wjert, 2019, Vol. 5, Issue 5, 56-71. *Review Article* ISSN 2454-695X

World Journal of Engineering Research and Technology
WJERT
www.wjert.org SJIF Impact Factor: 5.218

RELIABILITY ENHANCEMENT ON RADIAL DISTRIBUTION SYSTEM BY DISTRIBUTED GENERATION

Han Su Yin[1]* and Shwe Zan Aung[2]

[1]Professor, Dept. of Electrical Power Engineering, Yangon Technological University, Yangon, Myanmar.

[2]Project & System Design Engineer, Omega Integration Pte Ltd. Singapore.

Article Received on 08/07/2019 **Article Revised on 29/07/2019** **Article Accepted on 19/08/2019**

***Corresponding Author**
Han Su Yin
Professor, Dept. of Electrical Power Engineering, Yangon Technological University, Yangon, Myanmar.

ABSTRACT

This paper presents the Reliability Enhancement by Distributed Generation (DG). The study of the test system used in this paper is on Kalay distribution system, located at Kalay Township, Sagaing Division, Union of the Republic of Myanmar. To estimate the reliability of the test system and load flow conditions, the test cases are modeled and evaluated using ETAP (Electrical Transient and Analysis Program) Software and Newton-Raphson Method. According to the result, Distributed Generation can improve the voltage profile and reliability indices. Moreover, the estimation becomes more accurate by considering load flow constraint. The difference cases are presented by comparing reliability index ENS (Energy Not Supplied). In this paper, optimal placement of Distributed Generation (DG) in the distribution system is discussed and premeditated, which can improve the voltage profile, loss minimization and system reliability enhancement.

KEYWORDS: Reliability enhancement; distributed generation (DG); voltage profile; loss minimization; optimal placement.

INTRODUCTION

The fundamental requirement of the power system is to deliver electric energy to its loads sufficiently, efficiently and reliably. A power system consists of a generation, transmission and a distribution system. The distribution system is responsible for transferring electrical energy to the end users. It is the link between the utility system and the end customers. Many distribution systems used in practice have a single circuit main feeder and are defined as radial distribution systems. The mainstream distribution systems are designed to operate with a radial topology. Radial distribution systems have a set of series components between a substation and a load point, which usually includes breakers, lines, cables, transformers, switches, fuses and other equipment. A failure of any component in the series path will result in the outage at a load point and interruption may occur frequently because of the occurrence of the failures and faults in the distribution network.

Reliability is one of the essential roles in electric power system which defines stable and uninterrupted supply of power to the fulfillment of customer's needs. The distance of load points far from feeder causes increase the interruption frequency, interruption duration and decrease the supply voltage. Electricity supply interruptions and low voltage problem cause high disturbance to consumers and results in system unreliability. Usually, the utmost reliability problems in power system are caused by distribution network.

The Distribution Reliability is the ability of the distribution system to perform its function under stated conditions for a stated period of time without failure. Distribution Reliability is becoming significantly important in the current competitive climate because of the fact that the distribution system feeds the customers directly. Events on transmission and generation system can also cause interruption to customers but events on these systems are much less likely to affect customers than those on the distribution system.[1][2] Therefore, the improvement of reliability for distribution system including its protection system, transformer and allocating distributed generation should be considered to promote the overall power system reliability.

Reliable power system means serving consumer's loads without interruptions in supply voltage and it is one of the critical issues. Power system reliability has two aspects: system adequacy and system security. The system adequacy is the availability of sufficient generation, transmission and distribution facilities within the system to meet the required electrical energy to the customer demand. The term security is the ability of the system to respond to disturbances arising within the system and is therefore linked with system dynamics. Reliability assessment of a complete system is a significant ability in overall electric power system operation and planning.[3] Therefore, distribution reliability is one of the most important issue in the power system due to its high impact on system performance and electric power supply to the consumers. In typical reliability estimation, load flow constraint is not considered. But, study with load flow constraint can generate more accurate outcome.

In the present times, integrating of large Distributed Generation systems into the various power distribution systems have become very popular and it also keeps growing with fast speed. Distributed Generation has a key role to play in the future of electricity. There is no universal agreement on the definition of DG, which is also known as Embedded Generation or Distributed Generation or Dispersed Generation. In this research, DG means small-scale generation which is connected to the grid at distribution level voltage. DG energy resources are categorized as non-renewable (conventional) and renewable (non-conventional) energy resources.

