iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** VII **Month of publication:** July 2020

DOI: http://doi.org/10.22214/ijraset.2020.7044

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue VII July 2020- Available at www.ijraset.com

A Simple Design Method for Island Microgrid in Rural Area

Nabin Shrestha[1], Hironobu Matsuo[2]
[1, 2]*National University Corporation Shizuoka University, Hamamatsu, Shizuoka 432-8561, JAPAN*

Abstract: In developing country there is a perpetual growing demand for electricity with an efficient and reliable system of power supply. Power system is the most complex network with power generation, transmission and distribution system to consumer loads. The distribution network is an integral part of the power system and acts as an interface to consumer load points. The network incurs significant losses and voltage drop in the electrical system. Loss minimization and voltage stability are the main objectives of the distribution network design. This paper introduces optimal branch conductor selection for the microgrid using unified central load concept for radial distribution systems of microgrid. The conductor size defined by this approach will meet the maximum current carrying capacity and uphold the acceptable voltage levels of the radial distribution system for rural areas. The effectiveness of the proposed method in single line diagram is demonstrated through the design of microgrid as an example for a developing country. The comparison shows that the results by proposed central load method is in close similar normal representation of uniform consumer load and both are following similar trends. The voltage drops and total loss by proposed method is compared and verified with three phase and single phase network system along with unified end load representation by using ETAP simulation software.
Keywords: Microgrid design, Distribution network, Cable sizing, Load flow analysis, ETAP

I. INTRODUCTION AND BACKGROUND

A micro-grid system is usually defined as an electricity production and distribution system with a convenient combination of two or more types of distributed generating sources (DGs: wind turbines, PV panels, small hydro plants, fuel generator-set, biogas plants, etc.). They are small-scale power systems located closer to the load than typically found in conventional power plants. At present, more than 1.5 billion people worldwide do not have access to electricity in their homes. An estimated 80% of these people live in rural areas [1]. As an example, in the case of Tanzania, 77% of populations throughout the entire country are deprived of electricity facilities where they are obliged to rely upon firewood and other traditional sources of energy. As a developing country, it has been encountering difficulties in supplying energy to maintain its basic human needs, reducing poverty, creating and accumulating wealth and sustaining advances in social development. Only 65% of the urban areas and 17% of rural areas are electrified. So, 83% of the total energy consumption for cooking and heating in the rural areas which is mainly used as fuel is biomass [2]. Tanzania's power sector is dominated by state-owned TANESCO, which owns most of the country's transmission and distribution network and more than half of its generating capacity. 74.9 % and 24.7 % of total electrified households are electrified with the national grid and solar power, respectively. Current transmission and distribution losses are at 16.4%. The remaining (0.3 %) are electrified with individual electricity from other sources such as small generators. The expansion of the national grid to many isolated rural areas is not economically feasible to the country's large size, low rural population density and lower power consumption. They are planning to serve electricity to half the rural population, which may be more cost-effectively by decentralized options like microgird and mini grids than by centralized grid expansion. So, beyond the grid Small Power Producers (SPP) are responsible for the management of isolated micro- and mini-grids. Since most the DGs like diesel generator typically produces AC power, making it a viable distributed source for the low voltage (LV) AC microgird system, which is viewed as the best solution of power delivery to households in outlying areas where the utility grid is out of reach. In such microgirds, power loss in distribution lines tends to be large [3].

In this paper, it is investigated that a study case for the design of a stand-alone LV microgird system to power a fully AC loads of households of small village. The proposed site is located in the central region of the Morogoro Province called Katurukila village, which is shown in Fig 1.1. This is a suitable place for designing microgird system because there is not possibility to establish grid connected system in this rural area. This paper presents the easier way for basic design of the microgird for power supply in developing country. To achieve this, main parameters of an electrical system have been discussed and methods of design of different part is presented with using the Electrical Transient Analyzer Program (ETAP). It is effectively to conduct a microgird distribution system load flow analysis. Finally, it is ensured that all bus voltages and voltage drops are within acceptable ranges and that all power system components are within rated insulation limits.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue VII July 2020- Available at www.ijraset.com

