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ANALYSIS OF POWER SYSTEM RELIABILITY IMPROVEMENT FOR 74-BUS RADIAL DISTRIBUTION SYSTEM

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ABSTRACT

In Myanmar, electric power system planning is widely constructed because of more and more load growth and facing with failure of electricity, outage problems and system shut-down. Thus, not only making new power system network but also improving reliability of the existing system using suitable methods is very important to provide an adequate supply of electrical energy to its customers as economically and reliably as possible with an acceptable degree of continuity and quality that is designated by the term power system reliability, the primary function of an electric power system. No one wants to get the electricity interruption. 74- Bus radial distribution system is employed as a test system for a reliability assessment to understand the problems connected with the reliability of the power system and to suggest the most appropriate ways of getting the applicable results. Reliability analysis is carried out with the reliability assessment and reliability indices are calculated by using ETAP software. Also, expected energy not supplied, expected cost and annual service availability index is shown for various cases compared with base case. From the simulation results, the most relevant reliability arrangement for the improvement of radial distribution system is revealed clearly in this paper.

KEYWORDS: failure of electricity, system reliability, reliability assessment, radial distribution system.

INTRODUCTION

The issue of reliability plays an important role in the area of system planning. In reliability analysis, one is given the configuration of the system and the probability distributions of individual component failures. An electrical power can be broadly divided into the three segments of generation, transmission, and distribution. These segments are commonly referred to as functional zones. The functional zones of an electric power system can be combined to form hierarchical levels (HLs). Adequacy assessment techniques can also be grouped under this hierarchical generation to meet the system load requirement and this area of activity is usually termed as generation capacity reliability (HLI) evaluation. Both generation and the associated transmission facilities are considered at HLII adequacy assessment and are sometimes referred to as composite system or bulk system adequacy. HLIII adequacy assessment involves the consideration of all the three functional zones in an attempt to evaluate customer load point adequacies. The overall problem of HLIII evaluation can become very complex in most systems as this level involves all three functional zones, starting at the generating stations and terminating at the individual consumer load points. For this reason, the distribution functional zone is usually analyzed as a separate entity. Distribution system adequacy evaluation involves assessment of suitable adequacy indices at the actual consumer load points. There are two basic types of distribution system: meshed and radial configurations. A distribution system, however, is relatively cheap and outages have a very localized effect. Analysis of the customer failure statistics of most utilities shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer. In this paper, radial distribution configuration for reliability improvement system is only considered in detail.

RELIABILITY TECHNIQUES

There are two main categories of reliability evaluation techniques: analytical and simulation. There are merits and demerits in both methods. Analytical technique uses a mathematical model and evaluates the reliability indices from this model using direct numerical solutions with short computing time but assumptions are frequently required. Simulation technique is a method in which the reliability indices are determined by simulating the actual process and random behavior of the system. In this paper, simulation method is going to estimate the indices for the distribution system reliability analysis by simulating the actual process and random behavior of the system. This method treats the problem as a series of experiments. The use of simulation techniques is very important in the reliability evaluation of such situations. In general, if complex operating conditions are not considered and/or the failure probabilities of components are quite small, the analytical techniques are more efficient. When complex operating conditions are involved and/or the number of severe events is relatively large, simulation techniques are often preferable. An appropriateness of the evaluation technique and the quality of the input data used in the models and techniques must be analysed.

The basic steps of reliability system involved are to:

- Understand the way in which the components and system operate.
- Identify the way in which they can fail.
- Deduce the consequences of the failures.
- Derive models to represent these characteristics.
- Select the evaluation technique.

Reliability analysis is necessary for every power sector. There are three main tasks:

- Analyze the current reliability condition of the system.
- Find out the way how to improve our system's reliability based on the results from the research work.
- Forecast the expected reliability condition in future.

