Scientia Africana, Vol. 10 (No.1), June 2011. pp 21-27
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 - 1931*

NIGERIAN ELECTRIC POWER SUPPLY QUALITY IMPROVEMENT

A. O. Ibe, I. E. Sofimieari, and O. Oputa
Department of Electrical/Electronics Engineering
University of Port Harcourt

Received: 8-3-10
Accepted: 4-5-11

ABSTRACT

Improving the quality of the Nigeria electric power supply means improving voltage, transient and frequency stabilities. Power system voltages are controlled by the reactive power component of the power supply; hence voltage and transient stabilities can be improved by using reactive power compensators to either supply or absorb reactive power from the system when necessary. Power flow algorithm can be developed and used to monitor the various bus voltages. Power equations can also be used to forecast the extra quantity of reactive power that will be needed to aid voltage stability at any given time. Also, power equations will be used to test if the available compensation devices can protect the power system from probable transient voltages. Frequency stability can be improved by using real power balance method. Power equations will be used to check for balance in real power generated to the system and real power demanded from the system (plus estimated real power losses). If there is no balance, real power load will then be added or withdrawn from the system if the imbalance favour the real power generated or the real power demanded respectively.

INTRODUCTION

Improving the quality of an electric power in terms of improving its voltage stability can be done in various ways. Ruduck et al (2000), explained that voltage stability can be achieved in any power system by controlling the generator output voltage, this is done at the excitation system of the automatic voltage regulation unit (AVR) of the generator. However, this method will be to expensive and time consuming as it involves building of new generating plant. The transformer tap changing method is another method that can be used to make power system voltage stable (Donde, V and Hisken, I. A, 2002). However, the stability limit of the transformer must not be exceeded if the desired function will be well performed. Reactive power balance method is another method that can be use to aid voltage stability of a power system network, (Thukaran et al, 1997). This method is easy, but it reduces profit made by service providers since some costumers are denied services by using this method. The last method that can be use to improve voltage stability thereby improving the quality of power system is the reactive power compensation method. This method involves generating reactive power by some means and transmitting the generated reactive power to the power network (Abido, M. A, 2007). This is the latest method of aiding voltage stability and it is gaining fast recognition by the day. By using this method, transient stability can also be improved as some of these compensation devices have the ability of absorbing reactive power from the network in cases of voltage rise in the system.

Improving the electric power quality by improving its frequency stability can be done by increasing the real power generated at the generating plant. This can be achieved by a good model and design of the speed control unit of the generator (Karaagas et al 2001). Real power balance method can also be use to aid frequency stability in the power system by comparing real power generated and real power

Scientia Africana, Vol. 10 (No.1), June 2011. pp
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 - 1931*

demanded (and that lost) using power equations (Daniel Trudnowski, 2002).

Improving voltage stability in the Nigerian power system

This can be done by installing the different types of reactive power compensation devices of different capacities at the various buses of the Nigerian power system. Among these devices, the synchronous condensers and the static vars systems should mainly be used as the base reactive power compensators. This is because they regulate the quantity of reactive power they generate (in proportionality to the reactive power imbalance in the network). Their speed of operation is also faster than the other compensation devices. In addition, they reduce harmonic distortion level and increase power factor. The shunt capacitor can be use as reserve (or extra) reactive power generator. It should be use to generate extra reactive power when the base reactive power generators have been stretched to their limit (at peak periods).

Model to monitor voltage stability

If the Nigerian power system comprises of n number of buses, then for a particular bus k, the conjugate of the apparent power S^*_k of that particular bus is given as

$$S^*_k = \quad P_k - jQ_k = V_k^* \left[\sum_{i=1}^{n} Y_{ki} V_i \right] \text{ .... (1)}$$

(Ibe A. O, 2002)

Thus, for a particular real and reactive power of a bus k, the voltage V_k of the bus is given as

$$V_k = \frac{1}{Y_{kk}} \left[\left[\frac{P_k - jQ_k}{V_k^*} \right] - \sum_{i=1, i\neq k}^{n} Y_{ki} V_i \right] \text{..........(2)}$$

where Y_{ki} is the admittance connecting the k^{th} bus and the i^{th} bus.

