

Assessment of the Static Stability Margin and Voltage Profile Improvement in the SOUTH- SNEL Power Network using a SVC under MATLAB / PSAT Environment

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ABSTRACT

The huge increase in the demand of electric power and the economic constraints to build new facilities, lead the power systems to operate near of their stability limits. Indeed, instability has become a major problem in the management of power systems. Unavoidable disturbances such as short circuits, momentary unavailability of transmission lines, generators as well as transformers can affect the stability of the power system at any time and bring it into a state of instability or collapse. These collapses become a major problem for energy consumers, because the lack of energy leads them to use backup energy sources that are relatively expensive and polluting. This situation lowers the productivity of the industry, and for the national electric company of the Congo, (SNEL), the time to get rid of the magnetization of the network and to take all the loads, can generate penalties, which is a loss of revenue for the company. This paper aims to assess the stability margin and to improve the quality of electrical energy in the south-SNEL transmission system.

Keywords-- Stability Margin, Sensitivity Factor, Voltage Stability, SNEL, Voltage Collapse, SVC, PSAT

I. INTRODUCTION

The huge increase in the demand of electric power and the economic constraints to build new facilities, lead the power systems to operate near of their stability limits [1]. Indeed, instability has become a major problem in the management of power systems. Unavoidable disturbances such as short circuits, momentary unavailability of transmission lines, generators as well as transformers can affect the stability of the power system at any time and bring it into a state of instability or collapse. The stability of a power system is therefore the ability of the system to remain in an equilibrium state, for normal operating conditions, and to return to a stable equilibrium state after a disturbance [2].

The Flexible AC Transmission System (FACTS) can therefore only offer both benefits of increased stability

margin and improved power quality by placing it at strategic locations in the power system.

The work of optimal location of different types of FACTS devices in the power system has attempted to use different techniques such as genetic algorithm (GA), hybrid Tabu approach and simulated annealing. The best location for a phase change set was found by genetic algorithm to reduce the flow in heavily loaded lines resulting in increased load capacity of the power network while reducing losses [3].

The modeling of FACTS devices for power flow studies and the integration of these devices into power flow studies has been reported in [4, 5].

In this paper, we used the Matlab/PSAT toolbox to evaluate the stability margin of the South-SNEL transmission system which consists of 21 nodes. The procedure is to model the loads as voltage dependent, then gradually load the power network with a constant parameter until it collapses. This stability margin is a key indicator of the static stability of a power system, however its evaluation remains complex and depends on several parameters. Next we have evaluated the voltage sensitivity factor by calculating the voltage deviation at each node of the power network. The nodes which present a strong variation will be considered as the strategic place where the SVC will be placed in order to improve the voltage profile.

II. PRESENTATION OF SOUTH- SNEL POWER NETWORK

The South-SNEL power system includes four hydroelectric power plants represented at the NSEKE, NZILO, MWADINGUSHA and KONI nodes with an exploitable power of 468 MW [6]. A static compensator of 12.4 MVA is connected to KARAVIA node, a High Voltage Direct Current (HVDC) injection at KOLWEZI SCK node with three synchronous power compensators of 70 MVA. We have considered the NSEKE node as a balancing node, because it has the most powerful generator

in the network, i.e. 69 MVA, and this power is considered as base power. The generators are considered with the limitation on the reactive power. The simplified diagram of

the TRS SNEL South network is given in the Figure 1 below:

