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Island Operation during Integration of Wind Turbine: A Case Study of Geregu Camp Distribution Network In Ajaokuta Nigeria

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Abstract- *This paper analyses island operation during Wind Turbine on Geregu Camp in Ajaokuta LGA distribution network. A total of 85 kW can be harnessed through Wind Turbine from the study area. Wind Turbine was integrated into feeder 32 of Ajaokuta distribution network. The steady state analysis of feeder 32 of Ajaokuta distribution network with and without Wind Turbine integration were carried out in DIgSILENT Power Factory. The result shows that the load flow algorithm converges and the generator-load demand was balanced. While, transient stability analysis of feeder 32 of Ajaokuta network with and without Wind Turbine integration carried out in DIgSILENT shows that the rotor angle settled above stability limit of* 120^0 *for multi machine. The system became unstable when 3∅ short circuit fault was applied. Also, the steady state and transient stability analyses of the islanded network with Wind Turbine integration were carried out in DIgSILENT Power Factory. The results showed that Wind Turbine integration at islanded stage is stable* $(\delta = 63.7^0)$ *because of the diesel generator attached to the islanded network.*

Index Terms: *Renewable sources, Distributed Generation (DG), synchronization and grid-connected Wind Turbine.*

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I. INTRODUCTION

Energy plays important role in our daily life, modern energy services are powerful engine of economic and social development [1]. Efficient generation, transmission and distribution of energy in Nigeria is still a challenge. Data obtained from the Energy Commission of Nigeria (ECN) showed that the current power generation in Nigeria is far less than the national requirement [2]. Energy demand is four times higher than the peak power generation [3]. The continue rise in power demand in some parts of the country such as Geregu Camp in Ajaokuta LGA (study area) is alarming. This is occasioned by several hours of power outages per day, which has led to load shedding in the area since the power available cannot meet the load demand. Generation of electricity through Wind Turbine is considered as an option to cater for the generation and demand imbalances in the area There is growing concern that energy generation through fossil fuel are hazardous to both the environment and humans as such there is need to use Renewable Energy (RE) sources such as Wind Turbine, Solar PV, Biomass, Small Hydro, Tidal wave, etc. which are eco-friendly to complement some of these increasing energy demands [4]. They became more profitable, efficient, reliable and stable when they are grid connected. When these RE are connected close to the consumer they are termed Distributed Generation (DG) [5].

The DG can be isolated from the national grid due to preplanned (intentional) or accidental (unintentional) events, while the DG remains operational supplying power to the local loads thereby forming an island. Islanding describe a scenario where a section of transmission or distribution network, which contains DG, is separated from the main transmission or distribution grid. Subsequent to this separation the DG continues to power the load within the island created [5]. Fig. 1.0 shows schematic diagram of an island formed by a DG by opening at the PCC**.** The island can be designed to maintain a continuous supply of power during instability on the main distribution system. The distributed energy system can then supply the load demand of the island created until reconnection with the main utility grid.

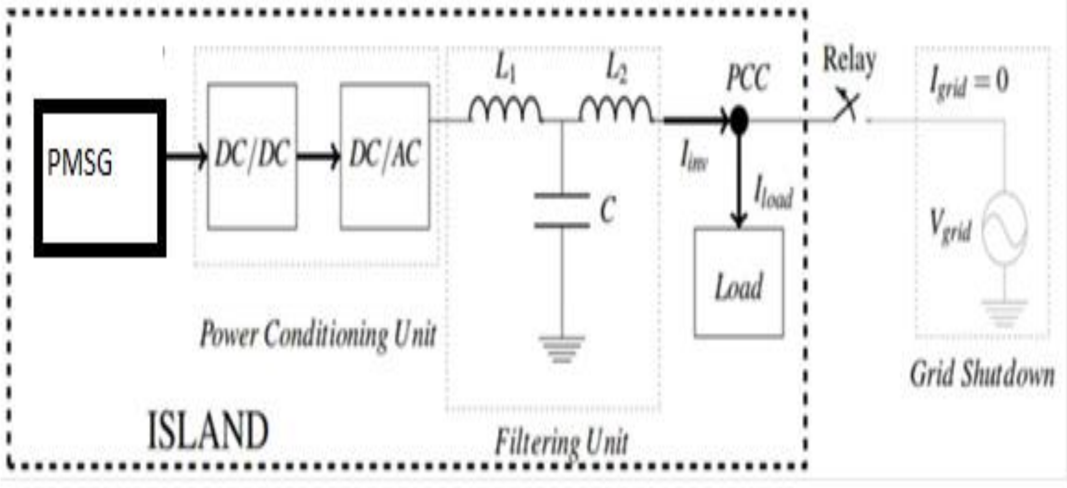


Fig: 1.0: Distributed Generation System in Island Operating Mode [9,10]