Technologies based on renewable energy include PV modules, Geo-thermal system and Wind turbines. As co-generation plants, fuel cells and heat engines use the technologies based on non-conventional resources.[4] Interconnecting a DG to the distribution feeder can have significant effects on the power system positively in terms of voltage & reactive power support, losses-reduction, and enhancement of reliability. But, negative impact of DG on power system may include voltage rises & fluctuations, frequency and voltage instability, etc.[5][6] Figure 1. shows different conventional and non-conventional energy resources which are integrated with the distribution system.

Figure 1: Distribution System with Distributed Generation.[7]

This research work will emphasis on assessment of reliability of distribution system. This paper is organized as follows. First section gives a brief introduction and present the background information of DG. In second section, the load flow analysis and reliability of electric distribution system are explained. Studying on the test system is mentioned in third section. An estimation and evaluation of reliability index and comparison results are presented in fourth section. Finally, conclusion is presented in fifth section.

METHODOLOGY

A. Load Flow Analysis

Power flow studies, commonly known as load flow, form an important part of power system analysis. The flow of active and reactive power is called power flow or load flow. The main purpose of the load-flow solution is to evaluate the magnitudes and phase angle of voltages at each bus and the active and reactive power flow in each line. In this paper, load flow analysis is suggested to observe for the lowest voltage load buses and to know the load flow conditions. There are different methods to determine the load flow for a particular system such as: Gauss-Seidel Method, Newton-Raphson Method and Fast Decoupled Method.

In solving a power flow problem, the system is assumed to be operating under balanced conditions and a single-phase model is used. Four quantities, which are voltage magnitude |V|, phase angle δ, active power (real power) (P) and reactive power (Q) are associated with each bus. The system buses are generally classified into three types, namely slack bus, load bus and generator bus.

The Newton-Raphson method is found to be more efficient and more practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required at each iteration. The Newton-Raphson load flow calculation is shown below. The injected current in term of admittance matrix,

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \quad (1)$$

The real and reactive power at bus i,

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \quad (2)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \quad (3)$$

The term $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{k} \quad (4)$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{k} \quad (5)$$

The new voltage magnitude and phase angle,

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \quad (6)$$

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \quad (7)$$

Where V is voltage magnitude and phase angle[8]

Load Flow Constraints: The limitations of load flow in power system are known as load flow constraint. In Myanmar, these constraints are regarded as follow:

± 5 % is for voltage constraint in High-Voltage Transmission system

± 10 % is for voltage constraint in Middle-and Low-Voltage Distribution system.[9]

B. Reliability Indices

Reliability Indices are the functions of various factors such as failure rate, repair time, switching time, etc. of various components. As factors are random in nature, reliability indices are also random in nature. Three primary indices, average failure rate, average outage duration and average annual unavailability or annual outage time are fundamentally important, but they do not always give a complete representation of system behavior and response. Therefore, the following reliability indices such as System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Energy Not Supplied (ENS) and Expected Energy Not Supplied (EENS) are included in the calculation to evaluate the complete scenario of reliability of distribution system. Three basic indices of reliability and the equation of reliability indices are shown in equations (8) through (14).[3][10]

Three basic reliability parameters are calculated as:

$$\lambda_s = \sum_{i=1}^{N} \lambda_i \text{ interruption/yr} \quad (8)$$

$$U_s = \sum_{i=1}^{N} \lambda_i r_i \text{ hr/yr} \quad (9)$$

These basic load point indices are the load point average failure rate (λ), the average outage time (r) and average annual unavailability or outage time (U).

The equation for reliability indices are as follow:

$$\text{SAIFI} = \frac{\text{total number of customer interruption}}{\text{total number of customer served}}$$

$$= \frac{\sum \lambda_i N_i}{\sum N_i} \text{ interruption/customer/yr} \qquad (11)$$

$$\text{SAIDI} = \frac{\text{sum of customer interruption duration}}{\text{total number of customer}}$$

$$= \frac{\sum U_i N_i}{\sum N_i} \text{ hr/customer/yr} \qquad (12)$$

$$\text{CAIDI} = \frac{\text{sum of customer interruption duration}}{\text{total number of customer interruptions}}$$

$$= \frac{\sum U_i N_i}{\lambda_i N_i} \text{ hr/customer interruption/yr} \qquad (13)$$

$$\text{ENS} = \sum L_{a(i)} U_i \text{ MWh/yr} \qquad (14)$$

Where **La(i)** is the average load demand at load point **i** and **Ui** is outage time at load point **i**.

