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Voltage Regulation Using Static Var Compensatorat Karu 132/33kv Substation in Abuja Nigeria

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--*ABSTRACT*--

This paper presentsvoltage regulation at Karu 132/33KV substation in Abuja, Nigeria using static var compensators. Flexible alternating current transmission systems (FACTS) devices aremodern electrical equipments that have gained wide applications in power transmission and grid stability. To improve the power quality and stability through good voltage profile, the role of static var compensators was examined using PowerFactory Digisilent software models. From the results gotten, the voltage profile at the busbar was greatly improved hence proving the efficiency of such device.

Keywords:*Static VAR, TCR, fixed capacitor, susceptance, real power, and reactive power.*

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I. INTRODUCTION

Voltage magnitude regulation is achieved by controlling the amount of reactive power generated or absorbed at key points of the network as well as by controlling the flow of reactive power throughout the network [1]. Voltage regulation is carried out locally by sources and sinks of reactive power, such as shunt capacitors, shunt reactors, rotating synchronous condensers and Static Var Compensators (SVCs). Shunt capacitors and reactors are only capable of providing passive compensation since their generation or absorption of reactive power depends on their rating, and the voltage level at the connection point. On the other hand, the reactive power generated or absorbed by synchronous condensers and SVCs is automatically adjusted in order to maintain fixed voltage magnitude at the connection points. A load that has positive reactive power (+Q) is said to “absorb” vars. Inductive loads therefore absorb vars. Conversely, a load that has negative reactive power (-Q) generates or supplies vars. Hence, capacitive loads supply or generate vars.

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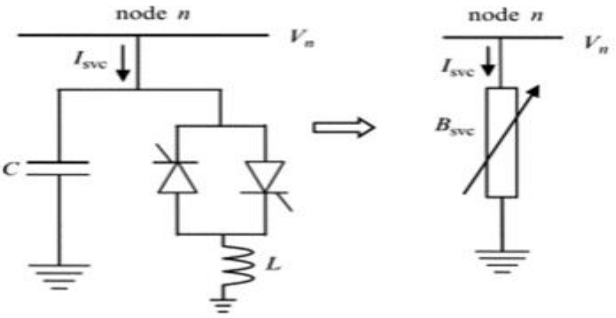
From the operational point of view, the SVC behaves like a shunt-connected variable reactance, which either generates or absorbs reactive power in order to regulate the voltage magnitude at the point of connection to the AC network [1]. In its simplest form, the SVC consists of a TCR in parallel with abank of capacitors. The thyristor’s firing angle (α) control enables the SVC to have an almost instantaneous speed of response.



(a) (b)

Figure (1a) SVC structure formed by fixed capacitor and TCR; and (1b) Variable susceptance representation.

It is used extensively to provide fast reactive power and voltage regulation support. It is also known to increase system stability margin and to dampen power system oscillations [2].The schematic representation of the SVC and its equivalent circuit are shown in Figure (1) above, where a TCR is connected in parallel with a fixed bank of capacitors.

An ideal variable shunt compensator is assumed to contain no resistive components, i.e. G_{svc} is equal to zero. Accordingly, it draws no active power from the network. On the other hand, its reactive power is a function of nodal voltage magnitude at the connection point, say node *n*, and the SVC equivalent susceptance B_{svc}. That is,

$P_n = 0$ ………………………………………………..(1)

$Q_n = -|V_n|^2 B_{svc}$ ……………………………………………….(2)

Where,

$$B_{SVC} = -\left\{\frac{X_L - \frac{X_C}{\pi}[2(\pi-\alpha) + Sin\ 2\alpha]}{X_C X_L}\right\} \text{……………………(3)}$$

α = the firing angle of the thyristors,
X_C = the capacitive reactance,
X_L = the inductive reactance.

When the SVC is operated in voltage regulation mode, it implements the following V-I characteristics.

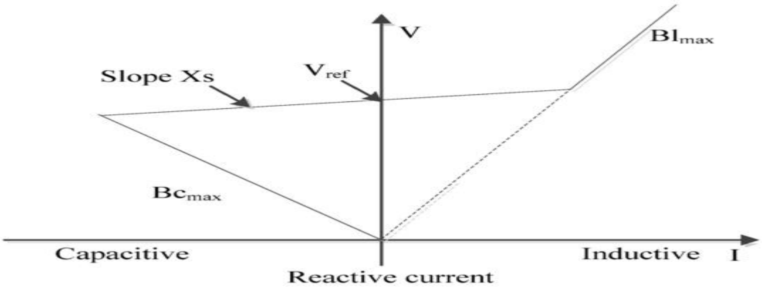


Figure (2) SVC V-I Characteristics.