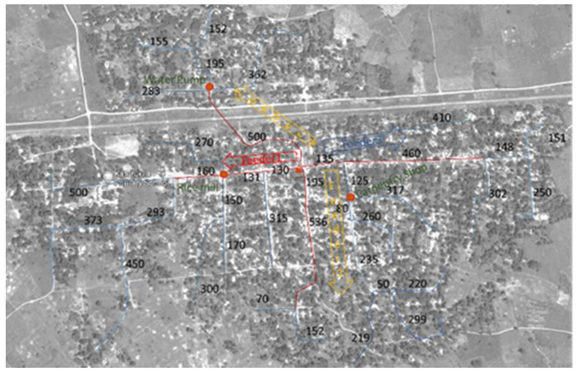

Figure 1.1 Katurukila Village "Google Maps"

II. LOAD MODELING FOR THE SIMULATION

The load is essential for the analysis, planning and control of power distribution systems. For example, studies have shown the importance of accurate load representations in the assessment of voltage stability [4]. The complexity and difficulty of load modeling are due to a large number of different load components, time and weather dependent compositions, and lack of measurements and accurate load data [5]. Commonly lumped models are used to represent LV networks. The integration of renewable DGs and the implementation of unified load management techniques emphasizes the need for more detailed LV load modeling. Most of the current research focuses on the characterization of LV residential load consumption profiles [6]. This chapter shows how to reduce the number of loads and simplify it, but also how to get the right results for the calculation, and clarifies the method creating lumped load. For verification, the connection of two integrated loads were considered as shown in figure 2.1. Figure a) is base case for normal connection representation for 4 loads. b) is equivalent unified load concept with central load representation. c) is that of end load representation. Where S is generator source, x is the length of each branch conductor and L is the connected load. Here ETAP simulation for cable selection is performed for radial network. The conditions are various uniform 12 balanced loads (average peak load of 50 -1000 VA, power factor of 85%) tapped at the various uniform distance (20 – 1000 m) and also for the central load and end load method with aluminum PVC cable. Power line is 3 phase 400V (230V in each) system. Considering the safety factor, the cable size was determined so that the voltage drop was within 7%.

The results from these analyses are shown in the table 2.1. The results show as follows; Under all conditions, the normal and central road representations have the same cable size and very close % V. On the other hand, in the calculation of the end load representation, there are many cases where the cable size is different. Regarding power losses, central road is relatively close to normal load. So, this central load representation method seems efficient to be applied to the microgird networks and the reference chart is functional in case of cable sizing, voltage drop and total power loss which indicates that it could be used within other radial microgird network structures. To prove the versatility of the reference chart, more data from other case studies can be analyzed. The main advantage is that this model applies to any location's network loads and obtains the data directly from the network for the lumped load representation in the single line diagram. This shows that correct results can be obtained while greatly reducing simulation input for unified balanced load case.

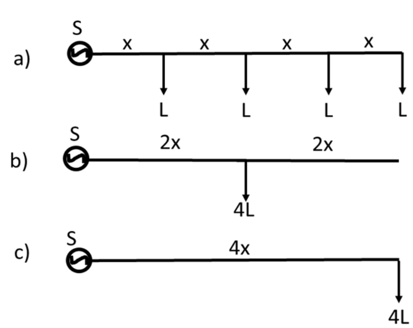

Figure 2.1 Three possible representation for load connection for four load cases

Table 2.1 Comparison of central load and end load representation with normal load configuration for 3 phase 400 V

