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Power Flow Analysis of Island Business District 33KV Distribution Grid System with Real Network Simulations

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Abstract
The solution to power flow is one of the most important problems in electrical power systems. Traditional methods have been previously used for power flow analysis, but with prevalent drawbacks such as abnormal operating solutions and divergences in heavy loads. This paper presents power flow analysis in a power system, by modelling a typical 33kV Distribution Network, and simulating using the NEPLAN software for power flow studies. Island Business Unit's (IBU) 33kV network of Eko Electricity Distribution Plc (EKEDP) for a scenario day is taken as case study in the analysis. The most important parameters of power flow analysis is utilized to find the magnitude and phase angles of the voltages at each Busbar, as well as the real and reactive power flowing through each distribution line within the network under consideration.
Keywords: Power flow, Distribution line, Real power, Reactive power, NEPLAN software

I. Introduction

In a power system, power flows from generating centers to load centers [1]. In this process, investigation is required in regards to bus voltages and the amount of power flow through transmission and distribution lines. Power flow study aims at reaching to the steady state solution of complete power networks [1]. Power flow study is performed during the planning of a new system or the extension of an existing system. It is also necessary to evaluate the effect of different loading conditions of an existing system [2]. Power flow studies are one of the most common and important tools in power system analysis and also known as the "Power Flow" solution which is used for planning and controlling a power system network [3]. This process is also used for determining balanced condition and single phase analysis problems in the voltage magnitude and phase angle at each bus, the active and reactive power flow voltage magnitude, voltage phase angle, real power injection and reactive power injections [3]. The load flow analysis gives us the sinusoidal steady state condition of the fully system voltages, real power and reactive power generated and absorbed and line losses [4]. Since the load is a static quantity of power system and it is the power that flows across the transmission lines, the tripper prefer to call this Power Flow studies rather than the load flow studies [3]. Power flow analysis is an importance tool involving numerical analysis applied to a power system [5].

The planning, design and operation of power systems require load flow computations to analyse the steady – state performance of the power system under various operating conditions and to study the effects of changes in equipment configuration. These load flow studies can be performed using computer programs designed specifically for this purpose [6].

Through the load flow studies we can obtain the voltage magnitudes and angles at each bus in the steady state [5]. This is rather important as the magnitudes of the bus voltages are required to be held within a specified limit. Once the bus voltage magnitudes and their angles are computed using the load flow, the real and reactive power flow through each line can be computed [7]. Also based on the difference between power flow in the sending and receiving ends, the losses System Engineering, the load (or power) flow study is an important tool involving numerical studies applied to a power system. A power flow study uses simplified notation such as a one line diagram and per unit system, and focuses on various forms of AC power (i.e. reactive, real and apparent) rather than voltage and current. It analyses the power system in normal steady state operation [9]. In the process of power flow study, investigation is required in regards to bus voltages and amount of power flow through transmission lines. Power flow study aims at reaching to the steady state solution of complete power networks.in a particular line can also be computed. Furthermore, from the line flow we can also determine the over and under load conditions [8].In Power System Engineering, the load (or power) flow study is an important tool involving numerical studies applied to a power system. A power flow study uses simplified notation such as a one line diagram and per unit system, and focuses on various forms of AC power (i.e. reactive, real and apparent) rather than voltage and current. It analyses the power system in normal steady state operation [9]. In the process of power flow study, investigation is required in regards to bus voltages and amount of power flow through transmission lines. Power flow study aims at reaching to the steady state solution of complete power networks.

