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Effects of Power Distribution Feeder Monitoring and Service Restoration through Cloud Computing on System Efficiency Improvement

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ABSTRACT: *The electrical power network as a whole consists of critical infrastructures which need continuous process of technological improvements for higher efficiency in terms of functions, reliability, and value. Nowadays, electric power systems (up to transmission level) are being upgraded with sophisticated communication and control technologies to enhance the system reliability, however poor monitoring gives rise to instabilities on the distribution portion of the total power system. These instabilities affect the overall availability and efficiency of the system. Therefore, it is essential to develop models and methods to improve monitoring and protection of the distribution system through which could improve availability of the entire power system.*

The methods of power distribution network improvement were studied with a view of developing an intelligent system capable of improving network's efficiency through availability improvement without putting those critical power infrastructures at a higher risk of instability. This research evaluated the rates of failure of critical infrastructure in conventional distribution networks through gathering and analysis of reliability data. The load on medium voltage feeders and distribution transformers were monitored remotely to detect the health conditions of the system after which faults were isolated thereby restoring normalcy. The impact of service restoration following fault conditions on distribution system availability without a complex Supervisory Control and Data Acquisition system on future power distribution systems was considered by comparing the system efficiency before and after monitoring. The automatic system which remotely monitors the state of the feeders and transformers continuously to determine the state of the network was designed. Abnormal conditions were automatically addressed through automatic sensors, isolators and switches which open or close depending on the status of individual feeder as detected by the sensing circuits. These circuits utilize sensors through remote operations for processing of data and actionable outputs in a virtual control room for automatic restoration, thereby reducing the system total downtime while improving the system availability.

The distribution system test bed showed that the technical losses on the system are high leading to poor efficiency and reliability, however, after monitoring the availability and efficiency of the network improved by about 70%. Therefore the designed network improved and stabilized the system delivery factor from 0.7635 to 0.9470. In the end, the over one hundred and thirty-eight million naira monthly reduction in the revenue loss after monitoring also reflects the milestone achieved in improving the technical and economic stability of power distribution networks.

The designed and developed system therefore improved the network's operational availability through the reduction of the total outage time and service restoration time.

Keywords*-Medium voltage, Feeders, Transformers, SCADA, Availability, Efficiency Infrastructure, Remote, Cloud Computation, Virtual control room, downtime, monitoring.*

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I. INTRODUCTION

As the world faces major challenges now and in the future, for the growth and improvement in the reliability of its electrical power infrastructure, the development of any country is dependent on the availability of electric supply. Remote laboratories, industries, educational institutions, hospitals and even other small and medium enterprises depend on highly reliable power supply for the smooth running of their day to day activities. Therefore, the consequences of unreliable supply can result in life threatening situations and lack of socioeconomic development. Needless to say, developing countries (like Nigeria) suffer these consequences more as electric utilities have a wide array of challenges to overcome whether they are in generation, distribution subsectors. Distribution companies however by virtue of their position on the power chain, face the most varied and complex technical and operational challenges. These challenges are mainly related to:

(i) Size and complexity of the network.
(ii) Direct interaction with end-users/ consumers of electricity

The distribution company, as the direct interface with electricity consumers, is thereby burdened with the duty of realizing/recovering the revenue that drives the entire power chain. Electricity consumers can be roughly divided in to three (3) categories-

(i) Residential consumers: Power intake is at low voltage only, Consumption is typically below 80A, and they are usually metered with prepaid meters.
(ii) Commercial consumers: Power intake is at low or medium voltage (when they have a dedicated transformer). They are usually metered with LV or MV MD meters.
(iii) Industrial consumers: Power intake is at Medium or High voltage (in some rare cases).

To ensure availability of power supply and accurate revenue realization, an electricity utility must ensure that adequate protection is in place for distribution transformers and feeders as well as put metering technology is in place for each consumer type. Adequate monitoring and punitive measures must also be put in place to ensure security of supply and proper customer behavior.

