Automated Distribution Network for Efficient Energy Management (A Study of New Owerri Business District)

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Abstract- Generally, the main objective of the electricity industry is to provide electricity to its customers constantly, efficiently and ensuring appropriate revenue collection. The electricity supply in New Owerri Business District is characterized by less than eight hours availability of supply to 11kv customers, poor supply situation, is the negative impact of over-billing leading to highly inefficient energy usage by customers. The ISO 50001 standard enables organizations to establish systems and processes that will improve energy performance, including efficiency, use and consumption. This is the standard adopted in this research. Distribution Network Automation intermsofdistributionnetworkreconfiguration(DNR), andsectionalisingswitch placement (SSP)are recognised as the most effective way for distribution network operators (DNOs) to increase operation efficiency and reliability. Automated tie-switches and sectionalising switches playa fundamental role in distribution networks which addresses load-shedding with dynamic pricing, resulted in a near equilibrium of demand and supply; eliminated load-shedding of 33kv and 11kv feeders; encouraged deployment of more renewable energy sources; reduced Co_2 emissions from electricity generation; creation of direct and indirect jobs; hence improving the economy.

Indexed Terms- Distribution Network Automation, reconfiguration, feeder.

I. INTRODUCTION

It is important to start implementing smart grid technologies from areas of low interruption factor, while tending to a gradual overhaul. Implementing Automation of Distribution Network as proposed in this work is a feasible and sustainable solution to mitigate the present incessant system collapse within the grid system. The ISO 50001 standard enables organizations to establish systems and processes that will improve energy performance, including efficiency.

This project was embarked upon because of the poor state of electricity supply being experienced in New Owerri Business District. The electricity supply is characterized by less than eight hours availability of supply to 11kV customers, poor supply quality, and a distribution network that lack resilience.

It is known that electricity "utility" distribution network is part of a power system that carries electricity from a high voltage transmission grid to industrial, commercial, and residential customers (Faulken berry L. M., 1996). The electric power generation, transmission and distribution companies are not only energy producers, but also significant power consumers. Power loss occurs when electricity is supplied to customers.

Electric power distribution system is an important part of electrical power systems that determines supply reliability or proper delivery of electricity to consumers.

Generally speaking, customer expectations on supply reliability are steadily increasing (Oliver Schroedel et al, 2011). The owners of distribution network are being required to improve the reliability of power delivery through making the whole operating condition more efficient. In some cases, explicit power quality criteria are even included in negotiated contracts between customers and utilities (Oliver Schroedel et al, 2011). Moreover, in liberalized markets, regulators typically require the utilities to

report on the reliability performance or even penalize them in case of violations in several countries.

Distribution Automation (DA) is the remote control of switches to locate, isolate faults and restore the service, when a fault occurs in the power distribution line. It also results into a highly reliable, self-healing power system that responds rapidly to real-time events with appropriate actions (Palak Parikh, 2011). This concept combines the ability to mix local automation, remote control of switching devices, and central decision making into a cohesive, flexible, and cost-effective operating architecture for power distribution systems (James Northcote-Green Robert Wilson, 2007).

Automation in the distribution field allows utilities to implement flexible control of distribution systems, which can be used to enhance efficiency, reliability and quality of electric service (Palak Parikh, 2011). From the analysis of Recloses and Sectionalizers, it is found that there is a significant improvement in the reliability of a distribution feeder and as a result, coordinated system of these devices can significantly improve the reliability indices SAIDI and SAIFI increasing (Oliver Schroedel et al, 2011).

The successful implementation of DA system results mainly in Operational & Maintenance benefits, financial benefits, and customer related benefits. These benefits are related to the improved reliability, reduced operation and maintenance expenses, reduced fault location time, increased revenue due to quick restoration, reduction in staffing, enhanced system efficiencies and consumer satisfaction.

