Impacts of SCIG and DFIG on Voltage Stability in Greater Banjul Area Utility, The Gambia

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***Abstract*—Wind unpredictability impacts power stability especially, in high demand areas. Voltage instability is not a new phenomenon for utility providers but the impact is greater with the increase integration of renewable energy systems. The existing 1 MW wind farm consists of an aging fixed speed squirrel cage induction generator (SCIG). The SCIG are known to drain huge amount of reactive power from especially weak utility networks such as the one in Gambia. DIgSILENT Powerfactory was used to analyze the impact of low voltage ride through (LVRT) of 1 MW squirrel-cage induction generator (SCIG) and 1 MW doubly-fed induction generator (DFIG) on the GBA utility network. The results showed a reduction in reactive power absorbed by the generators thereby increasing voltage stability.**

***Index Terms*—DFIG; SCIG; LVRT; Greater Banjul Area; The Gambia.**

I. INTRODUCTION

The Gambia is the smallest country in main land Africa and located west part of Africa. In 2013 Census showed Gambia has a total population of 1,882,450 which indicated a 5.6 % increase compared with previous estimates [1].

The Gambia has huge potential of renewable energy resources especially solar and wind. The Gambia has an annual average GHI NREL moderate resolution of 5.69kWh/m2 per day [2-4] and average wind speed NASA low resolution of 4.71m/s2. About 57% of 1.3 billion of African population has no excess to electricity especially in Sub-Sahara region which has the fastest growing economies in Africa [5-6].

About 46% of Gambian has excess to electricity in which renewable energy consists of less than 2 % of the total energy mix. Rural electrification is a huge challenge where about 11% have access to electricity [7]. The renewable energy law and feed-in tariff are already in place to provide the necessary standards and promotion of renewable energy investment [8].

The result of increasing fuel prices and environmental impact associated with the conventional power plants is convincing many countries in Africa to turn to renewable energy source of energy.

Wind power plants have increased due to the advancement in wind turbine technology and affordable cost. Many studies indicated that the squirrel-cage induction generator (SCIG) has a very poor performance during normal operation due to voltage instability from faults and disturbances [9-10]. This research focused on Technical analysis and comparison of SCIG and DFIG wind turbine grid integration in the Greater Banjul Area of the Gambia. The most widely used wind turbine generator type for units above 1 MW is the doubly fed induction machine therefore a potential replacement for SCIG wind turbine in Gambia. This research discussed the LVRT impacts of upgrading or replacing the existing SCIG wind turbine in Greater Banjul Area to DFIG wind turbine to improve grid stability.

II. THEORETICAL BASIS

Wind turbine technology operates on the principle of a rotating device that transforms the kinetic energy of wind into mechanical energy which could be used directly as in pumps in windmills or water pumping. This technology was a revolutionary source of energy which changed the history in wind power. The mechanical energy could also be indirectly transformed into electricity hence the name wind generator. [11]. Wind turbines of small capacities were first used in Scandinavia for electricity generation in farm land. The common sizes of wind turbines could range from 5 kW to 2 MW due to the increase in efficiency and lower investment costs.

Kinetic energy and potential power are given by [12-13]:

$$K_E = \frac{1}{2} m v^2 \tag{1}$$

$$P = \frac{1}{2} \dot{m} v^2 \tag{2}$$

Fluid mechanics gives the mass flow rate as:

$$P = \frac{1}{2} \rho A v^3 \tag{3}$$

Power Coefficient C_p is the ratio of power converted by the wind turbine compared with the available wind resource:

$$C_p = P_t / P \approx 59\% \tag{4}$$

where:

$$P = \frac{1}{2} C_p \rho A v^3 \tag{5}$$

The output power of the turbine can be written as:

$$P_{out} = \frac{1}{2} \eta C_p \rho A v^3 C_p \tag{6}$$

It is said that the C_p has a theoretical Betz limit of 59.3%

but most commercial wind turbines use a lower percentage of about 40%, consideration is also given to the conditions of location of installation. The wind speed rations are very important since the power out increases as the wind speed increases [11].

A. SCIG Wind Turbines

SCIG wind turbines are usually connected to the grid directly and hence the rotor speed depends on the amount of power generated. The rotor speed changes are very small and only amount to 1% and 2% and hence they are referred to fixed speed wind turbines. SCIG is not desirable for large and weak grid because of reactive power consumption which must be fully compensated by capacitors [13]. Figure 1 show the general structure of grid connected SCIG.