Power [VA] \ Length [m]		240 (20×12)			600 (50×12)			1200 (100×12)			2400 (200×12)			6000 (500×12)			12000 (1000×12)		
		Size [mm²]	V [%]	Loss [W]	Size [mm²]	V [%]	Loss [W]	Size [mm²]	V [%]	Loss [W]	Size [mm²]	V [%]	Loss [W]	Size [mm²]	V [%]	Loss [W]	Size [mm²]	V [%]	Loss [W]
600 (50×12)	Normal	6	99.75	1.4	6	99.38	2.9	6	98.74	5.8	6	97.46	12.4	6	93.46	32.7	16	95.06	24.6
	Central	6	99.77	1.6	6	99.42	4.1	6	98.84	8.2	6	97.64	16.8	6	93.82	45.5	16	95.41	32.9
	End	6	99.54	3.2	6	99.84	8.2	6	97.64	16.8	6	95.13	35.4	16	95.41	107.0	25	93.93	43.5
1200 (100×12)	Normal	6	99.50	5.9	6	99.74	12.3	6	97.45	25.2	6	94.78	51.3	16	95.06	48.7	25	93.52	60.7
	Central	6	99.54	6.5	6	98.84	19.4	6	99.07	33.6	6	95.13	70.9	16	95.41	65.8	25	93.93	87.1
	End	6	99.07	13.1	6	97.64	33.6	6	95.13	70.9	10	94.06	86.8	25	93.93	87.1	50	93.73	87.6
2400 (200×12)	Normal	6	99.00	19.5	6	97.46	50.2	6	94.77	103.3	10	93.67	126.7	25	94.49	128.3	50	93.27	129.4
	Central	6	99.07	26.1	6	97.64	67.3	6	95.13	142.0	10	94.06	174.0	25	93.93	174.0	50	93.73	175.0
	End	6	98.12	53.3	6	97.14	81.3	10	94.06	174.0	25	95.22	136.0	50	93.73	175.0	95	93.00	188.0
6000 (500×12)	Normal	6	97.46	124.3	6	93.38	336.6	16	95.06	244.1	25	93.52	318.6	70	93.90	283.9	150	93.75	267.8
	Central	6	97.64	168.0	6	93.82	455.0	16	95.41	329.0	25	93.93	345.0	70	94.31	387.0	150	94.18	363.0
	End	6	95.13	354.0	16	95.41	329.0	25	93.93	345.0	50	93.73	338.0	150	94.18	363.0	300	93.08	379.0
12000 (1000×12)	Normal	6	94.84	510.3	16	95.06	488.7	25	93.49	644.4	50	93.30	641.0	150	93.75	535.6	300	92.67	541.5
	Central	6	95.13	709.0	16	95.41	658.0	25	93.93	871.0	50	93.73	876.0	150	94.18	726.0	300	93.08	758.0
	End	16	94.06	868.0	25	93.93	871.0	50	93.73	876.0	95	93.00	941.0	300	93.08	758.0	-	-	-

III. MICROGRID DISTRIBUTION SYSTEM DESIGN METHOD

Basically a low voltage microgird distribution system for rural areas are supplied from the single point by diesel generation set or solar powered generation system for example. While designing it should cover the low cost design for serving basic lighting needs to more conventional designs that may be interconnected with the grid in the near future. This method purposes to search for the optimal cable selection including dimensioning of the distributed generators while satisfying the constraints of the bus voltage and the constraints of current flowing in the distribution lines. Figure 3.1 shows the flowchart illustrating the different steps of the proposed method [7], which is slightly changed the order.

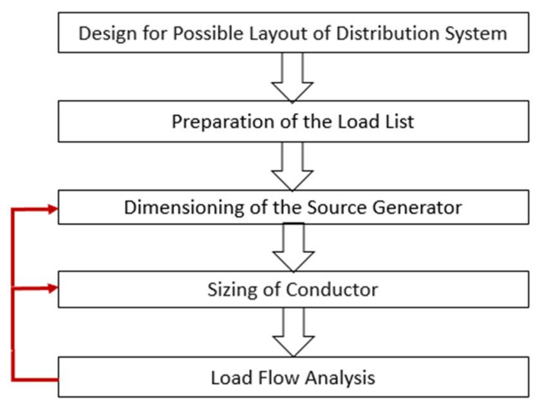

Figure 3.1 Flowchart for planning of distribution system

A. Design of Possible Layout of Distribution System

It is relatively easy to plan and build a radial network system and it is quite easy to determine its appropriate component rating [8]. A radial network is the simplest as it feeds at just one end, its initial cost is low and preferable when considering a LV system at the center of the load with a generation-station. So, for the basic configuration model, the traditional method is implemented to detailed maps which is available freely is used to measure the area and measure the distance between two key points. Then the optimal feeder path configuration is determined by incorporating heuristic rules by minimizing the route lengths [9]. The feeder path is configured by following the road, street, trails and paths going through the community. The rooting was carried out for particular specific area of the Katurukila village. It consists of four feeders as shown in figure 3.2 where feeder 1 serves in western part of village with length 3242m, feeder 2 and 3 serves in the southern and northern part of village with the length of 2402m and the feeder 4 in the eastern part of village with the length of 3661m. The total length is 9305 m.