P_k and Q_k are the real and reactive power of the k^{th} bus respectively.

V_i is the voltage of the i^{th} bus

V_k^* is the conjugate of the last calculated voltage value of the k^{th} bus under review. All the values of the parameters are given in their per unit values. After five to ten iterations, the calculated voltage value in per unit is then multiplied by the based voltage value. The result is then compared with the standard value to see if the bus under review is experiencing voltage stability or instability.

Model to forecast the extra quantity of reactive power to aid voltage stability

If it has been observed that voltage instability exist in a particular bus, then the reactive power generators (the static vars systems, synchronous condensers, e.t.c) installed at those buses to boost reactive power available at the buses have generated their rated reactive power capacity but could still not solve the voltage instability problem in that bus. Thus, the control engineer will need to switch on the reserve reactive power generators (mainly the shunt capacitors). But he has to know the quantity of reactive power he needs to generate to solve that particular voltage instability problem. We can calculate the exact reactive power value that can give rise to voltage stability whenever voltage instability occurs in a particular bus (Ibe A. O, 2002). This is calculated by the equation

$$Q_k = -I_m \left[V_k^* \sum_{i=1}^{n} \left(Y_{ki} V_i \right) \right] \text{..................(3)}$$

Where I_m means imaginary of the RHS and V^*_k is the proposed stability voltage value in it's per unit values is then multiplied

When Q_k is got in it's per unit value, it is then multiply by the base value to get the actual value in MVAr. The reactive power quantity originally available in that bus is then subtracted from the calculated reactive power value; the difference is the extra active power that will be generated into the power system.

If the initial reactive power available in that bus is Q_1, then the reactive power that should be generation Q_{nd}, is given as

$$Q_{nd} = Q_k - Q_1 \text{ ....(4)}$$

The shunt capacitor (or combination of shunt capacitors, or any of the reactive power compensation devices that kept for reserved purposes) that will give that value of reactive power is then switched on.

After this has been got, the control engineer will then test with equation (2) if the resulting reactive power generated has successfully solve the voltage instability problem in that particular bus.

Improving frequency stability in the Nigerian power system

Frequency instability in the Nigerian power system is caused by insufficient real power in the system. We shall therefore use the real power balance method to ensure that the real power load in the network is equal or less than the real power generated into the network. However, due to real power loss in the system that cannot be accurately estimated, accurate balance cannot be made.

Model to test for frequency Stability.

For a power system with n buses and k power generating stations, if the real power available in the i^{th} bus is P_{Gi} and the real power demand at that same bus is P_{Di}, then the real power balance equation for that bus is given by

$$P_{Gi} = P_{Di} + P_L \text{ ....}(5)$$

For $1 \leq I \leq n$

where P_L is the total real power losses at that i^{th} bus.

The real power balance for the entire power system is given as

$$\sum_{i=1}^{k} P_{Gi} = \sum_{i=1}^{n} P_{Di} + \sum P_L \text{ ....}(6)$$

where ΣP_L is the total of all the losses in the power system.

Since the line resistance is usually very small, the total real power losses of the system is usually only a fraction of the total real power available in a particular bus or a fraction of the real power generated to the entire system. It can be roughly estimated as 5% of the total real power. Hence, the real power balance equation can be written as

$$P_{Gi} = P_{Di} + 0.05 P_{Gi} \text{ ....}(7)$$

and

$$\sum_{i=1}^{k} P_{Gi} = \sum_{i=1}^{n} P_{Di} + 0.05 \sum_{i=1}^{k} P_{Gi} \text{ ....}(8)$$

for the i^{th} bus and the entire power system respectively.

At every power station or substation, the frequency of power can be monitored by the frequency meter in the control room. Whenever the reading of the power frequency on the frequency meter falls below the standard range, the control engineer can quickly check his monitoring meters to see the quantity of real power he has and the quantity demanded; he can then refer to equations (7) and (8) to see if the equality exist. If the equality does not exist, then some feeders or loads in that frequency instability bus, or some load centers in the entire power system should be thrown away from the system.