Therefore this paper reports the development of a procedure that can analyze the state of the key distribution network infrastructure, predict its dynamic behavior for reliable/secure operations and remotely interact with it to take appropriate decision

II. REVIEW OF CURRENT DISTRI-BUTION NETWORKS CHALLENGES

In a more connected world, pressures on electric utilities continue to increase and below are the most pressing pressures:

(i) Cost and Pricing Pressure: By 2050, the Electric Power Research Institute estimates that the average electric bill will probably go up by about 50 percent if the smart grid is deployed (Hostick et. al., 2014).
(ii) **Increasing Demand:** There will be 53% projected growth in worldwide energy demand by 2035 (EU Reference Scenario, 2016).
(iii) **Increasing consumers' expectations and concerns:** More than fifty percent (50%) of surveyed consumers with an opinion expect smart grid technologies will lower total household costs for energy use (Hostick et. al, 2014).
(iv) **Pressure on Aging Infrastructure:** At least eighty percent (80%) of feeders and power transformers in the world have more than 40 years of service (Denver Hydroelectric Research and Technical Service Group, 2005).

From all the pressure discussed above, a transition fully automated distribution network deployment is a must for electric utilities. The future plan for the distribution networks is a fully automated system (advanced/smart grid, which is the integration of IT, Communication tools, Control and intelligent monitoring devices into the system for improved system security and utilization of electricity supply at the consumers end. While a fully automated distribution grid might not be possible in the immediate, the monitoring of the critical equipment in distribution substations have a major link in achieving this future plan. This critical distribution equipment is the distribution transformer.

There are lots of work done on distribution network monitoring, most are however based on Supervisory Control and Data Acquisition. By the virtue of the position of the distribution network on the power chain (that is, it is the part of the network that should make revenue that will cover all expenses on generation, transmission and energy consumed), any electric utility want to have maximum value for any extra cost on reliability improvement. Therefore the way to go is having a scalable and low-cost solutionthat can unlock the door to the development of monitoring and self-healing in distribution networks by overcoming the cost barriers associated with the implementation of previous classical methods used so far.

The power companies are implementing numerous ways of improving reliability. In addition to supervisory control and data (SCADA) functions, replacing traditional manual switches with automatic switches can significantly improve reliability by reducing fault detection, isolation and service restoration time (Sadou et.al, 20101).

Some interesting monitoring solution done for distribution systems based on a scalable and data-driven approach are:

The division of the distribution system into a number of sections and estimations are performed for each section separately (Ferdowsi et. al, 2016). The monitoring is based on evaluation of the magnitude of the system voltage instead of the total network condition for simplicity.

The use of a data-driven technique such as artificial neural networks (ANNs), evaluations can be made possible without any system monitoring in real-time operation as well as with just a little few measurements at both Medium Voltage and Low Voltage levels (Ponci et.al, 2016).

Some literatures had tried gaining a rough understanding of distribution networks rather than targeting a very detailed and accurate picture ( ), and through this the average grid conditions can be evaluated.

III. FAULT MONITORING, DETECTION AND CONTROL TECHNIQUE

When the faulty section of the distribution network is isolated successfully, the algorithms for the fault analysis and detection stage will trigger the feeder controls through some automatic switches based on cloud computing calculations. With fault location capability integrated with the proposed monitoring and self-healing system. The type of outage can be determined by reenergizing the isolated feeder back h and if the parameters at the feeder nodes are measure and within their limits, the fault is termed a momentary fault and load capacities will be brought back in service. Thus the load on the distribution network is restored with losses rather than experiencing energy losses due to the faulty section. Consequently, energy, outage time and money can be saved.

Finally if the fault is a sustained interruption, the system sends an alarm describing the location of the faulty feeder. This minimizes the total downtime as interrupted consumers can be restored again to the distribution network after feeder faults have been cleared and normalcy restored. This was achieved through the service restoration algorithm implemented in Figure 2. This improved the service reliability and increases the operational efficiency of the network. The status of the distribution network feeder was monitored and logged per time in the cloud and alerts were sent when the system health was in a critical state or isolation was done to restore normalcy. Figure 1 shows the overall system circuit diagram and layout for the monitoring system functions.

