Power Distribution Networks' Critical Infrastructure Monitoring and Service Restoration through Cloud Computing for Reliability and Efficiency Improvement

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Abstract

The reliability of power supply is the greatest concern of any electric utility company. From inception till now power system engineers have always been concerned with supplying electricity to the loads reliably and efficiently. This may be realized by striking a balance between customer satisfaction and the associated expenses. 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 uncertainties on the distribution portion of the total power system. These uncertainties when introduced in the power grid affect the overall reliability and efficiency of the system. Therefore, it is critical to develop models and methods to improve monitoring and protection of the distribution system thereby improving power system reliability. This paper treats a two-fold objective. First, the load on low/medium voltage feeders and distribution transformers are monitored and next both pre-fault and fault conditions are detected and isolated thereby restoring normalcy. This work therefore designed an automatic system for remote monitoring and balancing of load on each feeder. Remote actions were done through automatic sensors, isolators and switches which opened or closed depending on the status of individual feeders as detected by the sensing circuits. Data processing for actionable outputs in a virtual control room was then realized through cloud computation. This paper gives a projection that will lead to improvement in stabilizing the distribution network through the reduction of total downtime and its impact.

Keywords- Customer satisfaction, Low/Medium voltage, Feeders, SCADA, Reliability, Infrastructure, Remote, Cloud Computation, Virtual control room, downtime, monitoring.

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 socio-economic 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 DISTRIBUTION 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 solution that 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

From some previous analysis of the system state assessment done (see Appendix I), a certain percentage of the total energy distributed will definitely be lost due to incessant outages caused by faults and other unplanned occurrences. These occurrences will definitely affect some of the feeders that were scheduled to be in service at a particular instant. The need for the design of an automatic system of monitoring which remotely monitors load on each feeder, detects faults and diagnose the kind of problem encountered as accurately as possible through automatic sensors, isolators and switches therefore arises. Figure 1 shows the functions of the overall block diagram for the designed smart medium voltage network.

For a medium voltage network which is under normal operating condition, the voltage level must not be exceeded beyond it limits and the load current must be maintained at the operating capacity of its rated feeders. The criteria for the following equations therefore must be met at all times:

$$|V| = |V_i| \leq (V_{rated} + 5\%)\ kV \quad (1a)$$

$$|V| = |V_i| \geq (V_{rated} - 5\%)\ kV \quad (1b)$$

$$|I| = |I_i| \leq (I_{rated})\ A \quad (2)$$

Else, the |A| and |V| measurement block in Figure 1 will sense an abnormal condition different from the trained levels and error, interruptions and system failures will be further investigated.

Knowing the facts above, suitable voltage and current sensors that can measure the voltage at the point of each feeder supply and the load current were selected. These sensors for measuring |V| and |I| were connected directly to the feeders.

Arising from the measurement block are great volumes of fundamental quantities of data that needs further computation and conditioning so that sense can be made out of them (such as estimation of power, energy, losses and so on). This non-fundamental quantities can all be obtained from the fundamental quantities. The need for computation will be divided into mathematical operations on acquired signals, preparation of data for base station alerts, data storing, system predictions and auto switching activities and other needed relevant