RELIABILITY ASSESSMENT ON RADIAL DISTRIBUTION SYSTEM

This is the case in the power systems, where the term reliability is divided to adequacy and security. The adequacy is related to the existence of sufficient generation of the electric power system to satisfy the consumer demand. The security is related to the ability of the electric power system to respond to transients and disturbances that occur in the system. The techniques for a radial distribution system are based on failure mode analysis including considerations of all realistic failure and restoration processes. These techniques also apply to distribution system adequacy assessment as this system has similar configurations and failure modes. In most systems, inadequacy of the individual customer points is caused mainly by the distribution system. Failures in the distribution system, although more frequent, have much more localized effects. Adding protective device is one of the most straightforward and effective methods for improving distribution system reliability. Assuming proper coordination, increasing the number of protective devices reduces the number of customers that experience interruptions after a fault occurs. The first step towards improving reliability is to place a protective device, typically a fuse, on all radial branches. Using protective device on radial system has a great effect on reliability of the system. A second of alternative reinforcement of improvement scheme is the installation of disconnecting switches at judicious points along the main feeder. These are generally not fault-breaking switches and therefore any short circuit on a feeder still causes the main breaker to operate. Moreover, if the distributed generation can be embedded independently of the main supply from the bulk supply point, then this source can continue to supply some of the loads when a failure occurs between the bulk supply point and the load centre being assessed. Distributed generation is always available but has a partial capability which is less than the maximum demand to increase the system reliability that can supply as a back-up source. In this paper, ETAP software is applied for performing a distribution system reliability analysis to generate the results. Electric distribution system reliability analysis involves modeling different components of distribution systems, computing reliability indices at load points and for the overall AC system that contribute to the load point, bus, system indices EENS and ECOST. The current distribution system reliability analysis, only AC system is considered and all switching devices operate successfully when required. Switching devices can be opened whenever possible to isolate a fault. Power supply can be restored to provide to as many load points as possible using appropriate switching actions and available distributed generation. The performance of the distribution system determines greater than 80% of the reliability of service to customers.

Overall distribution system performance indices can be calculated using the three basic load point indices. The following indices are used for the assessment of distribution system reliability.

Average failure rate at load point i, (f/yr)

$$\lambda_i = \sum_{j e N_e} \lambda_{ej} \tag{1}$$

Annual outage duration at load point i, (hr/yr)

$$U_i = \sum_{j e N_e} \lambda_{ej} r_{ij} \tag{2}$$

Average outage duration at load point i, (hr)

$$r_i = \frac{U_i}{\lambda_i} \tag{3}$$

Expected energy not supplied index at load point i, (MWhr/yr)

$$EENS_i = P_i U_i \quad (4)$$

System expected energy not supplied index, (MWhr/yr)

$$EENS = \sum EENS_i \quad (5)$$

Expected interruption cost index at load point i, ($/yr)

$$ECOST_i = P_i \sum_{j_e N_e} f(r_{ij})\lambda_{ej} \quad (6)$$

System expected interruption cost index, ($/yr)

$$ECOST = \sum ECOST_i \quad (7)$$

Interrupted energy assessment rate index at load point i, ($/kWhr)

$$IEAR_i = \frac{ECOST_i}{EENS_i} \quad (8)$$

System Interrupted Energy Assessment Rate Index, ($/kWhr)

$$IEAR = \frac{ECOST}{EENS} \quad (9)$$

Average energy not supplied index, (MWhr/customer.yr)

$$AENS = \frac{\sum EENS_i}{\sum N_i} \quad (10)$$

System average interruption frequency index, (f/customer.yr)

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} \quad (11)$$

System average interruption duration index, (hr/customer.yr)

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} \quad (12)$$

Customer average interruption duration index, (hr/customer interruption)

$$CAIDI = \frac{\sum U_i N_i}{\sum N_i \lambda_i} \quad (13)$$

Average service availability index, (pu)

$$ASAI = \frac{\sum N_i \times 8760 - \sum N_i U_i}{\sum N_i \times 8760} \quad (14)$$