Reliability indices are useful for determining what a customer can expect in terms of interruption frequencies and durations.[11]

C. Software

A number of software tools available for electrical engineer. Software like MATLAB/ SIMULINK, AutoCAD ELECTRICAL, PSIM and ETAP can be available easily. The software tool used in these analyses is ETAP, which is a fully integrated AC and DC electrical power system analysis tool. ETAP is the abbreviation of the 'Electrical Transient and Analysis

Program' and it offers a wide range of network analysis applications for electrical engineering. Modules are available to analyze generation plants, large industrial facilities, transmission systems, distribution systems as well as small commercial facilities. Moreover, ETAP Software can be used offline for power system simulation, online for real-time data management, or used to control real time systems and it is customizable; enabling clients to utilize the portions of the application they require without having to purchase the entire package. This software is the complete guide for electrical engineers and it offers a complete solution to all the electrical problems such as the power flow, arc flash & short circuit analysis, transient stability, relay coordination, cable selection and best possible power flow.

Here, this paper is focusing on evaluation of reliability indices and solving of the load flow analysis. The test system is modeled and evaluated in Electrical Transient and Analysis Program (ETAP). The procedures in ETAP are

1. Model reliability characteristic of each component
2. Implement user-defined parameters & settings
3. Calculate system reliability indices
4. Calculate load flow analysis to know load flow conditions

The load bus and system indices evaluated by ETAP software and some of them are;

1. System Average Interruption Frequency Index (SAIFI)
2. System Average Interruption Duration Index (SAIDI)
3. Expected Energy Not Supplied (EENS)
4. Average Energy Not Supplied (AENS)

The system voltage load buses and system losses are calculated by ETAP.

Test System

The analysis is tested in Kalay Distribution network. Originally, the electrification at Kalay is done by Diesel Generators and Mini-Hydro Power Plant before Myanmar National Grid is not supported. Since 2016, it started to generate and distribute electricity by Myanmar National Grid. Its distribution corresponds to provide the electricity to Kalay Township.

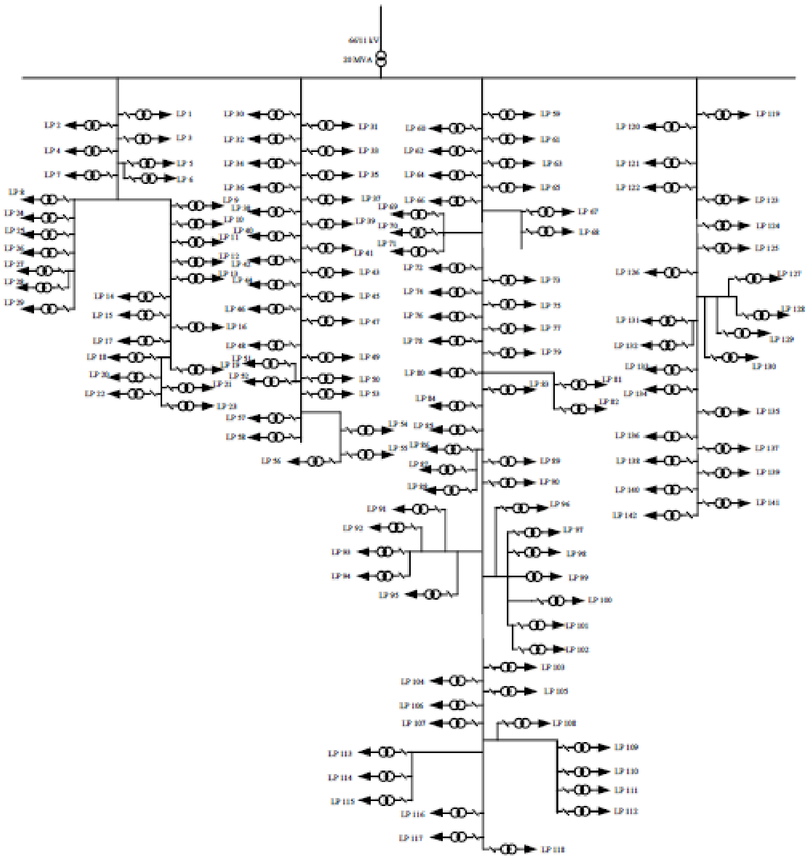

Figure 2: Single Line Diagram of Kalaymyo Distribution System.

The single line diagram of Kalay distribution network is shown in Figure 2.