As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (B_{cmax}) and reactor banks (B_{lmax}), the voltage is regulated at the reference voltage V_{ref}. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristics has the slope indicated in the figure above. The V-I characteristic is described by the following three equations:

$V_{ref} + I X_s$ if SVC is in regulation range ($-B_{cmax} < B < B_{lmax}$)
$V = \left\{ -I/B_{cmax} \right.$ if SVC is fully capacitive ($B = B_{cmax}$) …………(4)
I/B_{lmax} if SVC is fully inductive ($B = B_{lmax}$).

V	Positive sequence voltage (pu)
I	Reactive current (pu/pbase) (I> 0 indicates an inductive current)
X_s	Slope or droop reactance (pu/Pbase)
B_{cmax}	Maximum capacitive susceptance (pu/Pbase) with all TSCs in service, no TSR or TCR
B_{lmax}	Maximum inductive susceptance (pu/Pbase) with all TSRs in service or TCRs at full conduction, no TSC
Pbase	Three-phase base power specified in the block dialog box.

II. KARU SUBSTATION:

There are four 2-winding power transformers and nine feeders in the karu 132/33 KV substation. The transformers and feeders are as follows:

TR1 – this is a transformer rated 30MVA. It supplies
- Karshi Line 1: feeder 1

TR2- this is a transformer rated 30MVA. It supplies
- Karshi Line 2: feeder 2

TR3- this transformer is rated 60 MVA. It supplies the following feeders
- Kugbo: feeder 3
- Nyanya-Mpappe: feeder 4
- Jikwoyi: feeder 5

TR4 – this is a transformer rated 60MVA supplying
- Gidan-Daya: feeder 6
- Orozo: feeder 7
- Gidan-Mangoro: feeder 8