II. POWER IN THE WIND

The power in the wind is extracted by allowing it to blow past moving wings or blades that exert a torque on a rotor shaft. The amount of power transferred is expressed as [6]:

$$P = \frac{1}{2} C_p A \boldsymbol{\rho} v^3 \qquad (1)$$

where: P is power in watts, C_p is coefficient of performance, A is swept area of blade(s), m^2, $\boldsymbol{\rho}$ is density of air (kg/m^3) and v is average wind velocity (m/s), the wind power available to a wind turbine varies as the cube of the wind speed [6]. When the wind speed is doubled the power is multiplied eight times (power equation). As wind speed increases linearly with height above sea level, it is also a fact that extractable power available in wind increases with height. Wind speed is the most important parameter in the design and study of wind energy conversion devices [6]. Because so much power is generated by higher wind speed, much of the average power available to a wind mill comes in short bursts. The consequence is that wind energy does not have as consistent an output as fuel-fired power plant.

III. WIND TURBINE RESOURCES

The wind turbine resources assessment was based on wind speed data gathered for 60 days at 25 m height for the study area using anenometer. It was analyzed for daily and monthly averages. The wind speed data was used to estimate total extractable wind power for the study area. The monthly average wind speed of the study area collected by direct measurement is 3.145 m/s with a total extractable Wind Turbine of 85 kW as modeled in HOMER [7].

IV. LOAD ANALYSES OF AJAOKUTA DISTRIBUTION NETWORK

In the analyses of load distribution of Ajaokuta Steel Township electrical distribution the following network elements were considered: One step-down source transformer rated 168 MVA of voltage 330/132 kV, two step-down variable transformers rated 63 MVA and voltage 132/11 kV each.