Kalaymyo distribution substation is located in Kalay Township. Its distribution corresponds to provide the electricity to Kalay Township. For the distribution, one 20 MVA, 66/11 kV transformers are employed at the substation. The Kalay distribution feeder network has an 11kV system with substations and transformers which step down the voltage to 0.4kV at the secondary level. Currently, Kalaymyo substation is supplying electricity with four feeders namely; Myo Htawt, Aung Thit Sar, Da-Ka-Sa and Gyi Kone.[12] The data for this research was sourced from Kalaymyo substation.

Electric Transient Analysis Program (ETAP) software was used in reliability analysis and load flow computation in this paper.[13] The reliability analysis by means of ETAP helps to evaluate distribution system reliability with highly efficient analytical algorithms. For this purpose, Kalay Distribution system as shown in Figure 2. was modelled and analysed in ETAP.

A. Studying on the Existing System

This paper analysed the reliability prediction and load flow calculation to the distribution network of Kalay Distribution Substation. Table 1. presents type of cable and length of feeder in Kalay distribution system while Table 2. shows type and number of customers that supplies power to different types of customer loads: Government and Institution, Office and Building, Residential and Commercial.

Some of transformer data and load data of the test system for load flow calculation are presented in Table 3. These data are collected and calculated from the failure rate and outage time of Kalaymyo substation and some data are taken from sample data of IEEE system. Reliability data for each component is shown in Table 4. Parameter λ is failure rate per year, rp is replace time in hours and r is repair time for transformers, circuit breaker, fuse, cable and disconnecting switch.

Table 1: Line Data.

	Conductor Size	No. of Transformer	Line Length	Section Length	Total Connected Capacity
Myo Htawt	95 mm^2	29	9.537 miles	0.33 miles	5490 kVA
Aung Thit Sar	95 mm^2	29	3.72 miles	0.13 miles	5225 kVA
Da-Ka-Sa	95 mm^2	60	21.17 miles	0.35 miles	11075 kVA
Gyi Kone	95 mm^2	24	15.21 miles	0.63 miles	3090 kVA

Table 2: Load Data, Customer Types and Number.

Load Point	Customer Type	Average Load per Load Point	No. of Customer
1	Residential	650 kW	687
2,3,4,8,10,11,12,1,28,31,33,45,57,59,60,61,62,64,66,68,81,83,86,90,91,96, 103,104,106,113,114,115,120,121,135	Residential	104 kW	8880
5	G&I	163.8kW	1
6	G&I	83.2 kW	1
7	Residential	156 kW	316
9,32,34,35,36,41,43,54,85,107,122, 123,124,125	Commercial	52 kW	14
13,94,117,142	G&I	163.8 kW	4
14,22,65,70,72,73,74,80,126,128,131, 136,137,138,139,140,141	G&I	52 kW	17
15,37,53,71,87,132	O&B	83.2 kW	6
16,30,69,77,100	O&B	52 kW	5
17,18,20,23,78,82,99,129,130,133	G&I	26 kW	10
21,29,63,75,102,127	O&B	26 kW	6

24,25,51,56,58,76,105	Commercial	83.2 kW	7
26	Commercial	5.2 kW	1
27,89,97	Residential	83.2 kW	458
38,42,79	Commercial	104 kW	3
39,134	Residential	163.8 kW	499
40,44	Commercial	163.8 kW	2
46,50,84,89,98	Residential	163.8 kW	1584
47,108	Industry	52 kW	2
48,49,112,119	O&B	104 kW	4
52,101	Commercial	26 kW	2
55,116	G&I	156 kW	406
67	G&I	260 kW	6
91	Residential	416 kW	621
92	Industry	26 kW	1
95	O&B	163.8 kW	1
109,110	Industry	156 kW	2
111	O&B	13 kW	1
118	G&I	104 kW	1

Table 3: Transformer and Load Data.

Feeder Name	Transformer Name	Transformer Rating (kVA)	LF	PF	P (kW)	Q (kVA)
Myo Htawt	Office (1)	1250	0.65	0.8	650	487.5
	Civil Hospital	315	0.65	0.8	163.8	122.85
	Sayataw Kyaung	50	0.65	0.8	25	19.5
	Mingalar Garden	10	0.65	0.8	5.2	3.9
Aung Thit Sar	Phualpi AG Church	200	0.65	0.8	104	78
	Tazin (3) Street	315	0.65	0.8	163.8	122.85
	Royal City Hospital	160	0.65	0.8	83.2	62.4
	KaGyiWin	100	0.65	0.8	52	39
Da-Ka-Sa	GTU	500	0.65	0.8	260	195
	University (1)	300	0.65	0.8	156	117
	Tahan (2)	800	0.65	0.8	416	312
	Industrial Zone Exchange	25	0.65	0.8	13	9.75
Gyi Kone	Thoo Energy Petrol Station	100	0.65	0.8	52	39
	SaKaKha-10	160	0.65	0.8	83.2	62.4
	In Daing Kyi Village	315	0.65	0.8	163.8	122.85
	Yesan Kyon	50	0.65	0.8	26	19.5

Table 4: Component Reliability Data.