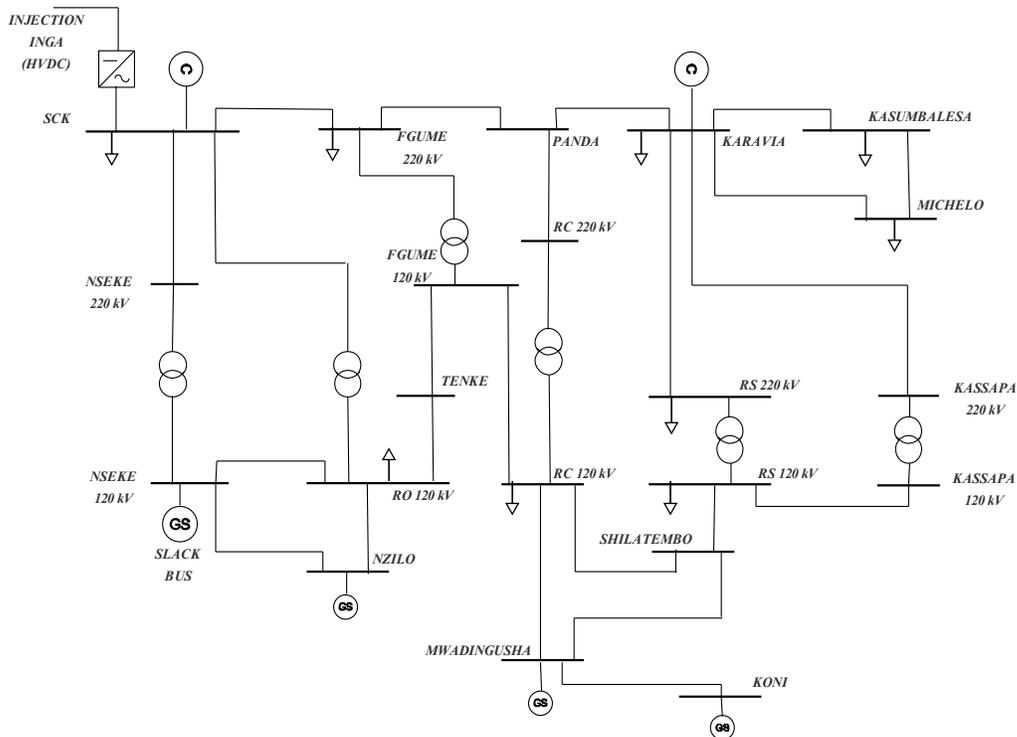


Figure 1: South-SNEL transmission network

III. LOADS

Loads of power systems are divided into industrial, commercial, residential and agriculture [7]. The load is modeled by the PQ model, i.e. it does not depend on the voltage and is defined by the equations (1) and (2) below, with a constant power factor:

$$P_i = \lambda P_{i0} \tag{1}$$

$$Q_i = \lambda Q_{i0} \tag{2}$$

with λ denoting the load factor; P_{i0} initial active power at node i ; Q_{i0} initial reactive power at node i

IV. GENERATORS

It is the essential component of power systems [8]. The power generated by the generators is defined by the following equation:

$$P_{Gi} = \lambda \times k_{Gi} \times P_{Gi0} \tag{3}$$

with P_{Gi0} the power generated by machine i in the initial case; k_{Gi} the contribution factor of each generator i to satisfy the load demand, the value usually used is 1.

V. TRANSMISSION LINES

The transmission line given in Figure 2 is modeled by an equivalent diagram in π . It is composed of a series impedance (resistance R in series with an inductive reactance X), and a shunt admittance which consists of a capacitive susceptance B (due to the capacitive effect of the line with the earth) in parallel with an insulating conductance G .

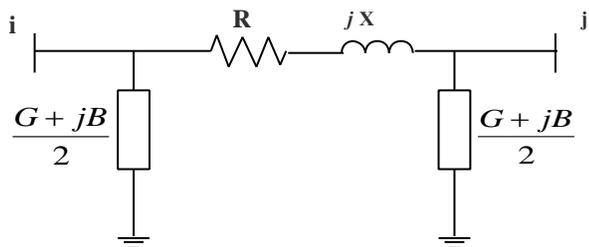


Figure 2: Transmission line

Legend: R resistance of the line, X inductive reactance of the line, B susceptance of the line, G conductance of the line.