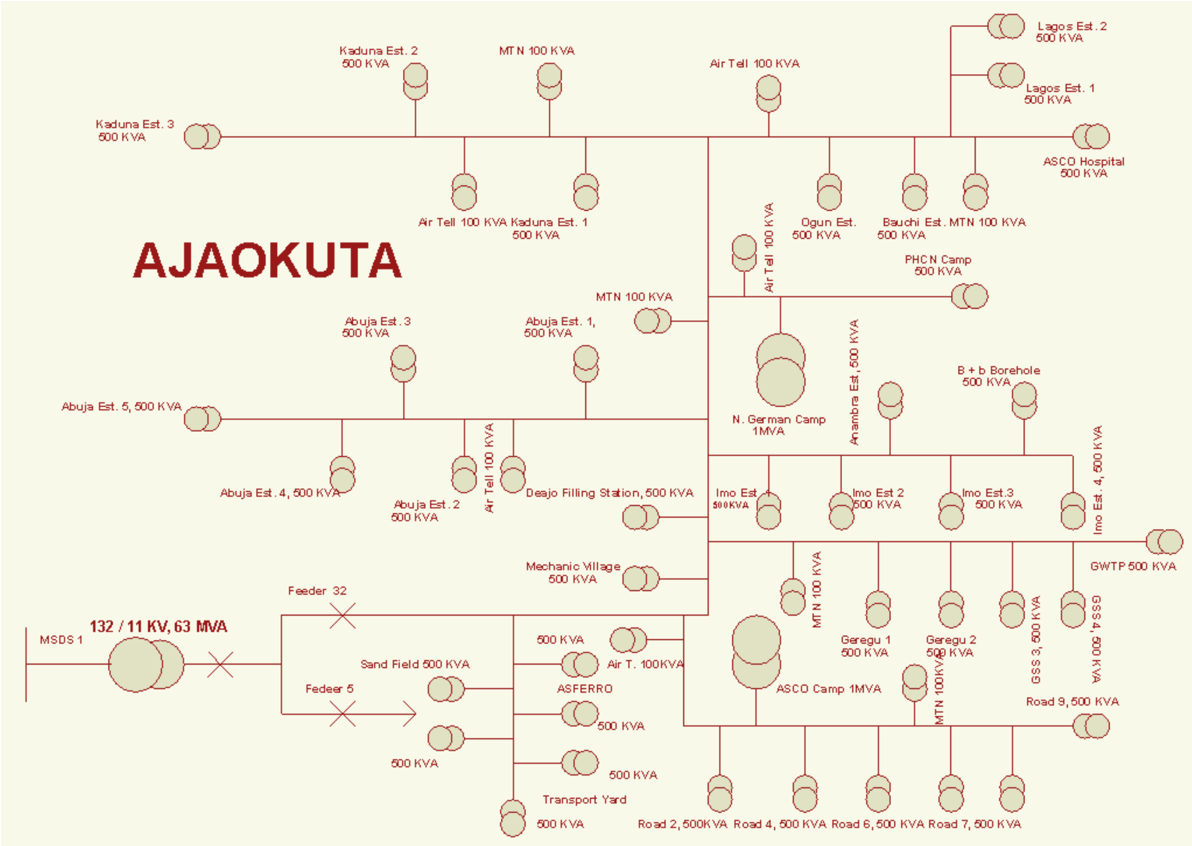


Fig: 2.0: Ajaokuta Electrical Distribution Network

The variable transformers are stationed at Main Step Down Sub-Station - 1 (MSDS-1), it has two feeders; feeder 5 and feeder 32 both supplying the Steel Township as shown in Fig. 2.0. There are two 1 MVA, thirty nine 500 kVA and ten 100 kVA step-down transformers connected on the distribution network. Line voltage of the injection transformers on feeder 32 are 11 kV, which the transformers step-down to 415 V. Modeling of the network was carried out in DIgSILENT Powerfactory [11]. Data available at the electrical distribution unit of Steel Territory Administration (STA) showed that the study area (Geregu Camp) highest load demand in the year is in May with 3.82 MW and the least was in August with 2.06 MW [4,8]. Ambitions to alter the current electricity distribution and corresponding actions are backed socially. Because power supply in the study area is not efficient, occasioned by low voltage profile, poor conductor connection, which often results in frequent load shedding and power outages. Hence, additional power generator such as Wind Turbine systems is required to complement power generation, which will increase access to electricity supply, reduce the issue of load shedding and power instability.

V. MODELING OF FEEDER 32 OF AJAOKUTA DISTRIBUTION NETWORK IN DIGSILENT

Fig. 3.0 shows modeling of feeder 32 of Ajaokuta distribution network in DIgSILENT, the modeling was carried out to determine the dynamic and steady state stability of the distribution network. The modeling shows each of these transformers and load connected to it, the results are analyzed in section VIII.

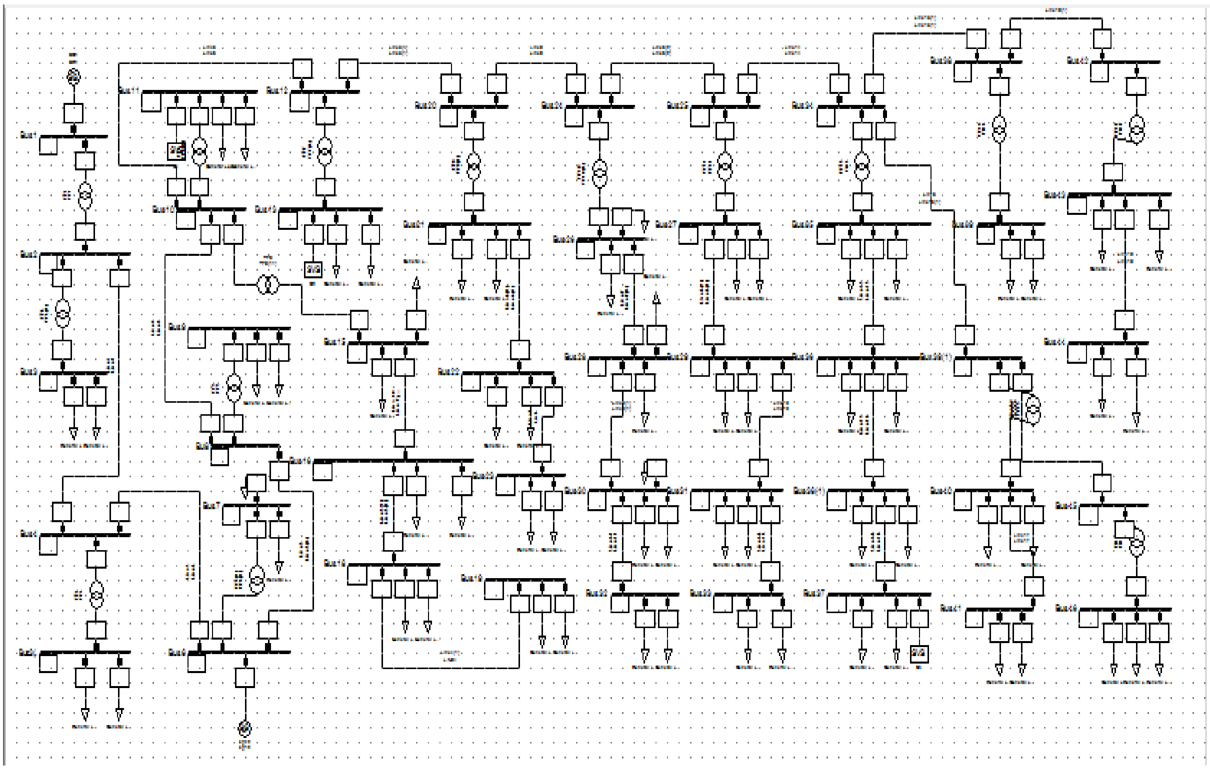


Fig: 3.0: Modeling of Ajaokuta Power Distribution Network Modeled in DIgSILENT

VI. FEEDER 32 OF AJAOKUTA NETWORK WITH WIND TURBINE INTEGRATION

Fig.4.0, shows modeling of Ajaokuta distribution network with Wind Turbine integration in DIgSILENT, this was done to compensate for instability in the network. The 85 kW output of Wind Turbine is integrated with feeder 32 of Ajaokuta network, the Wind Turbine is as indicated in the network. The grid-connected Wind Turbine was simulated the results are analyzed in section VIII.