		Component Type				
		CB	***Fuse***	***Transformer***	***Cable***	***DS***
λ (f/yr)	Myo Htawt	0.065	0.065	0.663	0.464	0.065
	Aung Thit Sar	0.022	0.022	0.225	0.158	0.022
	Da-Ka-Sa	0.055	0.055	0.558	0.39	0.055
	Gyi Kone	0.149	0.149	1.523	2.132	0.149
rp (hr)	Myo Htawt	10	10	71.5	28	10
	Aung Thit Sar	10	10	71.5	28	10
	Da-Ka-Sa	10	10	71.5	28	10
	Gyi Kone	10	10	71.5	28	10
r (hr)	Myo Htawt	3	2	15	4	1.5
	Aung Thit Sar	3	2	15	4	1.5
	Da-Ka-Sa	3	2	15	4	1.5
	Gyi Kone	3	2	15	4	1.5

Table 5: Simulation Result (Reliability Indices).

SAIFI	107.601 f/customer.yr
SAIDI	157.775 hr/customer.yr
ENS	1104.425 MWhr/yr

Table 6: Simulation Results (Reliability Indices with DG).

SAIFI	63.6683 f/customer.yr
SAIDI	129.2911 hr/customer.yr
ENS	445.6781 MWhr/yr

Test Results

Under different situations, three cases were analysed which shows diverse calculated results.

Case A. Reliability Analysis without DG

Using the test system and data, the current condition of system reliability and voltage profile is calculated. Figure 3. indicates modelling of the test system without DG in ETAP.

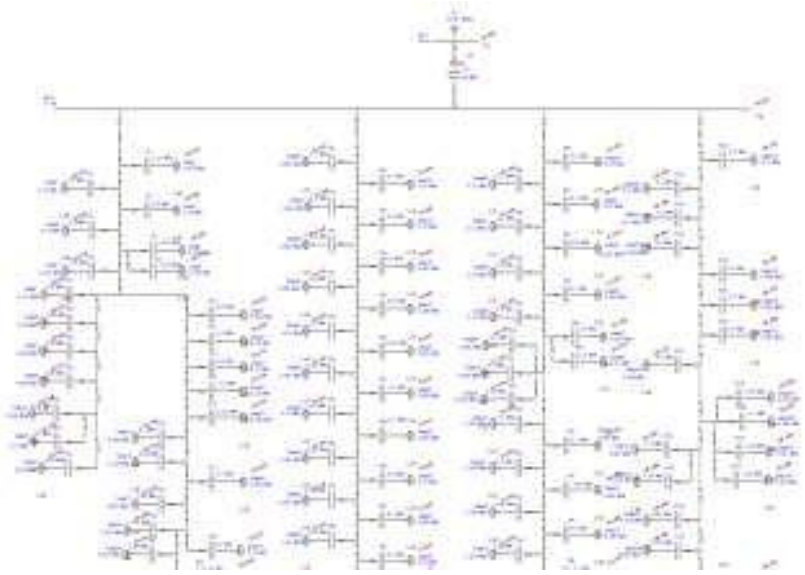

Figure 3: Reliability assessment of test system without DG by using ETAP Reliability evaluation result without DG is presented in Table 5.

Voltage profile with and without DG is expressed in Figure 4. From simulation results with and without DG, under-voltage buses can be observed.