Average service unavailability index, (pu)

$$ASUI = 1 - ASAI \quad (15)$$

Percent reduction of EENS, (%)

$$\%reduction = \frac{EENS_{base} - EENS_{proposed}}{EENS_{base}} \times 100 \quad (16)$$

Reliability indices at load points can be obtained by evaluating with the above equations. In the case of distribution system reliability evaluation, these indices can be divided into two fundamental groups. The first group contains the three basic load point indices: failure rate, outage duration, and annual outage time. The second group contains the system performance indices, in which the most commonly used ones are SAIFI, SAIDI, CAIDI, ASAI and ASUI. The EENS and ECOST for a bus are respectively defined as the expected energy not supply and expected interruption cost of the loads that are directly connected to that bus due to the outage of that bus. Reliability cost is depended on types of load and surveyed area. For residential load, the cost is lower than that of industrial load.

REQUIRED DATA FOR POWER SYSTEM RELIABILITY ASSESSMENT ANALYSIS

Collection of suitable data is therefore essential as it forms the input to relevant reliability models, techniques, and equations. The data should therefore reflect and respond to the factors that affect system reliability and enable it to be modeled and analysed. It should relate to the two main processes involved in component behaviour, namely, the failure process and the restoration process. It is important that they should be made fully aware of the future use of data and they will play in the later development of the system. The system under study is one of the 11kV distribution networks under Yangon Electricity Supply Board (YESB) in Myanmar. The distribution networks are located in Dagon Seikkan Township in Yangon City. Incoming line is 33kV and there are three 11kV outgoing line. Step down power transformer is used to distribute power and its rating is 10MVA. Some distribution transformers are not full load condition. Load of this system receives a voltage of 400V and type of load is lump load. Conductor size for 33kV is 120mm^2 and 11kV is 95mm^2. ACSR conductor is used for incoming and outgoing feeders. The distribution system is radial distribution system. In this paper, reliability assessment mode in ETAP software is exploited for an analysis of radial distribution system. To run a distribution system reliability analysis, reliability related data such as failure rates, repair times and switching times of network elements is provided. But, actual and accurate data for the test system is difficult to collect and use. Thus, a summary of these data for different types of elements is utilised from ETAP software to generate reliability indices for the reliability assessment of this system. Component reliability data of IEEE Std493-1997 for the 74-Bus radial distribution system is used to run reliability assessment program. These data are depicted in Table 1.

The main approach is to examine the existence of continuity between the supply points and the load points. Existence of continuity is associated not only with failures of line components but also with the switching logic of breakers and fuses, disconnecting switches and alternative supply. Frequency and duration indices are particularly important in distribution system adequacy assessment. Most customers are very concerned about how often outages are expected to occur and how long they are expected to last. The distribution system reliability indices are calculated using component failure data. The outage duration due to component failures are reduced by protective devices and alternative supply. These indices can be calculated by applying the above equations. In the test system, a distribution circuit uses a main feeder and three lateral distributors. A main feeder originates from the substation and passes through the major load centers. The individual load points are connected to the main feeder by lateral distributors with distribution transformers at their ends. A main feeder is constructed using single circuit that is defined as radial distribution system. Disconnecting switches are installed in the main feeder and fuses are usually provided on the lateral distributors. Faults on a lateral distributor or in a distribution transformer are normally cleared by a fuse. The faulted lateral distributor is then isolated and the supply is restored to the rest of the system. Besides, distributed generation is installed at Bus 46 that is two-third of the line length as an alternative supply.