II. NEPLAN Software Application to Newton-Raphson Power Flow Solution

A crucial aspect of the power flow problem for large power systems is the availability of computer software, which permits ready and easy implementation of the solution methods. Therefore, in order to enable the solution of power flow problem using the Newton-Raphson method, a suitable software package called NEPLAN was sourced and used for this purpose. NEPLAN software was chosen among other available software, because of its application on network expansion planning, i.e. determination of load centre using Geographical Information Systems (GIS), load forecasting (adding future plans in the network for modeling and simulation) and N-1 contingency planning. NEPLAN is planning and optimization software for electrical, heat, gas and water networks which has been developed by the BCP group in Switzerland. It is used to analyze, plan, optimize and manage power networks which includes optimal power flow, transient stability and reliability analysis. The software package can be used for transmission and distribution system analysis and the reliability software can provide reliability indices for individual load points and the overall power system. It can also provide information based on the cost of unreliability along with investment analysis and the Net Present Value (NPV) of different investment alternatives. NEPLAN uses the homogenous Markov process for the calculations and it handles up to second order contingencies. The NEPLAN tool is very flexible and user friendly planning tool where network designers can compile different topologies [11,12].

III. Power Flow Study of the Eko Electricity Distribution Plc (EKEDP) 33kV Grid

Island Business Unit's 33kV grid network, used as a case study is shown in figure 1 below:

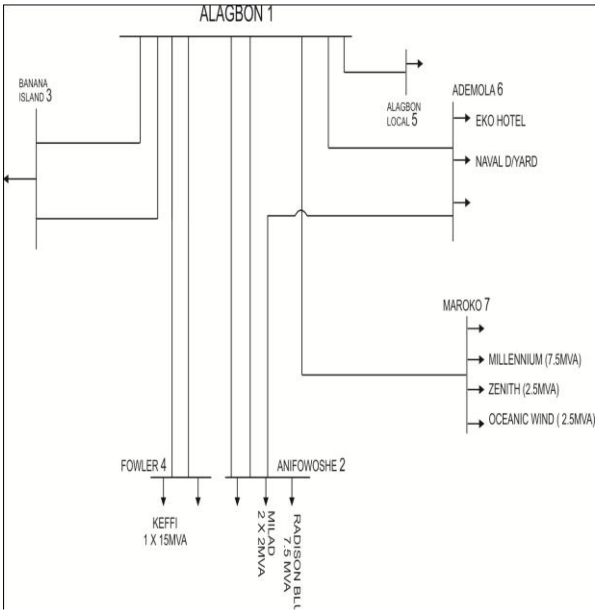

Figure 1: 33kV Network of Island Business Unit, EKEDP

Table 1 shows the line parameters and the route length of the 33kV Distribution Network considered. The Busbar links are:

1. Alagbon (ALG) – Ademola (ADM) Underground (U/G) Cable
2. Alagbon (ALG) – Alagbon Local (ALG/L) Underground Cable
3. Alagbon (ALG) – Anifowoshe (ANI) Underground Cable
4. Alagbon (ALG) – Fowler (FOW) Underground Cable
5. Ademola (ADM) – Maroko (MAR) 33kV Interconnector Cable (I/C)
6. Ademola (ADM)–Anifowoshe (ANI) 33kV Interconnector Cable (I/C)
7. Alagbon (ALG) - Banana Island (BAN/I) 33kV Interconnector Cable (I/C)

Table 1: Line Parameters and Route Length of the 33kV Distribution Network Considered.

S/N	Bus Link	Model	Route Length (km)
1	ALG-ADM	U/G Cable	6.13
2	ALG-LG/L	U/G Cable	0.15
3	ALG-ANI	U/G Cable	6.84
4	ALG-FOW	U/G Cable	3.00
5	ADM-MAR	33kV I/C	1.80
6	ADM-ANI	33kV I/C	2.40
7	ALG-BAN/I	33kV I/C	5.00

Reactance (X) = 0.093 ~/km
Susceptance (B) = 0.37 UF/km
Resistance (R) = 0.098 ~/km
Impedance (Z) = 0.135 ~/km
The network has seven (7) nodes (buses) without any generator bus. There are six (6) distribution lines (branches) of which one is mainly transformers connected in parallel. Although ALG busbar was considered as the slack bus, it is not a generator bus; however, it is the only source of supply to other busbars. The network load parameters are also shown in table 2.