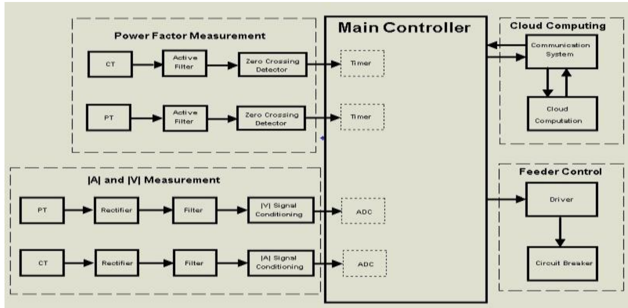

Figure 1: Overall block diagram for the monitoring and fault detection system

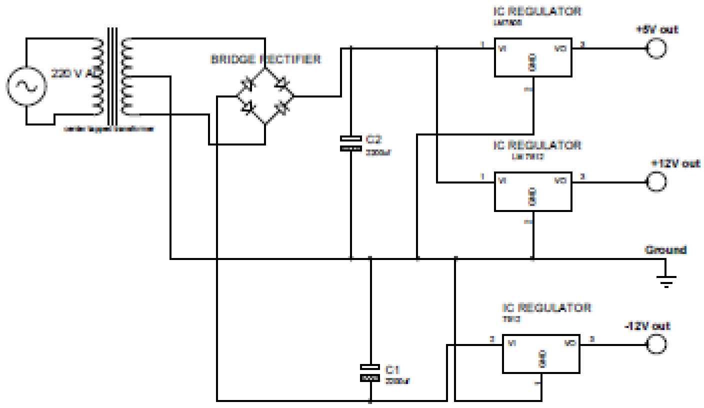

Figure 2: Energizing Circuit

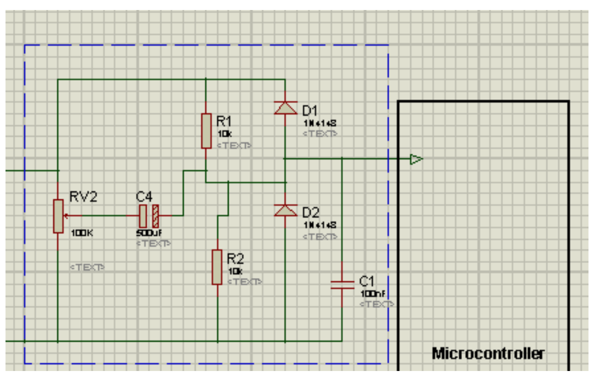

Figure 3: A-V Measurement Circuit

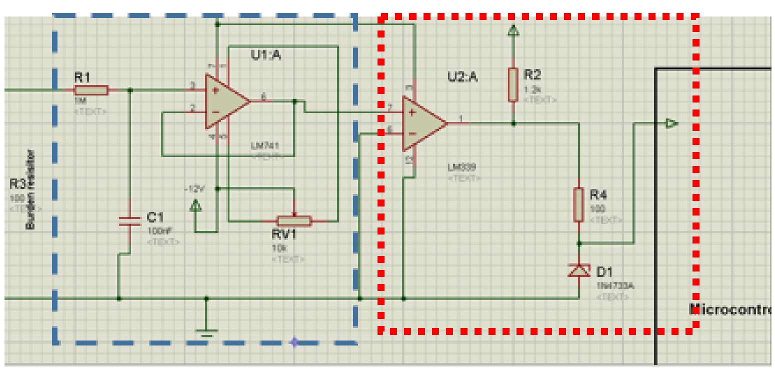

Figure 4: Power Factor Measurement Circuit

functions. There are different mathematical operations to be evaluated as summarized in Table 1 and these are basically done for power, energy and losses parameters that are not fundamental quantities like the voltage and current magnitudes.

The mathematical operations also will be used to deal with other customer related issues such as disconnection of erring customers (that is, electricity payment defaulters particularly for commercial, industrial or institutional consumers), and other interval or programmed functions like load shedding and bill generations. A computation bus with high accuracy and speed is therefore required since there are multiple task and functions involved and all at the same time too.

Table 1: Mathematical computation needed for non-fundamental units

S/N	NON FUNDAMENTAL UNITS	COMPUTATION REQUIRED
1	Peak Voltage	Comparison
2	Peak Current	Comparison
3	Real Power	Multiplication
4	Energy Used	Multiplication
5	Losses	Subtraction
6	Percentage Losses	Multiplication and Division

Also from Figure 1 is the zero crossing block which is the power factor measurement block. Since the measured Voltage and Current are sine waves, these quantities were first converted to square waves of the same frequency and period and this was achieved by the zero crossing detector. Therefore, this zero crossing detector (voltage comparator) is used to detect the sine waveform transition from positive and negative that coincides when the input crosses the zero voltage condition. This comparator compares the input signal with the reference voltage and since either of the voltage or current wave will cross first, therefore an interrupt will be triggered for counting before the other waveform crosses.

For data processing, logging and dash board, the use of a virtual control room was implemented through the internet of feeders. Here, all the operating conditions data as sensed by the measurement unit and calculated by the computation buses were logged in the cloud and accessed from anywhere and from there, further computations can be done such as reliability assessment of the system states.

