Full Paper

RELIABILITY EVALUATION AND IMPROVEMENT OF THE PHCN DISTRIBUTION NETWORK

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ABSTRACT

This paper presents the results of investigation of the reliability evaluation of the distribution system in Ile-Ife district of Nigeria. The degree of availability of electric supply to consumers is one way of assessing the system reliability. Feeder outage data were collected from the Ile-Ife district and these were analyzed to compute the various reliability indices of the system. The indices were compared with IEEE standard to categorize the reliability of the system. The use of distribution automation was also considered to improve the reliability of the system. This model consists of the remote terminal unit (RTU) that detects fault at the low voltage side of the distribution transformer, a transmitting system which automatically relay the condition of the transformer to the substation such that the fault repair crew could effect necessary repairs as quickly as possible. Results show that the reliability indices of the Ile-Ife distribution system are in the poor reliabilty range compared with the IEEE recommended values. It was also demonstrated that the use of automatic fault detection and relay system improves system reliability in the distribution supply network.

Keywords: *Reliability; distribution automation*

1. INTRODUCTION

Distribution system is an important part of power systems. Most of the customer interruptions in power systems are caused by contingencies in distribution systems. Most of the outages on the system are due to the faults in distribution systems hence, distribution system reliability evaluation has become one of the most important issues in power system analysis. Fault occurring on distribution feeder causes the protective system to disconnect the feeder from supply source hence disconnecting the customers on the feeder. The faults may be due to animals or trees that come in contact with distribution equipment, severe weather conditions such as lightning and wind storms, aging and infrequent maintenance of distribution equipment, and traffic accidents (Chow and Taylor, 1996; Warren, 1996; Parrish and Kvaltine, 1989); (Brown *et al.*, 2009; Nagaraj *et al.* 2004). The degree of availability of electricity supply to consumers is a way of assessing the system reliability. Satisfactory service as defined by the electric power consumer has been shown to be influenced by frequency and duration of outages.

In Nigeria electricity supply to consumers is so unpredictable and most times when it is available, it is at voltages below the acceptable limit. The feeders are mainly radial within sectionalizing facilities. Faults on the secondary of the distribution transformers are only detected when customers inform the utility.

A customer is primarily interested in his own service goodness while the utility may be interested in the service goodness provided to all customers on its system or the poorest service provided to any customer (Nagaraj *et al.*, 2004; Gaver *et al.*, 1964). Hence, two sets of reliability indices, *customer load point indices* and *system indices* have been established to assess the reliability performance of distribution systems. Load point indices measure the expected number of outages and their duration for individual customers and system indices measure the overall reliability of the system (IEEE, 1998). Reliability indices can be calculated using historical outage data, or predicted using stochastic methods. Various analytical methods are available for performing this predictive assessment. In this paper, the system reliability indices are calculated using the outage data collected from the power Holding Company of Nigeria, Ile-Ife distribution undertaking.

System reliability can be improved by reducing the frequency of occurrence of faults and by reducing the repair time by means of various design and maintenance strategies (Chow and Taylor, 1996; Gilligan, 1992; Meeuwsen *et al.*, 1997). The Nigeria system which is radial and has no distributed generation facilities has many options to reduce the outage duration of fault occurrences. In this paper, the use of distribution automation at the secondary of the distribution transformer is considered. An automatic fault detection and relay system was designed which has the capability to monitor the voltage and currents at the transformer secondary. Currently, fault clearing at the low voltage side is by fuse and hence detection is only when affected consumers report to the electric utility authority and this increases the outage time significantly. Also distribution automation is now being utilized world wide to improve the reliability of electricity supply at the distribution level. This paper considers the application of distribution automation to the Nigerian distribution network with Ile-Ife district as the study area. A model of an intelligent low voltage distribution supply network is proposed. The model consists of the remote terminal unit (RTU) that detects fault at the low voltage side of the distribution transformer, and a transmitting system which automatically relays its condition to the substation. The results reveals the fact that an intelligently controlled distribution supply network improves system reliability.