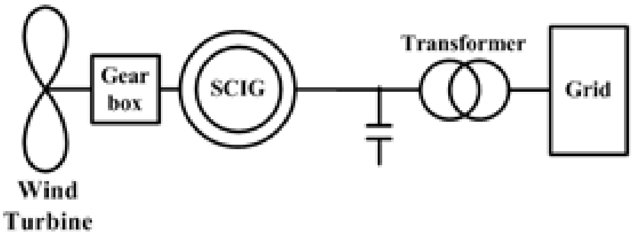

Figure 1: General structure of SCIG

B. DFIG Wind Turbines

The advantage of DFIG concept is independent of the rotor speed and only a percentage of power generated in the generator has to pass through the power converter. The DFIG is a variable speed wind generator hence allowing for change from mechanical speed to wind speed [13-14]. This is typically only about 20–30% compared with full power (100%) for a synchronous generator-based wind turbine concept, and thus it has a substantial cost advantage compared to the conversion of full power. A basic DFIG wind turbine setup comprises of an induction generator where the stator coil connected to the three-phase grid and the rotor coil connected to the grid network through a back-to-back semiconductor power converter [15]. Figure 2 showed the general structure of grid connected DFIG.

The rotor side converter (RSC) and grid side converter (GSC) coupled with other controllers makes the DFIG a very suitable and attractive wind turbine technology in future wind farms.

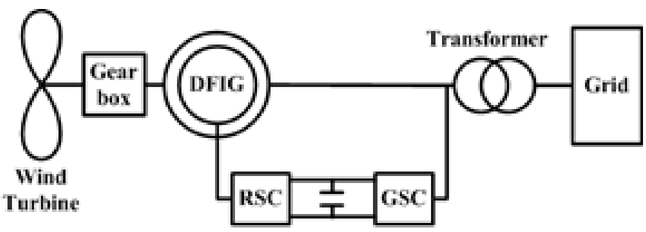

Figure 2: General structure of DFIG

III. Methodology

A. Simulation Test Mode

This research intended to analyze the impact of Wind power systems on the voltage of the Greater Banjul Area (GBA) utility network. The DIgSILENT powerfactory 15.1 simulation method was used analyze the voltage control strategy for a doubly-fed induction generator (DFIG) and squirrel cage induction generator (SCIG). Faults were triggered very close and far away from the PCC. The faults and their impact on voltage rise and fall and the reactive power injection at the PCC will be studied and plotted. The simulation model designed a single line diagram of the existing 11/33 kV grid network of the Greater Banjul Area (GBA). The single line diagram of the GBA grid network is designed and simulated in Figure 3 using actual data and conditions specific to the GBA grid network to identify the challenges and suggest suitable and cost effective solutions.

Figure 3 below showed the part of the grid network or Bijilo bus where the wind power systems is connected. The existing GBA grid integration is solely based on trial cases where the independent power producers did not consider the effects of using old and reuse wind turbine generators will have on the entire GBA network. The wind plants pose a huge challenge to the stability of the GBA network stable voltages due to high demand and aging grid infrastructure.

The use of controllable power generation operation at optimal power coefficient due to variable speed could be over solved by the use of DFIG connected with PWM controllers in the wind power plants. The single line diagram was modified by connecting DFIG and SCIG to the PCC/bus bar which has a station controller which is part of the DIgSILENT powerfactory library. The two wind turbine generators are connected to the Bijilo substation. Faults near the generator caused by LVRT increases the risk of damage and system failure. A bypass circuit is used to prevent high rotor currents using a PWM-converter.

The purpose of the modification on the wind farm design is intended to reduce the reactive power absorbed by the generators. Figure 4 showed a single line diagram representing SCIG and DFIG connected to the grid network via Bijilo substation. DFIG and SCIG are designed with inbuilt controllers as shown below to stabilize the network. The PWM, capacitors, soft starters and rectifiers also play a very vital role in the control mechanism to reduce and maintain a stable grid network absent excess grid over currents.