B. Preparation of Load Lists

The load data of line length is calculated to find present load requirement. The first step in any planning procedure is to establish a projection of the load over time for the given area. This is determined by the number of households and other industrial loads present at the location. In the rural areas mostly the domestic household load types are lighting loads and the sockets loads (household devices like TV, radio, and charging mobile). In the beginning the location is studied and a rough estimate of load types and demand are consequently obtained for about 234 households and some motor loads like water pump, rice mills and carpentry shops. For the load calculation TANESCO procedure for the non-electrified rural village method is shown by Henrik Blennow [10]. Here each household load is considered as 191W with power factor of 85% and loads at the various branch section are calculated as shown in Table 3.1 and some lumped loads at the branch consisting of sum of all lateral branch loads with conductor losses connected to it. For example, as seen on table 3.1 Load130 represents the load at 130m branch section with total connected load of 1550VA of feeder1. Similarly, Load80S represents the sum of the loads in the 80m branch and beyond this section.

Table 3.1 Load summary of proposed site

S.N.	ID	Rating[VA]	PF[%]
1	Laod130	1550	85
2	Load70S	217	85
3	Load80S	6300	85
4	Load125	1490	85
5	Load131	1550	85
6	Load135	1610	85
7	Load148	459	85
8	Load149S	465	85
9	Load150S	7440	85
10	Load151S	465	85
11	Load160	496	85
12	Load195S	901	85
13	Load250	775	85
14	Load270S	838	85
15	Load283S	878	85
16	Load293	908	85
17	Load302S	935	85
18	Load315S	3760	85
19	Load317S	985	85
20	Load362	1120	85
21	Load373S	1160	85
22	load410	1270	85
23	Load450	1390	85
24	Load460	5480	85
25	Load500	1550	85
26	Load500S	1550	85
27	Load536	6390	85
28	Carpentry Shop	10 kW	85
29	Rice Mill	12 kW	85
30	Water Pump	11 kW	85

C. Dimensioning of the Source Generator

In ETAP, the operation mode of the synchronous generator is dependent on the configuration of operations such as swing, voltage control, MVAR control and power factor control mode. For the load flow analysis of independent microgird system, synchronous generator is considered to operate on swing mode through swing bus for reference so that the voltage magnitude and angle of the generator terminals remain at the operating values defined. A generator is sized in such a manner that on average the running load will not be below 30% of its rated kVA capacity in order to protect the generator from engine related reliability issues. Capacity of generator should be more than the 15-30% of the total load connected so that the reserve capacity can be utilized for temporary fluctuation and load growth that may result in more stable operation. In the condition above mentioned, total 90.77kVA (77.16kW) comprising 51.95kVA (44.16kW) household load and 38.82kVA (33kW) of commercial load. So the size of diesel generator is decided 120kVA.

D. Sizing of Conductor

The selection of conductor depends on the power carrying capacity, cost, growth of the load, and reliability & efficiency. While unequal conductor lengths result in different voltages at each load, the proper selection of conductors can eliminate voltage differences. For the safety and reliability Aerial Bunched Cables (ABC) is ideal for rural distribution but for the effective and proper sizing for effective and economic sizing of the conductor following cable Ampacity, and voltage drop studies are essentials. This section uses a three-phase, four-wire system to reduce transmission losses and simplify calculations, and assumes that the load is balanced. The conductor size of the feeder is assumed to be the same in consideration of safety at the time of an accident.

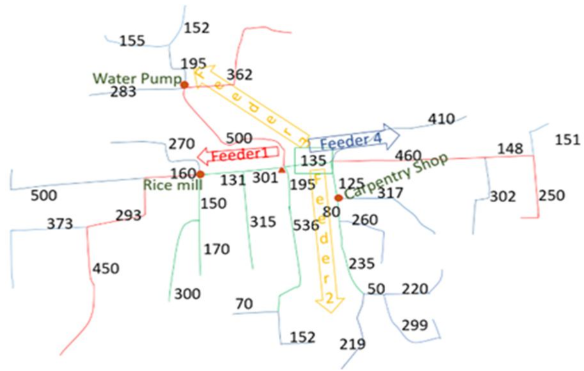

Figure 3.2 Layout for cabling of distribution system of Katurukila Village

1) *Cable Ampacity:* It is the maximum current that the conductor can carry without damaging its insulation. By considering load wattage bellow the point *W*, voltage *V*, power factor $\boldsymbol{cos\Phi}$ and electrical efficiency $\boldsymbol{\eta}$, it is possible to calculate the current *I* that passes through the cable in the ideal situation for three phase.

$$I = \frac{W}{\sqrt{3} \times V \times \eta \times cos\Phi} \qquad (1)$$

It is possible to select cable cross-section by obtaining its ampacity effectively, but this cross-section must be determined in real circumstances taking into account physical and environmental factors. The cable capacity for passing current also depends on the ambient condition and the method of laying the cable. Then the cable size that corresponds to this derated current is selected.