Table 1. Component reliability data for the 74-Bus radial distribution system

Component	Active failure (f/yr)	Permanent failure (f/yr)	Switching time (hr)
Power Grid	0.643	-	4
Line	0.0246	0.0246	8
Bus	0.001	-	2
Transformer	0.003	0.003	72
Lump Load	0.02	-	-
Circuit Breaker	0.0176	0.0264	44.5

SIMULATION RESULTS AND DISCUSSIONS

In order to illustrate the reliability assessment analysis, 74-Bus existing radial distribution system is shown in Figure 1 as a research area. Load flow of this system must be run at first. After that, the required individual component data for reliability assessment is used from Table 1. In this paper, reliability indices are calculated by using the evaluation techniques. Mathematical equations in ETAP software that are described above is applied to evaluate the reliability of existing radial power distribution system. In this base case, no protective device is used in the sytem. There are two failure modes in this model, designated as passive and active failures, respectively. In the reliability assessment on existing system (base case), SAIFI is 3.7737 f/customer.yr, SAIDI is 101.9648 hr/customer.yr, ASAI is 0.9884 pu and AENS is 9.5370 MWhr/customer.yr.

By analysing reliability indices of existing data, the reliability assessment of improved system for the proposed system can be focused. The outage duration due to component failures are reduced by protection and sectionalizing schemes. Adding protective device and connecting distributed generation to the distribution network is one of the most effective methods for improving distribution system reliability. In this paper, disconnecting switches, fuses and distributed generation (DG) are used in the test system to reduce the interruption time and to improve the availability of electric power. Provision of disconnecting switches at judicious points along the main feeder, installing the fuse at the tee-point in each lateral distributor and DG for an alternative supply at overloaded feeder for the analysis of reliability improvement is described with the following cases. Only disconnecting switches are used along the main feeder, only fuses are exploited in the distributor and only DG for an alternative supply at overloaded feeder are described with Case I, Case II and Case III.

Moreover, Case IV is the combination of disconnecting switches and fuses and addition of disconnecting switches and DG is for Case V. Case VI and Case VII are fuses with DG and fuse joins together with disconnecting switch and DG. Results of reliability indices for base case and various improved cases are generated by using ETAP software. From the simulation results, reliability indices for various cases are clearly depicted in Table 2. By comparing the simulation results of base case and seven improved cases, it is clear that Case VI, the case of using fuse and DG is the best case and suitable for the proposed system. Figure 2 shows the best case of 74-Bus radial distribution system for the proposed configuration.