The above cited researches clearly reveal the importance of the technology in addressing mainly, reliability and efficiency issues for the specified distribution networks, but before deciding to go ahead with the technology, the potential drawbacks, interruption causes, power outage levels and shortcomings of the old system should be studied in detail. Then, it should be verified that these identified problems could be mitigated by deploying DA for that specific utility company or distribution network. The aim of this research is, therefore, to develop an appropriate distribution automation model that can

potentially mitigate the power outages occurring on the existing Enugu Electricity Distribution system.

II. METHODOLOGY

In this research, Automation of Distribution Network involves automation and energy efficiency. A structured and persistent approach is applied to achieve success this Automation of Distribution Network.

- Present State of New Owerri Business District Distribution Network

Power distribution network in Enugu Electricity Distribution is effected at a primary voltage of 33 and 11kV consisting entirely of 3-phases, 3-wire feeders and is stepped down to a utilization voltage of 240V (3-phase, 4 wire). The distribution system in Enugu Electricity Distribution consists of 32,373.39 km of 33kV and 11kV; 95,000km of 220V lines and 6,339 distribution transformers (Palak Parikh, 2011). Even though, there are many efforts and launched projects to modernize Enugu Electricity Distribution's underground electric cable installation, the medium voltage (MV) and Low Voltage (LV) networks are still dominated by overhead lines.

In the radial distribution network structure of Enugu Electricity Distribution, there are manually controlled three phase switches (MCOS) or section switches located on the beginning of each branch circuit that can interrupt the supply for planned outages like maintenance or unplanned outages of various disturbances. But, the network is not suited with additional equipment such as remote controlled switches, automatic reclosers, sectionalizes, remotely controlled fault passage indicators, etc. which would contribute a lot in improving the overall reliability. In a radial distribution system, only one path is connected between each customer and the substations. i.e. The electrical power flows from the substation to the customer along a single path which if interrupted results in complete loss of power to the customer. Such system has only one power source for a group of customers and is usually suitable for sparsely populated areas. For a city like New Owerri, with a population density of $5,165.1/km^2$ and with a huge power demand such kind of network configuration is unsuccessful and that was exactly

what has been witnessed for the past years. On top of this, the whole system can only be operated manually which makes it difficult to monitor the system state as well as to take any action.

Knowing this Enugu Electricity Distribution Company, EEDC (formerly known as Power Holding Company of Nigeria, PHCN) planned to modify the system to a ring system by installing several switching stations in between various substations (Enugu Electricity Distribution Company, Data Source: Strategic Management and Programming Office). However, only few of the total number of feeders per substation, which are believed to encounter many faults, have been made to interconnect to other substations.

In the existing distribution system, pinpointing the exact or even approximate location of faults is difficult, even though fault passage indicators are installed in various switching stations. Dispatchers still depend on telephone calls from customers and substation Operators. Customers' calls only provide an approximate location of the outage. Once the approximate location of outages is known, line crews are dispatched to drive along the lines to look for damage. After the damaged area is located, it has to be isolated from the rest of the system if the fuse protecting that line has not operated. This is done by first opening the substation breaker and then manually operating the switches or removing the fuses. Coordination between the line crews and dispatchers is maintained via portable radio to perform this task properly or via mobile telephone. The next step is to restore power to those parts of the system which are undamaged but have lost power because of problems elsewhere in the system. The power to these parts may be provided from alternates routes. The dispatchers determine such possible routes and ask the line crew to operate the isolators. Most of the isolators cannot be operated under load; therefore, the substation breaker is opened before operating the isolators. Since the whole process is done manually, it takes a long time. This is depicted in figs. 1 and 2. Automation of this function requires installation of devices such as reclosers, remotely controlled Sectionalizers and installation of sensors on the feeders and/or at customer locations to detect interruption of service.
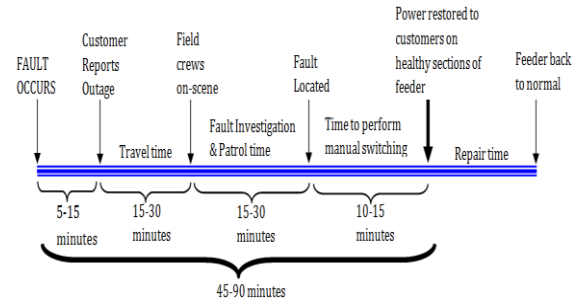

