

Application Of Short Circuit Current Analysis as A Predictive Tool Against Grid Collapse in Nigeria Power System

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Abstract- The 330 kV power network in Nigeria experiences several major problems such as voltage instability, aged and dilapidated transmission facilities, and total power network collapse. In assessing voltage instability, the orthodox approach uses load flows and the continuous power flow technique. Though reliable, this approach is expensive and not very applicable in real time conditions. Short circuit current assessment is therefore proposed as an effective method of predicting and preventing voltage instability in the Nigerian power system. This is based on analyzing the relationship that exists among short circuit ratio (SCR), impedance level, and maximum power transfer capability. Through this process, short circuit boundaries which determine voltage vulnerable points are established. Short circuit current assessment was carried out using PSS/E software under normal and contingency states for Nigeria's power network. Findings reveal that buses with relatively lower short circuit current experience exponential reduction in statutory voltage levels. As a result, short circuit current monitoring becomes an instant indicator for corrective measures to be implemented.

Keywords: Short-Circuit Ratio, Voltage Failure, Stability, Grid Collapse, Real-Time

I. INTRODUCTION

The Nigerian electricity grid system faces fundamental weaknesses within its structure that regularly cause both total and partial collapses of the system (Alayande, 2024; Edeh, 2024). Given that the grid system uses radial transmission lines extensively, it is extremely vulnerable to major voltage collapse and fault issues (Adebisi et al., 2024; Ajenikoko et al., 2025). Such failures occur due to load generation imbalance, faults within the system, aging equipment, and operator error (Edeh, 2024). Essentially, voltage collapse occurs when the system

cannot deliver the required reactive power to maintain voltage stability.

For the purpose of establishing SCCA as a preventive measure against such blackouts, this section evaluates the inherent structural vulnerabilities in Nigeria's grid structure, the limitations of traditional methods of voltage stability assessment (Mokred et al., 2023), the connection between grid resilience and short circuit capacity, and the shortcomings of current methodologies. As per Onohaebi and Lawal (2020), the underlying structure of the Nigeria National Grid becomes the key factor responsible for its continuous vulnerability. The vulnerability arises from the large geographic distance that exists between power generation centers and their respective load centers.

More specifically, there exists two types of generation centers in Nigeria: Central generation centers comprising hydroelectric sources and Southern Generation Centers based on thermal generators within Niger Delta. In comparison, the North region comprises the largest number of load centers, which introduce high levels of transmission impedance into the system. Hence, moving power across these long distances causes dramatic reductions in reactive power and extreme technical losses (Onah et al., 2022), make the outermost peripheral nodes susceptible to swift voltage reductions and often require them to function below the statutory guidelines. According to Samuel et al, (2022), the collapse of the national electricity system in Nigeria is caused by a lack of reactive power compensation locally.

In times of high loads and unexpected outages in the transmission lines, the grid is unable to produce

enough reactive power needed for maintaining the voltage levels. As a result, the electrical grid constantly operates at the edge of instability and overloading. In such an unstable environment, a slight reduction of voltage or any other contingency may set off a cascade of voltage failures within the grid and ultimately cause a system blackout. Particularly, a trip of a critical line will overload the other lines that will be receiving excess power resulting in under-voltage and eventual blackouts.

Adewole et al. (2021) used standard load flow and CPF methods to determine voltage profile characteristics of vulnerable buses in the Nigerian power system. While these static methods are able to correctly identify the critical bifurcation point, i.e., the point where the voltage is at its maximum possible load on a voltage nose curve, the heavy dependence of these solvers on iterative non-linear computations through algorithms such as the Newton-Raphson solver imposes serious computational shortcomings while modeling transient grid contingencies. In particular, the standard power flow equations tend to face issues in convergence or diverge numerically when they are close to the voltage stability limit, meaning they are practically useless when they need to be most helpful. On the other hand, time-domain modeling requires the collection of extensive data sets for all state variables from throughout the network. According to Sambo et al. (2022), the absence of real-time telemetry capabilities at NCC Nigeria has been problematic.