In the generation and transmission portion of electrical power systems, significant electronic control for system monitoring has been in place. The distribution subsection of the power system in Nigeria, however, has not utilized any degree of control or monitoring despite the fact that the existing distribution network is a product of rapid urbanization and infrastructural developments in various parts of the country at the consumers' end in the past few years. Though the loads increase in many differing geographies, the distribution subsection of the Power Holding Company generally adopts similar methods of system control and monitoring (Farhangi, 2010). The growth of the distribution subsection of electrical power system, however, has increased greatly. Despite such increase, the basic topology of the existing distribution subsection of the electrical power system has remained unchanged. The distribution network is a critical part of electric power system as over 50 percent of interruptions (outages) occurs in the distribution network (Qingle *et al.*, 2010). The difference between the contemporary distribution grid and an intelligent grid is serious since the distribution network is the key part to control and ensure good quality of the low voltage consumers' power supply. The distribution section of a power system include: distribution feeders, distribution substations, transformers, etc.

The Power Holding Company of Nigeria has traditionally used manual methods for gathering information concerning the quality of the electricity being distributed and concerning the actual distribution of energy. Unfortunately, it ends there as fault or outage is not detected until a customer reports it and then tracing starts. This has adverse effects on the reliability indices of the distribution system when compared with internationally accepted standards. The reliability evaluation of Ile–Ife district is presented in the next section. To improve the reliability of the distribution network, an automatic fault detection and control method must be designed through Distribution Automation (DA) which is the act of increasing intelligent control over distribution supply network (Northcote-Green and Wilson, 2007; Caird *et al.*, 2003). Hence, the electric utility knows there is a fault immediately it occurs and this on the long run reduces the total outage time at each interruption by eliminating the time lapse between fault detection and actual repairs (Pahwa, 2005; Billinton and Allan, 1996). This will in turn improve the reliability of the distribution system.

Therefore, there is a need for a distribution system that can be electronically controlled through a Distribution Automation remote terminal unit that is reliable in operation and performance (Caird *et al.*, 2003). The structure and operation of intelligent distribution network requires a lot of processes such as: signal sensing, exchange of signals between the remote terminal unit and exchange of signals between the remote (intelligent) terminal unit and the base (control) station (Qingle *et al.*, 2010). The remote (intelligent) terminal unit needs to have information gathering ability to detect and report faults. The design of a remote terminal unit for an intelligent distribution system which detects fault as well as reports it is very important (Northcole-Green and Wilson, 2007; Caird *et al.*, 2003). The duties of a RTU are system monitoring, automatic fault detection and fault reporting, done through the microcontroller configured through software that is capable of detecting any abnormality automatically within few minutes of occurrence.

2. RELIABILITY ANALYSIS OF DISTRIBUTION SYSTEM OF ILE-IFE DISTRICT

The distribution system studied is a typical 33kV/11kV and 11kV/415V radial networks. Outage data were collected from PHCN Ile-Ife district's office. The summary of the outages is as shown in Table 1. The reliability indices were then computed from the data and compared with internationally accepted standard values. Furthermore, data on actual outage duration (from time of fault occurrence to restoration time) were also collected from 415V consumers and summarized in Table 2. After analysis, the methods of improving the reliability of the distribution network were considered and discussed briefly.

The following reliability indices were computed from the two sets of data:

$$SAIFI = \frac{\text{Total number of customer interruptions}}{\text{Total number of customer served}} /yr. \tag{1}$$

$$SAIDI = \frac{\text{Sum of customer interruption durations}}{\text{Total number of customers}} \; h/yr. \tag{2}$$

$$CAIDI = \frac{\text{Sum of customer interruption durations}}{\text{Total number of customer interruptions}} \; h \tag{3}$$

$$ASAI = \frac{\text{Customer hours of available service}}{\text{Customer hours demanded}} \; pu \tag{4}$$

SAIFI is a measure of how many sustained interruptions an average customer will experience over the course of a year and SAIDI is a measure of how many interruption hours an average customer will experience over the course of a year. CAIDI is a measure of how long an average interruption lasts, and is used as a measure of utility response time to system contingencies. Lastly, ASAI is the customer-weighted availability of system and provides the same information as SAIDI (Brown, 2009).