- Apo: feeder 9

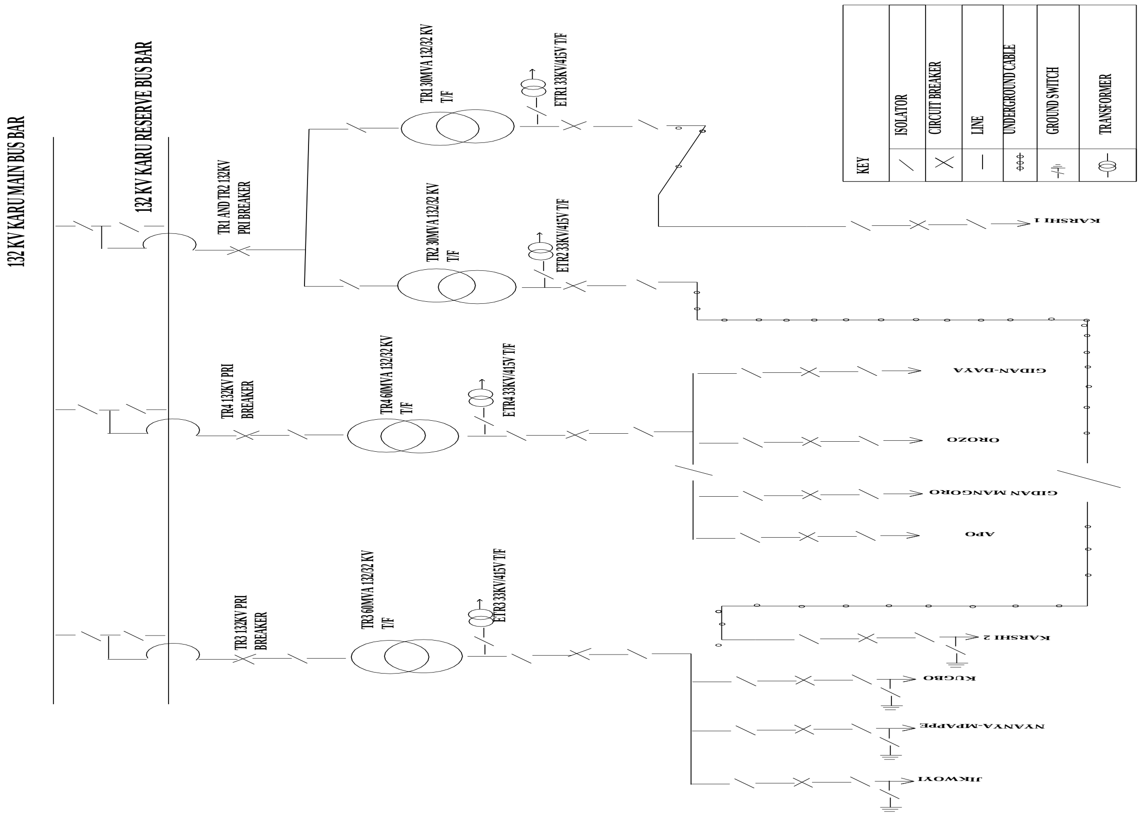


Figure (3) Single line diagram of Karu 132/33KV substation.

To carry out load flow analysis, we made the following assumptions:

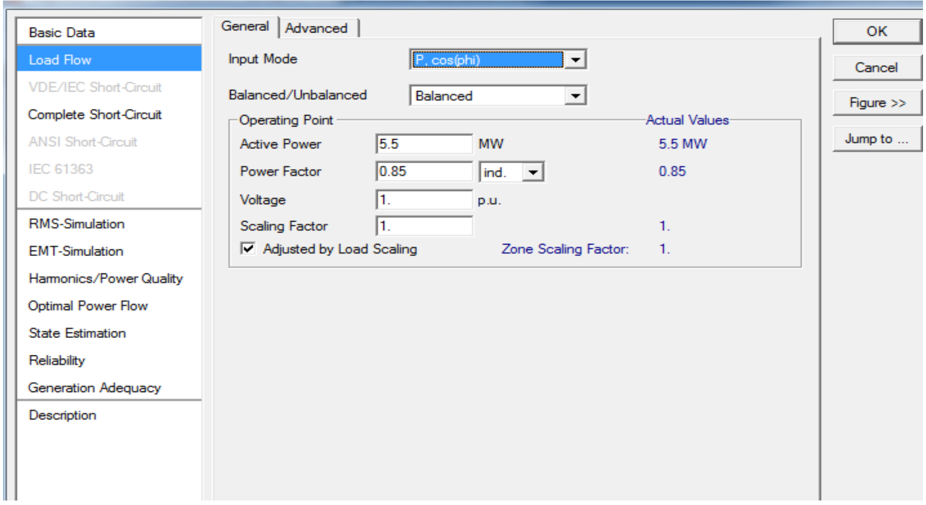
- An external grid connected to the 132KV incoming bus bar is considered as the reference bus
- A nominal voltage of 33KV at the bus bar of the receiving end
- The average temperature of the transmission line is taken to be 70 degrees Celsius
- Since the feeder length are low, they are neglected
- The system frequency is taken to be 50Hz
- The transformers have tap changers assumed to be in the neutral position
- The system is in steady state condition
- The marginal limit for voltage is 98% to 102%
- Critical limit for voltage is 95% to 105%

III. SIMULATION DATA AND EQUIPMENT PARAMETERS

Table1: Karu Peak Load Data for August 2018:

	PEAK LOAD (MW)	PEAK LOAD (MVAR)
KARSHI LINE 1	13.4	6.5
KARSHI LINE 2	16.4	7.9
KUGBO	15.6	7.5
NYANYA-MPAPPE	7.9	3.8
JIKWOYI	6	2.9
GIDAN-DAYA	5.5	2.7
OROZO	20	9.7
GIDAN-MANGORO	9.4	4.5
APO	5.6	2.7

Table 2: Load Parameters as entered in PowerFactory



Input Mode: P, cos(phi)