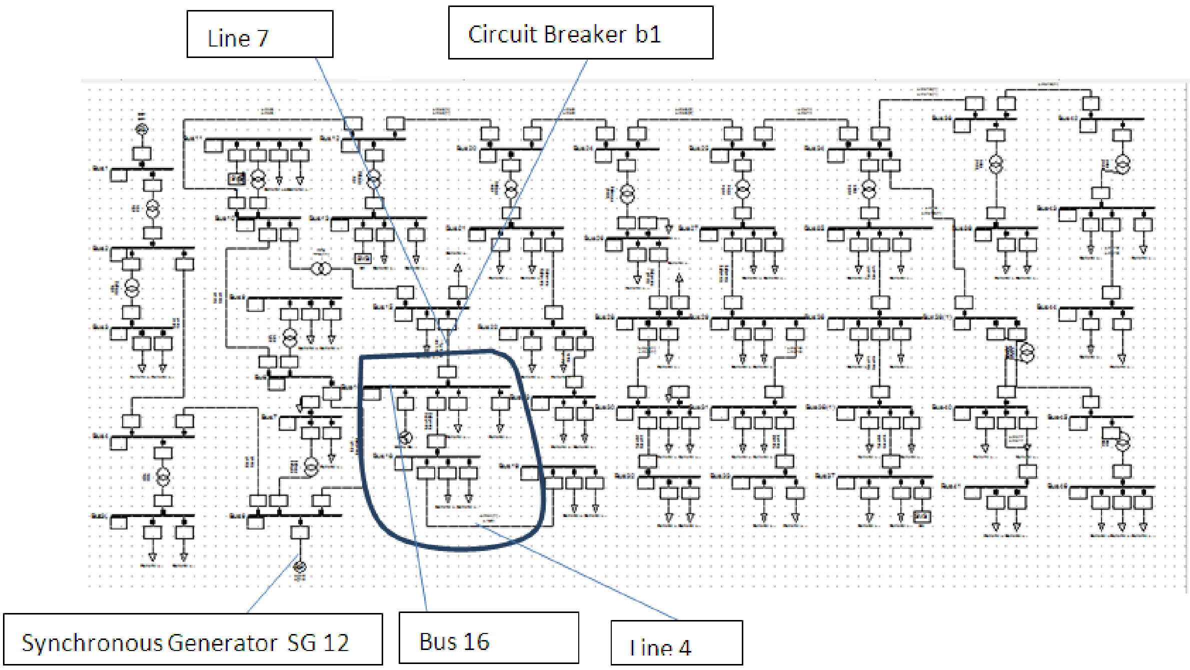


Fig.4.0: Modeling of Grid-Connected Wind Turbine on Ajaokuta Power Distribution Network Modeled in DIgSILENT.

VII. ISLANDED NETWORK (STUDY AREA) INTEGRATED WITH WIND TURBINE MODELED IN DIGSILENT

Fig.5.0 shows modeling of the islanded network with Wind Turbine integration on the distribution network in DIgSILENT. When there is an unintentional fault on the main utility grid (i.e. feeder 32) leading to tripping off of circuit breaker 1 (Fig.2.0), the study area is islanded from the grid as indicated in the network. The feasibility study carried out for the study area shows that a total of 85 kW can be harnessed through Wind Turbine from the study area. The islanded network with Wind Turbine integration is modeled in DIgSILENT and the result is analyzed section VIII.

