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CORRESPONDENCE and COMMUNICATION:

Istanbul Gelisim University Faculty of Engineering and Architecture
Cihangir Mah. Şehit P. Onb. Murat Şengöz Sk. No: 8
34315 Avcilar / Istanbul / TURKEY
Phone: +90 212 4227000
Fax: +90 212 4227401
e-Mail: ijet@gelisim.edu.tr
Web site: http://ijet.gelisim.edu.tr
https://dergipark.org.tr/en/pub/ijet
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On behalf of the editorial board of International Journal of Engineering Technologies (IJET), I would like to share our happiness to publish the 28th issue of IJET. My special thanks are for members of Editorial Board, Publication Board, Editorial Team, Referees, Authors and other technical staff.

Please find the 28th issue of International Journal of Engineering Technologies at http://ijet.gelisim.edu.tr or https://dergipark.org.tr/en/pub/ijet. We invite you to review the Table of Contents by visiting our web site and review articles and items of interest. IJET will continue to publish high level scientific research papers in the field of Engineering Technologies as an international peer-reviewed scientific and academic journal of Istanbul Gelisim University.

Thanks for your continuing interest in our work,

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Istanbul Gelisim University
hhselim@gelisim.edu.tr

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Failure's Severity Affecting Railway Operation Based on Sensitivity Analysis: A Case Study of Addis Ababa Light Rail Transit (AALRT)

Ruhama Minwuyelet*, Daniel Tilahun*

*African Railway Centre of Excellence (ruhamaminwuyelet@gmail.com)
**Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa, Ethiopia

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Abstract

Operation delays and trip cancelations affect the reliability of the operation and customer's satisfaction. This review work adopts a case study of AALRTS operation system employing operation data and incident records of AALRTS. The purpose of this paper is assessing the failures frequency and the time it takes to get back to its operation aiming that how sensitive it is for the reliability of the operation. An extensive literature review has been used to approach the problem in which the sensitive failure`s analysis methods have been identified. The method that has been used to investigate the failure`s magnitude was sensitivity failure analysis by considering the case study of AALRTS. The method has been implemented to identify different failure modes through the analysis of the case how sensitive the failures are to the normal operation. The results that have been discovered from the analysis are: - the safety incidents and equipment failures are the major groups that affect the normal operation of AALRTS. When we go to the depth level-crossing incidents and power outages are the major sensitive failures (from safety incidents and equipment failures) that can reduce the reliability of the operation dramatically. Finally the researcher would like to recommend that giving a due attention for those sensitive failures might improve the reliability of the railway operation.

Keywords: Train delay incidents, operation reliability, failure`s severity, failure modes and sensitivity analysis.

1 Introduction

A railway transportation system is the finest transportation mode comparing to other transportation modes, when it is reliable. A bit failure in railway system may result a huge damage on the infrastructure or the rolling stock. It can also cause casualties. There is no transportation mode which is out of failure, but by improving the quality of the transportation system, we can improve the safety of our passengers and make reliable our transportation system. Railway transportation needs a huge investment for construction whereas the life cycle of the system will depend on the Reliability, availability, maintainability and safety (RAMS) of the system. Railway system is composed out of the infrastructure and the rolling stock (train).

Failure consequences of the railway system are:-

- causalities and operational shut-down
- Derailment
- Financial losses and
- Lots of maintenance works

Failures on railway system, that can affect the normal operation, can be triggered by three different causes, i.e.:-

- Safety incidents
- security incidents and
- Equipment failures

Safety incidents: - Safety incidents consist of significant accidents like: - People seriously injured and killed, Suicides and attempted suicides, Overall workforce safety, Workforce safety on track or trackside.

Security incidents: - security incidents can be caused by: - thefts, bombing and any actions performed and that can affect the security of passengers and the infrastructure as well.

Equipment failures: - Equipment failures entail: - Signaling failures, Telecommunication failures, Power supply failures, track Failures, structure failures, rolling stock failures and other failures. Some commonly observed equipment failures can be caused by: - ageing, wear on the rail, damages of equipment's and insufficient maintenance works.