2) *Verification of the Cable Size with The Permissible Voltage Drop:* Percent voltage drop is defined by the following equations.

$$\Delta V\% = \frac{\Delta V}{V_N} \times 100\% = \frac{n \times I \times L \times (R_L cos\Phi + X_L sin\Phi)}{V_N} \times 100\% \qquad (2)$$

Where, n= 2 for single phase system and n=√3 for three phase system, ΔV is absolute value of voltage drop [V], V_N is system rated voltage [V], *I* is Line or cable current [A], *L* is line or cable length [km], R_L is line or cable resistance at operating temperature [ohm/km], X_L is line or cable reactance [ohm/km] and $cos\varphi$ is load power factor.

Since there are different methods for physical arrangement of cables but voltage drop method is found to be effective to get the required acceptable cable cross section. A voltage drop occurs in the conductor while current flows through it. Generally, voltage drop can be ignored for small lengths of conductors, but in the case of smaller diameter and long length conductors, significant voltage drop occurs in the system.

The proposed method first select the cable size based on the section 2 and evaluates the losses, bus voltage and current throwing through each branch sections by performing multiple load flow analysis in ETAP. Optimum conductor size after performing several successive simulations PVC aluminum cable of diameter of 35 mm^2 is selected by the analysis.

E. Load Flow Analysis

Load flow studies are used to ensure a consistency, efficiency and cost-effectiveness of electrical power distribution from generators to consumers via microgird. The active and reactive power flows from the generator to the connecting loads over various networking buses and branches in the system. For this study, three-phase and single-phase load flow analyses are done with ETAP for the accurate analysis of the voltage profiles and energy loss with respect to the feeder loading, power factor, conductor size, feeder length and distributed generator capacity is then performed with the Newton-Raphson (N-R) Methods [11]. For the simplicity of simulation and limitation of space available, the loads of rural households are represented using a central lumped load method.

IV. RESULTS OF LOAD FLOW ANALYSIS AND DISCUSSION

A. Single Line Diagram Configuration of Proposed System

The proper single line diagram designed is represented by the figure 4.1. Distribution layout of 25 bus system shown in the figure 3.2 is implemented in ETAP. The single line diagram is drawn and their parameters are entered. There are four distribution feeders diverge out through feeder bus (FB). Feeder 1 is from the branch Line1-130a, feeder 2 from branch line6-536a' feeder 3 from branch line7-500a and the last feeder 4 starts with the branch line9-135b. The Gen1 shows the main diesel generator of 120 kva rating in the central area of the microgird distribution system. Then the power is distributed to the individual loads through the feeder bus at 400V. All of the distribution lines are constructed using the PVC Al 35mm2 conductors which is obtained using above previous procedures by fulfilling the maximum voltage drop of less than 7% and power loss condition.

