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Solving Voltage Dip Problems of An Inter-Connected Transmission System Using RPBs AND SLFEs

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Abstract: **–** Electrical devices are design to operate at certain range of voltages, when the voltage input to them goes out of the range, their efficiency is affected. Hence, the need to ensure that the buses in a transmission system run within the certified value ($\pm 5\%$ of rated values) cannot be overemphasized. This is because whenever the voltage of a particular bus in the transmission system dips below the stated value of the rated voltage, all substations and equipment in that particular bus runs at reduced efficiency and damages may even result. The first is for the control engineer to notice which bus is experiencing voltage dip (VD); the other is to rectify it. To do this, static load flow equations (SLFEs) will be used to monitor the various bus voltages for any VD. Whenever it occurs in any bus, reactive power banks (RPBs) installed in all the buses will be used in its solutions. These RPBs have the ability to generate reactive power which add up and increase the reactive of the system giving raise to voltage stability of the system. In this paper, a 10-bus system voltage was monitored using Gauss-Seidal iterative method of solving SLFEs by a program written in visual basic (VB). This revealed VD in buses 2, 4, 6 and 7 with 300kV, 298kV, 270kV and 306kV respectively. Further simulation shows that by generating RP of 31.8MVAr, 41.7MVAr, 69.2MVAr and 25.6MVAr respectively, the VD problem shall be rectified.

Key Words: *voltage dip power banks equations*

NOMENCLATURE

S_k^*	Complex Power of 'k' bus.
P_k	Real Power of 'k' bus.
Q_k	Reactive Power of 'k' bus
Q_{nd}	Reactive Power needed to aid Voltage Stability in a particular bus.
V_i	'i' bus voltage.
V_k	Voltage of 'k' bus
V_k^*	Conjugate of V_k
Y_{ki}	Admittance connecting 'k' and 'I' bus
n	Number of buses in the interconnected transmission system.
k	bus under review.

I. INTRODUUCTION

VD in transmission systems is simply when transmission voltage falls below the recommended range of values. This can be as a result of fault in the line or at a particular bus in an interconnected system, overloading in a particular bus. When this occur in any bus in an interconnected system, all substations and loads in that bus also suffer the effect; hence, the need to monitor and prevent all the buses of the system from experiencing this effect. This paper shall use the Static Load Flow Equations (SLFE) in monitoring various bus voltages in an interconnected transmission system and on noticing any bus where the voltage is out of standard, then it will be assumed that the stability limit of any Reactive Power Bank (RPB) installed at that particular bus (if any) has being exceeded, possible ways of solving the challenge shall then be considered.

Power supply voltage among other factors or variables depends on the reactive power (RP) of the supply. Hence, automating the RP can be used to control the system voltage. This means that generating extra RP to the system by any means can boost voltage thus healing VD.

In early times, capacitors are found in transmission lines to compensate for some (reactive) power losses encountered along the line. It can also reduce voltage dip by a high margin during switching operations when found on these lines [1]. The use of RPBs have since graduated from ordinary line capacitor for reducing voltage dips and compensating for the losses to three phase sophisticated RPBs in synchronous condensers, Static Vass devices, e.t.c., thanks to power electronics. They generate (and degenerate as the case may warrant) only reactive power (RP). Their operations are automated as they only gives the exact RP needed to ensure system stability. They are available at different voltage and power rating.

The synchronous condensers as one of the recent RPBs are essentially synchronous motors with no mechanical output. It takes a small amount of real power from the power supply to generate RP to the power system [2]. They are salient poles designs of 6 to 8 poles and are connected to power bus directly or through transformers. The excitation current of the synchronous condenser is varied automatically to generate the required reactive power. These synchronous condensers can deliver lagging (or absorb leading) vars (KVAr or MVAr) when its excitation is positive, it can also deliver leading (or absorb lagging) vars if the excitation current is negative. The Static Vars Device or Controllers (SVC) tries to solve the problem of the synchronous condensers taking real power form the system as it is a static devices. There are basically two types of SVC, the Fixed Capacitor – Thyristor Controlled Reactor (FC-TCR) and the Thyristor – Switched Capacitor Controlled Reactor (TSC-TCR). In any of the two, real power is not taken from the system as they are static devices; however, the TSC-TCR is more flexible and requires smaller rating of reactor and consequently generates fewer harmonic [3]. Other types of RPB include the Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensators (SSSC), e.t.c. These RPBs have another advantage of improving power factor.