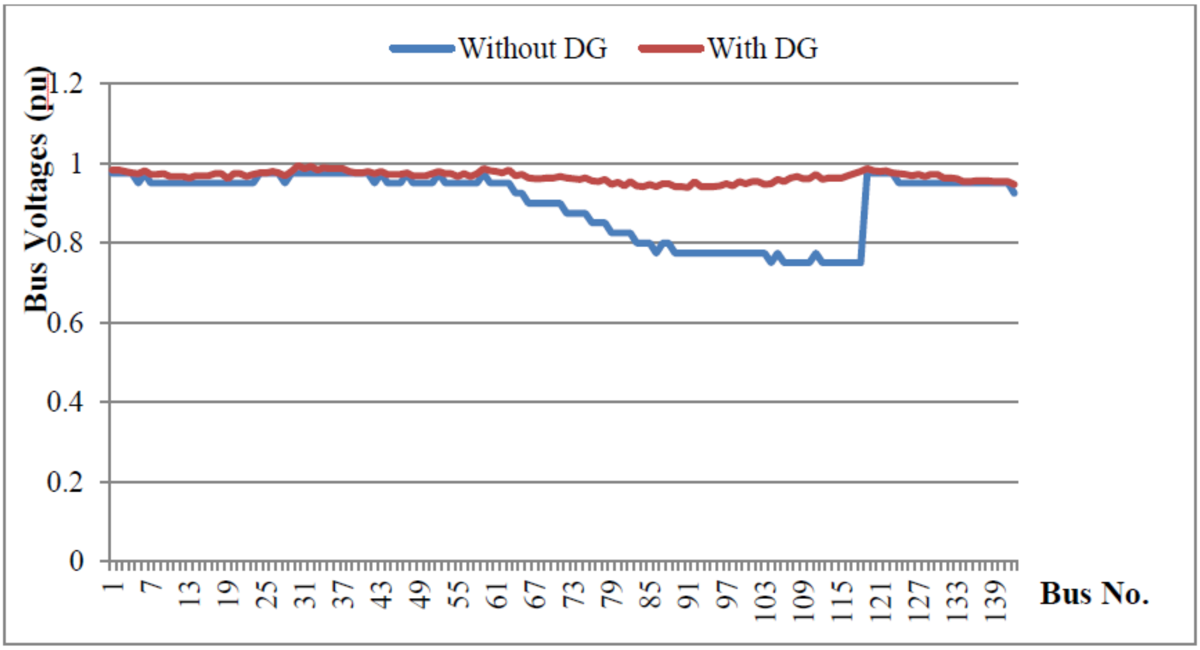

Figure 4: Voltage profile with and without DG.

Case B. Reliability Index ENS considering load flow constraint

Reliability estimation considering load flow constraint is forecasted as follow. In this estimation, number of under voltages buses and the test system peak time (hr) should be considered. The total load (MW) of under voltages buses are 1464 kW and the peak time (hr) per day for the test system is 2 hr. Therefore, estimation result considering the load flow constraint condition for Energy Not Supplied (ENS) is calculated.

ENS = 2173.125 MWhr/yr

Case C. Reliability Index ENS with DG Integrated

As mentioned above, load flow analysis is a study to observe load buses with the lowest voltage and to see the load flow conditions. The voltage profile with DG can be shown in Figure 5.

The proper location of DG plays a very important role to upgrade the system reliability, to reduce the system losses and to improve the system voltage profile. Since DG can promote the voltage profile and system reliability, the location for DG is usually set at the load bus with lowest voltage.

As a consequence, the DG is connected at a load bus from the Da-Ka-Sa feeder. Table 6. express the simulation result (Reliability Indices with DG).

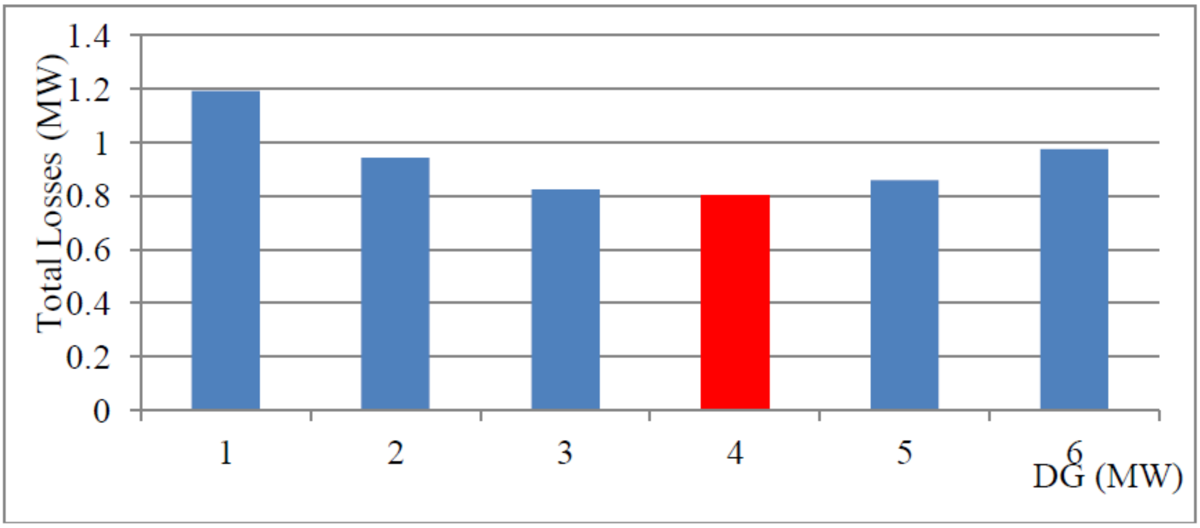

Figure 5: Comparison of Loss vs DG Rating.