Since the AALRTS operation has been started recently, the truck structures aren`t exposed to ageing whereas the other causes might be the real causes of equipment failures.

There are various methods that can used to predict failures in railway operation system; it is believed every method has its own purpose and drawback. This paper presents a new way of failure analysis technique based on the failure`s sensitivity to predict on what percent railway operation has been affected.

A failure mode, effects and criticality analysis (FMECA) [1] is a widely used failure analysis method which has a little difference with that of FMEA (Failure Mode and Effects Analysis) method. The failure data can be gathered either from the system`s field data or by the use of statistical data. [2] Criticality of risks in railway projects can be identified based on fuzzy and sensitivity analysis methods (Jelena M. Andrić, Jiayuan Wang, and Ruoyu Zhong, Published: 1 March 2019). Studying the causes of accidents and mitigating strategy is also one way of tackling failures. [3] There are some researchers who conducted their research on causes of train delays. This issue is also the concern of this paper. The number of delayed trains and corresponding probability are evaluated by MLE estimation, Railway Disruptions and Their Impact on Delayed Traffic in Chinese High-Speed Railway has been analyzed by a regression model, the model gives a detail description how Railway Disruptions is related to the number of delayed trains it can be assessed by using statistical analysis. (Peijuan Xu, Francesco Corman, Qiyuan Peng 2016). [4] [5] Sensitivity analysis has been employed for railway projects to analyze their effect on financial reliability. [6] FMEA (Failure Mode and Effects Analysis) has been used to assess the failures on different railway infrastructure equipment's and rolling stock components. I.e. switches and turnouts, door system of rolling stock, and so on. All of The failure modes aim to reduce maintenance cost by adapting preventive maintenance and eliminating corrective maintenance. Maintenance based approaches are also the ways that reduce the frequent occurrences of failures by improving the maintenance quality. The way suggested can be improving preventive maintenance or condition based maintenance. [7] [8]

Different researches have been conducted to improve the maintenance trend in order to improve the reliability of the system. Condition based maintenance (CBM) has been applied to minimize life cycle cost of the freight car components. [9] Bayesian methods could also use as a fault diagnostic method, it is quite important since it give a clear way to identify the accident occurrence on the specified structure by combining the empirical knowledge and statistical data. [10][11] the reliability of railway system will also be improved by improving our maintenance trend. Implementing preventive maintenance will improve the safety of the equipment's and as the same time minimize exaggerated costs of maintenance. Reliability centered maintenance (RCM) has been also applied in railway networks. [12] [13] (FMECA) has an extra advantage on (FMEA) since it can assess and provide the critical failures with their causes and effects. The critical failures on turnouts can be also addressed by expert approach [14]. FMEA (Failure Mode and Effects Analysis) is one of the most commonly applicable methods in different engineering applications including railway system. It bears reliability and safety analysis. [15] - [19]

Most researchers have also used a fault tree analysis method to predict the occurrences of failures. Fault tree analysis method can be a timed fault tree analysis (Zhaoguang Peng, Yu Lu, Alice Miller, Chris Johnson and Tingdi Zhao, 2014) or event tree analysis. A timed fault tree analysis method can define which faults need to be eliminated instantly, and it can also predict how much time has been left at least to eliminate the root failure in order to prevent accidents. [20-23]

"Probabilistic defect based risk assessment approach" for railway failure analysis uses defects as a cause. [24] Sensitivity analysis has been also applied to analyze effects of critical speed in railway vehicle dynamics. We can observe that the other researchers have used Sensitivity analysis method for the purpose of assessing financial reliability on railway projects, effects of critical speed in railway vehicle dynamics. But the researcher of this paper on the other way has used Sensitivity analysis method to identify how failures are sensitive concerning railway operation. Train delay incidents have a major effect on the reliability of the operation system, so that it has been analyzed on its effect on transit service reliability and on customer satisfaction by Barron, A., P.C. Melo, J.M.Cohen, and R.J. Anderson. (Barron, A., P.C. Melo, J.M.Cohen, and R.J. Anderson 2012) Rail accident investigation for railway safety improvement and risk management of railway infrastructure; have got a wide coverage in the research areas of railway technology. [25-30]