The circuits for the energizing system, AV measurement and power factor measurement are shown in Figures 2, 3 and 4 respectively. The energizing circuit is a -12V 5V +12V power circuit. From Figure 3, the variable resistor RV2 set the voltage level using voltage divider rule to take a portion of the input voltage that is safe for the microcontroller. C4 is a filter (DC blocking capacitor). R1, R2 with D1, D2 are network called diode chopper which prevents the input voltage from going above or below acceptable level. In like manner, in Figure 4 the blue box is an active filter designed around LM 741. The red box is the actual zero crossing detector. LM 339 is a comparator that compares the non-inverting input (+) with inverting (-). The inverting input is connected to the ground (0V) and whenever the signal is crossing zero volt, the output of the comparator changes.

IV. CONCLUSION

Based on the results from the summary of outages as attached in the Appendix, the efficiency and reliability of the distribution system would improve significantly if a monitoring and control system is incorporated with energy conservation in mind. Therefore with the load shifting approach, the overall impact of the system on consumers can then be investigated in future researches and presented in publications to come. This model therefore can be adapted by individuals and distribution utilities for a better network reliability and efficiency.

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APPENDIX I: Average Events Monthly Summary

S/N	Feeder Name	Origin of Outage	Frequency of Interruption	Outage Duration (Hours)	No of Customers Affected	Customer-Hours Interruption (CHI) (Hours)
1	JERICHO 15MVA T-2A	IBEDC	1	3.52	7882	27718.37
		TCN	7	16.35	5268	86138.63
2	JERICHO 15MVA T-2B	IBEDC	1	3.52	1948	6850.47
		TCN	7	16.55	1344	22243.23
3	AGODI 1 33KV	IBEDC	13	41.87	203	8490.65
		TCN	7	28.40	1743	49490.67
4	AGODI 2 33KV	IBEDC	23	43.02	2036	87568.97
		TCN	16	69.80	1555	108540.37
5	IYAGANKU 33KV	IBEDC	20	4.90	1	4.90
		TCN	3	54.98	9	486.07
6	SAMONDA 33KV	IBEDC	40	22.13	1	25.13
		TCN	2	108.42	1	125.57
7	ELEYELE 33KV	IBEDC	19	15.32	30	452.12
		TCN	14	21.65	23	504.18
8	INTERCHANGE 33KV	IBEDC	33	26.63	408	10856.80
		TCN	29	64.77	386	25010.00
9	EXPRESS 33KV	IBEDC	48	16.95	1	16.08
		TCN	20	60.23	1	47.92
10	LIBERTY 33KV	IBEDC	20	37.43	8	313.87
		TCN	15	43.07	9	374.73
11	OLUYOLE 33KV	IBEDC	23	13.48	11	143.27
		TCN	17	41.98	11	462.47
12	ERUWA/LANLATE 33KV FDR	IBEDC	66	76.95	3635	279677.57
		TCN	36	25.50	3808	97097.47
13	APATA 33KV FDR.	IBEDC	35	4.02	117	469.95
		TCN	4	22.43	109	2441.40

APPENDIX II: ***Summary of Outages/Energy Loss in Ibadan Region (AVERAGE ANALYSIS PER MONTH)***

S/N	FEEDER	DURATION (Hrs)	FREQUENCY OF INTERRUPTION	AVERAGE POWER Loss (MW)	WAT (₦)	ENERGY LOSS (kWh)
1	AGODI 1	28.40	13	0.0	30.0	0.00
2	AGODI 2	69.80	23	0.0	30.0	0.00
3	APATA	22.43	35	10.0	30.0	224,333.33
4	ELEYELE	21.65	19	0.0	30.0	0.00
5	ERUWA	25.50	36	16.0	30.0	408,000.00
6	EXPRESS	60.23	48	13.0	30.0	783,033.33
7	INTERCHANGE	64.77	29	16.0	30.0	1,036,266.67
8	IYAGANKU	54.98	20	0.0	30.0	0.00
9	LIBERTY	43.07	20	7.0	30.0	301,466.67
10	OLUYOLE	41.98	23	17.0	30.0	713,716.67
11	JERICHO T2A	16.35	7	0.0	30.0	0.00
12	JERICHO T2B	16.55	7	0.0	30.0	0.00
13	SAMONDA	108.42	40	0.0	30.0	0.00
	TOTAL	574.13	320			3,466,816.67