Table 1: Summary of outages at 11kV (Source: PHCN, Ile-Ife district)

Feeder	Outage Frequency (f)	Outage Duration (h)	Failure Rate λ_i (f/Yr)	Average Annual Outage Time U_i (h)	Number of Customers N_i	Average annual failure ($\lambda_i N_i$)	Average Annual Unavailability ($U_i N_i$)
1	238	643.5	0.0293	18.85	15701	460.04	296035.29
2	61	68.5	0.0071	0.49	4162	29.55	2024.19
3	22	32.0	0.0025	0.08	3517	8.79	281.36
4	41	80.0	0.0047	0.38	8214	38.61	3088.47
5	199	626.5	0.0245	15.35	9102	222.99	139708.87
6	214	744.5	0.0267	19.88	15956	426.03	317175.76
7	99	284.0	0.0117	3.32	6161	72.08	20471.77
8	38	273.0	0.0045	1.23	7059	31.77	8671.98

Table 2: Summary of outages at 0.415kV (Source: Consumers)

Feeder	Outage Frequency (f)	Outage Duration (h)	Failure Rate λ_i (f/Yr)	Average Annual Outage Time U_i (h)	Number of Customers N_i	Average annual failure ($\lambda_i N_i$)	Average Annual Unavailability ($U_i N_i$)
1	300	720	0.037	26.64	15,701	580.94	418,274.64
2	192	360	0.0229	8.24	4,162	95.31	34,311.53
3	456	3060	0.080	244.8	3,517	281.36	860,961.60
4	240	180	0.028	5.04	8,214	229.99	41,398.56
5	360	1440	0.0492	70.85	9,102	447.82	644,858.50
6	300	2160	0.0455	98.28	15,956	726.00	1,568,155.68
7	180	360	0.0214	7.70	6,161	131.85	47,464.34
8	589	5800	0.1990	1154.20	7,059	1404.74	8,147,497.80

Table 3: Summary of reliability indices

Feeder	33/11kV				0.415kV			
	SAIFI (interruptions/ customer yr)	SAIDI (h/customer yr)	CAIDI (h/customer)	ASAI	SAIFI (interruptions/ customer yr)	SAIDI (h/customer yr)	CAIDI (h/customer)	ASAI
IASV	0.0100	1.1000	2.56	0.9998	0.001	1.1000	2.56	0.9995
1	0.0293	18.8545	643.5	0.9978	0.037	26.64	720	0.9969
2	0.0071	0.4863	68.5	0.9994	0.0229	8.244	360	0.9990
3	0.0025	0.0800	32	0.9991	0.08	244.8	3060	0.9721
4	0.0047	0.3760	80	0.9995	0.028	5.04	180	0.9994
5	0.0245	15.3492	626.5	0.9982	0.0492	70.848	1440	0.9919
6	0.0267	19.8781	744.5	0.9977	0.0455	98.28	2160	0.9887
7	0.0117	3.3228	284	0.9996	0.0214	7.704	360	0.9991
8	0.0045	1.2285	273	0.9998	0.1990	1,154.2	5800	0.8682

Table 3 shows the computed reliability indices from Tables 1 and 2 and the comparison with the internationally acceptable values. The data collected from PHCN are very reliable since they always keep a daily record of outages or interruptions. The data obtained from consumers were not as reliable as data from PHCN since not all the consumers keep records of outages from time to time; however, this analysis was, to an extent, based on consumers who record fault outages except for feeders 3 and 8. From Table 3, the reliability indices obtained at 33/11kV reveals that for all the feeders (1-8), the reliability of the distribution network can be said to be averagely 40.4% when compared with the internationally accepted standard. Take for instance feeder 6 that has the lowest ASAI at 11kV, the average interruptions 26.7 out of every 1000 customers at 11kV as against the IASV of 10 out of every 1000 customers and this applies to all the other indices. On the other hand, the reliability indices obtained from Table 3 at 415V reveals that for all feeders (except 3 and 8), the reliability of the distribution network, particularly at the low voltage consumers' end can be said to be averagely 21.9% when compared with the internationally accepted standard.