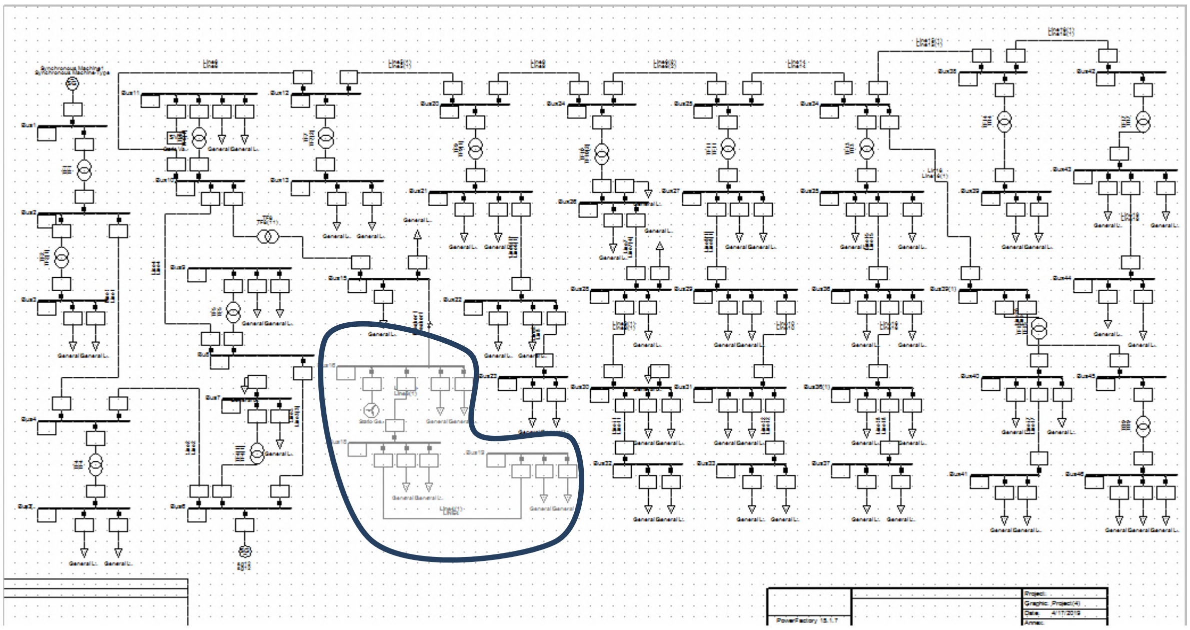


Fig.5.0: Modeling of Geregu Camp (Study Area) Distribution Network in Island Mode Powered by Wind Turbine modeled in DIgSILENT.

VIII. Results and Analyses

Results of Steady State Analyses of Feeder 32 of Ajaokuta Network Modeled in DIgSILENT

This section presents the steady state results and analyses of feeder 32 of Ajaokuta distribution network. Three case studies are presented with two scenarios considered in each: Ajaokuta distribution network, the network with Wind Turbine integration and Islanded network with Wind Turbine integration. Parameters such as: voltage magnitude, active power, reactive power and current of the network were measured.

Case Study 1: Steady State Stability Analyses Result

Scenario 1: Ajaokuta Distribution Network without DG Integration

Table 1.0 shows the load flow report of feeder 32 of Ajaokuta distribution network without DG integration. The load flow in DIgSILENT shows bus voltage, active power, reactive power and current loading. The load flow report helps in analysing the steady-state of the network.

Table 1.0: Load Flow Report of Feeder 32 in Ajaokuta Distribution Network without DG/HDG Integration

Bus No	Voltage (pu)	Active Power (MW)	Reactive Power (MVar)	Current (kA)	Loading (%)
1	1.00	0.20	0.08	0.62	70.62
3	1.01	0.30	0.10	0.44	70.54
4	1.01	132.56	53.27	7.43	74.33
6	1.01	150.03	59.78	8.94	80.75
7	1.01	0.30	0.10	0.44	31.51
10	1.01	-15.56	-5.80	0.86	43.19
12	1.01	-12.95	-4.65	0.72	35.78

15	1.00	0.20	0.09	0.31	60.98
16	1.00	0.30	0.10	0.44	60.23
20	1.01	-12.54	-4.46	0.69	69.27
21	1.01	0.30	0.10	0.44	40.36
22	1.01	0.30	0.10	0.44	40.36
24	1.01	-10.84	-3.86	0.60	59.87
25	1.01	-8.03	-2.86	0.44	44.37
26	1.01	0.50	0.20	0.75	58.48
27	1.00	0.20	0.08	0.30	58.84
28	1.01	0.30	0.10	0.44	40.36
30	1.01	0.30	0.10	0.44	43.84
31	1.10	0.20	0.08	0.30	58.84

From Table 1.0 above the load flow analysis of bus-16 feeding the study area shows that: Voltage is 1.0 pu, active power is 0.3 MW, reactive power in bus-1 is 0.1, the power factor is at 0.95 and the current in the bus-16 is 0.44 kA, while loading is 60.23% but the voltage on bus-26 which feeds the study area is 1.01 pu, active power is 0.5 MW, reactive power is 0.2 MVar and current is 0.75 kA, while the loading is 58.48%. Some parts of the network indicate overloading of 75%. The load flow of the network algorithm converges and the generator-load demand was balanced.

Scenario 2: Feeder 32 in Ajaokuta Distribution Network with Wind Turbine Integration

An assumption was made that wind speed is constant and the wind turbines were producing their maximum rated power Table 2.0 shows the load flow report of feeder 32 of Ajaokuta distribution network with Wind Turbine integration. The load flow in DIgSILENT shows bus voltage, active power, reactive power and current loading. The load flow report helps in analysing the steady-state of the network.