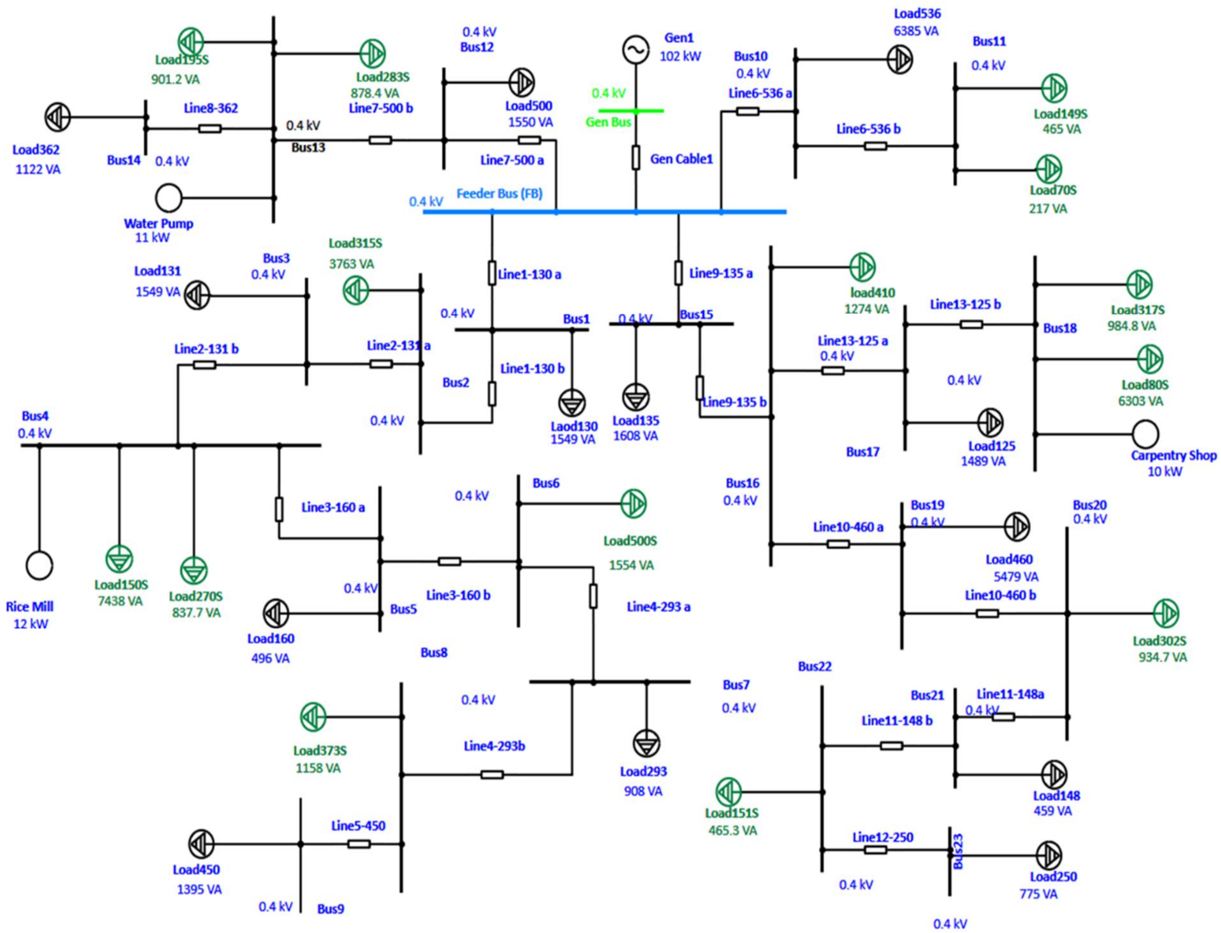

Figure 4.1 Proposed 25 Bus microgrid network of three Phase system

B. Load flow Study Results and Discussion

Table 4.1 presents the loading of the buses for feeder branches of three phase power and single phase supply mode for constant power load for 25 bus microgird network. The conductor size of single phase is 70 mm^2 instead of 35 mm^2 to make the cross sections same. It verifies the total load demand of the system which can be summarized as 85.2 kW, 49.9 kVAR and 86.3% lagging power factor for three phase system and 104.1 kW, 64.7 kVAR and 84.93% lagging power factor for single phase system. Here result verified the normal operation of source generator for three phase system whereas single phase system source generator is overloaded. It also can be seen that bus 1 and bus 15 are found to be heavily loaded as compared to other buses. So, this table provides the understand the loading of the microgird distribution network and helpful to consider setting the safety apparatus and resizing the cable for reduce the cost and in predicting the most optimal placement of DGs that can reduce the impact of the variation of its active and reactive power. In the table and from the analysis it is seen that a major amount of power losses occurs at the branches when using a heavy load with low voltage levels.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue VII July 2020- Available at www.ijraset.com

Table 4.1 Bus loading comparison for single phase and three phase system

Feeder No.	Bus ID	Three Phase		Single Phase	
		Active Power [kW]	Reactive Power [kvar]	Active Power [kW]	Reactive Power [kvar]
1	1	32.21	19.02	38.52	24.11
	2	30.27	18.16	34.49	22.89
	3	26.56	16.14	29.02	20.30
	4	24.78	15.30	25.61	19.42
	5	4.72	2.90	4.90	2.93
	6	4.28	2.64	4.41	2.66
	7	2.95	1.82	2.99	1.82
	8	2.17	1.34	2.19	1.35
	9	1.19	0.74	1.19	0.73
2	10	6.01	3.72	6.02	3.72
	11	0.58	0.36	0.58	0.36
3	12	16.20	9.77	18.42	14.02
	13	14.19	8.92	14.22	13.18
	14	0.77	0.58	0.79	0.49
4	15	28.68	17.14	32.07	21.45
	16	26.80	16.25	28.75	20.31
	17	18.46	11.28	19.31	15.15
	18	16.98	10.50	17.30	14.27
	19	6.91	4.28	6.96	4.28
	20	2.24	1.39	2.44	1.39
	21	1.45	0.90	1.45	0.90
	22	1.05	0.65	1.06	0.65
	23	0.66	0.41	0.66	0.41