Comparing the reliability indices at 33/11kV with 0.415kV, at 0.415kV, it was seen that the availability of power supply at 11kV does not necessary mean availability at 415V as the availability index at 0.415kV is lower than that of 11kV by a percentage of 18.1. This is because to a reasonable extent, the electric utility knows about the occurrence of a fault at 33/11kV as soon as it occurs through the circuit breaker at the substation and goes just about it immediately, this was reflected in the reliability indices of Table 3. On the other hand at 415V, it takes an average of 8-12hours before just one customer on a faulty feeder decides to report an interruption or an outage, this can make the outage duration for a particular fault as long as 20-24hours or even more. Hence, there is a need for methods of improving the reliability indices at the low voltage consumers' end. The next section quickly discusses the methods that can be used to improve the reliability at the consumers' low voltage end.

3. METHODS OF RELIABILITY IMPROVEMENT

Reliability of the system can be improved by making the system more flexible and with the use of distribution automation. Some of the methods that can improve the reliability of the Nigerian distribution network include

1. **Load transfer:** Most of the Nigerian distribution systems are single radial feeders. By constructing additional feeders, it will be possible to transfer load from one feeder to another during scheduled maintenance and when faults occur and hence maintain continuity of supply to consumers.
2. **Use of isolators:** This is another method of improvement achieved by providing isolators at judicious points along the main feeder. After the fault has been detected beyond the isolator, it is opened and supply restored to the healthy section of the feeder. This procedure allows restoration of all load points between the supply point and the isolator.
3. **Use of distribution automation:** Distribution automation uses a range of intelligent control methods which are able to automatically detect fault on the feeders, switch the load to another feeder, isolate the faulty section of a feeder, and automatically open and close circuit breakers. Hence the outage time is greatly reduced and overall system reliability improved.

In this paper, the use of automatic fault detection and relay to substation is considered. Since the system currently do not have facilities for load transfer, feeder sectionalisation and automatic fault detection, this method can be easily implemented to improve the system reliability. The structure and operations are presented in the next section.

4. STRUCTURE AND OPERATION OF INTELLIGENT DISTRIBUTION SYSTEM

From the structure of the contemporary distribution network and the components required for control, an intelligent distribution system is designed. The system consists of base control at the substation, transformer, voltage and current sensors, intelligent remote terminal unit (RTU) and the communication network. The remote terminal units (RTUs) are connected to the substation through a suitable wireless communication network.

The primary functions of RTU are system monitoring, fault detection and fault reporting. When the system is normal, the ratio of the voltage to current gives the line impedance. During open circuit faults, the voltage is high while the current tends to zero; hence the impedance tends to infinity. Also during short circuit faults, the current is very large while the voltage is very low; hence the impedance tends to zero. The sensing unit uses these extreme conditions to determine the status of the transformer and sends appropriate signal to the substation through the communication unit. The structure of the RTU is as shown in fig.1.

The RTU includes a signal conditioning circuit and a microcontroller system. The voltage transformer (VT) is a voltage sensor that outputs an analogue voltage signal. In a typical 11/0.415kV substation, the VT output will be about 220-240V. This is stepped down by a suitable voltage conditioner to produce a lower voltage of about 5V. Similarly, the current transformer is a current sensor that outputs an analogue current signal of about 5A when stepped down by a suitable current conditioner which is converted to about 5V. The output signals of the voltage and current conditioners are further conditioned to be accessible to the microcontroller. This is done by first passing the signals to the amplifier or buffer and then the amplified signals are digitalized through the digital to analogue converter and fed into the microcontroller. The microcontroller performs system monitoring through software that is capable of detecting faults. When it detects fault condition a message is sent through the communication link to the substation.

5. CONCLUSION

This paper has shown the level of reliability of the distribution network in Nigeria using the Ile-Ife district as a case study. It was demonstrated that all the reliability indices of the system deviate significantly from the internationally accepted standard values. Results also showed that the reliability of the 415V feeders is by far lower than the reliability at 33/11kV for the same system. This is due to poor system monitoring at the low voltage consumers' end.

A simple monitoring system was developed for the secondary side of the distribution transformer and if put into use, and PHCN mobilise to rectify faults immediately they are informed, the outage time will be greatly reduced and this will improve the overall reliability indices of the system.

Hence, this paper concludes that incorporating distribution automation into the Nigerian distribution network for adequate system monitoring and control will definitely reduce the total outage time and improve the reliability of the distribution network on the long run.

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