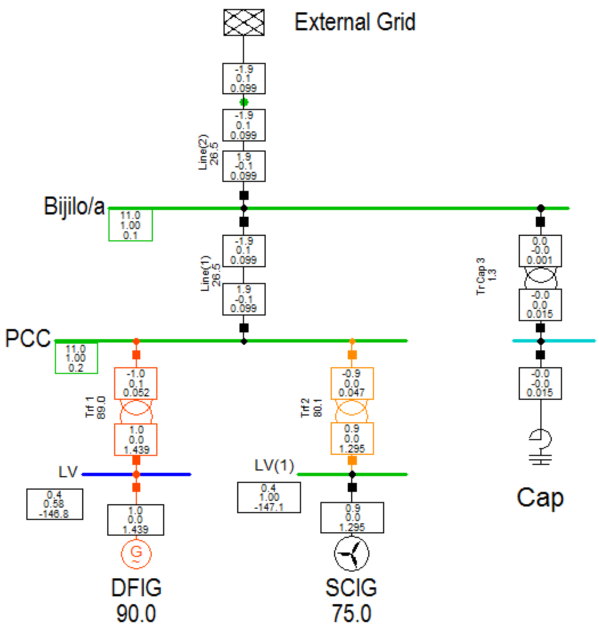

Figure 4: 1 MW DFIG and SCIG

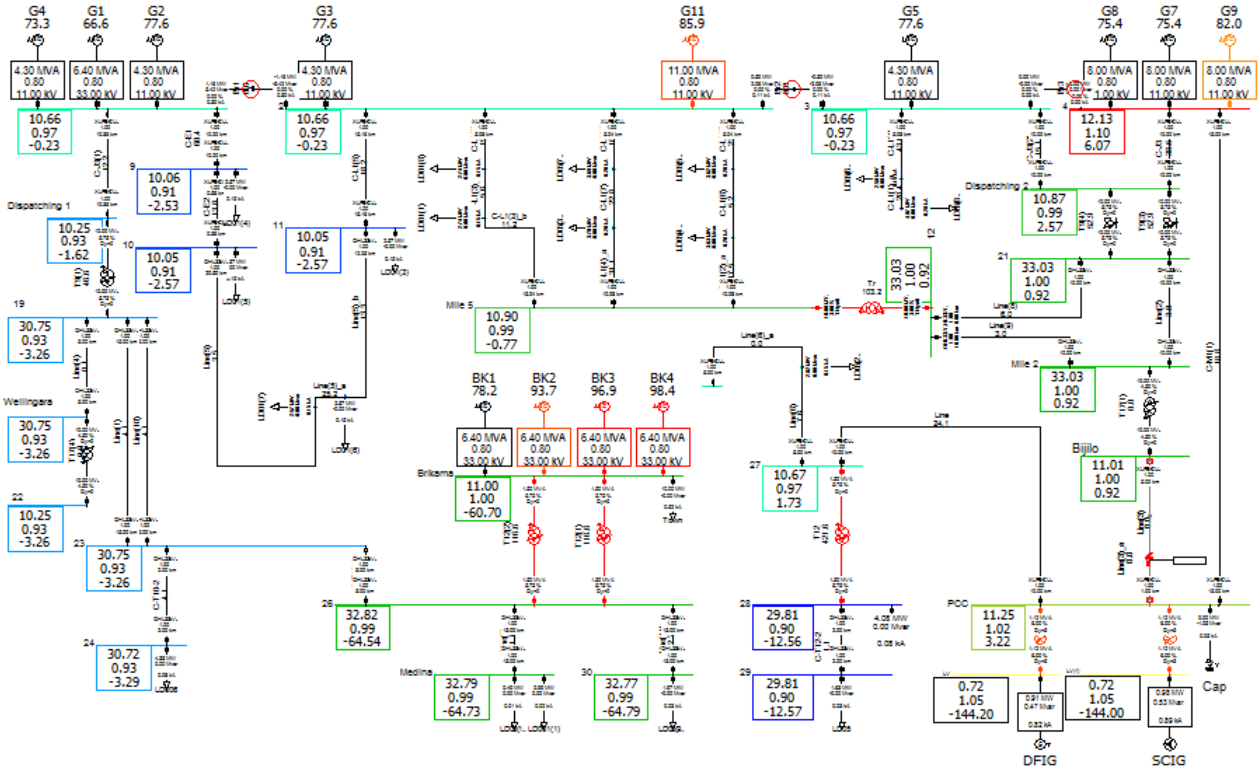

Figure 3: GBA Grid Network

IV. Results and Discussions

This part of the study analyzed the effects of wind integration on the GBA utility network. The behavior before and after the disturbances and will be analyzed. The impact of low voltage ride through on the PCC/ bus and the wind turbine generators is the focus of this research so as to ascertain and select the most suitable wind turbines generators for the existing conditions of the GBA grid.