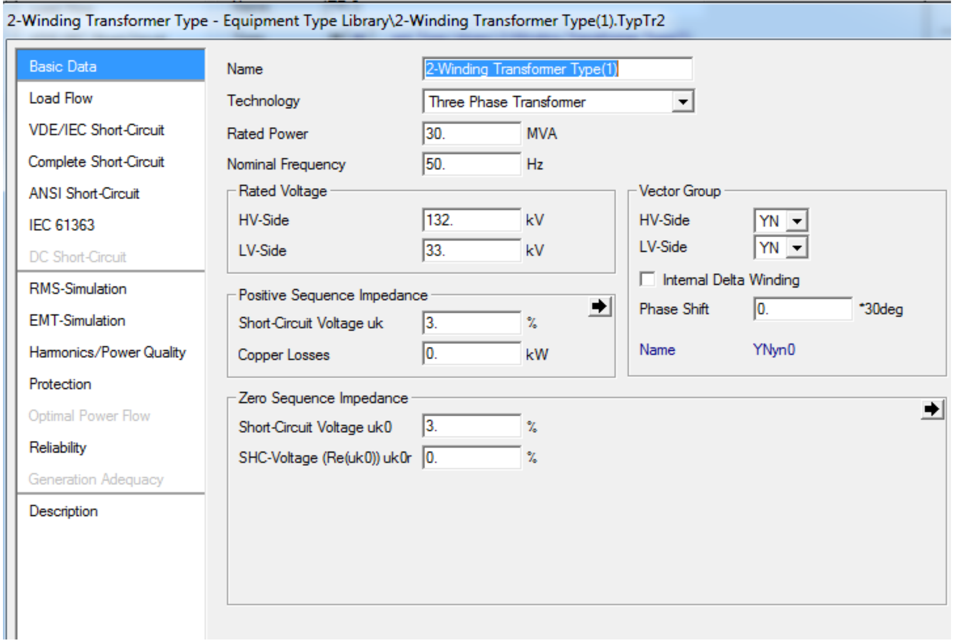
Balanced/Unbalanced: Balanced

Operating Point — Actual Values

Active Power	5.5	MW	5.5 MW
Power Factor	0.85	ind.	0.85
Voltage	1.	p.u.	
Scaling Factor	1.		1.

☑ Adjusted by Load Scaling — Zone Scaling Factor: 1.

Table 3: Transformer Parameters as entered in PowerFactory



2-Winding Transformer Type - Equipment Type Library\2-Winding Transformer Type(1).TypTr2

Name: 2-Winding Transformer Type(1)