VI. POWER FLOW EQUATION

Considering that the powers are balanced at node i , the power balance for a power network of n nodes gives:

$$S_i = S_{Gi} - S_{Di} = P_{Gi} - P_{Di} + j(Q_{Gi} - Q_{Di}) \tag{4}$$

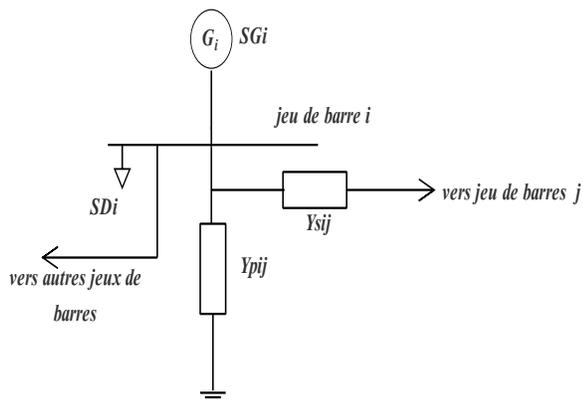


Figure 3: Bus with generation, load and transmission line

Where: S_{Gi} is the generated power and S_{Di} is the requested power

VII. POWER FLOW IN A TRANSMISSION LINE

The power flow in transmission lines allows us to locate overloaded lines and to evaluate the power losses. The power lost in a transmission line connecting nodes i and j is given by:

$$P_{ij} - jQ_{ij} = V_i^* Y_{ij} (V_i - V_j) + V_i^* V_i Y_p \tag{5}$$

$$P_{ji} - jQ_{ji} = V_j^* Y_{ij} (V_j - V_i) + V_j^* V_j Y_p \tag{6}$$

with P_{ij} and Q_{ij} respectively the active and reactive losses when the power flows from node i to node j ; P_{ji} and Q_{ji} respectively the active and reactive losses when the power flows from node j to node i .

VIII. VOLTAGE STABILITY

The multiplication of interconnected power systems has led to several research works on angular stability which have contributed to the attenuation of angular oscillations [9]. However, disturbances cause voltage drops without altering the synchronization of the generators, this phenomenon is known as voltage collapse. It is mainly caused by:

- Generation too far away from consumption,
- Local lack of reactive energy [9].
- Loads called too large

Variations in active power ΔP and reactive power ΔQ are the key parameters that lead the network to voltage collapse or Jacobian matrix singularity.

$$\begin{bmatrix} \Delta P(x, \lambda) \\ \Delta Q(x, \lambda) \end{bmatrix} = f(x, \lambda) = 0 \tag{7}$$

where x represents the state vector of the power flow problem that encompasses the vectors of voltages V and phase shifts δ ; the variable λ represents a scalar parameter or the load factor used to simulate the load increase that leads to system collapse.

The increases in consumed active power P_{Di} , consumed reactive power Q_{Di} , and generated power P_{Gi} at node i , can be expressed as a function of the initial active power P_{Di0} , the initial reactive power Q_{Di0} , the initial generated power P_{Gi0} and the lambda load parameter λ expressed by the following system of equations:

$$\begin{cases} P_{Di} = \lambda P_{Di0} \\ Q_{Di} = \lambda Q_{Di0} \\ P_{Gi} = \lambda k_{Gi} P_{Gi0} \end{cases} \tag{8}$$

IX. LOAD MARGIN

The load margin is the most commonly used index in the evaluation of static voltage stability: it is the amount of additional load that would cause a voltage collapse. In simpler terms, it is the distance between the current operating point and the point that would cause voltage collapse. In most static voltage stability studies, the load is chosen as the critical parameter that drives the system to collapse.

X. OPTIMAL LOCATION OF THE SVC

The optimal location of the SVC is realized at the critical node. This node is identified using the voltage sensitivity factor (*VSF*) given by:

$$VSF_k = \frac{dV_k}{\sum_{i=2}^{NB} dV_i} \tag{9}$$

with *VSF_k* voltage sensitivity factor of node *k*; *dV_k* tangent at node *k* around the voltage collapse point; *NB* number of nodes.