Fig. 1: Activity-time diagram for a permanent feeder fault without automation
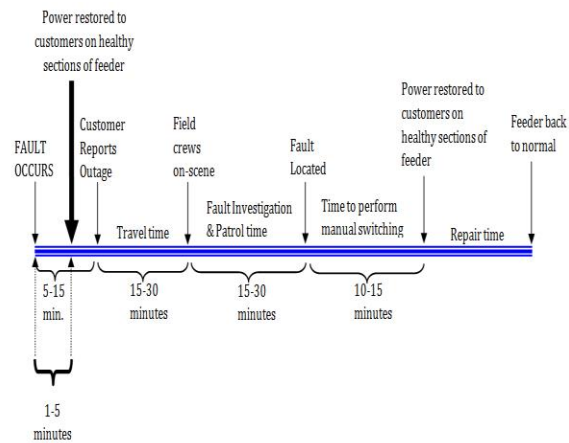

Fig. 2: Activity-time diagram for a permanent feeder fault with proposed automation model

• Reclosers

A recloser is a device with the ability to detect phase and phase-to-ground overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time, and then to automatically reclose to reenergize the line. If the fault that originated the operation still exists, then the recloser will stay open after a preset number of operations, thus isolating the faulted section from the rest of the system. Thus, the recloser, with its opening/closing characteristic, prevents a distribution circuit being left out of service for temporary faults.

Reclosers are used at the following points on a distribution network:

• In substations, to provide primary protection for a circuit,
• In main feeder circuits, in order to permit the sectioning of long lines and thus prevent the loss of a complete circuit due to a fault towards the end of the circuit,

- In branches, to prevent the tripping of the main circuit due to faults on the spurs.

- Sectionalizers

A sectionalizer is a device that automatically isolates faulted sections of a distribution circuit once an upstream breaker or recloser has interrupted the fault current and is usually installed downstream of a recloser. Since sectionalizers have no capacity to break fault current, they must be used with a back-up device that has fault current breaking capacity. Sectionalizers count the number of operations of the recloser during fault conditions. After a preselected number of recloser openings, and while the recloser is open, the sectionalizer opens and isolates the faulty section of the line.

Therefore, the switching needed to restore power to unfaulted parts of the system can be accomplished remotely. Moreover, since the location of the outage is known, the crew is sent to the precise location instead of asking to go in a general area. Thus, the whole process of outage location and service restoration can be accomplished more efficiently by less people in much less time.

- Power interruptions in the Existing Enugu Electricity Distribution System in New Owerri

The frequency and duration of interruptions occurring on the different feeders of Enugu Electricity Distribution system are given in Table 1 and plotted in figs. 3 and fig. 4, respectively. The system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI) are calculated as discussed below and are listed in Table 3.

a) System Average Interruption Duration Index (SAIDI)

This index measures the total duration of an interruption for the average customer during a given time period. To calculate SAIDI, each interruption during the time period is multiplied by the duration of the interruption to find the customer-hrs/mins of interruption. The customer-hrs/mins of all interruptions are then summed to determine the total customer- hrs/mins. To find the SAIDI value, the customer-hrs are divided by the total customers served.

The formula is,

$$\text{SAIDI} = \frac{\sum(r_i * N_i)}{N_T} \qquad (1)$$

Where,

r_i= Restoration time (hrs./mins.)
N_i = Total number of customers interrupted
N_T= Total number of customers served

- System Average Interruption Frequency Index (SAIFI)

The System Average Interruption Frequency Index (SAIFI) is the average number of times that a system customer experiences an outage during the year or time under study. The SAIFI is found by dividing the total number of customers interrupted by the total number of customers served.