Table 2.0: Load Flow Report of Feeder 32 in Ajaokuta Distribution Network with Wind Turbine Integration

Bus No	Voltage (pu)	Active Power (MW)	Reactive Power (MVar)	Current (kA)	Loading (%)
1	1.00	0.30	0.10	0.44	70.58
3	1.00	0.30	0.10	0.44	70.58
4	1.01	0.80	0.31	0.04	42.59
6	1.01	15.00	60.00	8.41	80.78
7	1.00	0.39	0.10	0.44	70.58
10	1.01	-15.51	-6.33	0.87	43.63
12	1.01	-12.9	-5.24	0.73	36.26
15	1.00	0.29	0.09	0.30	60.19
20	1.01	-12.5	-4.98	0.70	70.08
21	1.00	0.39	0.10	0.44	70.58
22	1.00	0.39	0.10	0.44	73.63
24	1.01	-10.8	-4.38	0.61	60.70
25	1.01	-8.99	-3.38	0.45	45.24
26	1.00	0.50	0.20	0.75	58.41
27	1.00	0.20	0.08	0.30	58.77

From Table 2.0 above the load flow analysis of bus-26 which feeds the study area shows that the voltage on bus-26 is 1.0 pu, active power is 0.5 MW, reactive power 0.2 MVar and current is 0.93 kA, while the loading is 58.41%. and voltage on bus-27 is 1.0 active power is 0.20 MW, reactive power is 0.08 and current is

0.30, while the loading is 58.77%. The load flow algorithm converges and the generator-load demand was balanced with Wind Turbine integration.

Case Study 2: Transient Stability Analyses of feeder 32 of Ajaokuta Network in DIgSILENT

This section presents transient stability analyses and results of feeder 32 of Ajaokuta distribution network. To investigate the transient stability of the developed model a self-clearing three-phase short circuit was applied on the distribution line (L-3). The choice of this line was influenced by the fact that it is one of the major lines in the system as the PCC bus is directly linked to the lin-3. However similar results were obtained even if the fault location was changed. The fault was introduced after 2 seconds cleared after 0.2 seconds by tripping the circuit breaker B_1. The post fault behavior of the system was observed: The Ajaokuta network, network with network with Wind Turbine integration and Islanded network with Wind Turbine integration. Parameters such as the active power, reactive power, terminal voltage and the rotor angle of the network were measured. The results as modeled in DIgSILENT [11] are as shown in Fig 6.0 to Fig 9.0.

Scenario 1: Transient Analyses of Ajaokuta Distribution Network

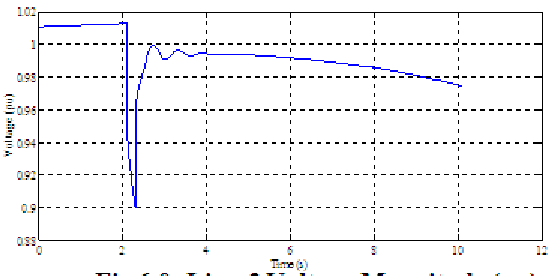


Fig 6.0: Line-3 Voltage Magnitude (pu)

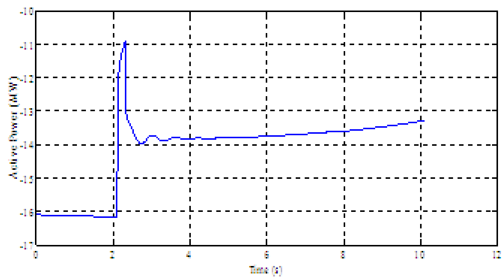


Fig. 7.0: Line-3 Total Active Power (MW)

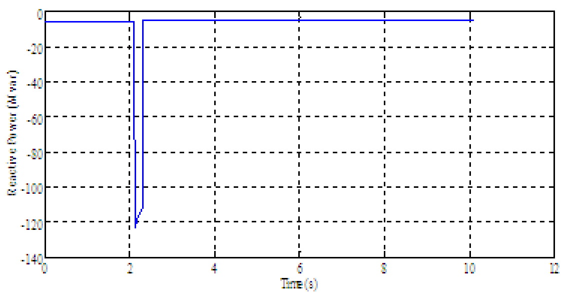


Fig 8.0: Total Reactive Power in Line-3

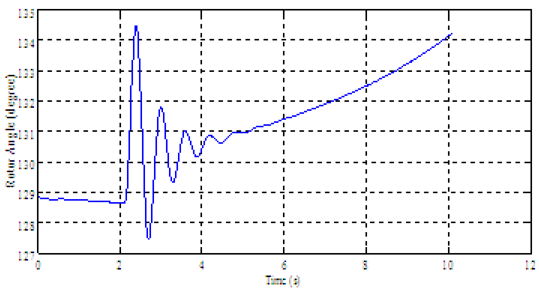


Fig 9.0: Rotor Angle (degree) of Synchronous Generator

Fig.6.0 to Fig.9.0 shows the results when a 3Ø short circuit was applied at Line 7 of the main network at 2 seconds. The fault was cleared after 0.2 seconds. Fig.6.0 shows that the voltage magnitude reduces from 1.01 pu to 0.9 pu when fault lasted for 0.2 seconds and increases to 0.975 pu for 7.98 seconds after the fault was cleared. Fig. 7.0 shows that the active power increases from -16 MW to -11 MW within 0.2 seconds when the fault was applied and later reduces to -13.4 MW when the fault was cleared. The reactive power in Fig.8.0 show a decline from -0.2 MVAR to -120 MVAR within 0.2 seconds when fault was applied and later increases to -0.2 MVAR after the fault was cleared. The rotor angle in Fig.9.0 increases to 134.5^0 when fault was applied and later settled at 134^0 when the fault was cleared. The rotor angle settled above stability limit of 120^0 for multi machine. The system is unstable.