Improving Transient stability in the Nigerian power system

Transient occur in a very short period of time. It is caused in the Nigerian power system by fault conditions, lightning striking lines, and switching of heavy loads (voltage dips). Transient stability can be maintained by using the shunt reactors, the static vars system and the synchronous condensers. Equation 3 can also be used to test if the shunt reactor (when it is switched on), the static vars systems and the synchronous condenser (all put together) can reduce the high voltage as it travels from one point (where it is generated) to another in the power system by reducing the high value of the reactive power generated along the power line during transient.

Model to test if reactive power absorbers can protect system against probable transient voltage

For a high voltage value of V_k to occur in a particular bus k, the reactive power absorber of that bus that can reduce this high voltage should have a capacity of Q_k as shown in equation 3 above and in this case, V_k^* is the conjugate of the expected or probable (high) transient voltage.

Hence, the shunt reactors (when switched on), the synchronous condensers and the static vars system should in combination have that reactive power absorbing capacity of Q_k. Its real value got by multiplying the per unit value of Q_k obtain from calculation by the base reactive power.

The synchronous condenser and the static vars system can absorb or generate reactive power from/to the power system, depending on which and the quantity is needed. This can take care of the unnecessary sharp rise in voltage that is encountered during faulty conditions of the power system. The shunt reactors will only be switched-on during cloudy and stormy weather as this is when lightning strokes are likely to strike and cause transient instability. The shunt reactors will only be switched on during bad weather because they absorb reactive power from the power system; hence, if they are always switched on, they will be absorbing the reactive power that we are trying to boost.

However, other protective systems should be installed at various stages of the Nigerian power system. These include the power generating stations which include the generators and the transformers, the bus bars, the feeders, transmission and distribution lines, and even distribution transformers. They should be well protected to prevent them from being damaged by faulty or transient voltages.

The process of calculating the various bus voltages is very complicated, lengthy and consumes a lot of time. Hence, we must find an easy way of computing the bus voltages for the control engineer. MATLAB version 7.5.0 can be use to do these computations. It is relatively easy, it saves time and it is not complicated.

SIMULATION EXAMPLE

An eight bus power system network (shown below) shall be use to analyze and assess the algorithm developed.

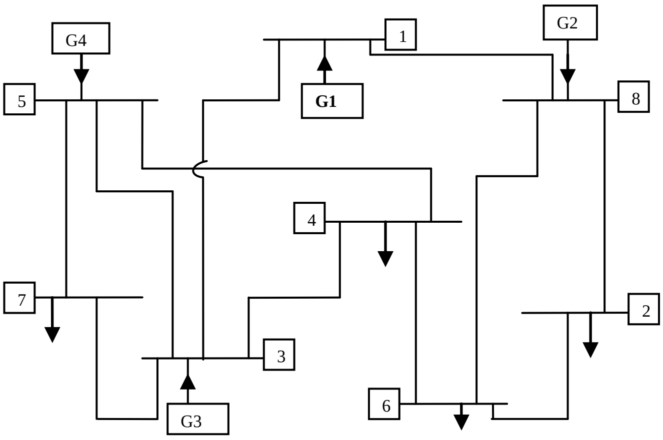

Fig 1: 8-Bus System

Their bus specification is given the table below

Table 1: Bus Data in Per Unit Values.

Bus	P_G	Q_G	P_D	Q_D	V
1	0.55	0.30	0.460	0.245	….
2	0.00	0.00	0.644	0.240	1.02<0
3	0.90	0.25	0.000	0.000	1.04<0
4	0.00	0.00	0.527	0.345	1.00<0
5	0.50	0.20	0.000	0.000	1.00<0
6	0.00	0.00	0.835	0.300	1.00<0
7	0.00	0.00	0.668	0.450	1.01<0
8	0.85	0.50	0.000	0.000	1.02<0

The admittance connecting the lines are given in the table below.

