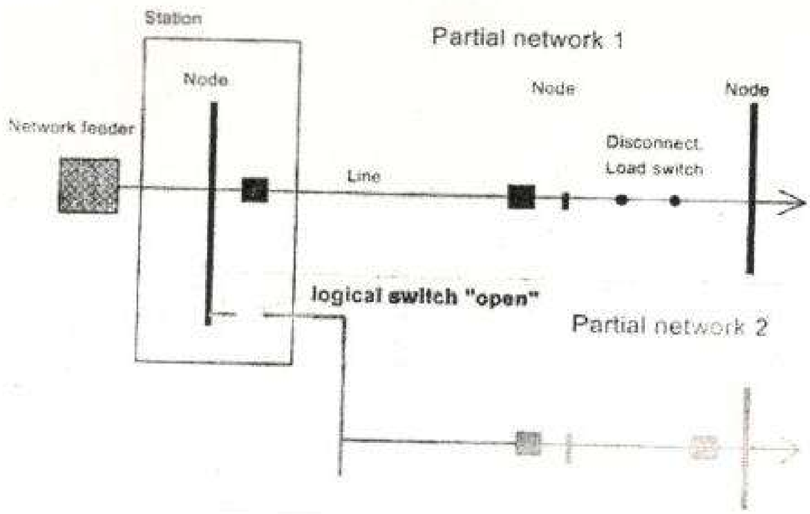

Figure 2

TABLE 1: Statistics for the Analysis of Voltage Profiles

STANDARD DEVIATION

$\sqrt{(\frac{\sum X^2 f}{n} - (x)^2)}$

ZONE	NODE	BUSBAR VOLTAGE (V)			
		CASE 1	CASE 2	CASE 3	CASE 4
	BIRNIN KEBBI 3	329.4	329.4	329.4	329.4
	KANO 3	328.0	284.7	295.3*	293.1
	KAINJI 3	330.0	330.0	330.0	330.0
NW/CENTRAL	KADUNA 3	328.6	314.9	323.6	321.8
	JEBBA G.S. 3	330.0	330.0	330.0	330.0
	JEBBA T.S. 3	330.0	330.0	330.3	329.9
	SHIRORO 3	330.0	330.0	330.0	330.0
NE	JOS 3	331.7	289.1	323.0	317.3
	GOMBE 3	341.9*	268.6*	330.0	330.0
	OSOGBO 3	327.3	327.3	327.3	280.2*
	AYEDE 3	318.3	318.3	318.3	282.6
SW	AKANGBA 3	322.0	322.0	322.0	306.7
	IKEJA – WEST 3	323.6	323.6	323.6	308.4
	AJA 3	329.5	329.5	329.5	329.5
	EGBIN 3	330.0	330.0	330.0	330.0
	AJAOKUTA 3	335.0	335.0*	335.0*	332.7*
	BENIN 3	329.9	329.9	329.9	[illegible]27.7
	ONITSHA 3	309.1	309.1	309.1	306.2
	NEW HAVEN 3	302.8*	302.8	302.8	299.8
SE	SAPELE 3	330.0	330.0	330.0	330.0
	DELTA IV 3	332.1	332.1	332.1	330.8
	ALADJA 3	331.1	331.1	331.1	330.2
	ALAOJI 3	309.3	309.3	309.3	3.06.2
	AFAMIV 3	311.0	311.0	311.0	307.9
		39.10	66.40	39.70	52.50
		325.87	318.65	323.44	317.52
		9.10	16.93	10.22	15.99

TABLE 4.2: Statistics for the Analysis of Line Losses

	PARAMETER	CASE			
		1	2	3	4
Input	P_{ins} MW	3040.80	3045.80	3037.41	3075.34
	Q_{ins}MVar	181.40	465.02	351.74	1278.0
Output	P_{loss}, MW	40.80	45.80	37.41	75.34
	Q_{loss}, MVar	1498.6	1394.2	1507.5	581.22
Efficiency (%)		98.66	98.50	98.77	97.55

*P_{out} = 3000MW

APPENDEX I:

POWER GENERATING STATIONS, TYPES AND RATINGS

Station	Type	Nos. of units	KVout	MWout
Kainji	Hydro	8	16.0	760
Afam I-III	Gas Turbine	12	10.5	260
Afam IV	Gas Turbine	6	11.5	450
Afam V	Gas Turbine	5	11.5	750
Egbin	Steam Turbine	6	16.0	1320
Egbin*	Gas Turbine	9	11.5	270
Jebba	Hydro	6	16.0	570
Sapele	Steam Turbine	6	16.0	720
Sapele*	Gas Turbine	4	10.5	300
Shiroro	Hydro	4	16.0	400
Delta II	Gas Turbine	6	11.5	120
Delta III	Gas Turbine	6	11.5	120
Delta IV	Gas Turbine	6	11.5	600

APPENDIX II:

SYSTEM LOADING PROFILE

Busbar	Zone	Load (MW)
BIRNIN KEBBI 3	NW	78
KANO 3	NW	180
KADUNA 3	Central	140
JOS 3	NE	118
GOMBE 3	NE	120
JEBBA T.S.3	Central	30
SHIRORO 3	Central	200
AYEDE 3	SW	230
OSOGBO 3	SW	210
AJAOKUTA 3	SS	17
AKANGBA	SW	260
IKEJA WEST 3	SW	350
BENIN 3	SS	150
ONITSHA 3	SS	180
NEW HAVEN 3	SS	100
AJA 3	SW	120
EGBIN 3	SW	75
DELTA IV 3	SS	78
ALADJA 3	SS	44
ALAOJI 3	SS	200
AFAM IV 3	SS	120
TOTAL		**3,000**

As at 2004