For the sizing of DG, there are many methods. The system is tested with 1MW, 2 MW, 3MW, 4MW 5MW and 6 MW DG and calculated the losses in each case respectively. The results are plotted in Fig 5: Comparison of Loss vs DG Rating. It is observed that the suitable amount is obtained at 4 MW and it is selected for the feeder.

Fig 6: shows the voltage profile after integrating DG into the system.

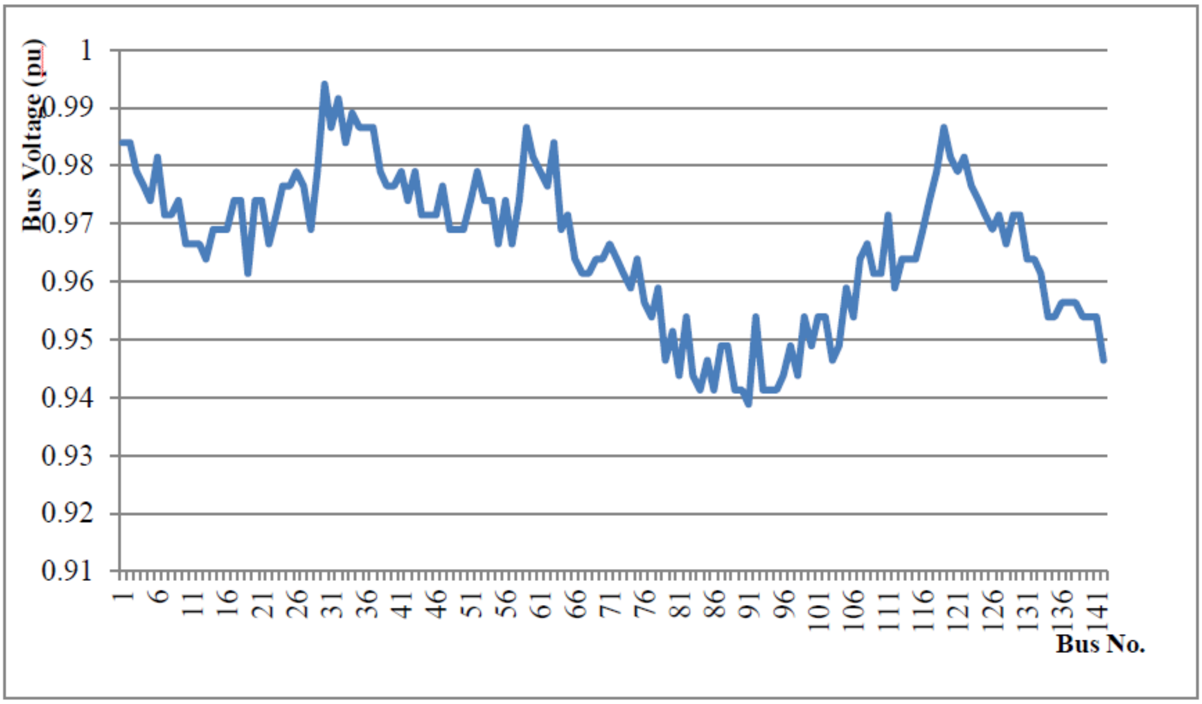

Figure 6: Voltage profile with DG.