XI. RESULTS AND DISCUSSION

From Figure 3, it can be noticed that as the power demand increases, the voltages progressively decrease until reaching the critical value at the collapse point which

corresponds to the maximum load factor $\lambda_{max} = 1.5385$ pu which is equivalent to a power of 106.2 MW. At this point, almost all generators reach their reactive power limits. We can also notice that the voltage variation of these three curves is different, which explains why the three nodes give different responses in terms of voltage instability.

Beyond this point, the voltages drop abruptly and uncontrollably; this is the voltage collapse phenomenon. This phenomenon can be explained as follows: when the load increases, the current flowing in the line also increases, resulting in a voltage drop that is all the greater as the current is greater, and therefore the voltage across the load decreases. The stability margin of our power network is estimated to 37.2 MW.

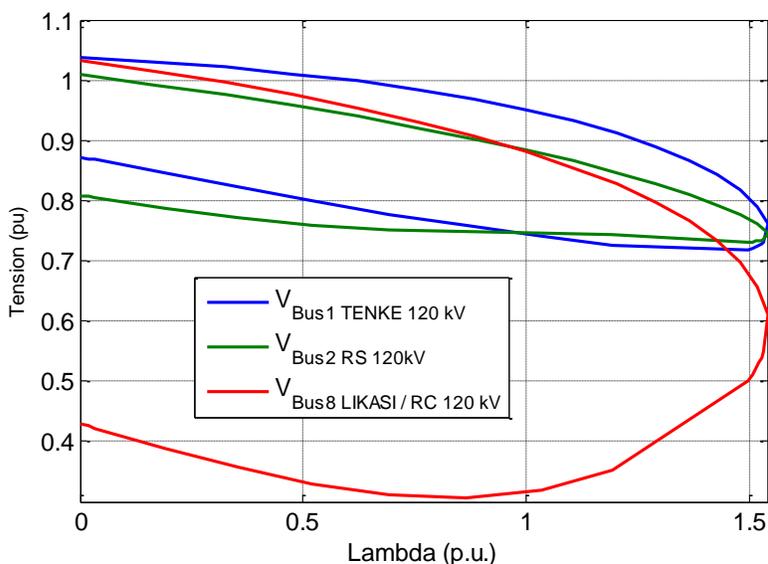


Figure 4: Voltage collapse curve

Figure 4, represents the voltage profile for the nominal load. We can notice that the LIKASI RC and RS 120 kV nodes have lower voltages compared to the others. This voltage degradation at the RS node is due to the long distance between generation and consumption on the one hand, and by the high power demand on the other hand. On

the other hand, the RC node is close to the generation centers compared to other load nodes, but has a high voltage drop. This high voltage drop can be reflected in the reactive energy transfer sensitivity, which is even higher if the short-circuit power is low, i.e. 928.5 MVA for RC.

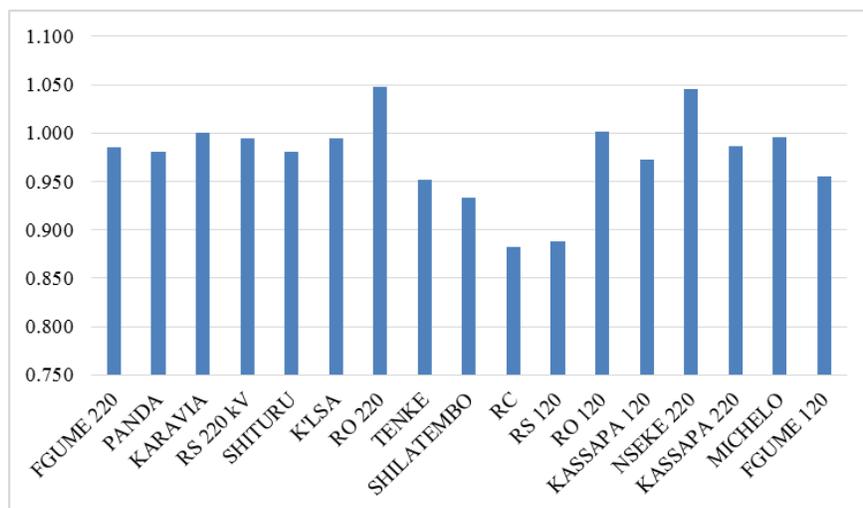


Figure 5: Voltage profile

From Figure 5, it is important to note that the reactive energy transfers always go in the direction of decreasing voltages, while the active energy transfers are in the direction of decreasing relative angles, where we can

observe a significant transfer of active power at the RS 120 kV node that results in a relatively large decrease in the voltage angle, or -58.6° ,