Scenario 2: Transient Analyses of Feeder 32 of Ajaokuta Distribution Network with Wind Turbine Integration

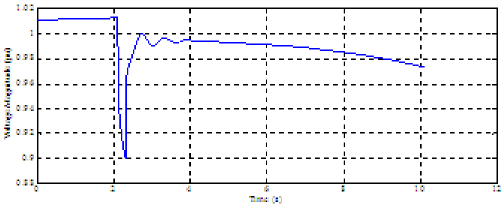


Fig.10.0: L-3 Voltage Magnitude (pu)

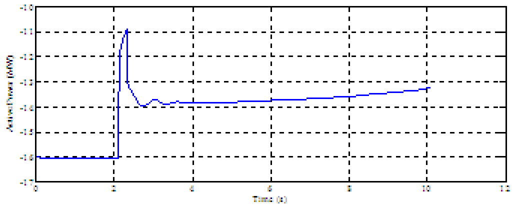


Fig.11.0: L-3 Active Power (MW)

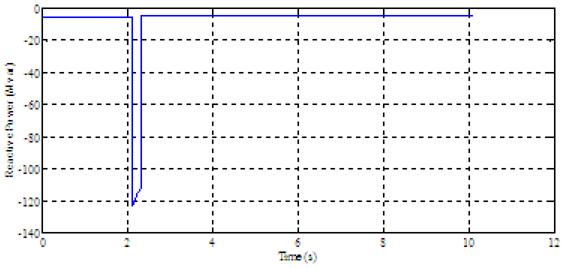


Fig.12.0: L-3 Reactive Power (Mvar) Synchronous Generator

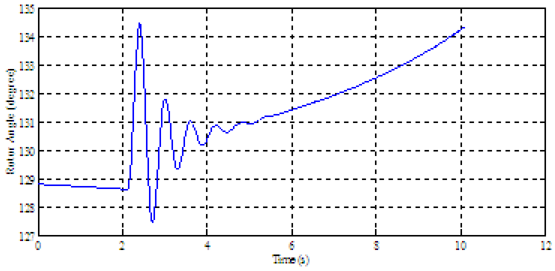


Fig. 13.0: Rotor Angle (degree)

Fig. 10.0 to Fig. 13.0 show the results when a 3∅ short circuit was applied at 2 seconds on Line 7 with Wind Turbine integration. The fault was cleared after 0.2 seconds. Fig. 11.0 shows that the voltage magnitude reduces from 1.01 pu to 0.9 pu when fault lasted for 0.2 seconds and increases to 0.975 pu for 7.98 seconds after the fault was cleared. Fig. 4.9 shows that the active power increases from -16 MW to -11 MW within 0.2 seconds when the fault was applied and later reduces to -13.4 MW when the fault was cleared. The reactive power in Fig.12.0 shows a decline from -0.2 MVAR to -120 Mvar within 0.2 seconds when fault was applied and later increases to -0.2 MVAR after the fault was cleared. The rotor angle in Fig.13.0 increases to 134.5^0 when fault was applied and later settle at 134^0 when the fault was cleared. The rotor angle settled above stability limit of 120^0 for multi machine, the system is unstable. This is when compared to the case when three phase short circuit fault was not applied.

Case Study 3: Island Operation of the Study Area

The island was created by applying three-phase fault into the main feeder 32 of Ajaokuta distribution network branches. This tripped off circuit breakers-1 that feeds the PCC of bus-16 (Fig.3.3) creating an island. The island created was powered by the integration of Wind Energy. Results of the feasibility study for the study area as modeled in HOMER simulation tool shown in Section III. Showed that a total of 85 kW can be harnessed form Wind Energy from the study, this was synchronized with 248.8 kW load demand of the study area. The short fall of 25.8 kW is catered for by the diesel generator of 30 kW connected with the islanded network. Worthy of note is that the diesel generator also acts as the reference machine in the islanded network. Simulations were carried out to compare the transient response of the voltage magnitude, active power, reactive power and rotor angle of the study center network. DIgSILENT was used to investigate post effect of the three phase short circuits fault on line-3 at 0.415 kV. The study area islanded network with Wind Energy integration is also analyzed for transient stability.

VIII. ISLANDED NETWORK WITH WIND TURBINE INTEGRATION

A three-phase fault was applied on Line-3 of the network with Wind Turbine integration, this line was chosen because is close to the PCC and a major line on the network. The three phase fault tripped off circuit breaker-1 (Fig 2.0) which led to unintentional islanding of the study area from the utility grid. The load flow of the islanded network was calculated as a diesel generator was connected to the network to cater for the load demand short fall as well acts as reference machine.