Kundur (1994) established that the short-circuit capacity or fault current level at a transmission bus is inversely proportional to its Thévenin equivalent impedance (Z_{th}). A high short-circuit capacity reflects a low system impedance, designating a robust network node capable of defending its voltage profile against sharp fluctuations in active and reactive power loads. Consequently, the short-circuit ratio (SCR)—which compares the short-circuit MVA to the rated capacity of the connected generation or load—has become a definitive metric for identifying weak power systems.

Eje et al. (2024) used this model to illustrate how localized short-circuit index analysis allows system operators to measure real-time modifications in grid strength without having to run time-intensive, non-

linear load flow calculations. Going further with this process, Ajao et al. (2025) have been able to establish how any unplanned disconnection or de-isolation of a power line causes instantaneous increases in the Thévenin impedance of the nodes, resulting in immediate reduction in three-phase fault current capacity. Although Oladimeji et al. (2025) argued for the use of automated control frameworks to ensure stable functioning of the Nigerian grid to avoid complete blackouts, their recommendations were not based on any real-time application matrix.

This paper tries to fill this gap in practice by proposing a localized short-circuit threshold that is customized specifically to the topological configuration of the Nigerian 330 kV network.

II. NETWORK MODELING OF NIGERIAN POWER SYSTEM (CASE STUDY)

Figure 1 presents the structural design of the Nigerian 330 kV electrical transmission grid that was designed under the Siemens PTI PSS/E software. This actual grid is made up of a transmission distance of 5,523.8 kilometers of the high voltage transmission lines that have 32 bulk supply substations that have 330/132 kV configuration. These bulk supply substations have an installed transformation capacity of 7,688 MVA that translates into 6,534.8 MW with regard to operation at power factor of 0.85 [(Sadiq et al., 2013)].

The installed capacities at these 330/132 kV substations are reported to be averaging 7,364 MVA which is approximately 95.8% of installed infrastructural maximum capacity. These power inputs consist of generation input from the hydro and thermal power plants amounting to 7,461 MW. Verified generator capacity, operational bus loads and line impedances were obtained directly from TCN system archives [(TCN, 2024)] to develop this grid model.

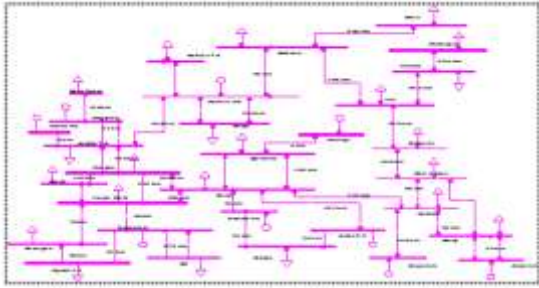


Fig. 1 Nigeria 31-bus, 330 kV Grid Network modelled in PSS/E

III. METHODOLOGY

Headroom capacity of fault level is an indicator of short circuit capacity based on the assessment of the margin that exists between the existing fault level and the highest rated fault level of the equipment. According to engineering principles, when connecting a new generator or load, it is necessary to use the metric for the sake of network stability and safety of the equipment (Roadnight Taylor, 2022).

In order to avoid any problems with network security, fault levels should always be lower than the rating of the equipment installed in the network system. Fault levels depend on the rating of the switchgear in the vicinity of the point where it will be connected to the network. “Headroom” refers to the degree of susceptibility of bus voltage in some section of the network and represents the calculated fault level in the same area of the network. Safety margins of about 5% below the ratings of switchgear are usually used by some distribution network operators.

The extra capacity of switchgear in case of bus with maximum fault current cannot be allowed to take more short-circuit fault current. Therefore, this is a principle of exclusion when choosing number of candidate buses that can be prone to voltage collapse. Generally, a distribution network operator will not allow any increase of short circuit fault current of any bus, hence making it exceed the design fault currents of the network (Baran & El-Markaby, 2005).

A. Baseline Fault Analysis:

The maximum active power (Pmax) and reactive power (Qmax) transferable to a bus are directly

bound by its short circuit MVA; a degradation in maps directly translates to a shrinking voltage stability margin. The primary advantage of utilising SCCA over standard PV/QV calculation pipelines is mathematical simplicity; short circuit calculations are governed by linear matrix operations (), which execute orders of magnitude faster than iterative load flows. Consequently, tracking percentage drops in localised short circuit capacity offers a reliable, real-time computational shortcut to forecast an impending voltage collapse (Oladimeji et al., 2025).