The voltage profile comparisons for feeder 1 to feeder 4 are shown in from figure 4.2 to figure 4.4 It can be observed form the figures that three phase system has improved voltage profile as compared with the single phase system. Bus voltage is gradually decrease with increasing the distance from the generator bus for three phase system while that of single phase system decrease rapidly. The minimum voltage is 372.0 V (7.00 %V) for three phase and 171.2 V (25.57 %V) for single phase at bus 9 in feeder 1. The total power losses for active power are 5.31 kW and 24.21 respectively.

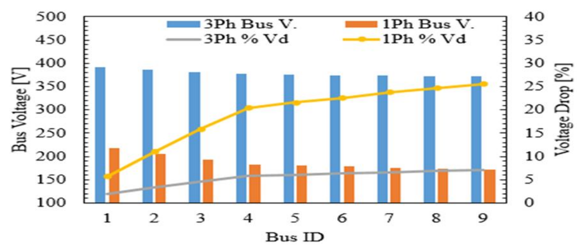

Figure 4.2 Voltage profile comparison for feeder 1

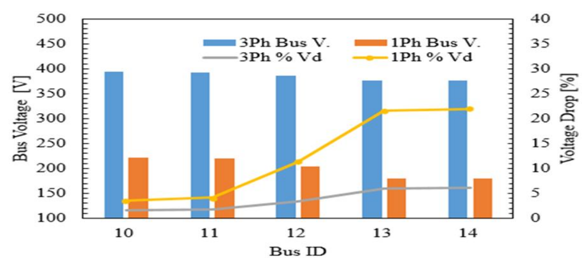

Figure 4.3 Voltage profile comparison for feeder 2 and feeder 3

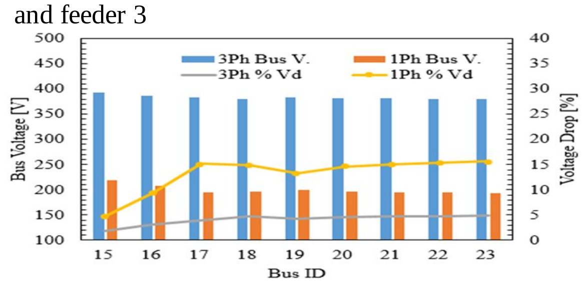

Figure 4.4 Voltage profile comparison for feeder 4

The summary of results obtained are presented on table 4.2, which shows the power flow, real power loss, reactive power loss, power factor and percentage loading on the lateral branches between two successive connecting buses for three phase system. The three phase system has better performance validating all the network parameters, although the cable size is remained same for both systems. However, in actual operation, care must be taken in connecting the loads so that the three phases are balanced. To confirm the results, the voltage profile from the simulation results for the feeder 2 with unified central load concept at Bus10 and Bus11 is found to be valid for while comparing with normal representation of each single loads on distribution system.

Table 4.2 Load flow study on branch of three phase system

Line ID	From Bus	To Bus	Active Power [kW]	Reactive Power [kvar]	PF [%]	Loading [%]	Loss [W]
1-130a	FB	1	32.89	23.16	81.8	56.0	676.0
1-130b	1	2	30.90	22.29	81.1	53.8	624.0
2-131a	2	3	27.07	20.26	80.1	48.4	510.0
2-131b	3	4	25.25	19.41	79.3	46.2	464.0
3-160a	4	5	4.74	2.90	85.3	8.2	17.7
3-160b	5	6	4.30	2.64	85.2	7.4	14.6
4-293a	6	7	2.96	1.82	85.2	5.1	12.8
4-293b	7	8	2.18	1.34	85.2	3.8	6.9
5-450	8	9	1.19	0.74	85.0	2.1	3.2
6-536a	FB	10	6.10	3.73	85.3	9.9	87.9
6-536b	10	11	0.58	0.36	85.0	1.0	0.8
7-500a	FB	12	17.15	13.76	78.0	30.6	777.0
7-500b	12	13	15.06	12.88	76.0	28.4	669.0
8-362	13	14	0.93	0.58	85.0	1.6	1.6
9-135a	FB	15	29.24	20.89	81.4	50.0	560.0
9-135b	15	16	27.31	20.00	80.7	47.8	510.0
10-460a	16	19	7.01	4.28	85.3	11.7	105.0
10-460b	19	20	2.25	1.39	85.1	3.8	11.2
11-148b	21	22	1.06	0.65	85.0	1.8	0.8
11-148a	20	21	1.45	0.90	85.1	2.5	1.5
12-250	22	23	0.66	0.41	85.0	1.1	0.5
13-125a	16	17	18.70	15.00	78.0	34.3	243.0
13-125b	17	18	17.22	14.21	77.1	32.2	232.0