Failure analysis models and methods have been developed chronologically. Recent publications deeply analyze the methods by gathering different failure modes and studying their effects. Some researchers have used this Failure Mode and Effects Analysis as a means of railway risk assessment and hazard identification. [30-33]

Whenever there come research results it is an intellectual attitude to investigate the reason why and how the results have been achieved.

Gaps identified are:-

There are lots of models and methods which have been used for fault analysis of railway system, but most of them aim to predict faults at component level i.e. signaling system or door system, switches and crossings and so on, but not at operational level. This research paper aims to assess the criticality of failures in the aspects of affecting railway system operation. The normal operation of railway system could be affected by different kinds of failures that result in: - train delays, canceled trips and Part (short) routes. But which failures in what percent is affecting the operation are not clearly defined yet. So that filling this gap was my intention by tackling this problem systematically and giving a clear justification on the targeted case.

2 Analysis

2.1 Preparation

Reliability, availability, maintainability and safety (RAMS) of railway operation system are highly affected by the internal and external failures of the system and the time taken to recover the failures. Common consequences of failures are: - trip cancellations, Part (short) routes, Damages, Operation Delays and so on. Sensitivity analysis has an imperative significance in an extensive range of engineering uses. The method which has been used in this paper is sensitivity analysis approach. The method helps to recognize the most sensitive failures that can affect the normal operation of railway system. The sensitivity of the failure is also dependent on the time of recovery and the frequency of occurrences. The case study has been taken for the year of 2019. The figure below tries to indicate the major Failures affecting railway operation versus their consequences.