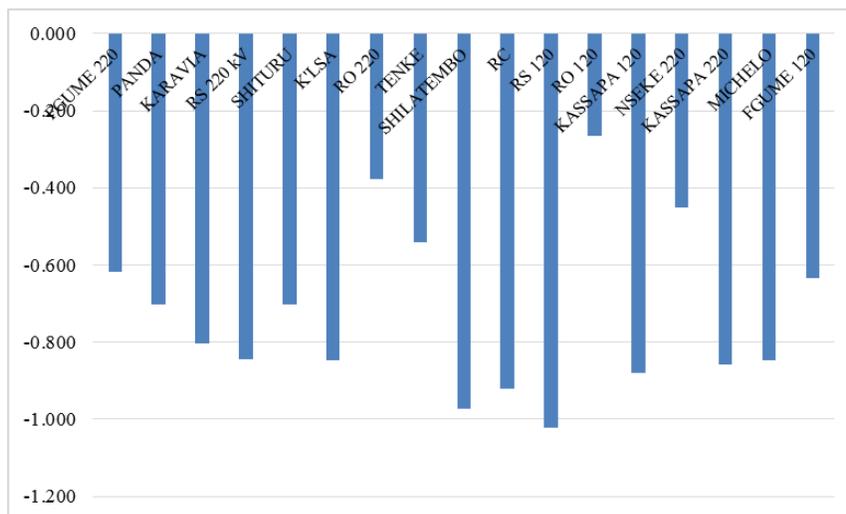


Figure 6: Angles profile

Table 1 shows the results of the power distribution, i.e., the electrical state of the network for the constraints imposed on the *PV*, *PQ* and balance nodes. For each bus, the first column represents the nominal voltages (*pu*), and the second column represents the phase shifts of the voltages with respect to the balance node. The other columns represent the active and reactive powers generated by the different production machines and those consumed by the loads connected to the network nodes. Thus we can directly observe that the powers delivered by the generators are far greater than those assigned to them,

so the generators are operating in overload. The machines are therefore unable to cover all the loads of the network simultaneously, hence the selective load shedding is used to ensure the balance between production and consumption,

Bus	V	phase	P gen	Q gen	P load	Q load
	[p.u.]	[rad]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus1 RO 220kV	1,048	-0,377	0,000	0,000	0,000	0,000
Bus1 TENKE 120 kV	0,952	-0,540	0,000	0,000	0,000	0,000
Bus10 NSEKE 220 kV	1,045	-0,450	0,000	0,000	0,000	0,000
Bus11 KLZ SCK 220kV	1,045	-0,463	2,174	5,955	0,145	0,130
Bus12 FUNGURUME 220 kV	0,985	-0,618	0,000	0,000	2,304	1,116
Bus13 KARAVIA 220 kV	1,000	-0,840	0,014	6,486	2,391	1,158
Bus13 KASUMBALESA 220 kV	0,995	-0,847	0,000	0,000	0,391	0,158
Bus13 LIKASI / PANDA 220 kV	0,981	-0,703	0,000	0,000	0,000	0,000
Bus2 NSEKE 120 kV	1,060	0,000	12,428	1,580	0,000	0,000
Bus2 RS 120 kV	0,888	-1,023	0,000	0,000	3,651	1,768
Bus3 FUNGURUME 120 kV	0,955	-0,635	0,000	0,000	0,000	0,000
Bus3 RS 220kV	0,995	-0,844	0,000	0,000	0,000	0,000
Bus4 KASAPA 220kV	0,986	-0,858	0,000	0,000	0,000	0,000
Bus4 NZILO 120 kV	1,045	-0,183	1,174	1,760	0,000	0,000
Bus5 KASAPA 120kV	0,972	-0,881	0,000	0,000	0,000	0,000
Bus5 KLZ / RO 120 kV	1,002	-0,265	0,000	0,000	3,493	1,692
Bus6 LIKASI / SHITURU 220 kV	0,981	-0,703	0,000	0,000	0,000	0,000
Bus6 MICHELO	0,996	-0,846	0,000	0,000	0,391	0,158
Bus7 MWADINGUSHA 120 kV	1,045	-0,952	0,493	1,686	0,000	0,000
Bus7 SHILATEMBO 120 kV	0,933	-0,974	0,000	0,000	0,000	0,000
Bus8 LIKASI / RC 120 kV	0,882	-0,920	0,000	0,000	1,826	0,884
Bus9 KONI 120 kV	1,045	-0,950	0,203	-0,095	0,000	0,000