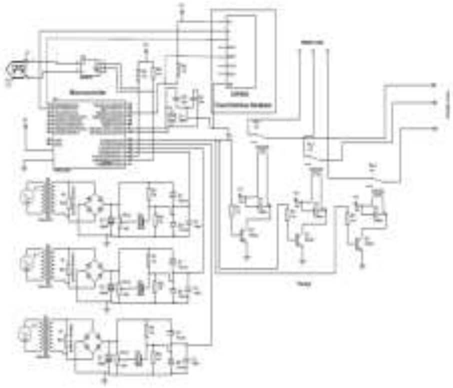

Figure 1: Overall Circuit Diagram

IV. RESULTS

Switching response time

The monitoring system was designed to detect faults within five (5) seconds after send actionable output instructions after three (3) calls to the internet. In like manner, the automatic isolation of faulty feeders will take place after another three (3) calls to the internet within five (5) seconds after receiving the actionable output instructions. A call to the internet takes an average of twenty (20) seconds therefore the total of six (6) calls to the internet makes one hundred and twenty (120) seconds. It is then safe to report that the designed monitoring system perfects monitoring and isolation for the first level check (FLC) within one hundred and thirty (130) seconds, that is approximately two and half (2 ½) minutes. This same procedure is repeated for the second level check (SLC) which starts immediately after the expiration of FLC and then loads are brought back in service or permanently left isolated after about one hundred and thirty (130) seconds, that is approximately two and half (2 ½) minutes. Isolation is done immediately the feeder is found wanting after the FLC and only brought back into service after SLC returned a satisfactory report. The stability of the readings at that node determines if the load remains in service or permanently isolated. Table 1 illustrates the switching time response for isolation and restoration for all types of feeder health conditions.

Impacts of monitoring

The effects of distribution networks monitoring can be viewed as both economical and improved availability or reduced outages. These effects are evaluated below.

3.1.1.1 Reduction in customer-hours interruption

From Table 4.6, there was considerable reduction in the customer hours of interruption. This implied that more customers have more useful energy availability on the network and hence reduction in energy loss as well as increase in the total revenue generated.

Reduction in total energy loss

Energy losses after monitoring was calculated as below and summarized in Tables 2 and 3. From the results of calculated energy loss, the percentage loss reduction was calculated, this reflected almost eighty (80) percent reduction in the amount of energy loss.

Total Energy Loss before monitoring (TEL1) = 5,970,474 kWh
Total Energy Loss after monitoring (TEL2) = 1,337,713 kWh

$$\text{Percentage Loss Reduction} = \frac{\text{TEL1} - \text{TEL2}}{\text{TEL1}} \text{x } 100\%$$

$$= \frac{4{,}632{,}761}{5{,}970{,}474} \text{x } 100\%$$

$$= 77.59\%$$

V. CONCLUSION

This work covered the evaluation of distribution networks failure by analyzing the types and causes of failure, composition of the total downtime, energy loss and revenue loss. The type of interruptions either sustained or transient) goes a long way in determining how the problem of self-healing and automation can be tackled.

The research developed a methodology for strategic monitoring placement for the estimation of abnormal load currents or fault currents in power distribution systems based on accurate fault localization, isolation and automatic restoration. A review of past literature showed that faults currents are currently one of the most critical power quality interruptions and disturbances. The economic losses resulting from prolonged interruption of residential, commercial and industrial processes caused by fault currents have been estimated in the range of hundreds of millions or even billions of funds annually both in developed and developing countries. The continuous disruption of equipment in households, business and industry leads to serious revenue losses.

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Table 1: Switching response time

TYPE OF FEEDER HEALTH CONDITION	1	2	3	4	5	6
FLC % DEVIATION FROM RATED CURRENT VALUE	< 20%	20% - 40%	20% - 40%	40%-50%	≥50%	≥50%
NORMAL	65 s	65 s	65 s	-	-	-
ABNORMAL	-	-	-	65 s	65 s	65 s
ISOLATE TEMPORARILY	-	-	-	-	*	*
RESTORE	-	-	-	-	65 s	65 s
SLC % DEVIATION FROM RATED VALUE	< 20%	< 20%	> 40%	40%-50%	« 50%	≥50%
TOTAL ISOLATION OR RESTORATION TIME	0	0	0	0	130 s	130 s
ALARM/ ISOLATION/ RESTORATION STATUS	-	-	Alarm	Alarm & Isolation	Isolation & Restoration	Isolation & Alarm

Table 2: Summary of Outages/Energy Loss in Ibadan Region (AVERAGE ANALYSIS PER MONTH)