Technology: Three Phase Transformer

Rated Power: 30. MVA

Nominal Frequency: 50. Hz

Rated Voltage

HV-Side: 132. kV

LV-Side: 33. kV

Vector Group

HV-Side: YN

LV-Side: YN

☐ Internal Delta Winding

Phase Shift: 0. *30deg

Name: YNyn0

Positive Sequence Impedance

Short-Circuit Voltage uk: 3. %

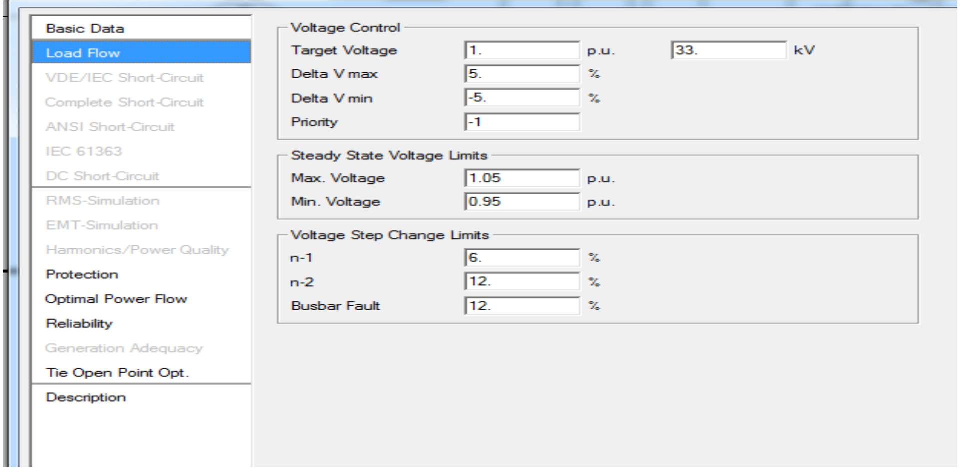
Copper Losses: 0. kW

Zero Sequence Impedance

Short-Circuit Voltage uk0: 3. %

SHC-Voltage (Re(uk0)) uk0r: 0. %

Table 4: Bus Parameters as entered in PowerFactory



Voltage Control

Target Voltage	1.	p.u.	33.	kV
Delta V max	5.	%		
Delta V min	-5.	%		
Priority	-1			

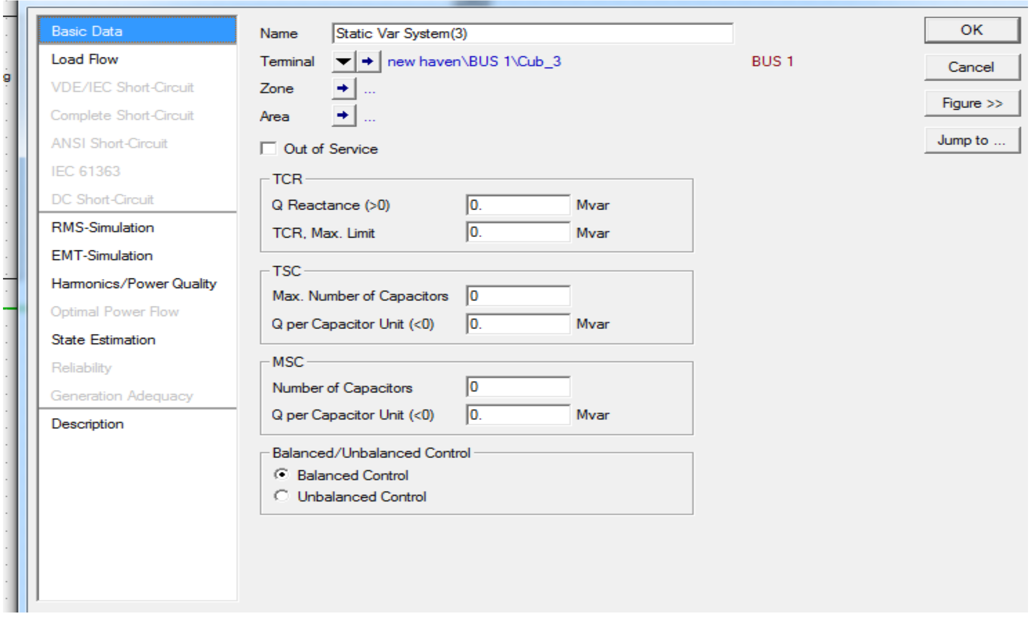
Steady State Voltage Limits

Max. Voltage	1.05	p.u.
Min. Voltage	0.95	p.u.

Voltage Step Change Limits

n-1	6.	%
n-2	12.	%
Busbar Fault	12.	%

Table 5: Static Var System parameter as entered in PowerFactory



Name: Static Var System(3)

Terminal: new haven\BUS 1\Cub_3 BUS 1

Zone: ...

Area: ...

☐ Out of Service

TCR

Q Reactance (>0): 0. Mvar

TCR, Max. Limit: 0. Mvar

TSC

Max. Number of Capacitors: 0

Q per Capacitor Unit (<0): 0. Mvar

MSC

Number of Capacitors: 0

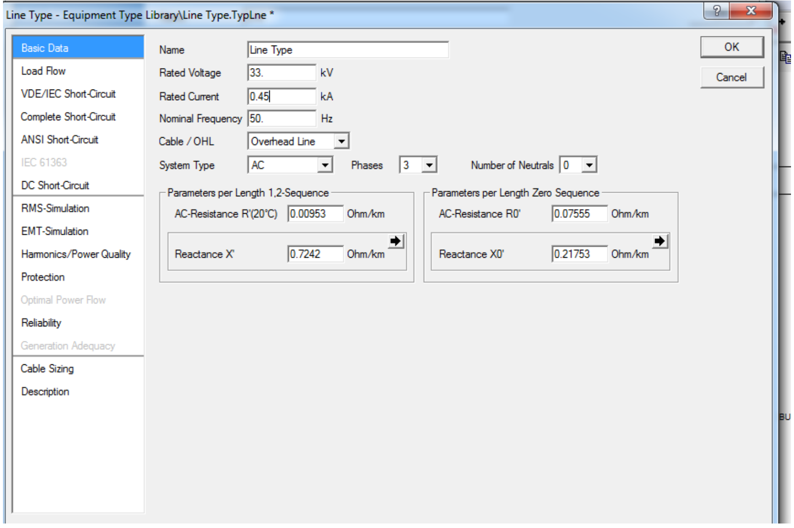
Q per Capacitor Unit (<0): 0. Mvar

Balanced/Unbalanced Control

● Balanced Control

○ Unbalanced Control

Table 6: Transmission Line parameters as entered in PowerFactory



Name: Line Type

Rated Voltage: 33. kV

Rated Current: 0.45 kA

Nominal Frequency: 50. Hz

Cable / OHL: Overhead Line

System Type: AC

Phases: 3

Number of Neutrals: 0

Parameters per Length 1,2-Sequence

AC-Resistance R'(20°C): 0.00953 Ohm/km

Reactance X': 0.7242 Ohm/km

Parameters per Length Zero Sequence

AC-Resistance R0': 0.07555 Ohm/km

Reactance X0': 0.21753 Ohm/km

Table7: Recorded and Simulated Load Voltages with and without SVC:

