PSAT Model- Based Voltage Stability Analysis for the Kano 330KV Transmission Line

S.M. Lawan
Department of Electrical Engineering, Kano University of Science and Technology, Wudil Nigeria

Abstract

Voltage instability problems increasing day by day because of demand increase. It is very important to analyze the power system with respect to voltage stability. This paper investigates the voltage stability analysis of Kano 330KV Transmission line. The test system network consisting of 11 buses, 4 generating stations, 4 transmission lines and 1 control centres, Power System Analysis Toolbox (PSAT) software was used to carried out simulation analysis, using the relevant data as obtained from power holding company of Nigeria [PHCN], to determine bus voltages, real and reactive power flows and losses of the transmission lines and generators The results obtained showed that the Maximum Loading Point is max λ = 3.97 p.u. Also load active powers are in base and maximum cases are P base = 7.00 p.u. and P max = 7.189 p.u. respectively. The weakest bus also is identified bus8 with voltage 0.948 p.u. Also load active powers are in base and maximum cases are P base = 9.67p.u. and P max = 17.67 p.u. respectively. The weakest bus also is identified bus8 with voltage 0.948 p.u

Key words: PSAT, 330KV Transmission Line, Voltage Stability, Power Flow

I. Introduction

As power systems become more complex and heavily loaded, voltage stability becomes an increasing serious problem. Voltage problems have been a subject of great concern during planning and operation of power systems due to the significant number of serious failures believed to have been caused by this phenomenon. It is therefore necessary to develop Voltage Stability Analysis (VSA) tools in today's Energy Management Systems (EMS). [1]

Indeed, numerous authors have proposed voltage stability indexes based upon some type of power flow analysis. A particular difficulty being encountered in such research is that the Jocobian of a Newton-Raphson power flow becomes singular at the steady state voltage stability limit. In fact, this stability limit, also called the critical point, is often defined as the point where the power flow Jacobian is singular. As a consequence, attempts at power flow solutions near the critical point are prone to divergence and error.

This paper demonstrates how singularity in the Jacobian can be avoided by slightly reformulating the power flow equations and applying a formulation will be implemented in the ATC Toolbox with MATLAB and tested on 330kv buses to determine power flow solution using POWERSAT (PSAT) technique [2].

II. Continuation Power Flow

The conventional power flow has a problem in the Jacobian matrix which becomes singular at the voltage stability limit. This problem can be overcome by using continuation power flow [3].Figure 1 shows the predictor – corrector scheme used in the continuation power flow.

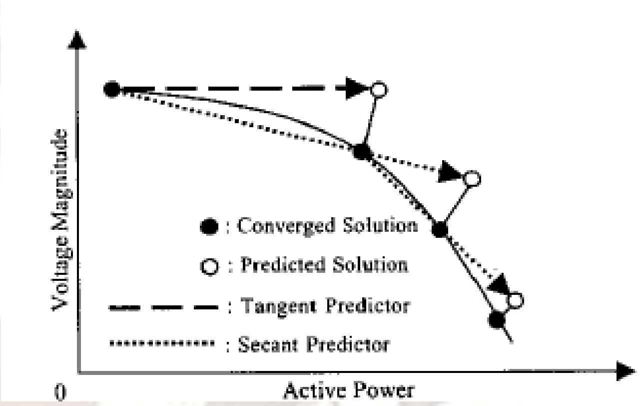

Figure1. An illustration of the Continuation power flow [3]

From the Newton-Raphson, load flow equations can be written as:

$$P_i - \sum_{j=1}^{N} Y_{ij} V_i V_j \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (1)$$

$$Q_i - \sum_{j=1}^{N} Y_{ij} V_i V_j \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (2)$$

The new load flow equations consists of load factor can be expressed as:

$$P_{Li} = P_{i0} + \lambda(K_{Li} S_{\Delta base} \cos\psi_i)$$
$$Q_{Li} = Q_{Li0} + \lambda(K_{Li} S_{\Delta base} \sin\psi_i)$$

(3)

Where the following definitions are made;

P_{Li0}, Q_{Li0} – original load at bus *i*, active and reactive respectively.