According to (VanZyl & Gaunt (2005), the fault current level is given as:

$$I_{base} (Amp) = \frac{MVA_{base}}{\sqrt{3} kV_{base}} \quad (1)$$

$$Z_{base} = \frac{(kV_{base})^2}{MVA_{base}}$$

$$Fault\ current\ (I_f)\ pu = \frac{1}{|Z_{TH} (pu)|} \quad (2)$$

$$(I_f)\ pu * I_{base} (Amp) = fault\ current\ (Amp) \quad (3)$$

$$(I_f) (kA) = \frac{Fault\ current\ (I_f)\ (Amp)}{1000} \quad (4)$$

The headroom capacity () for bus equipment is evaluated as given in equation (4);

$$(\gamma_b) = (K_b + 0.05 K_b) - (I_f) (kA) \quad (5)$$

Where: K_b = switchgear rated capacity (kA),

$$\gamma_b = \text{Headroom capacity}$$

According to Fsaha et al. (2022), symmetrical (three-phase) and asymmetrical (single line-to-ground) faults were applied systematically across major transmission hubs. The system strength at a given network node is directly proportional to its short circuit capacity. The short circuit capacity (S_{SC}) at the bus (i) is calculated using the pre-fault voltage

(V_i) and the Thevenin equivalent impedance (Z_{th}) .

A high short circuit current implies low Thevenin impedance, meaning the bus can withstand significant load changes or reactive power deficits without drastic voltage drops. Conversely, a low short circuit current indicates a weak bus highly prone to voltage collapse. The Short Circuit Ratio connects fault analysis directly to dynamic voltage stability. It is expressed as:

$$SCR = \frac{S_{sc}}{P_n} \quad (7)$$

Where P_n is the nominal rated power of the load? The post-fault variations were tracked alongside with the corresponding V_i , and the stress testing was through incrementally loading of active and reactive loads at selected buses until voltage collapse occurred.

B. Analysis of Weak Bus

The theoretical framework, into an operational predictive tool, the Transmission Company of Nigeria (TCN) can deploy the algorithm of the three-tiered preventative framework as depicted below in Figure 2.

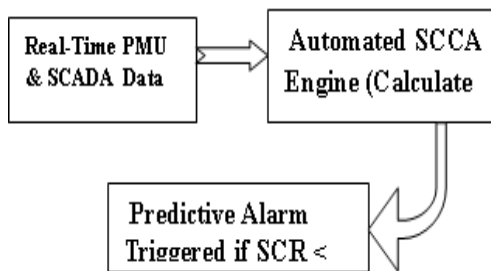


Fig 2 Three-tiered preventative framework

The online tracking method of impedance measurement using phasor measurement units (PMUs) placed at major 330kV substations is used to estimate the real-time Thevenin equivalent. This is then automatically followed by an SCCA program, which instructs the NCC energy management system at Oshogbo to compute background short-circuit analysis every 30 seconds. Whenever the expected

SCR of the bus falls below 2.0, the software system initiates automatic remedial action. In conclusion, it was observed that the buses in the northern loop have the least amount of short circuit current at the initial state.

As the reactive loads increased, there was a 85% increase in Thevenin impedance Z_{th} of the weak bus in question, thus reducing the short-circuit current to 5.2kA from 9.8kA. Also, when the SCR falls below 1.5, the weak bus is characterized by a non-recoverable voltage cascading, thereby making it fall below the statutory requirement of 0.85p.u. Therefore, we can conclude that the rate of change of short circuit capacity $\left(\frac{\Delta S_{sc}}{\Delta t}\right)$ works as a diagnostic tool for detecting impending voltage collapse.

IV. SIMULATION RESULTS AND DISCUSSION

The simulations revealed a direct correlation between diminishing short-circuit current thresholds and the system's proximity to the point of voltage collapse. To execute the pre-fault calculations, the simulation utilizes a system base of 100 MVA and a nominal line voltage of 330 kV, extracting initial bus voltages directly from the base load-flow solution.