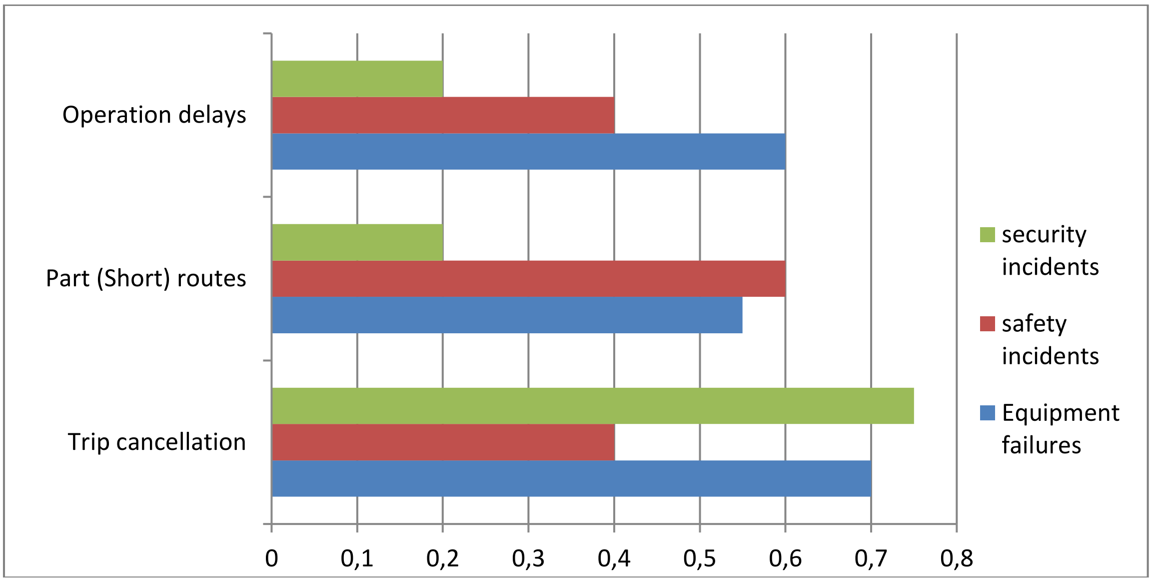

Figure 1: Major Failures affecting railway operation versus their consequence

2.1.1 Frequency Analysis of failures

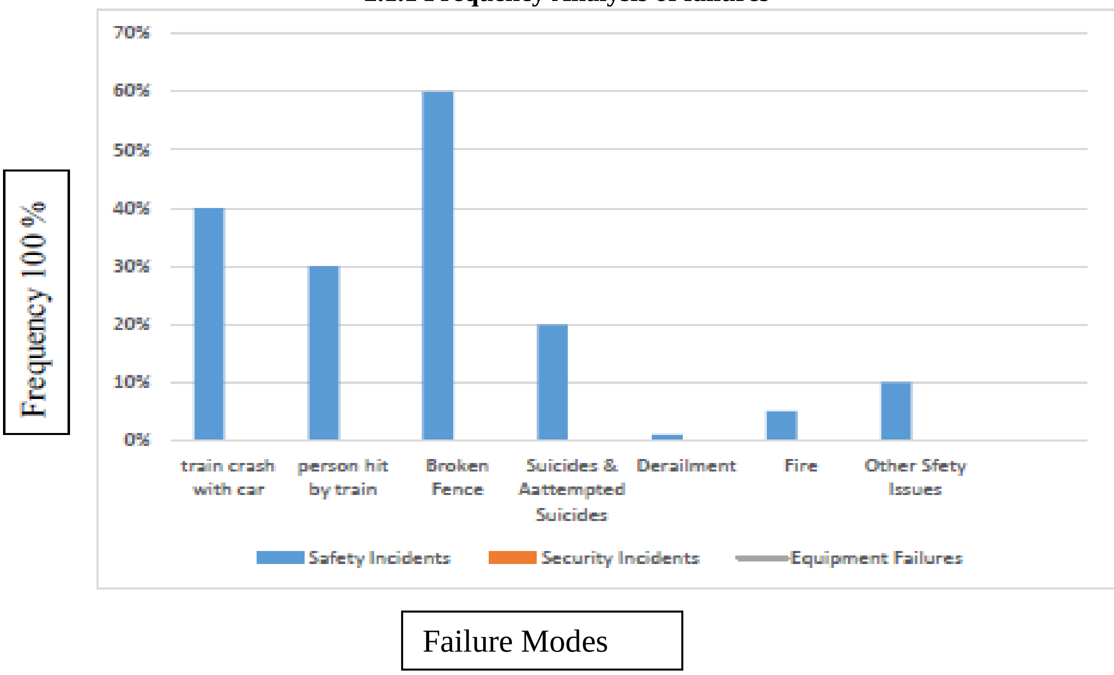

Figure 2: Frequency Analysis of Safety incidents

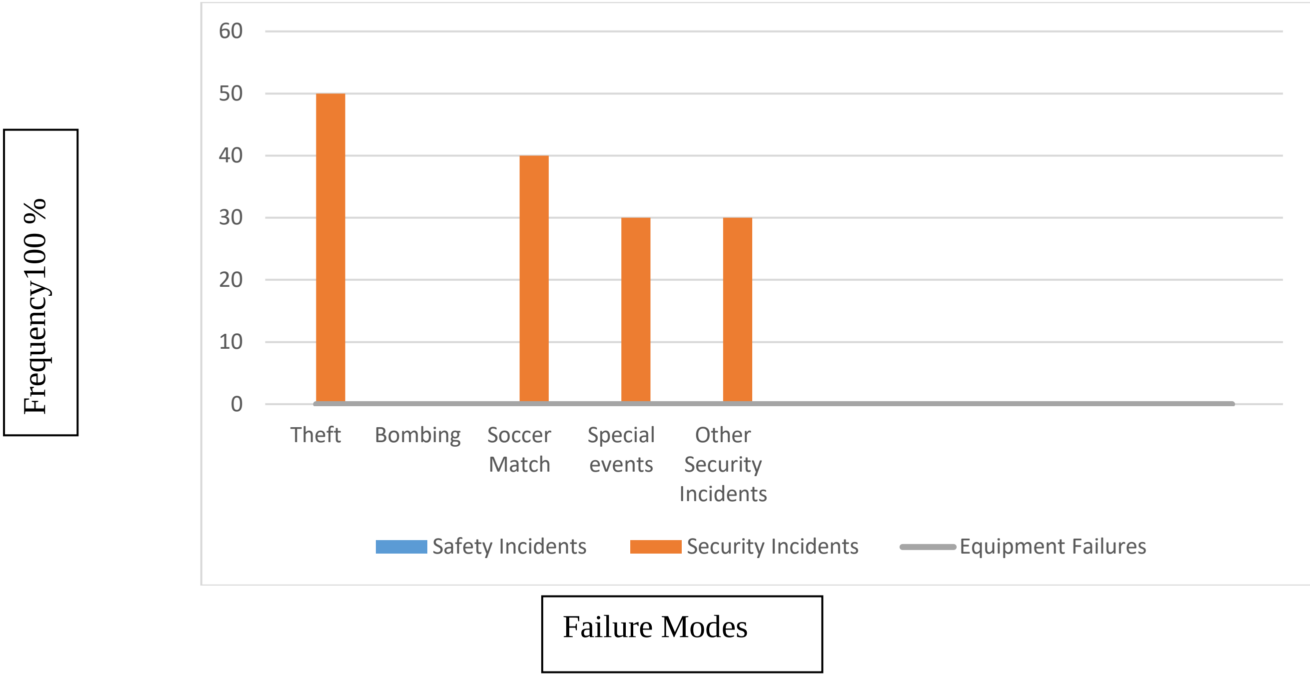

Figure 3: Frequency Analysis of Security incidents

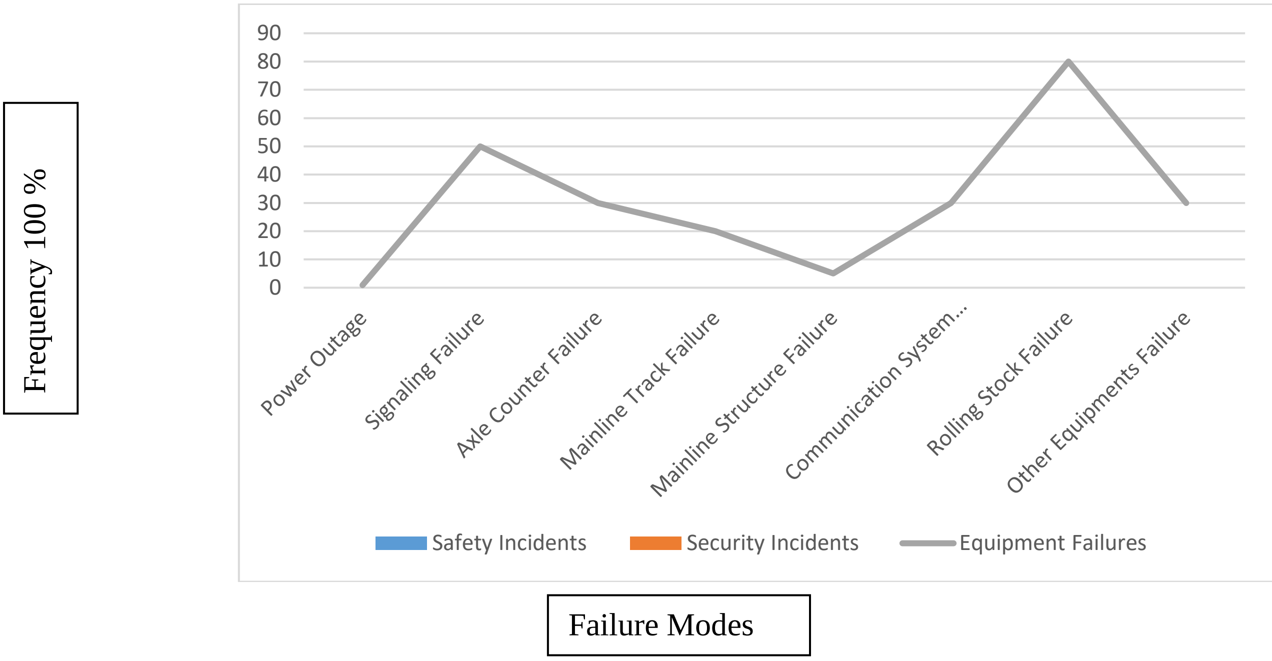

Figure 4: Frequency Analysis of Equipment Failures

Figure 5: Frequency Analysis of All Failures

2.2 Details

2.2.1 Sensitivity Analysis of failures affecting the normal operation of railway system

Table 1: Sensitivity analysis of Safety incidents on railway operation

Sensitivity Out of 100%	**Train crash with cars**	**Person hit by train**	**Broken Fence**	**Suicides and attempted suicides**	**Derailment**	**Fire**	**Other Safety issues**
train delay hours	30%	10%	30%	10%	8%	2%	10%
number of trip cancellations	10%	10%	40%	10%	0%	5%	25%
number of part routs	15%	5%	60%	3%	0%	2%	15%
Time taken for recovery	35%	35%	10%	8%	0%	2%	10%

Table 2: Sensitivity analysis of security incidents on railway operation

Percent of Sensitivity Out of 100%	**Thefts (thefts of power cables and other equipment's from the infrastructure)**	**bombing**	**Football Match**	**Other Security incidents**