Table 2: Line Admittance in Per Unit Values.

Line	G	B
1-3	0.704861	-2.236108
1-8	1.005340	-2.347592
2-6	0.568435	-2.965321
2-8	1.213456	-1.905629
3-4	0.812304	-2.437604
3-5	1.061503	-3.021124
3-7	1.641236	-2.137604
4-5	1.756023	-0.961326
4-6	0.851297	-1.223107
5-7	1.021301	-3.420070
6-8	0.582187	-1.572981

The various bus voltages of this particular eight bus power system network can be computed with MATLAB version 7.5.0.

SIMULATION RESULTS

The computation using MATLAB version 7.5.0 gives the following results in the table below. Note that a common base voltage of 132KV was used.

Table 3: Simulation Result 1

BUS	VOL (PU)	VOL (KV)
1	$0.997650 + j0.047457$	130
2	$0.902345 - j0.098176$	120
3	$1.030176 + j0.068551$	134
4	$0.901314 - j0.007473$	118
5	$1.052510 + j0.050086$	135
6	$0.8031527 - j0.1259511$	107
7	$0.927710 - j0.01200$	122
8	$0.989624 + j0.047201$	131

Table 4: Simulation Results **2**

BUS	REACTIVE POWER (PU)
2	0.318
4	0.417
6	0.692

Table 5: SIMULATION RESULT 3

BUS	VOL (PU)	VOL (KV)
1	$0.998650 + j0.047475$	133
2	$0.902345 - j0.098176$	129
3	$0.997176 + j0.0669051$	130
4	$0.996414 - j0.008573$	128
5	$0.998910 + j0.057086$	131
6	$0.927822 - j0.183514$	131
7	$0.927810 - j0.01280$	122
8	$0.989624 + j0.047201$	131

DISCUSSION OF RESULTS

The results of simulation 1 gave the bus voltages and show that buses two, four and six are experiencing voltage instability. To estimate the minimum quantity of reactive power to be generated in those buses to aid voltage stability, the control engineer should perform his simulations using per unit voltage value of 1.00 + j0.00 for the buses experiencing voltage instability. The results of the simulations gave the reactive powers shown below (simulation results 2). When a minimum of these reactive powers of the results of simulation 2 have been generated at the respective buses, another simulation to know the resultant voltage stability status of the bus can then be performed. The voltages obtained after this simulations are given in the table below (simulation result 3). The results show that voltage stability has been achieved in all the buses.

Application of real power balance model to test for frequency stability

At all times, a frequency meter is always in front of the control engineer with which he can monitor the frequency of the power he is transmitting. Thus, he can always notice whenever there is a drop in the power supply frequency, hence, when the frequency fall away from the standard range (of 49.75Hz to 50.25Hz), the control engineer can quickly refer to equation 8 developed earlier to see if there is a balance between the real power generated and that generated and lost (in combination). Referring to the power system network under analysis, the total real power generated is

$$\sum_{i=1}^{4} P_{Gi} = P_1 + P_3 + P_5 + P_8$$

$$\sum_{i=1}^{4} P_{Gi} = 0.550 + 0.900 + 0.500 + 0.850 = 2.80PU$$

The total real power demanded is

$$\sum_{i=1}^{8} P_{Di} = P_1 + P_2 + P_4 + P_6 + P_7$$

$$\sum_{i=1}^{8} P_{Di} = 0.550 + 0.644 + 0.527 + 0.835 + 0.668$$

$$= 2.674PU$$

Earlier, we concluded that an approximate real power lost in any system is 5% of the total real power generated. Hence, we can take the total real power loss as

$$\sum P_L = 0.05 \sum_{i=1}^{4} P_{Gi}$$

$$\sum P_L = 0.05 \times 2.80 = 0.14PU$$

The sum of the real power demanded and that lost is

$$\sum_{i=1}^{8} P_{Di} + \sum P_L = 0.14 + 2.674 = 2.814PU$$

By comparing, it is observed that that real power generated is less than the sum of the real power demanded and that lost by 0.014PU

The results obtained shows that there is real power deficiency in the power network under review by 0.014PU. With a common base (apparent) power of 100MVA and an assumes power factor of 0.8, the actual real power deficiency in the network is

0.014 × 0.8 × 100 = 1.12MW

This particular system will therefore be running with frequency instability. To aid frequency stability, real power load of 1.12MW should be withdrawn from the system. But if the system is not suffering from frequency instability, then the assumed losses may be more than the true one.