SAIFI is found as:

$$\text{SAIFI} = \frac{\sum(N_i)}{N_T} \qquad (2)$$

Where,

N_i = Total number of customers interrupted
N_T = Total number of customers served

From table 1, it can be seen that the annual SAIDI is about 209 Hrs., which means that on the average each customer in New Owerri Enugu Electricity Distribution Network was without power supply for 209 Hrs. due to interruptions on MV- feeders during that year. It can also be seen that the annual SAIFI is about 184, indicating power for each customer in Enugu Electricity Distribution has been interrupted on the average 184 times in a year. According to the reliability standard set by EEDC, these reliability indices clearly illustrate that the reliability of the power network is very poor.

- Causes of Interruptions

The faults in the electricity network may have various forms as illustrated in table 2. These faults could be mainly of two types, namely, transient (temporary) and permanent faults. Usually, transient faults occur when phase conductors electrically contact other phase conductors or ground momentarily due to trees, birds or other animals, high winds, lightning, flashovers, and so on. Transient faults are cleared by a service interruption of sufficient length of time to extinguish the power arc or electric discharge. Here, the fault duration is minimized and unnecessary fuse blowing is

prevented by using instantaneous or high-speed tripping and automatic reclosing of a relay-controlled power circuit breaker or the automatic tripping and reclosing of a circuit recloser (TuranGonen, 2014).

The breaker speed, relay settings and recloser characteristics are selected in a manner to interrupt the fault current before a series fuse is blown, which would cause the transient fault to become permanent. Permanent faults are those which require repairs by repair crew in terms of (TuranGonen, 2014):

- Replacing burned-down conductors, blown fuses, or any other damaged apparatus
- Removing tree limbs from the line
- Manually reclosing a circuit breaker or recloser to restore service

From Fig. 5 pie chart plot, it can be seen that, 55% of the total number of power interruptions are due to distribution related problems such as Distribution Permanent Earth Fault (DPEF), Distribution Permanent Short Circuit (DPSC), Distribution Transient Earth Fault (DTEF), Distribution Transient Short Circuit (DTSC), Distribution Line Over Load (DLOL) and the rest 45% are due to others like generation, transmission problems and operational or intentional isolation.

Fig. 6 pie chart plot shows the duration of interruption in Enugu Electricity Distribution based on specific fault type. Similarly, it can be seen that 45.92% of the total duration of interruptions are due to distribution related problems and the rest 54.08% are due to others as mentioned above. The above percentage figures clearly demonstrate that distribution related problems account significant share for the cause of the interruptions which can be improved by employing appropriate mitigating technology.
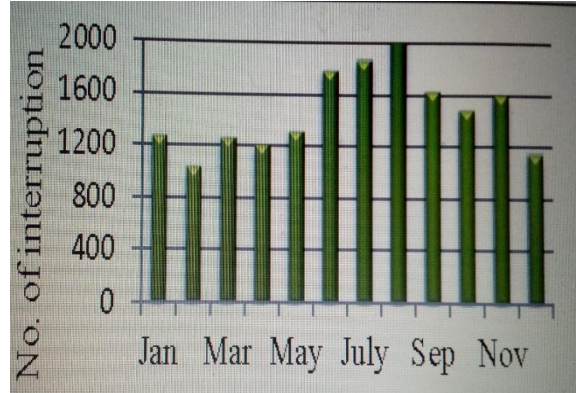