A. *Low voltage ride through (LVRT) simulation at 0%*

A three-phase short circuit is applied to the terminal near the PCC bus. The short circuit was applied at 0 seconds and the fault is cleared again after 0.1 seconds. The simulation evaluated produced from EMS results over a period of 1 second has the following results. Figure 5 show when the fault is applied at 0%, the voltage drops to zero and stay at the zero value until the fault is removed after 0.1seconds or 100 ms. When the fault is removed, the voltage returns back to its original value before the fault. During this fault, the grid contribution positive sequence is very high.

Figure 6 show the results of active and reactive power applied during at 0 second. Since the voltage dropped at zero, the active and reactive power also drops to zero.

The DFIG and SCIG wind turbine simulation results indicated in Figure 7 show that when the fault is applied, the current drops near zero for the DFIG and returns to where it was before the fault was applied but the current for the SCIG dropped below zero during the fault and returned to a much lower figure compare with the DFIG.

It appeared the SCIG continue to rise slowly and eventually returned to its original value after 1 second. This makes the SCIG very unstable and unpredictable especially for weak utility network where a long duration fault could affect the entire network. The increase in energy demand requires a stable and predictable power generation to support economic growth.

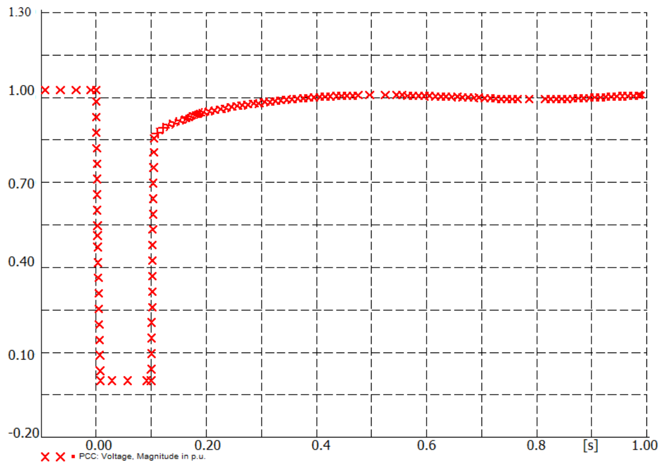

Figure 5: PCC voltage magnitude (p.u)

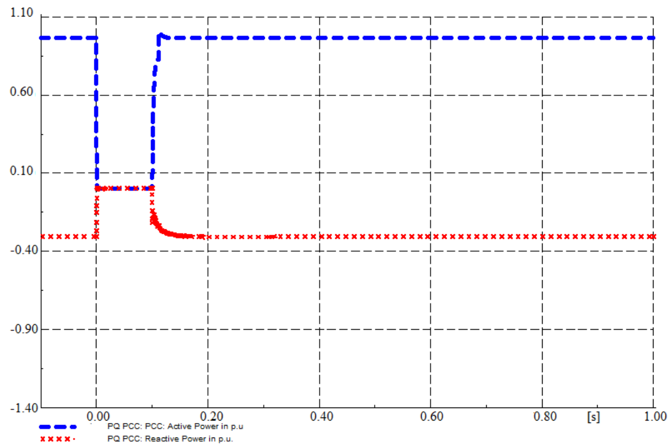

Figure 6: Active and Reactive power at the PCC

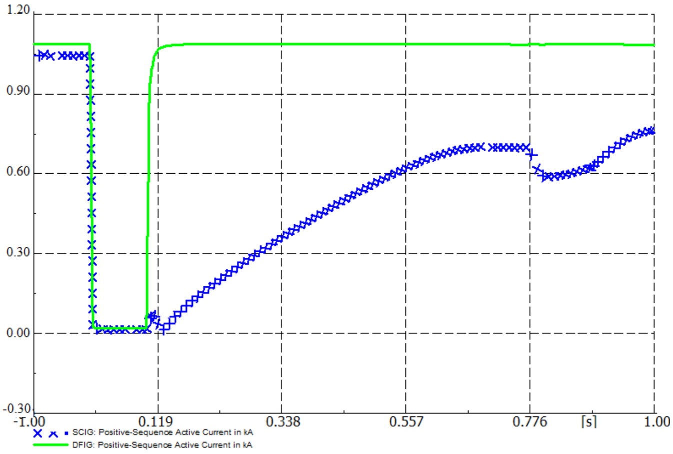

Figure 7 Positive active current kA DFIG and SCIG

Before the fault was applied the active and reactive power was constant, but once the fault was applied, the active power dropped when the fault was applied. The DFIG and SCIG voltage support for the LVRT increases the reactive power contribution which rises until it reaches the limited depending on the generator controller and its ratings. The active power returned to its original position when the faults stop at 0.1 second or 100 ms as shown in figure 8 below. The reactive power of the SCIG rose very high during the start of fault and drop to zero before the fault was removed. The reactive power for the DFIG remained high until the fault was removed and returned to zero.