S/N	FEEDER	DURATION (Hrs)	FREQUENCY OF INTERRUPTION	AVERAGE POWER Loss (MW)	TARIFF (₦/kWh)	ENERGY LOSS (kWh)	REVENU LOSS (₦)
1	AGODI 1	28.40	13	10.0	30.0	284,000.00	8,400,000.00
2	AGODI 2	69.80	23	17.0	30.0	1,186,600.00	35,598,000.00
3	APATA	22.43	35	10.0	30.0	22,430,000.00	672,900,000.00
4	ELEYELE	21.65	19	13.0	30.0	281,450.00	8,443,500.00
5	ERUWA	25.50	36	16.0	30.0	408,000.00	12,240,000.00
6	EXPRESS	60.23	48	13.0	30.0	782,990.00	23,489,700.00
7	INTERCHANGE	64.77	29	16.0	30.0	1,036,320.00	31,089,600.00
8	IYAGANKU	54.98	20	6.0	30.0	329,880.00	9,896,400.00
9	LIBERTY	43.07	20	7.0	30.0	301,490.00	9,022,700.00
10	OLUYOLE	41.98	23	17.0	30.0	713,660.00	21,409,800.00
11	JERICHO T2A	16.35	7	8.5	30.0	138,975.00	4,169,250.00
12	JERICHO T2B	16.55	7	7.5	30.0	124,125.00	3,723,750.00
13	SAMONDA	108.42	40	1.5	30.0	162,630.00	4,878,900.00
	TOTAL	574.13	320			5,970,474	845,261,600.00

Table 2: Summary of customer interruption hours and energy loss after monitoring

S/N	**FEEDER NAME**	**ORIGIN OF OUTAGE**	**NO OF CUSTOMER AFFECTED**	**Customer-Hours Interruption (CHI) (Hours)**	**AVERAGE POWER Loss (MW)**	**ENERGY LOSS (kWh)**	**OUTAGE DURATION (HOURS)**	
							TRC	SUS
1	JERICHO 15MVA T-2A	IBEDC TCN	7882 5268	0	10.0	0	3.52	0
2	JERICHO 15MVA T-2B	IBEDC TCN	1948 1344	0	17.0	0	3.52	0
3	AGODI 1 33KV	IBEDC TCN	203 1743	4648.7	10.0	125,400	29.33	12.54
4	AGODI 2 33KV	IBEDC TCN	2036 1555	46624.4	12.0	274,800	20.12	22.90
5	IYAGAN	IBEDC	1	2.60	16	4,160	2.30	2.60

	KU 33KV	TCN	9					
6	SAMONDA 33KV	IBEDC TCN	1 1	12.08	13	157,040	10.05	12.08
7	ELEYELE 33KV	IBEDC TCN	30 23	300.6	16	160,320	5.30	10.02
8	INTERCHANGE 33KV	IBEDC TCN	408 386	3357.84	6.0	4,938	18.40	8.23
9	EXPRESS 33KV	IBEDC TCN	1 1	6.53	7	45,710	10.42	6.53
10	LIBERTY 33KV	IBEDC TCN	8 9	66.64	17	141,610	29.10	8.33
11	OLUYOLE 33KV	IBEDC TCN	11 11	46.53	8.5	35,955	9.25	4.23
12	ERUWA/ LANLATE 33KV FDR	IBEDC TCN	3635 3808	187202.5	7.5	386,250	25.45	51.50
13	APATA 33KV FDR.	IBEDC TCN	117 109	119.34	1.5	1,530	3.00	1.02
	TEL*					**1,337,713**		

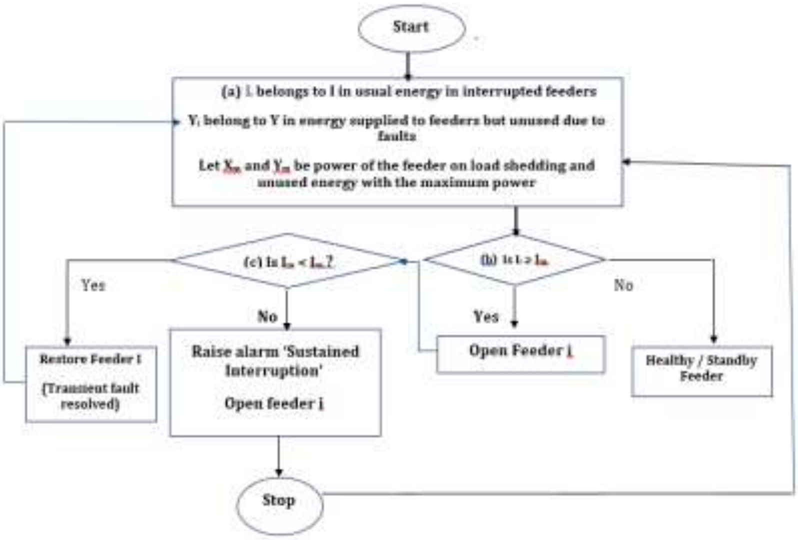

Figure 2: Flowchart of fault analysis, isolation and self-healing stage

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