II. MODEL FORMULATION

2.1 MODEL TO MONITOR BUS VOLTAGE OF THE SYSTEM

If there are ‘n’ buses in the interconnected transmission system, the complex power of a particular bus k, is

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

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

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

By specifying one of the buses as the slack bus and using the Gauss-Seidel iterative method, a number of iterative computations (may be five) of V_k can be obtain (or when the difference between two successive calculated values of V_k from two successive iterations is less than 0.00005). The resulted voltage is then compared with the standard range (i.e, $\pm 5\%$ of the normal or expected voltage value). If it lies between that ranges, then that particular bus voltage is okay; if not, that bus is in a state of voltage dip.

2.2. MODEL TO FORECAST RP TO SOLVE VOLTAGE DIP

If it has been observed that VD exist in a particular bus, then the stability limit of those RPBs installed at those buses have been exceeded (if any). Thus, the control engineer will need to switch on the reserve RPB available. But he has to know the quantity of RP to be generated to solve that particular voltage instability problem. This is very important as per cost effectiveness. This RP can be forecast by the equation given below,

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

I_m is the imaginary park of the RHS.
V_k^* is the conjugate of the proposed stability voltage.
If the initial RP available in that bus is Q_1, then the RP that should be generated Q_{nd}, is given as

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

III. SYSTEM ANALYSIS

A 10-bus, 330kV transmission system representing the southern Nigeria region with the admittance characteristics shown in the table below shall be analyzed.

TABLE 1: TRANSMISSION LINE PARAMETERS

Line	G	B
1-3	0.704861	-2.236108
1-8	1.005340	-2.347592
1-10	0.773642	-2.427535
2-6	0.568435	-2.965321
2-8	1.213456	-1.905629
2-9	1.116351	-2.004437
2-10	1.135285	-1.886253
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
6-9	0.983551	-1.737255
9-10	1.109431	-2.020735

The circuit diagram for the transmission network is given below.

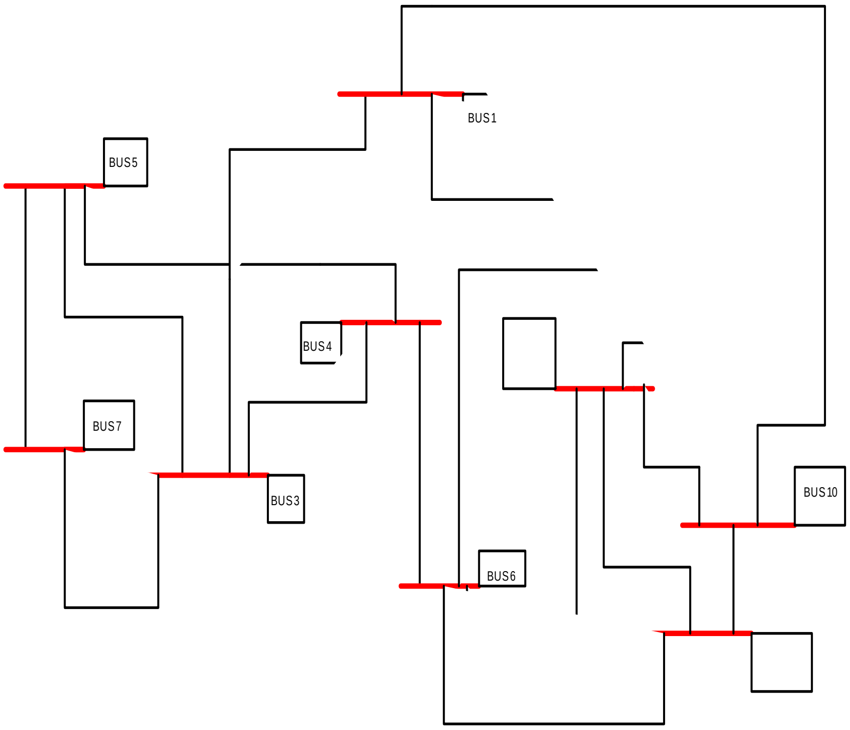

FIG 1: Southern Nigeria 330kV Transmission System Network
(Source: Power Holding Company of Nigeria; Afam, Rivers State Nigeria)

At a particular time of a day, the bus power specifications were collected and recorded as found in the table below with a common base voltage and power of 330KV, and 100MVA respectively.