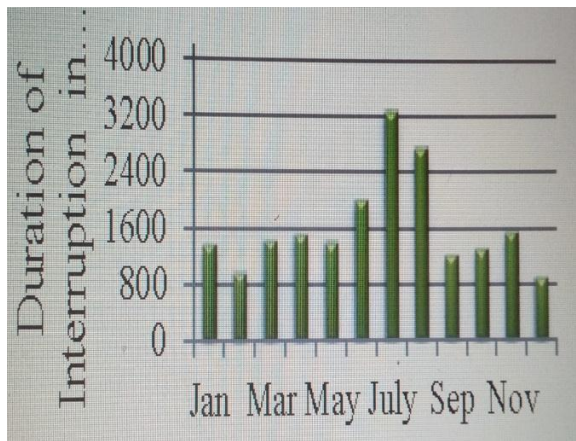Fig. 3: Frequency of interruption in New Owerri at feeder level (11kV) the year 2020, (Source: EEDC)

Fig. 4: Duration of interruption in New Owerriat feeder level(11kV) the year 2020, (Source: EEDC)

- Overview of Proposed Automated Feeder System

Fig. 7 demonstrates the proposed model for the automated feeder system to detect feeder faults, determine the fault location, isolate the faulted section of the feeder and finally restore service to healthy portions of the feeder. The local scheme involves detection, location of the fault and isolation of the affected area through various field components. Whereas, the centralized scheme which involves the central station is needed to monitor and restore the service of the feeder system.

The main components to be needed for the feeder automation are protection relay (R), automatic reclose (RC), sectionalized (S) and tie switches (Tie) or load break switch. The number of sectionalizes considered in this model are four, but it may vary depending on the total length of the feeder and loading level in each section.
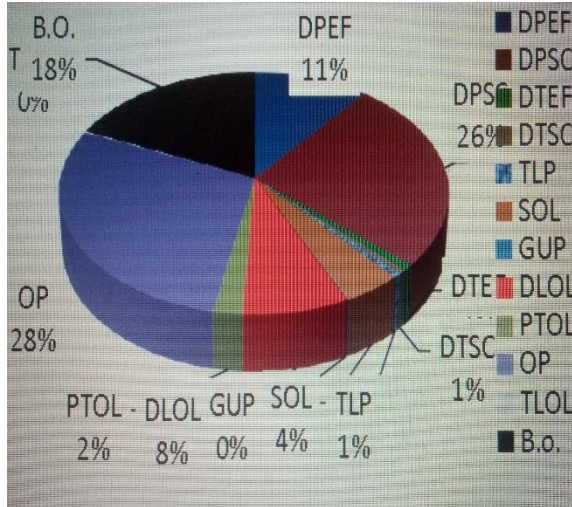
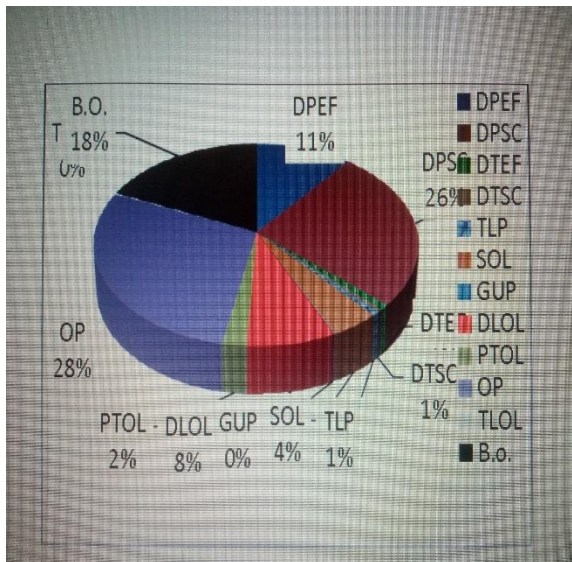Fig. 5: Average percentage of Frequency of
interruption

Fig. 6:   Average percentage of Duration of
interruption for feeders in Enugu Electricity
Distribution based on fault type.