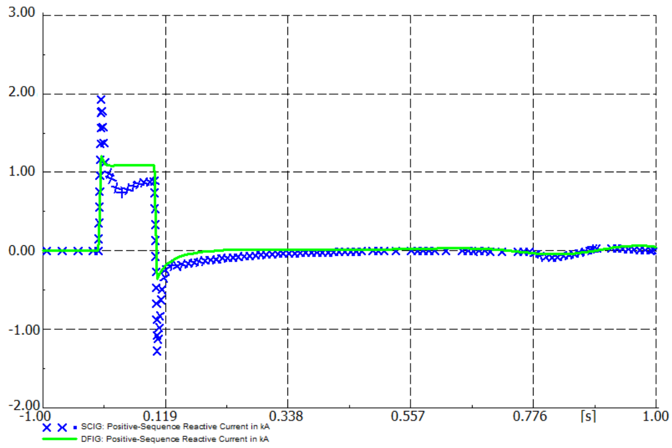

Figure 8: reactive power current kA DFIG and SCIG

B. Low voltage ride through (LVRT) simulation at 30%

A three-phase short circuit is applied at the same terminal above the PCC couple with fault impedance which will cause the voltage drop of 30% at the PCC bus. The short circuit was applied at 0 seconds and the fault is cleared again after 0.5 seconds or 500 ms. The Simulation evaluated produced from EMS results over a period of 1 second has the following results. Figure 9 below show when the fault is applied at 0 second, the voltage this time dropped to voltage near zero and stay at that voltage value until the fault is removed after 0.5 second or 500 ms, once the fault is removed the voltage returned back to 0.6 and rises steadily to 0.85 before returning back to its original value before the fault. Voltage 0.80 and above is considered acceptable under Gambia grid requirements [8]. During this fault, the grid contributed positive sequence is very high. The longer the fault duration the more the voltage drops and longer it takes to return to its original position before the fault.

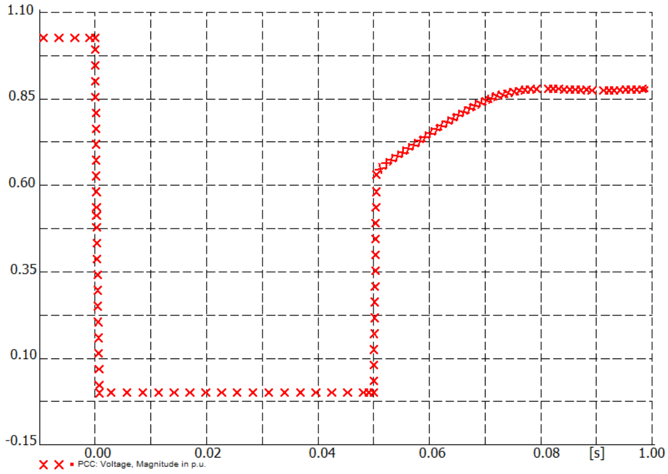

Figure 9: PCC positive sequence voltage in p.u

Figure 10 show that the reactive power values are higher and at 0.3 pu compare with figure 4 above. The reactive power contribution is higher than the active power at the PCC.

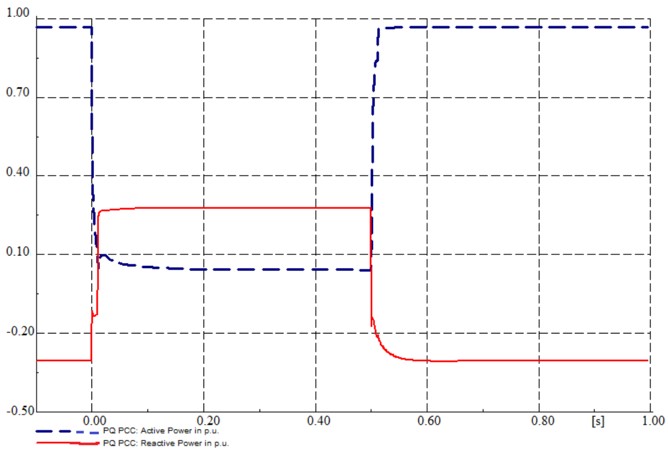

Figure 10: PCC Active and reactive power

Figure 11 showed the DFIG and SCIG positive sequence current in kA. The DFIG showed a return to the normal current after the fault at 0.5 ms while the SCIG continue to show low current values.