Bus	**P_G(MW)**	**Q_G(MW)**	**P_D(MW)**	**Q_D(MW)**	**V**
1	0.550	0.300	0.460	0.245	….
2	0.000	0.000	0.644	0.240	$1.02\angle 0$
3	0.90	0.25	0.00	0.00	$1.04\angle 0$
4	0.00	0.00	0.527	0.345	$1.00\angle 0$
5	0.50	0.20	0.000	0.000	$1.00\angle 0$
6	0.00	0.00	0.835	0.300	$1.00\angle 0$
7	0.00	0.00	0.668	0.450	$1.01\angle 0$
8	0.85	0.50	0.000	0.000	$1.02\angle 0$
9	0.95	0.50	0.000	0.000	$1.02\angle 0$
10	0.00	0.00	0.526	3.120	$1.00\angle 0$

TABLBE 2: BUS POWER SPECIFICATIONS

The bus specifications are given below

Bus	**Bus specification**
1	Slack bus
2	PQ bus
3	PV bus
4	PQ bus
5	PV bus
6	PQ bus
7	PQ bus
8	PV bus
9	PQ bus
10	PQ bus

Monitoring of the bus voltage is archive by Gauss-Seidal iterative computations method with bus 1 used as the slack bus and using five iterations with a computer aided computation by a program written in Visual Basic (VB), the following results were obtained.

TABLE 3: SIMULATION RESULTS A

BUS	VOL (pu)	VOL (kV)	REMARK	$Q_{nd}(MVA)$
1	$0.99878\angle 2.72°$	329	Voltage Okay	Nil
2	$0.90767\angle -6.21°$	300	Voltage Dip	31.8MVAr
3	$1.00245\angle 3.80°$	330	Voltage Okay	Nil
4	$0.90134\angle -0.47°$	298	Voltage Dip	41.7MVAr
5	$1.00370\angle 2.72°$	331	Voltage Okay	Nil
6	$0.80324\angle -8.91°$	270	Voltage Dip	69.2MVAr
7	$0.92780\angle -0.74°$	306	Voltage Dip	25.6MVAr
8	$0.99075\angle 2.73°$	330	Voltage Okay	Nil
9	$0.99056\angle 1.86°$	327	Voltage Okay	Nil
10	$0.98745\angle 3.16°$	326	Voltage Okay	Nil

TABLE 4: SIMULATION RESULTS B

BUS	VOL (pu)	VOL (kV)	REMARK
2	$0.98485\angle -7.31°$	325	Stable
4	$0.96970\angle -3.17°$	320	Stable
6	$0.96402\angle -2.14°$	318	Stable
7	$0.97576\angle -3.14°$	322	Stable

IV. DISCUSION OF RESULTS

The results of simulation A on table 3 gave the respective bus voltages and show that buses two, four six and seven are experiencing VD as indicated by the remark because their voltages differ from the rated voltage of 330kV by less than 5% of the rated voltage of 330kV (which is about **313.5kV**). It also gave an estimated minimum quantity of RP to be generated in those buses to aid voltage stability. RPBs of the estimated capacity are then switched on that the respective buses, another simulation is then made to check if after switching on the RPBs, the VD experienced in the affected buses have been rectified and the results are given in simulation B of table 4. It shows that all the buses have started enjoying standard voltage as a result of that action.

V. CONCLUSION

It has been proven that voltage of a power supply can be controlled by the RP component of the power. Hence, when there is a dip in voltage of the supply, it can be corrected if the RP component can be increased. RPBs have been used to generate these RP into the transmission system network. However, these RPBs have some stability limits, thus, when their limits have been exceeded, other banks should be switched on to aid voltage stability. SLFEs have been used in this research to monitor various bus voltages in the system analyzed. Buses 2, 4, 6 and 7 were observed to be suffering from VD as shown in the result of simulation result A and the

SLFEs also predicted the values of the respective RPBs that will aid voltage improvement in the affected buses. After the banks have been switched on, the results of simulation B shows that the buses and the entire system bus voltages are within the standard limit.

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