In the model, three medium voltage lines or outgoing
feeders from the same substation or neighboring
substations are considered for interconnection, so
that, it is possible to restore the service to the healthy
sections of the contingent feeder from either of the
remaining two routes by taking their loading into
consideration. i.e. The operator checks which feeder
is strong enough to carry the additional load and
closes the respective tie switch to restore the service
to the healthy section of the contingent feeder. When
a transient fault occurs at any of the sections,

theassigned/responsible recloser will try to reclose
the circuit automatically and restores the feeder to its
normal condition. If a permanent fault occurs in
either of the sections, the recloser will lock out after
its third trial and the fault detectors which employ
fault location algorithm by taking the network
structure information and obtained measurements of
fault currents and voltages as input located at each of
the sectionalizers will detect the fault, report and give
flash. Then, the nearby sectionalizers surrounding the
fault will automatically open which makes the faulted
section to be isolated. After that, the operator closes
the circuit breaker and simultaneously checks
whether the alternate feeder can carry the additional
load (downstream to the isolated section) of the
faulty feeder. Finally, the operator will remotely
close the respective tie switch which will supply the
disconnected load until the permanent fault is
cleared. All of the above activities including the
coordination of the protective and isolation devices
are discussed in detail above.

III.   RESULTS AND DISCUSSION

The protection scheme of a 11kV distribution feeder
feeding loads at different sections is done with
Tavrida Electric Automated Relay Manager
(TELARM) software tool as shown in fig. 8. Only
four sections are considered for the ease of
demonstration and the same principle can be applied
to any number of sections whenever needed. It is
assumed that the recloser will lockout after 4 number
of trips with reclosing times 1, 5, 10 and 60 sec. for
first, second, third and reset reclosingsrespectively . S
ectionalizers S 1 , S2 and S 3 are set at 3, 2 and 1 shot
respectively. If the autorecloser trips the fourth time
(after the third reclosing shot), the fault is regarded as
permanent. Hence, further autorecloser operation is
locked out. During the process of auto reclosing,
various sections would be removed out of the line
with the help of sectionalizers to power the healthy
portion of the feeder. If the fault is permanent in
nature, then the automation control unit can intervene
to restore the service to healthy sections from other
alternative feeders by sending remote switching
commands to sectionalizers. The cycle of switching
of the different reclosers and sectionalizersis
described during this time as follows. Fig. 9 presents
the state of the reclosers and sectionalizers under

permanent fault at section 3 (between S2 and S3) by using different colors where green represents closed state, violet represents open state, yellow represents reclose time, blue represents tripping time and red represents open and lockout state. Primarily, R performs the first reclosing cycle and trips again as presented above. Then, R times out for 5 seconds and S3 trips and locks out. Then, R closes for a second time. S2 and S1 sense the control voltage and close the first time. A fault current passes through R and R trips for the third time and times out for 10 seconds.

Table 1: Frequency and duration of interruption in New Owerriat all feeders, (Source: EEDC)

No.	Period	Frequency of	Duration of	SAIDI Values	SAIFI Values
1.	Jan, 2020	1,265	1,348.58	13.50	12.39
2.	Feb, 2020	1,029	953.88	9.35	10.64
3.	Mar, 2020	1,260	1,413.15	14.26	12.42
4.	Apr, 2020	1,210	1,507.03	19.22	12.10
5.	May, 2020	1,308	1,402.55	14.12	14.94
6.	June, 2020	1,781	2,001.22	22.96	18.02
7.	July, 2020	1,864	3,280.00	34.50	19.06
8.	Aug, 2020	2,363	2,742.00	28.49	22.36
9.	Sep, 2020	1,628	1,208.00	11.89	17.96
10.	Oct, 2020	1,483	1,290.00	11.95	15.32
11.	Nov, 2020	1,596	1,527.00	19.87	17.15
12.	Dec, 2020	1,145	872.00	8.85	11.31
	Total (year 2020)	17,932	19,545.61	209	184

At this point, the control voltage is lost and S2 trips the second time and locks out. Finally, R closes for the third time and the fault on section 03 is isolated. The Operator in control unit will try to remotely close S2 and S3 after clearance of the permanent fault.

Similarly, all transient and permanent faults are created at various sections of the feeder for demonstrating the responses of the various switching and protection devices installed throughout the feeder.