K_{Li} - multiplier to designate the rate of load change at bus *i* as λ changes.

Ψ_i - power factor angle of load change at bus i.

III. PSAT METHOD

PSAT is a Matlab toolbox for electric power system analysis and control. The command line version of PSAT is also GNU Octave compatible. PSAT includes power flow, continuation power flow, optimal power flow, and small signal stability analysis and time domain simulation. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides a user friendly tool for network design.

PSAT core is the power flow routine, which also takes care of state variable initialization. Once the power flow has been solved, further static and/or dynamic analysis can be performed. These routines are:

1. Continuation power flow;
2. Optimal power flow;
3. Small signal stability analysis;
4. Time domain simulations;
5. Phasor measurement unit (PMU) placement.

In order to perform accurate power system analysis, PSAT supports a variety of static and dynamic component models, as follows:

- Power Flow Data: Bus bars, transmission lines and transformers, slack buses, PV generators, constant power loads, and shunt admittances.
- CPF and OPF Data: Power supply bids and limits generator power reserves, generator ramping data, and power demand bids and limits.
- Switching Operations: Transmission line faults and transmission line breakers.
- Measurements: Bus frequency and phasor measurement units (PMU).
- Loads: Voltage dependent loads, frequency dependent loads, ZIP (impedance, constant current and constant power) loads, exponential recovery loads, thermostatically controlled load, Jimma's loads, and mixed loads.
- Machines: Synchronous machines (dynamic order from 2 to 8) and induction motors (dynamic order from 1 to 5).
- Controls: Turbine Governors, Automatic Voltage Regulators, Power System Stabilizer, Over-excitation limiters and Secondary Voltage Regulation (Central Area Controllers and Cluster Controllers).
- Regulating Transformers: Load tap changer with voltage or reactive power regulators and phase shifting transformers.
- FACTS: Static Var Compensators, Thyristor Controlled Series Capacitors, Static Synchronous Source Series Compensators, Unified Power Flow Controllers, and High Voltage DC transmission systems.
- Wind Turbines: Wind models, Constant speed wind turbine with squirrel cage induction motor, variable speed wind turbine with doubly fed induction generator, and variable speed wind turbine with direct drive synchronous generator.
- Other Models: Synchronous machine dynamic shaft, dynamic phasor RLC series circuit, sub-synchronous resonance model, Solid Oxide Fuel Cell, and sub transmission area equivalents.

Besides mathematical routines and models, PSAT includes a variety of utilities, as follows:

1. one-line network diagram editor (Simulink library);
2. GUIs for settings system and routine parameters;
3. User defined model construction and installation;
4. GUI for plotting results;
5. Filters for converting data to and from other formats;
6. Command logs.

Finally, PSAT includes bridges to GAMS and UWPFLOW programs, which highly extend PSAT ability of performing optimization and continuation power flow analysis [4]

IV. Under Study Network

Our test system is Kano 330KV Transmission system. Stimulated diagram of System with the following components and statistics as shown in table 1and 2 below:

Table 1: Network Statistics

Buses	11
Lines	8
Transformers	4
Generators	4
Loads	2

Table2: Solution Statistics

Number of Iterations	4
Maximum P mismatch [p.u.]	0
Maximum Q mismatch [p.u.]	0
Power rate [MVA]	100