Scenario 1: Load Flow Report of the Islanded Network with Integrated Wind Turbine

Bus No	Voltage (pu)	Active Power (MW)	Reactive Power (MVar)	Current (kA)	Loading (%)
15	1.00	0.16	0.70	0.10	65.12
16	1.00	0.03	0.10	0.15	8.95
18	1.00	0.05	0.10	0.16	65.12
19	1.00	0.05	0.10	0.16	28.32
22	1.00	0.30	0.10	0.44	41.31

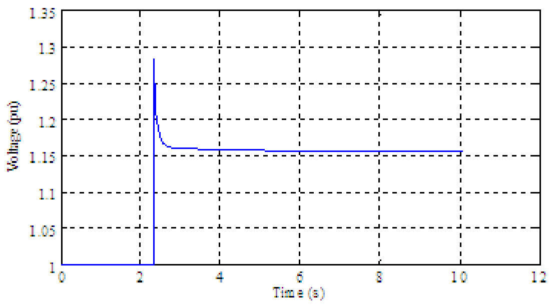
Diesel Generator of 30 kW was connected to scenario-2 to cater for the shortfall of 25.8 kW and also act the reference machine in the network to ensure a stable network. The islanded network was modeled in DIgSILENT as shown in Fig. 28.0.

IX. RESULTS OF TRANSIENT STABILITY ANALYSES OF THE ISLAND NETWORK IN DIGSILENT

The islanded network consists of two distribution lines, three bus bars and a total load demand of 248.8 kW. A three-phase fault was applied on Line-7 of the network with Wind Turbine integration. This line was chosen because is the major line within the island. The three phase fault tripped off circuit breaker b1 (Fig.2.0), the line was removed, which led to unintentional islanding of the study area from the utility grid. The load flow of the islanded network was calculated. A diesel generator of 30 kW was connected to the network to cater for the short fall of 25.8 kW of the load demand and also act as the reference machine. The results show that there is overvoltage (V=1.15 pu) in the system as shown in Fig 14.0. Also, the system suffers from insufficient reactive power as shown in Fig 16.0. The rotor angle of the synchronous generator settled at ($\delta = 65.9^0$) when Wind Turbine is integrated. The islanded network is stable both during steady state and even after introduction of 3∅short circuit fault.

X. CONCLUSION

Unintentional islanding of DG most often leads to instability within the island formed. Hence, the need for efficient Island operation of Wind Turbine DG. This paper analyses island operation of Wind Turbine Distributed Generation on Ajaokuta LGA distribution network. A total of 85 kW can be harnessed from the study center. The steady state and transient stability analyses of Ajaokuta distribution network and Ajaokuta network with Wind Turbine integration were carried out in DIgSILENT Power Factory. Also, the steady state and transient stability analyses of islanded network of the study area with Wind Turbine integration were carried out in DIgSILENT Power Factory. The analyses showed that Wind Turbine integration at islanded stage is stable ($\delta = 63.7^0$) because of the diesel generator. The analysis of feeder 32 of Ajaokuta distribution network during the steady state analysis and the transient stability shows that the stability limit is bridged and the system is prone to instability but the islanded network is stable both during the steady state and transient stability analysis.



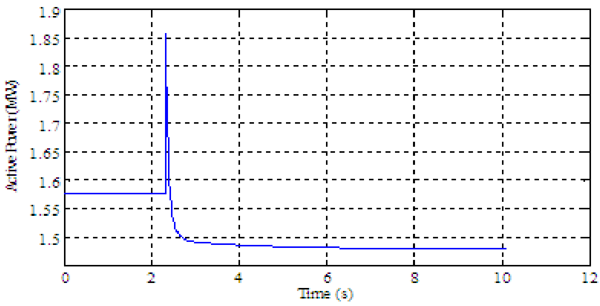
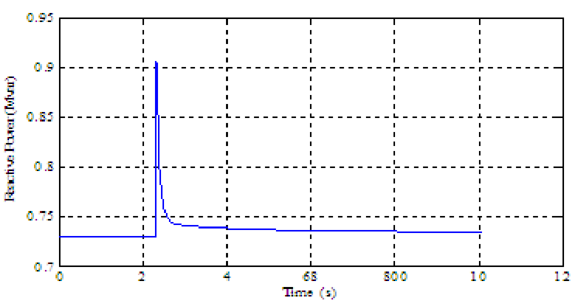


Fig 14.0: Voltage Magnitude (pu) **Fig 15.0: Active Power (MW)**



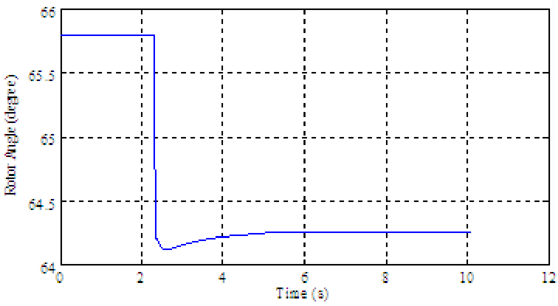


Fig 16.0: Reactive Power (Mvar) (degree)

Fig 17.0: Rotor Angle

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