Table 2: Acronyms and Description of Faults System

Fault Acronym	Fault Type
DPEF	Distribution Permanent Earth Fault
DPSC	Distribution Permanent Short Circuit
DTEF	Distribution Transient Earth Circuit
DTSC	Distribution Transient Short Circuit
TLP	Transmission Line Problem
SOL	System Over Load
GUP	Generation Unit Problem
DLOL	Distribution Line Over Load
PTOL	Power Transformer Over Load
OP	Operational (Intentional)
TLOL	Transmission Line Over Load
B.O.	Blackout

Table 3: Comparison of reliability indices of the existing feeder and the proposed automated

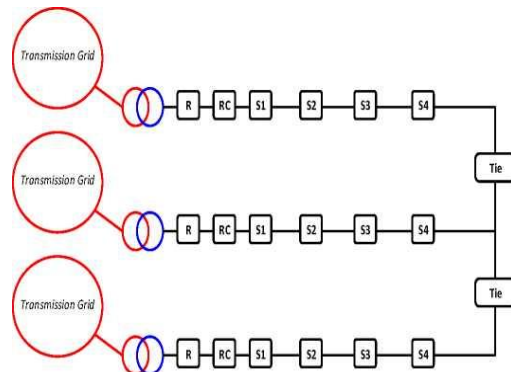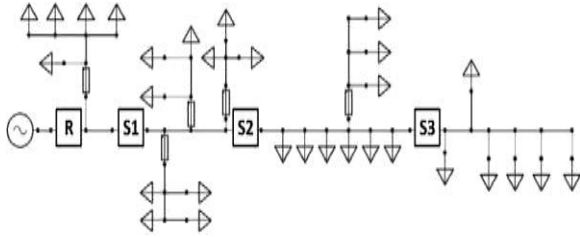| No.	Reliability Index	Average standard reliability indices of the existing feeder system	Average standard reliability indices of the proposed model
1.	Annual SAIDI (hrs.)	21.67	5.611
2.	Annual SAIFI (no.)	30.22	3.117

Fig. 7: Model of proposed Automated Feeder

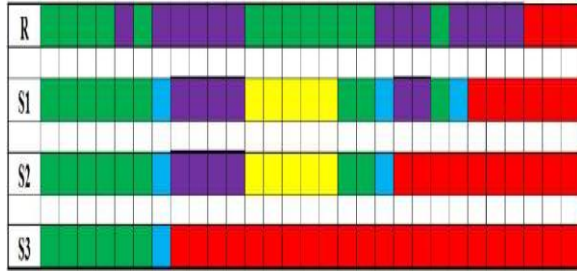Fig. 8: Single line diagram of a Feeder Obtained using TELARM

Fig. 9: Simulation result: State of Recloser and Sectionalizers under permanent fault at section 3 (Green indicates closed position, violet indicates open position, blue indicates tripping time, yellow indicates reclose time and red indicates open & lockout)

CONCLUSION

The reliability analysis of the existing Enugu Electricity Distribution distribution system reveals that around 55% of the total number of power interruptions are due to distribution system related problems and the rest 45% are due to others like generation, transmission problems and operational interruptions. Similarly, around 46% of the total duration of interruptions are caused by distribution system related problems and the rest 54% are due to the others.

Thus, it is observed that majority of the power interruption problems are related to the existing distribution system network. The effectiveness and potential benefits of implementing distribution system automation, specifically feeder automation to the distribution network of New Owerri, is investigated through simulation studies of the existing distribution system with proposed automation. The simulation results presented in Table 3 reveal that with the proposed distribution system automation, the system average duration index

SAIDI) is improved by more than 69% and the system average frequency index (SAIFI) is improved by more than 88% as compared to those of the existing distribution system. These results clearly demonstrate that the system automation is capable of potentially mitigating the frequent interruptions and outage problems occurring in the existing New Owerri Distribution system.

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