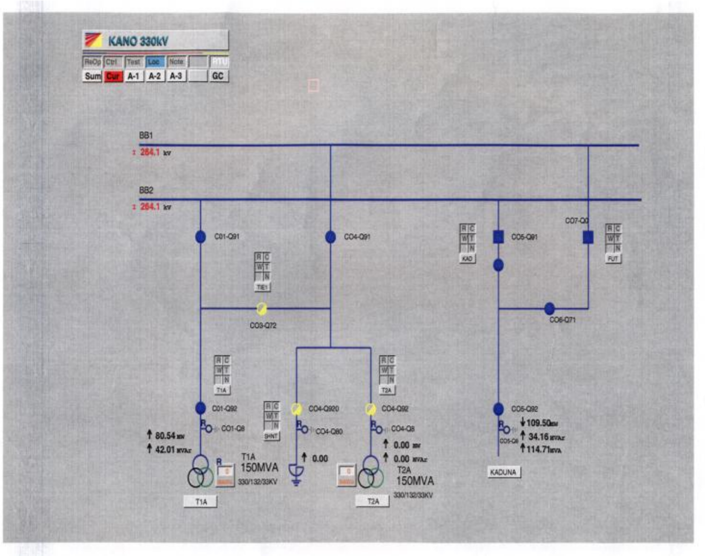

Fig. 2 Kano 330KV Transmission system

In this system generation unit are modeled as standard PV buses and loads are represented as constant PQ loads. The P and Q load powers are not voltage dependent and are assumed to change as follows:

$$P_l = P_{l0}(1+\lambda) \quad (4)$$

$$Q_l = Q_{l0}(1+\lambda)$$

Where P_{L0} and Q_{L0} are the active and reactive base loads, whereas P_L , and Q_L , are the active and reactive loads at bus L for the current operating point as defined by λ , table 2

V. Simulation Results

To analyze of static voltage stability to survey contingencies of power system (like the line outages and/or generation unit outages) with Psat software [5]. The continuation power flow for normal system manner is done that all generation units and lines are in the network and in fact no contingencies has occurred in system. Maximum Loading Point is max λ = 3.97 *p.u.* Also load active powers are in base and maximum cases are P *base* = 7.00 *p.u.* and P max = 7.189 *p.u.* respectively. The weakest bus also is identified bus8 with voltage 0.948 *p.u.* Also load active powers are in base and maximum cases are P *base* = 9.67*p.u.* and P max = 17.67 *p.u.* respectively. The weakest bus also is identified bus8 with voltage 0.948 *p.u*

A. *The results of simulation for the network with CPF method* Table 3, 4,5 and 6 shows the results of single generation units' applying continuation power flow.

B.

Table 3: Power Flow Results

Bus	**V [p.u.]**	**phase [rad]**	**P gen [p.u.]**	**Q gen [p.u.]**	**P load [p.u.]**	**Q load [p.u.]**
Bus 01	1.030	0.353	7.000	1.825	0.000	0.000
Bus 02	1.010	0.183	7.000	2.284	0.000	0.000
Bus 03	1.030	-0.119	7.189	1.724	0.000	0.000
Bus 04	1.010	-0.296	7.000	1.936	0.000	0.000
Bus 05	1.007	0.241	0.000	0.000	0.000	0.000
Bus 06	0.979	0.065	0.000	0.000	0.000	0.000
Bus 07	0.963	-0.082	0.000	0.000	9.670	-1.000
Bus 08	0.948	-0.323	0.000	0.000	0.000	0.000
Bus 09	0.974	-0.560	0.000	0.000	17.670	-2.500
Bus 10	0.985	-0.414	0.000	0.000	0.000	0.000
Bus 11	1.009	-0.234	0.000	0.000	0.000	0.000

Table 4: Line Flows

From Bus To Bus	**Line [p.u.]**	**P Flow [p.u.]**	**Q Flow [p.u.]**	**P Loss [p.u.]**	**Q Loss [p.u.]**
Bus 05 Bus 06	1	7.000	1.002	0.123	1.191
Bus 06 Bus 07	2	13.877	1.210	0.202	2.008
Bus 07 Bus 08	3	2.002	0.079	0.048	0.303
Bus 08 Bus 09	4	1.954	-0.224	0.047	0.382
Bus 08 Bus 09	5	1.954	-0.268	0.047	0.293
Bus 11 Bus 10	6	7.189	0.866	0.129	1.245
Bus 09 Bus 10	7	13.856	0.177	0.204	2.026
Bus 07 Bus 08	8	2.002	0.123	0.048	0.391