Table 2: Hourly Loads (in MW) for the Selected day Showing the condition of the Network

Scenario Day		**17-01-2014**					
Specified Hours of the Day		**02:00**	**06:00**	**09:00**	**12:00**	**21:00**	**23:00**
#	**Load Feeders**						
1	FOW1	8.7	-	-	-	9.7	-
2	FOW2	-	-	9.6	-	-	-
3	ADM1	-	-	10.6	-	6.7	-
4	ADM2	-	-	-	-	-	-
5	ANI	-	-	11.7	-	9.3	3.0
6	BAN/I1	-	-	3.0	-	-	-
7	BAN2	-	-	-	-	-	-
8	ALG 1X15 MVA	-	-	3.6	-	-	-
9	ALG 1X15 MVA	4.5	-	-	-	-	-
10	MAR	-	-	-	-	-	-

3.1 Modelling for Power Flow Studies
To carry out power flow analysis, fig.1 is modelled to suit the application of the NEPLAN software as shown in fig. 2 below. It involves opening of dialog box and inputting all the necessary parameters in the box as shown in fig. 2:

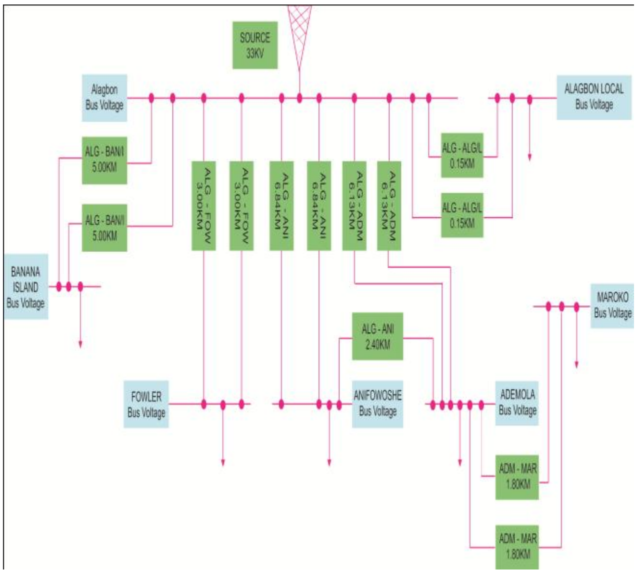

Figure 3: Model of the Setup of Island BU

3.2 Power Flow Results and Discussion
The results of the power flow studies carried out for 17/01/2014 are as shown in Tables 3a to 5d.

Table 3a:Bus Bar Power Flow Results at 02:00Hrs

Bus	**Voltage**		**P (MW)**	**Q (MVar)**	**Input P (MW)**	**Input Q (MVar)**
	(kV)	**Angle (Deg.)**				
ADM	0	0	0	0	0	0
ALG	33	0	0	0	13.19	8.161
ALG/L	32.99	-0.1	4.5	2.789	0	0
ANI	0	0	0	0	0	0
BAN/I	0	0	0	0	0	0
FOW	32.88	-0.1	8.7	5.342	0	0
MAR	0	0	0	0	0	0

Table 3b:Bus Bar Power Flow Results at 09:00Hrs

Bus	**Voltage**		**P (MW)**	**Q (MVar)**	**Input P (MW)**	**Input Q (MVar)**
	(kV)	**Angle (Deg.)**				
ADM	32.711	-0.1	10.6	6.569	0	0
ALG	33	0	0	0	38.73	18.658
ALG/L	32.997	0	3.6	2.231	0	0
ANI	32.645	-0.2	11.7	7.251	0	0
BAN/I	32.942	0	3	1.859	0	0
FOW	32.868	-0.1	9.6	5.95	0	0
MAR	0	0	0	0	0	0