Figure 6 gives the sensitivity factors at the different nodes of the network. We can notice a high voltage sensitivity at the LIKASI RC node, i.e. 0.273. This means that this node experiences a large voltage drop as the load increases. It is therefore considered as the weak or critical node of our

network. Therefore, installing a SVC in this node will give the best voltage stability margin compared to other load nodes. Nodes with very low or zero VSF, such as KARAVIA and RS 220 kV nodes, are insensitive to load variations,

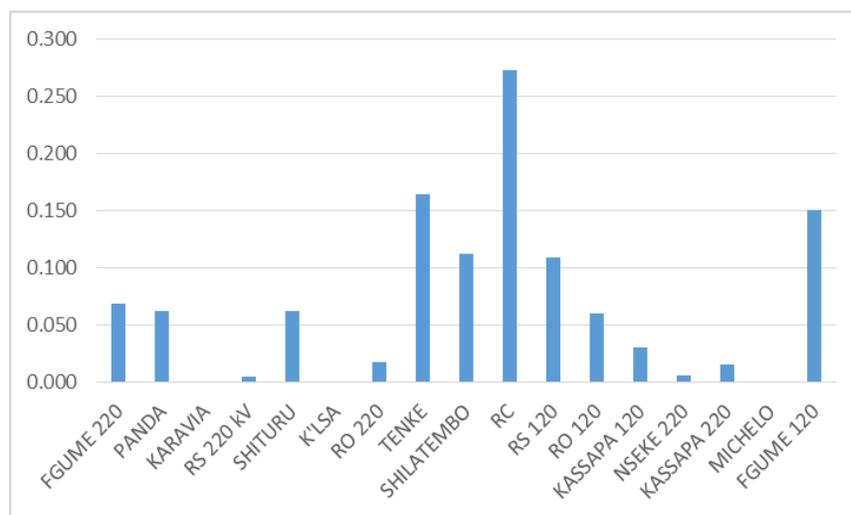


Figure 7: Voltage sensitivity factor

Figure 7 shows the voltage profiles, with and without SVC, the installation of SVC at the RC node, remarkably improves the voltage profile at the different load nodes except at the RS 120 kV node, which undergoes a slight improvement but is still unacceptable,

as it is less than 0.95 pu. This node can be considered as a critical node for another case with SVC,