Bus 01 Bus 05	9	7.000	1.825	0.000	0.822
Bus 02 Bus 06	10	7.000	2.284	0.000	0.886
Bus 04 Bus 10	11	7.000	1.936	0.000	0.862
Bus 03 Bus 11	12	7.189	1.724	0.000	0.859

Table 5: General Summary Report

Power	Total Generation	Total Load	Total Loses
Real Power [p.u]	28.19	27.34	0.85
Reactive Power [p.u]	7.77	-3.50	11.27

Table 6: Newton-Raphson Method for Power Flow Computation

Iteration	Convergence
1	0.048618
2	0.0030922
3	1.7363e-005
4	4.4468e-010

Table 7: State Matrix Eigen values Summary

Dynamic Order	24
Number of Eigen values with Re(MU) < 0	19
Number of Eigen values with Re(MU) >0	0
Number of real Eigen values	16
Number of Complex Pairs	4
Number of Zero Eigen values	6

VI. CONCLUSION

The Study 330KV network has a relatively low voltage drop in the transmission lines though, there was an obvious improvement over the existing case, some buses and generators of high reactive power values need to be compensated using either the conventional compensators such as reactors, capacitor banks, and tap changing transformers or the use of FACTS devices. This however will enable the 330KV transmission network to be used very close to its thermal limit, yet still remain very stable, reduce transmission line congestion and maintain grid stability and effective interconnectivity.

Reference

[1] X. Wang, G.C. Ejebe, J. Tong, & J.G. Waight "Preventive/Corrective Control for Voltage Stability Using Direct Interior Point Method" IEEE Transaction on Power Systems, Vol. 13, No. 3, August 1998, pp. 878 883.

[2] Werner C. Rheiboldt, & John V. Burkardt 'Psat Toolbox in Matlab' ACM Trans. On Mathematical Software, Vol. 9, no. 2, 1983, pp 215-235

[3] Venkataramana Ajjarapu, Colin Christy,1992. "The continuation power flow a tool for steady state voltage stability analysis", IEEE Transactions on Power Systems, Vol.7, No. 1. February.

[4] A. P. Lerm, C. A. Canizares, and A. S. Silva, "Multi-parameter bifurcation analysis of the South Brazilian power system," IEEE Trans. Power

[5] F. Milano, "Power System Analysis Toolbox," Version 1.3.4, Software and Documentation, July 14, 2005.

[6] Operation Technology Inc, '*Electrical Transient Analyzer Program (ETAP)*' 2001.

[7] IEEE Standards Board Approved by American National Standard Institute "IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE Std 399 – 1991)

[8] PHCN 2011 report on generation profile of the country.

[9]. Komolafe,O.A And Omoigui M.O"An Assessment Of Reliability Of Electricity Supply In Nigeria.,"Conference Proceedings Of The 4th International Conference On Power Systems Operation And Planning (ICPSOP),ACCRA,Ghana, July 31-August 3,2000,Pp 89-91

[10] A. P. Lerm, C. A. Canizares, and A. S. Silva, "Multi-parameter bifurcation analysis of the South Brazilian power system," IEEE Trans. PowerSyst., vol. 18, pp. 737–746, May 2003.

[11] W. Marszalek and Z. W. Trzaska, "Singularity-induced bifurcations in electrical power systems," IEEE Trans. Power Syst., vol. 20, pp. 312–320, Feb. 2005.

[12] T. Gou and R. A. Schlueter, "Identification of generic bifurcation and stability problems in power system differential-algebraic model," IEEE Trans. Power Syst., vol. 9, pp. 1032–1044, May 1994.

[13] Y. V. Makarov, D. J. Hill, and Z.-Y. Dong, "Computation of bifurcation boundaries for power systems: A new _-plane method," IEEE Trans. Circuits Syst. I, vol. 47, pp. 536–544, Apr. 2000.

Appendix A: Existing Kano Transmission Line System

Appendix B: Kano 330KV Transmission Network