Table 3c:Bus Bar Power Flow Results at 21:00Hrs

Bus	**Voltage**		**P (MW)**	**Q (MVar)**	**Input P (MW)**	**Input Q (MVar)**
	(kV)	**Angle (Deg.)**				
ADM	32.825	-0.1	6.7	4.152	0	0
ALG	33	0	0	0	25.83	11.922
ALG/L	0	0	0	0	0	0
ANI	32.725	-0.2	9.3	5.764	0	0
BAN/I	0	0	0	0	0	0
FOW	32.867	-0.1	9.7	6.012	0	0
MAR	0	0	0	0	0	0

Table 3d:Bus Bar Power Flow Results at 23:00Hrs

Bus	**Voltage**		**P (MW)**	**Q (MVar)**	**Input P (MW)**	**Input Q (MVar)**
	(kV)	**Angle (Deg.)**				
ADM	0	0	0	0	0	0
ALG	33	0	0	0	10.28	4.565
ALG/L	0	0	0	0	0	0
ANI	32.69	-0.2	10.2	6.321	0	0
BAN/I	0	0	0	0	0	0
FOW	0	0	0	0	0	0
MAR	0	0	0	0	0	0

Table 4a:Power Flow Results Showing Network Loading at 02:00Hrs

Bus	**P (MW)**	**Q (MVar)**	**Current**	
			(kA)	**Angle (Deg.)**
ADM	0	0	0	0
ALG/L	4.5	2.789	0.093	-31.8
ANI	0	0	0	0
BAN/I	0	0	0	0
FOW	8.7	5.392	0.18	-31.8
MAR	0	0	0	0
	13.2	8.181		

Table 4b:Power Flow Results Showing Network Loading at09:00Hrs

Bus	**P (MW)**	**Q (MVar)**	**Current**	
			(kA)	**Angle (Deg.)**
ADM	10.6	6.569	0.225	-32.2
ALG/L	3.6	2.231	0.074	-31.8
ANI	11.7	7.251	0.246	-32.1
BAN/I	3	1.859	0.062	-31.8
FOW	9.6	5.95	0.198	-31.8
MAR	0	0	0	0
	38.5	23.86		

Table 4c: Power Flow Results Showing Network Loading at21:00Hrs

Bus	**P (MW)**	**Q (MVar)**	**Current**	
			(kA)	**Angle (Deg.)**
ADM	6.7	4.152	0.142	-32.2
ALG/L	0	0	0	0
ANI	9.3	5.764	0.195	-32.1
BAN/I	0	0	0	0
FOW	9.7	6.012	0.2	-31.8
MAR	0	0	0	0
	25.7	15.928		

Table 4d:Power Flow Results Showing Network Loading at23:00Hrs

Bus	**P (MW)**	**Q (MVar)**	**Current**	
			(kA)	**Angle (Deg.)**
ADM	0	0	0	0
ALG/L	0	0	0	0
ANI	3.00	1.859	0.062	-32
BAN/I	0	0	0	0
FOW	0	0	0	0
MAR	0	0	0	0
	3.00	1.859		

Table 5a:Lines Power Flow Results at 02:00Hrs

Bus Link	**P (MW)**	**Q (MVar)**	**Current**		**P Loss (MW)**	**Q Loss (MVar)**
			(kA)	**Angle (Deg.)**		
ALG - BAN/I	0	0	0	0	0	0
ALG – BAN/I	0	0	0	0	0	0
ALG – FOW	0	0	0	0	0	0
ALG – FOW	0	-0.38	0.007	89.9	0	-0.38
ALG – ANI	0	0	0	0	0	0
ALG – ANI	0	0	0	0	0	0
ALG – ADM	0	0	0	0	0	0
ALG – ADM	0	0	0	0	0	0
ALG – ALG/L	0	0	0	0	0	0
ALG - ALG/L	0	0	0	0	0	0
ADM– MAR	0	0	0	0	0	0
ADM– MAR	-4.5	-2.77	0.092	148.4	0.0004	-0.02
ADM– ANI	0	0	0	90	0	-0.02
	-4.5	-3.15			0.0004	-0.42