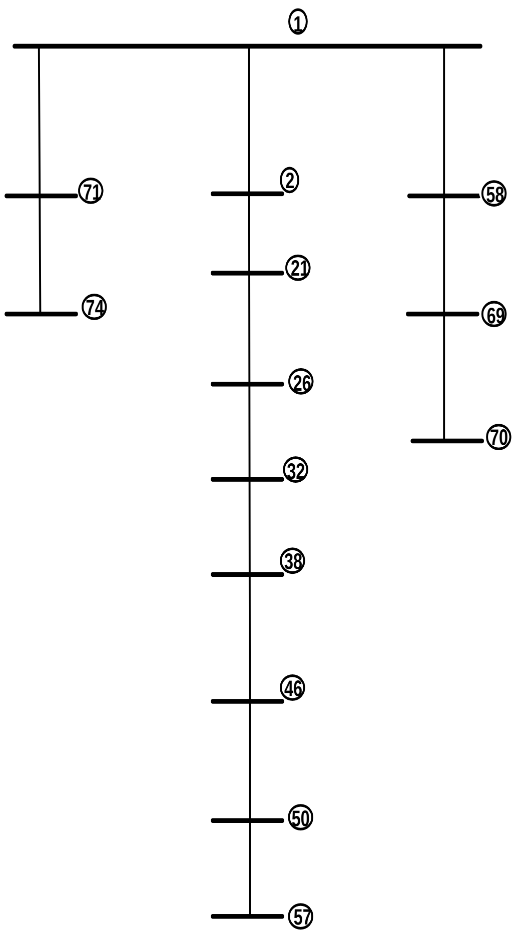

Figure 1. Typical 74-Bus existing radial distribution system

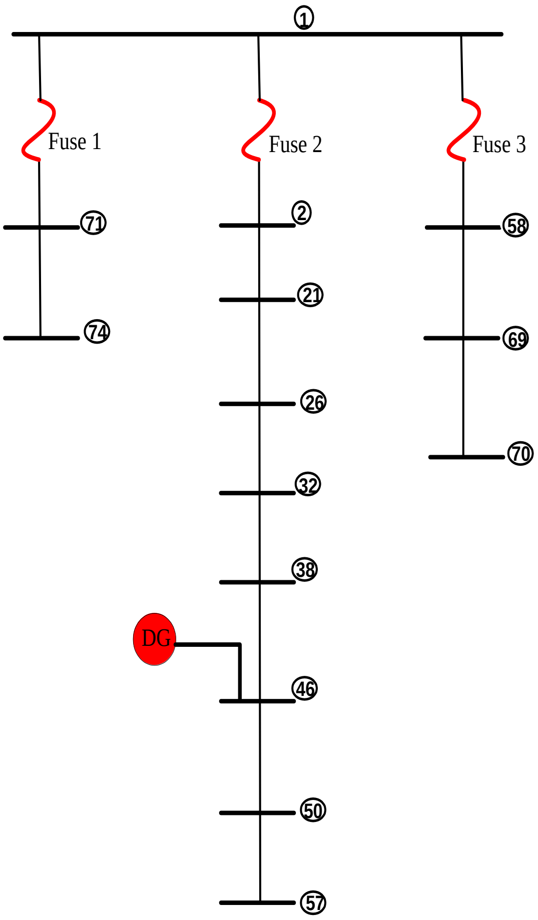

Figure 2. Proposed system of 74-Bus radial distribution system

Table 2. Resulted reliability indices for base case and various cases

Case	SAIFI (f/customer. yr)	SAIDI (hr/customer. yr)	ASAI (pu)	EENS (MWhr/yr)	ECOST ($ / yr)	AENS (MWhr/customer. yr)
Base	3.7737	101.9648	0.9884	696.198	1,725,958.00	9.5370
Case I	3.6981	76.1756	0.9913	438.152	1,047,620.00	6.0021
Case II	2.7699	67.1545	0.9923	358.942	871,875.30	4.9170
Case III	2.5474	99.6042	0.9886	681.273	1733,434.00	9.3325
Case IV	2.7942	68.3770	0.9922	367.293	893,378.40	5.0314
Case V	2.5733	73.8861	0.9916	424.297	1,057,855.00	5.8123
Case VI	1.5158	62.2636	0.9929	314.372	800,641.10	4.3065
Case VII	1.5215	62.5483	0.9929	318.655	811,677.20	4.3651

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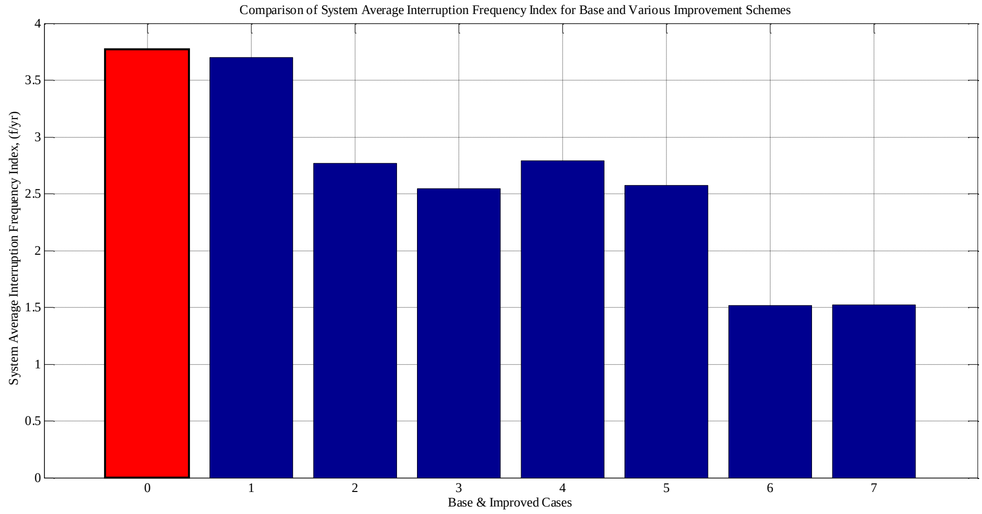