CONCLUSION

With the reactive power compensation devices installed in all the buses of the Nigerian power system, voltage stability will be enjoyed in the buses. In cases where the devices have been stretched to their limit thereby causing voltage instability, the power equation can be used to detect it, as bus six (with a voltage of 107KV) was detected. Extra reactive power to aid voltage stability can then be estimated and generated to give rise to voltage stability. This was demonstrated when 0.629PU reactive power was generated to bus six which increased the voltage to 131KV. The calculated voltage values may be different from the original or practical bus voltage values. Errors are due to the approximations made during computations in successive iterations. However, the difference is always less than 1KV.

Transient stability can also be achieved by installing these compensation devices as they can also absorb reactive power to reduce transient voltage.

With real power balance between real power generated and real power demanded, frequency stability can also be achieved in the Nigerian power system.

ACKNOWLEDGEMENT

We acknowledge the assistance given to us by the P.H.C.N head office, Asaba, Delta State for providing us with the necessary data that was used in this work.

REFERENCES

Abido, M. A. (2009): “Power systems stability enhancement using FACTS” the Arabian Journal for Science and Engineering, Vol 34, no 2B, pp 154-173.

Donde, V. and Hiskens, A. I. (2002): “Voltage stability and control using tap changing transformer” International Journal of Electric Power and Energy Systems, vol. 8, no. 2, pp. 81–97.

Gupta, B. R. (2005): “Power system analysis and design”. 4th edition, Schand and company limited, pp 581-585.

Gupta, J. B. (2005): “A course in power systems”. 10th edition, Saneev Kumar Kataria limited, pp 413-436 (part III).

Ibe A. O. (2002): “Power system analysis”. Odus press, Enugu, pp 85-105.

Jabbar, R. A., Al-Dabbagh, M., Akmal, M. and Latif, K. (2002): “Reducing voltage dip on switching on heavy duty loads on power system” IEEE Transaction on Energy Conversion Vol. 3, no. 3, pp. 147-152.

Jignesh, M. S. (2003): “Voltage stability and control” Ph.D. Seminar, Indian Institute of Technology, Bombay, India.

Kundur Praha (1994): “Power system stability and control”. Tata McGraw-Hill publishing company lomited, pp 629-990.

Moran, L., Pastorini, I., Wallace, R. and Dixon, J. (2000): “Simultaneous voltage imbalance and current harmonic compensation using series active power filter” Proceedings of IEE/PESC (2000), pp 12221-1228

Pastrascu, C., Popescu, D. and Iacob, A. (1999): “Electrical power quality improvement using controlled reactive power filters” IEEE Transactions on Power Systems, vol. 6, no. 2, pp. 118-126.

Ruduck, H., Gomez E. and Rios S. (2000): “Modeling of excitation systems of generators’ AVR systems”. International conference on power system monitoring and control.

Thukaram, D., Parthasarathy, K., Khincha, H. P., Narendranath Udupa, and Bansilal, A. (1997): “Voltage stability improvement: case studies of Indian power networks”. Electr. Power Energy Syst. Vol 18, issue 7, pp 161–168.

Tor, O. B., Karaagas, U. and Benlier, E. (2001): “Step-Response Test of a Unit at Ataturk Hydro Plant and Investigation of the Simple Representation of Unit control System” Proceedings of the 40th IEEE Conference on Decision and Control, Orlando.

Ware John, (2006): “Power factor correction and improvement on power system” IEEE Transactions on industrial applications, Vol. 26, No. 4, pp. 719-725.