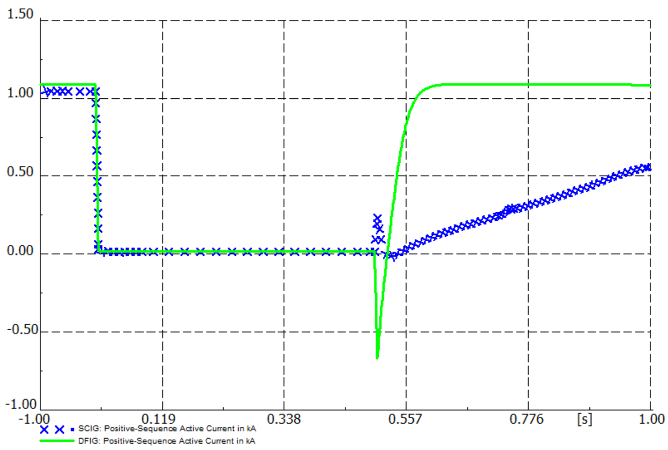

Figure 11: Positive sequence current kA for DFIG and SCIG

The reactive power in Figure 12 is not limited and depends on the generator controller. The reactive power will rise and remain constant to compensate for the duration of the fault from 0 to 0.5 seconds for the DFIG while it will rise and drop before the fault is removed for the SCIG. The DFIG is better than the SCIG in reactive power compensation and hence more desirable for large scale wind turbines in Gambia.

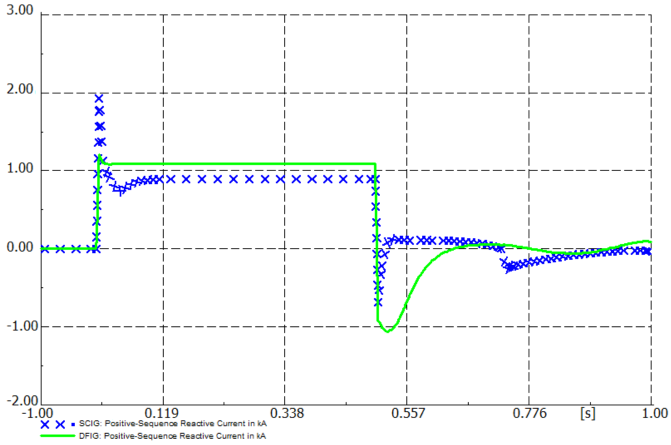

Figure 12: DFIG and SCIG reactive power in kA

The simulation results from the above graphs show that the DFIG could be a better alternative for wind power grid integration in Gambia. The return to active power and the rapid reactive power compensation after a fault is the reason why many countries prefer the DFIG for large scale wind powers. The Gambia is yet to have a grid code, the simulation used assumptions similar to German grid code [16].

V. CONCLUSIONS

The research presented the design of 30 bus model base on the Greater Banjul Area gird network using the DIgSILENT Powerfactory simulation software to identify a possible solution for problems that arise due to faults. The designed GBA network considered the existing input parameters in the dynamic system. The results showed that SCIG was barely stable and not generating sufficient power to compensate reactive power demand, while the DFIG indicated a remarkable stability matched with sufficient reactive power compensation. The voltage instability problems could therefore, be addressed by using improved wind turbine generators such as DFIG which improve the reactive power compensation due to disturbance or faults. Further studies could be done to address not only the voltage instability but other factors such as smart voltage control mechanism, frequency fluctuation and smart grids control in the GBA utility network to improve power quality. Improved power quality and stability will go a long way in addressing the meeting the increasing energy demand in the GBA region and hence speed up economic growth in The Gambia.

APPENDIX

Tables 1 and 2 show the impact on the utility network buses and generators before and after low voltage fault ride through.

Table 1
Bus voltages before fault

Bus	1	2	3	4	Brlkama	PCC
p.u	1.0	1.0	1.0	1.13	1.0	1.03
kV	11	11	11	12.40	11	11.36

Table 2
Bus voltages after fault

Bus	1	2	3	4	Brlkama	PCC
p.u	0.97	0.97	0.97	1.10	1.0	1.02
kV	10.66	10.66	10.66	12.13	11	11.25

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