Case C. Comparison Analysis

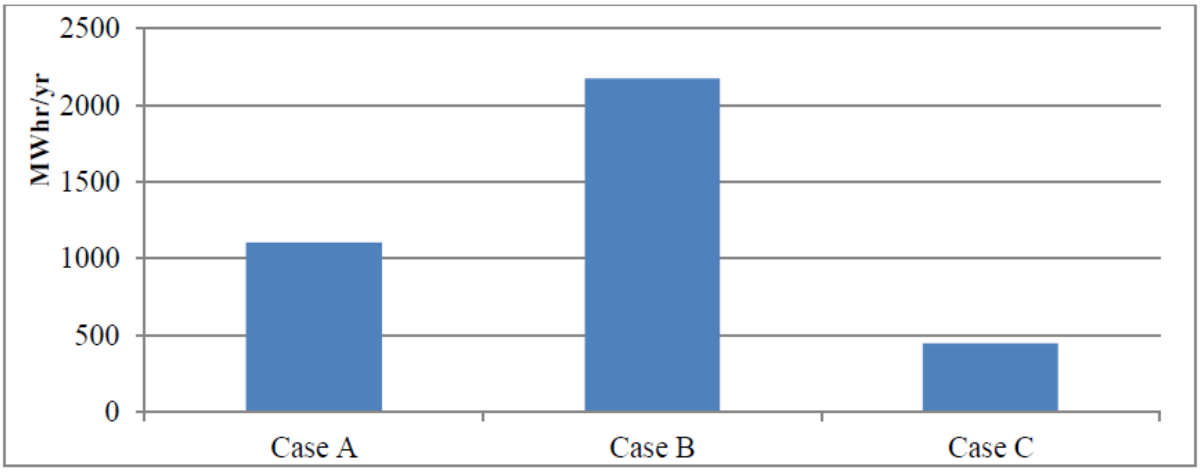

Figure 7: Comparison of ENS.

In Figure 7, three tested cases are compared to check the improvement of ENS (Energy Not Supplied). Case A is indices without DG/ without considering load flow constraint, and Case B is the indices with considered load flow constraint. When considering the load flow constraint, the resulted ENS increases from the current condition and the estimation is closely represented the actual condition. And case C is reliability improvement by Distributed Generation in feeders.

CONCLUSION

As presented in this paper, the estimation of reliability indices and solving of the load flow analysis is done using ETAP (Electrical Transient and Analysis Program). The Newton-Raphson method is adopted for the calculation of load flow analysis. According to the tests, the reliability indices and voltage profile can be improved by connecting Distributed Generation into the system. If the load constraint is not considered, the amount of ENS is (1104.425 MWhr/yr) without DG. But, when the load constraint is considered, the amount of ENS becomes (2173.125 MWhr/yr) without DG. When the Distributed Generation is integrated into the system the amount of ENS becomes (445.6781 MWhr/yr). From the ENS comparison results, it can be conducted that considering load flow constraint is more approximate with actual values. Therefore, it is more suitable for actual reliability estimation.

ACKNOWLEDGMENT

I would like to express my sincere appreciation to Kalay Substation for their supports on data collecting. I also would like to acknowledge special thanks to all my seniors and colleagues from Department of Electrical Power Engineering for their help, support and encouragement towards this paper.

REFERENCES

1. Author (), Hand book of Power Quality, John Wiley and Sons Ltd
2. G.V. K Murthy, Dr. S.Sivanagaraju, Dr. S.Satyanarayana and B. Hanumantha Rao, () Reliability improvement of Radial distribution system with distributed generation" International Journal of Engineering Science and Technology (IJEST).
3. Billinton R. and Allan R.N. (1984), Reliability Evaluation of Power Systems", 2nd Edition, Plenum Press, New York.
4. Ilyas, M., Tanweer, S.M., and Rahman, A. (2013) Optimal Placement of Distributed Generation on Radial Distribution System for Loss Minimization & Improvement of Voltage Profile, International Journal of Modern Engineering Research (IJMER) 3, No. 4 (August): pp 2296-2312.
5. P. P Barker. and R. W. De Mello (2000) Determining the impact of distributed generation

on power system s: Part 1- Radial distribution systems, IEEE Power technology, Inc, Vol. 3, pp. 1645-1656.

6. I. Hernando-Gil, I-sorin Ilie, J.L.Acosta and Sasa Z. Djokic (2012) “Impact of DG and Energy Storage on Distribution Network Reliability : A comparative Analysis,” 2nd IEEE energycon conference & exhibition.
7. Ahmah, S., Asar, A.U., Sardar, S., and Noor, B. (2017) “Impact of Distributed Generation on the reliability on Local Distribution System”. International Journal of Advanced Computer Science and Applications, Vol. 8, No. 6.
8. Saadat Hadi (1999) Power System Analysis 3rd Edition, McGraw-Hill Inc.
9. Myanmar Electric Power Enterprise
10. P. Mazidi and G. Sreenivas (2011) “Reliability assessment of a distributed generation connected distribution system,” International Journal of Power System Operation and Energy Management (IJPSOEM), Nov.
11. U.S Department of Energy (2012), Reliability Improvements from the Application of Distribution Automation Technologies-Initial Result
12. Kalay Substation and Distribution Network, “Documents of System Data and Load Data”, Sagaing Division, Myanmar.
13. http://www.etap.com/.