Figure 3. System average interruption frequency index (SAIFI)

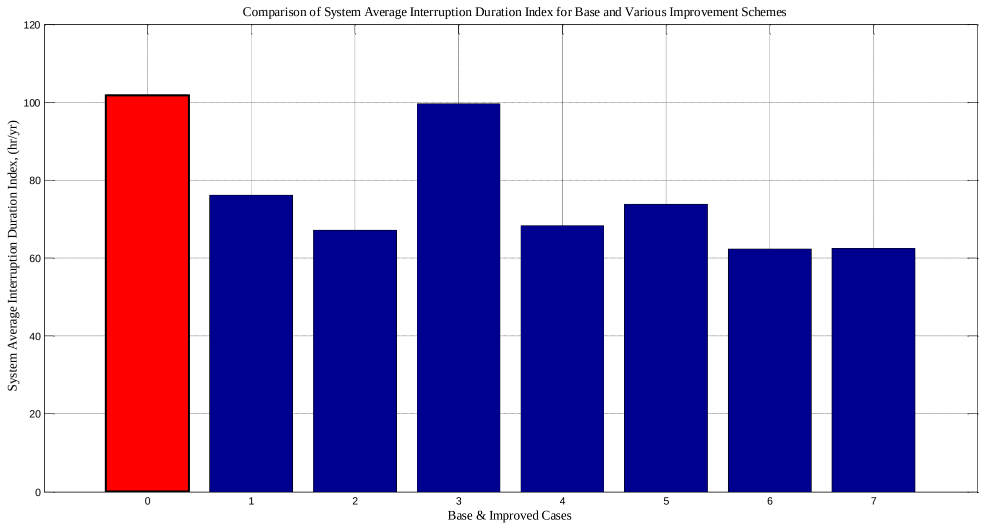

Figure 4. System average interruption duration index (SAIDI)

The values of system average interruption frequency index (SAIFI) and system average interruption duration index (SAIDI) are reduced obviously compared with base case that is shown in Figure 3 and Figure 4. Therefore, the value of expected energy not supply for the improvement reliability system is also decrease from 696.198 MWhr/yr to 314.372 MWhr/yr. Also, average service availability index (ASAI) is improved from 0.9884 pu to 0.9929 pu. Besides, the comparison of the base case and the best case suitable for the proposed system is generated to study obviously in Table 3.

Table 3. Comparison of the base case and the proposed case

Case	SAIFI (f/customer. yr)	SAIDI (hr/customer .yr)	ASAI (pu)	EENS (MWhr/yr)	% Reduction	ECOST ($ / yr)	Saving ($ / yr)
Base	3.7737	101.9648	0.9884	696.198	-	1,725,958	-
Proposed	1.5205	62.4981	0.9929	315.389	55	803,262	922,696

CONCLUSIONS

In this paper, 74-Bus radial distribution system is exploited for analysis of reliability improvement. For the calculation process of reliability indices, ETAP software is used to generate for the results of both base case and seven improved cases. By comparing the results of the 74-Bus radial distribution system between the base case without using protective devices and the case with protective devices and DG, it is clear that Case VI, the case of using fuse and DG is the best case and appropriate for the proposed system. By analysing the results of the test system between the base case without using protective devices and the case of using fuse with DG, the expected energy not supply of the system (EENS) is reduced from 696.198 MWhr/yr to 314.372 MWhr/yr and the percentage reduction in EENS is decreased to 55%. Thus, saving cost is 922,696.00 $/yr. In this case, DG is available for all time and its capacity is less than its maximum demand. Also, annual service availability index is improved from 0.9884 pu to 0.9929 pu. By analysing the data in Table 2 and Table 3, the reliability improvement by installing the disconnecting switches, fuses and DG can be observed. In this way, the reliability condition of all load points can be found out.

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