The numerical analysis indicates that any node experiencing a Short-Circuit Ratio (SCR) drop below 2.0 is classified as electrically weak. This threshold marks the point where a bus becomes highly susceptible to voltage instability and control system oscillations. Table 1 and Figure 3 detail the short-circuit fault current levels across the 21 candidate buses. The data reveals that four of these buses possess a positive headroom capacity, exposing them to severe voltage fluctuations.

Specifically, Bus 21 (Maiduguri) and Bus 20 (Gombe) fall strictly below the $SCR < 2.0$ threshold, identifying them as critically weak nodes facing an imminent risk of voltage collapse. Similarly, Bus 11 (Birnin Kebbi) and Bus 18 (Kano) register within the $2.0 \leq SCR \leq 3.0$ range, designating them as moderately weak buses that remain highly vulnerable

to voltage variations. Ultimately, these simulation outputs confirm a direct, mathematical relationship between diminishing short-circuit current thresholds and the system's proximity to a total voltage collapse point.

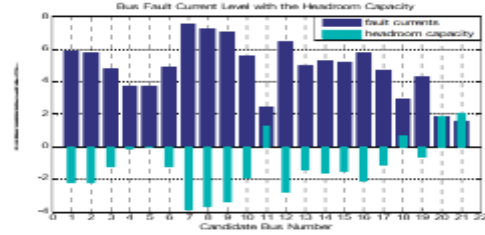


Fig 3 Bus short circuit current level with the headroom capacity

Table 1

S/N	BUS NAME	RTh	XTh	Short Circuit Current at Bus (kA)	Short Circuit Ratio (SCR)	Headroom Capacity (5% Safety Margin)
1	Aja	0.0164	0.0280	1.7058	5.9134	-2.2384
2	Jebba T S	0.0151	0.0294	1.9405	5.8189	-2.1439
3	Aladja	0.0160	0.0360	2.2476	4.8742	-1.1992
4	Shiroro T S	0.0200	0.0472	2.3612	3.7510	-0.0760
5	Abuja	0.0203	0.0472	2.3212	3.7370	-0.0620
6	Alaoji	0.0199	0.0339	1.7051	4.8847	-1.2097
7	Ikeja-West	0.0148	0.0205	1.3789	7.5860	-3.9110
8	Benin	0.0140	0.0222	1.5789	7.3061	-3.6311
9	Akangba	0.0152	0.0225	1.4800	7.0664	-3.3914
10	Ajaokuta	0.0155	0.0303	1.9503	5.6370	-1.9620
11	B/Kebbi	0.0256	0.0749	2.9230	2.4283	1.2466
12	Osogbo	0.0147	0.0257	1.7455	6.4750	-2.8000
13	Kaduna	0.0184	0.0331	1.7925	5.0719	-1.3969
14	Makurdi	0.0189	0.0308	1.6276	5.3186	-1.6436
15	Ayede	0.0170	0.0327	1.9252	5.2136	-1.5386
16	Onitsha	0.0168	0.0285	1.6915	5.7997	-2.1247
17	Jos	0.0192	0.0357	1.8572	4.7447	-1.0697
18	Kano	0.0263	0.0587	2.2274	2.9864	0.6885
19	New-Haven	0.0193	0.0399	2.0603	4.3371	-0.6621
20	Gombe	0.0431	0.0932	2.1628	1.8737	1.8012
21	Maiduguri	0.0488	0.1067	2.1874	1.6393	2.0356

SCR > 3.0: Strong bus; high voltage stability.

2.0 ≤ SCR ≤ 3.0: Weak bus; vulnerable to voltage fluctuations.

SCR < 2.0: Very weak bus; high risk of voltage collapse.

V. CONCLUSION

This paper validates the application of Short Circuit Current Analysis (SCCA) as a reliable predictive

measure against voltage collapse on the Nigerian National Grid. By monitoring localised short circuit currents and Short Circuit Ratios (SCR), operators can identify network vulnerabilities faster than

traditional power flow methods allow. Implementing this real-time predictive index will significantly reduce the frequency of total grid collapses in Nigeria, improve system reliability, and safeguard industrial loads.

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