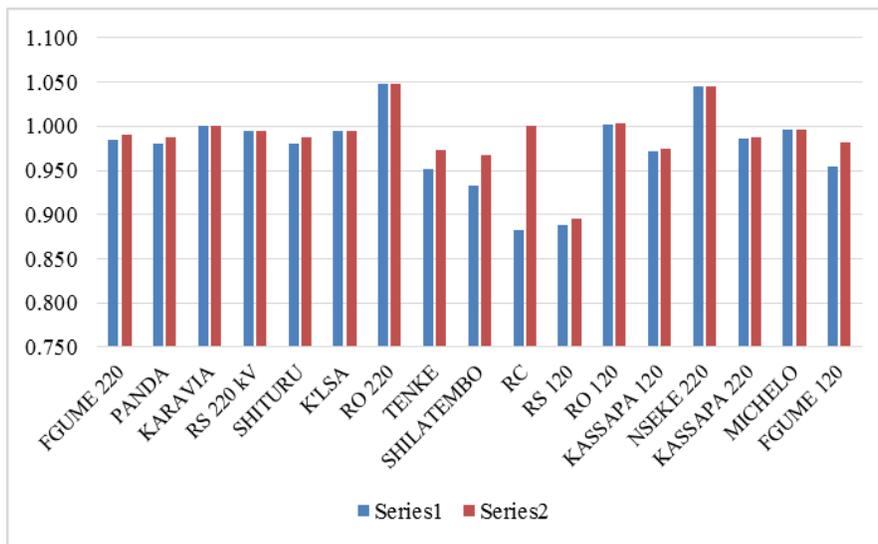


Figure 8: Voltage profile

Legend: series 1, without SVC; series 2, with SVC.

Figure 8 illustrates the influence of SVC on the static voltage stability. We can see that installing SVC at the RC node increases the voltage stability margin up to 1.7423 pu with the initial case of 1.5385 pu. Thus, we benefit from an increase in the static voltage stability margin of 0.2038 pu or 14.1 MW. We can also notice that

the SVC maintains the voltage at the RC node around the reference value $V_{ref} = 1.0019 pu$, via an appropriate susceptance regulation. The bifurcation curve (PV) appears flat because of the sufficient reactive energy support

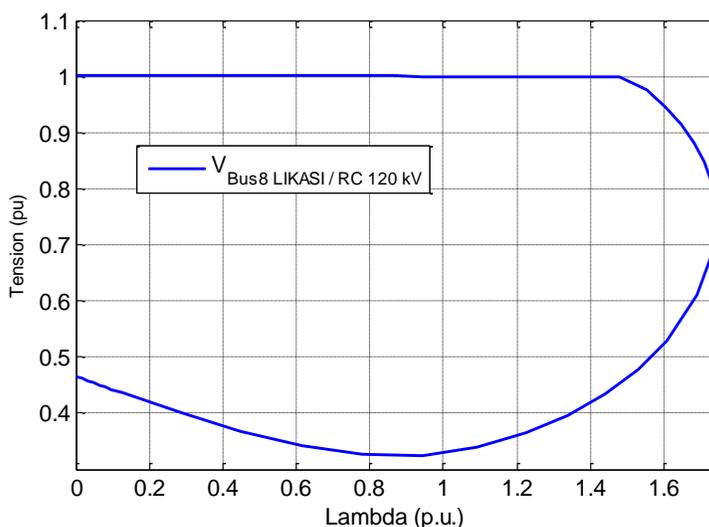


Figure 9: Voltage collapse curve to RC node

To better visualize the optimality of our site selection, as well as the effectiveness of the voltage sensitivity factor, the SVC is installed in different nodes of

the network and a comparative study is conducted with the critical node (LIKASI RC) given in the following Table 2 :

Table 1: Comparison of the stability margin at different nodes

Nœud	TENKE	RS	FUNGURUME 120 kV	PANDA
Lambda λ (pu)	1.6523	1.6548	1.6697	1.5844

XII. CONCLUSION

The problem of choosing the location of the SVC was discussed, and the LIKASI RC node was selected as the most favorable location for the implementation of the SVC. The voltage deviation to the nodes or VSF is the key parameter that allowed us to orient our choice towards the LIKASI RC. The presence of this SVC in the power network allowed us to both increase the stability margin and improve the voltage profile in all nodes except the RS node which can be considered as a weak node for another SVC placement. A comparative study was performed by placing the SVC in other nodes of the network, the response given by the LIKASI RC node remains satisfactory.

Further work may focus on a comparison of performance between this method and those of SVC placement by swarm particles multi-objective.

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