Table 5b:Lines Power Flow Results at 09:00Hrs

Bus Link	**P (MW)**	**Q (MVar)**	**Current**		**P Loss (MW)**	**Q Loss (MVar)**
			(kA)	**Angle (Deg.)**		
ALG - BAN/I	-3	-1.228	0.057	157.7	0.0044	-0.628
ALG – BAN/I	0	-0.631	0.011	89.9	0	-0.631
ALG – FOW	0	-0.377	0.007	89.9	0	-0.377
ALG – FOW	-9.6	-5.573	0.195	149.8	0.033	-0.347
ALG – ANI	-11.7	-6.28	0.235	151.6	0.1077	-0.754
ALG – ANI	0	-0.847	0.015	89.8	0.0001	-0.847
ALG – ADM	10.68	5.113	0.207	-25.6	0.0796	-0.694
ALG – ADM	0	0	0	90	0.0001	-0.763
ALG – ALG/L	-3.6	-2.212	0.074	148.4	0.0002	-0.019
ALG - ALG/L	0	-0.019	0	90	0	-0.019
ADM– MAR	0	0	0	0	0	0
ADM– MAR	0	0	0	0	0	0
ADM– ANI	0	-0.124	0.002	89.8	0	-0.124
	-17.2	-12.18			0.225	-5.201

Table 5c:Lines Power Flow Results at21:00Hrs

Bus Link	**P (MW)**	**Q (MVar)**	**Current**		**P Loss (MW)**	**Q Loss (MVar)**
			(kA)	**Angle (Deg.)**		
ALG - BAN/I	0	0	0	0	0	0
ALG – BAN/I	0	0	0	0	0	0
ALG – FOW	0	-0.38	0.007	89.9	0	-0.38
ALG – FOW	-9.7	-5.64	0.197	149.8	0.0337	-0.35
ALG – ANI	-9.3	-4.79	0.185	152.6	0.066	-0.79
ALG – ANI	0	-0.85	0.015	89.8	0.0001	-0.85
ALG – ADM	6.73	2.641	0.126	-21.4	0.03	-0.74
ALG – ADM	0	0	0	90	0.0001	-0.77
ALG – ALG/L	0	0	0	0	0	0
ALG - ALG/L	0	0	0	0	0	0
ADM– MAR	0	0	0	0	0	0
ADM– MAR	0	0	0	0	0	0
ADM– ANI	0	-0.12	0.002	89.8	0	-0.12
	-12.3	-9.14			0.1299	-4.01

Table 5d:Lines Power Flow Results at 23:00Hrs

Bus Link	**P (MW)**	**Q (MVar)**	**Current**		**P Loss (MW)**	**Q Loss (MVar)**
			(kA)	**Angle (Deg.)**		
ALG - BAN/I	0	0	0	0	0	0
ALG – BAN/I	0	0	0	0	0	0
ALG – FOW	0	0	0	90	0.0001	-0.86
ALG – FOW	0	0	0	0	0	0
ALG – ANI	0	0	0	0	0	0
ALG – ANI	0	0	0	90	0	-0.13
ALG – ADM	0	0	0	0	0	0
ALG – ADM	0	0	0	0	0	0
ALG – ALG/L	0	-0.126	0.002	89.9	0	-0.13
ALG - ALG/L	-3	-0.871	0.055	163.7	0.0057	-0.86
ADM– MAR	0	0	0	0	0	0
ADM– MAR	0	0	0	0	0	0
ADM– ANI	0	0	0	0	0	0
	-3	-0.997			0.0058	-1.97

IV. DISCUSSION

The power flow analysis was carried out for Islands Business Unit's 33kV distribution network having seven (7) Bus bars and seven (7) distribution Lines. The minimum and maximum distribution line lengths are 0.18km and 6.84km respectively. Alagbon bus was used as the only source of supply and hence chosen as the slack bus for the power flow study.