BUS	BUS VOLTAGE FROM RECORDED VALUE(KV)	BUS VOLTAGE WITHOUT SVC WITH SIMULATION(KV)	BUS VOLTAGE WITH SVC WITH SIMULATION(KV)
1	32.4	32.5	33.0
2	32.3	32.4	33.0
3	32.4	32.7	33.0
4	31.9	32.0	33.0

IV. GRAPH SHOWING VOLTAGES WITH AND WITHOUT SVC:

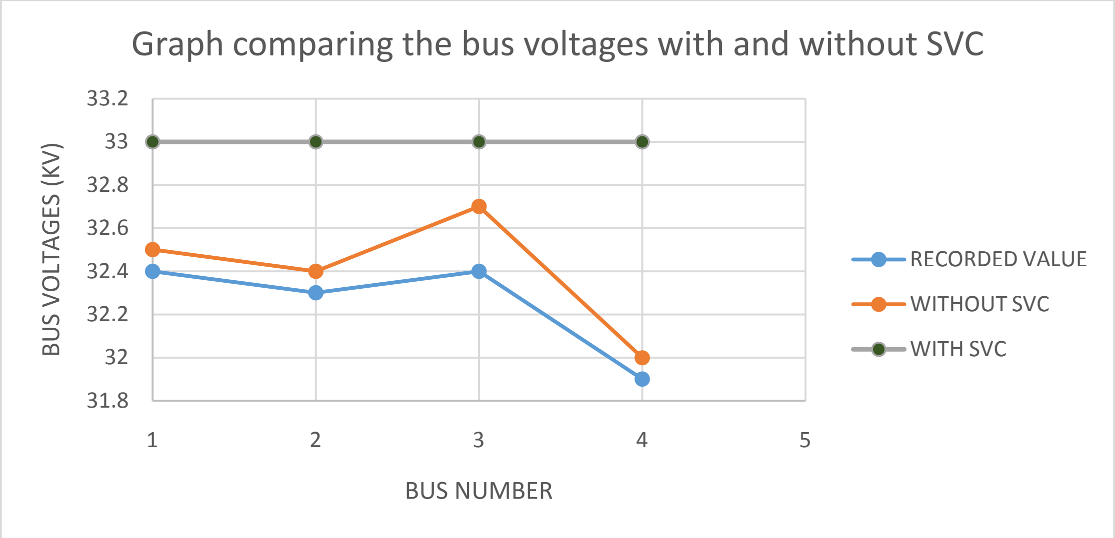


Figure (9) Graph comparing Bus voltages, Recorded, simulated with and without SVC.

TABLE8:SVC data after simulation

BUS	SVC DATA (MVAR)	SVC DATA (KA)
1	-8.5	0.149
2	-10.5	0.185
3	-11.3	0.197
4	-26.4	0.461

TABLE 9: Transformer loading before and after SVC

TRANSFORMER	LOADING WITHOUT SVC (%)	LOADING WITH SVC (%)
TR1	53.3	44.7
TR2	66.5	54.7
TR3	52.8	49.2
TR4	82.0	67.5

V. CONCLUSION

The simulations were carried out, with all the parameters above, using*PowerFactory Digsilent software models.* The summary of the results are as shown in figure 9 above and tables 8 and 9.. By the result, the SVC was able to effect proper compensation at the various buses, hence offering a good voltage profile. This therefore confirms our expectations thereby proving the device's feasibility.

REFERENCES

[1]. Miller. T.J.E. (ed), *Reactive Power Control in Electric Systems*, John Wiley & Sons, New York, 1982.
[2]. Kundur. P., *Power System Stability and Control*, the EPRI Power System Engineering Series, McGraw-Hill, New York, 1994.

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