V. CONCLUSION

A simple method for designing microgrid distribution system is shown in this paper. The selection procedures of the electrical equipments and distribution cables are presented. Then, load flow analysis was taken for checking the following factors like the sizes of equipment, losses and voltage drops. The proposed method for the distribution system planning with unified central load method representation is developed on the use of low voltage radial distribution system. This methodology will be applied to quantify in a case for the load modeling, cable sizing and generator sizing with the voltage on any section of the distribution network. An equivalent single phase system of balanced three phase system and that of three phases system are compared and three phase system is indicated to be techno economically efficient regarding conductor size, voltage profile and losses. Here the source generator is sized 120kVA and the distribution conductor size is 35 mm^2 (Al) for the same diameter case. Finally, the load flow analysis results from applicable ETAP simulations confirm that the components of microgrid distribution system considering three phase system are correctly sized to fully satisfy design requirements related with voltage profile, optimum losses and power factor compensation.

Since 25 Bus three phase system is considered for the microgrid distribution as base case, voltage or current imbalance is a major power quality issue to be solved. A single generator source is used in this study and there are possibilities of extension or addition of various distributed generators (DGs) with certain percentage of load growth every year. Island microgrid networks of remote areas or could be tied to the national grid when large amount of energy is produced.

VI. ACKNOWLEDGEMENT

This work has been partially supported by Science and Technology Research Partnership for Sustainable Development (SATREPS) in collaboration between Japan Science and Technology Agency (JST, JPMJSA1804) and Japan International Cooperation Agency (JICA).

REFERENCES

[1] Marcus Wiemann, Simon Rolland, Guido Glania, “Hybrid Mini-grids for Rural Electrification”, Alliance for Rural Electrification, pp.6-13, 2011.
[2] Kees Mokveld & Steven von Eije (RVO.nl), “Final Energy report Tanzania”, Ministry of Foreign Affairs, Netherland, pp.3-5, 2018.
[3] C. Li, S. Chaudhary, M. Savaghebi, J. Vasquez, and J. Guerrero, “Power flow analysis for low-voltage AC and DC microgrids considering droop control and virtual impedance”, IEEE Tran. Smart Grid, 8 (6), pp. 2754-2764, 2017.
[4] Dzafic, M. Glavic and S. Tesnjak, “A component-based power system model-driven architecture,” IEEE Trans. Power Syst., 19 (4), pp. 2109-2110, 2004.
[5] A. Capasso, W. Grattieri, R. Lamedica, and A. Prudenzi, “A bottom-up approach to residential load modelling,” IEEE Trans. Power Syst., 9 (2), pp. 957-964, 1994.
[6] L. M. Hajagos and B. Danai, “Laboratory measurements and models of modern loads and their effect on voltage stability studies”, IEEE Trans. Power Syst., 13 (2), pp. 584-592, 1998.
[7] H. L. Willis, Power Distribution Planning Reference Book 2nd Edition, CRC Press, 2004.
[8] E. Hossain, E. Kabalci, R. Bayindir, and R. Perez, “A comprehensive study on distributed network technology”, Int. J. Renew. Energy Res., 4 (4), pp. 1094–1107, 2014.
[9] Rakesh Ranjan, B. Venkatesh, and R. D. Das, “A new algorithm for power distribution system planning”, Electrical Power Syst. Res., 62 (1), pp. 55-65, 2002.
[10] Henrik Blennow, “Method for Rural Load Estimations- a case study in Tanzania”, Lund, pp. 85-101, 2004.
[11] A. Ben-Israel, “A Newton-Raphson Method for the Solution of Systems of Equation”, J. Math. Anal. Appl., 2 (15), pp. 243-252, 1996.