From the Power flow results in tables 3a to 3d the Busbar voltage evaluated ranges from 32.654kV to 32.997kV, which are respectively 98.92% and 99.99% of the ideal 33kV voltage value. These voltage values are in order because they are within acceptable deviation limits from the ideal value. Also, summing the components of Input active power, P, and input reactive powers, Q, at each scenario and comparing with the corresponding output power, P_2, and output reactive power, Q_2. Then, obtaining an algebraic sum of the active power $(P = P_2 - P_1)$ and reactive power $(Q = Q_2 - Q_1)$ shows that it is only at 02:00Hrs that the net active power is a negative value, thus, necessitates the net reactive power Q to be a positive value. This clearly implies that the output power ishigher than the input. The greater the value of output power, the more fault-prone the system is. While the condition of power system at other scenario times such as 09:00Hrs, 21:00Hrs and 23:00Hrs are very stable, their net active power, P and net reactive power, Q, are positive and negative values respectively. However, these values also account for losses at the various buses, which can be explained in terms of available power and customer demand at that time. Tables 4a to 4d presented results showing network loading at different scenario times. Importantly, current in magnitude and phase angle, drawn by utility customers based on the available power were presented. In tables 5a to 5d, Lines power flow results at different scenario time were presented. At 02:00Hrs of scenario, the output power P (MW) = 0 and Q (Mvar) = 0.377 on ALG – FOW distribution line shows that the line was energized (soaked) but either no load was drawn or a very negligible load was drawn by point load power utility customers, since the percentage loading stood at 1.54% with zero percentage loss; while the power loss of 1.86% is within acceptable deviation standard of ±5%. At 09:00Hrs, ALG – BAN-I (Line 2), ALG – FOW (Line 1) and ALG – ANI (Line 2), ALG – ALG-L (Line 2) and ADM – ANI (Line 1), there are also zero output power, P, with output reactive power, Q, not zero. These lines equally have certain percentage of line loading with active power loss being zero. The implication is that the line are energized but not loaded at various 11kV outgoing feeders. The low percentage loading recorded may be due to point load customers connected along the lines. The current column shows that ALG – ANI (Line 1), ALG – ADM (Line 1) and ALG – FOW (Line 2) with 0.235kA, 0.207kA and 0.195kA loads respectively are considered heavily loaded lines compared to others. Also, the Active power loss for the two lines ALG – ANI (Line 1) and ALG – ADM (Line 1) are relatively higher (i.e 0.1077MW and 0.0796MW) and still the acceptable standard limit, compared to ALG – FOW (Line 2), whose active power loss is 0.0333MW. The lengths of these distribution lines play a major factor in this regard. ALG – ANI line is 6.84km, ALG – ADM line is 6.13km and ALG – FOW line is 3.0km. The total active power loss in the network at this 09:00 Hrs scenario hour was 0.2251MW, which is higher than other network active power losses obtained in the remaining scenario times of the same day (for example, at 02:00Hrs, P_L loss = 0.0004MW, at 21:00Hrs, P_L loss = 0.1299MW, at 23:00Hrs, P_L loss = 0.0058MW) may not be unconnected with the fact that daily business activities start mostly at 08:30Hrs. Therefore, 09:00Hrs to 15:00Hrs is considered the peak period of energy consumption on a commercial/industrial 33kV feeder. This further confirmed that the Island Business Unit's 33kV distribution network under study comprises of both commercially and industrially viable 33kV feeders.

V. CONCLUSION

This paper presents modelling and simulation of a typical 33kV Distribution network for power flow. NEPLAN software was used to achieve this. The results of this power flow study are also presented. Because the power flow results obtained shows that high reactive power flows within the Distribution network, reactors are recommended to be installed in strategic locations in the Distribution Network. There is also the need to site two new 33/11kV, 15MVA Injection Substations in two locations within the distribution network, particularly between ALG-ANI and ALG-ADM Busbars, where relatively high power losses are observed as a result of the long distances of 6.84km and 6.13km respectively between the Busbars. Finally, overloaded lines within the distribution network could be taken care of by the addition of new lines. But, for economic system operation and maximum load point reliability level, four is the maximum number of lines for any load bus.

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