train delay hours	35%	0%	35%	30%
number of trip cancellations	25%	0%	50%	25%
number of part routs	25%	0%	50%	25%
Time taken for recovery	25%	0%	50%	25%

Table 3: Sensitivity analysis of Equipment Failures on railway operation

Sensitivity Out of 100%	**Power Outage**	**Signaling Failure**	**Axel Counter Failure**	**mainline Track failure**	**mainline Structure failure**	**Communication system Failure**	**Rolling Stock Failure**	**Other Equipment failures**
train delay hours	35%	6%	6%	2%	0%	6%	30%	15%
number of trip cancellations	60%	8%	0%	4%	0%	0%	20%	8%
number of part routs	60%	10%	0%	0%	0%	0%	25%	5%
Time taken for recover	40%	10%	5%	5%	0%	10%	20%	10%

2.3 Results and Discussion

The results that have been discovered from the analysis of the data indicate the percentage of sensitivity of failures on the normal operation of AALRTS. I have tried to analyze the issue by grouping in three major categories:-safety incidents, security incidents and equipment failures. Concerning the frequency of failures, safety incidents particularly level-crossing incident is the major failure happening frequently, while within Security incidents theft is the major failure happening frequently relative to other incidents. Finally power outage among the group of equipment failures is the major failure happening frequently. But it is not wise enough to conclude that "a failure happening frequently is a failure highly affecting the operation"; because in-order to affect the operation the failure should have a direct effect in the operation.

Concerning the sensitivity analysis, power outage is the first failure that can be able to stop the operation automatically; secondly signaling failures take the second portion; then it is possible to observe Communication system Failures and rolling stock failures will take the next portion of affecting the operation. The other failures will exhibit less effect in the operation one after the other. Safety incidents depending on their severity will affect the operation accordingly. Among the Safety incidents level-crossing incidents take a wider coverage of sensitivity. The sensitivity of Security incidents is very low comparing to other groups; because they don`t have a direct relation to the normal operation.

2.4 Conclusion and Recommendation

Finally the researcher would like to conclude her argument based on the results of the analysis. Power failure is the major failure that can reduce the reliability of the operation; whereas safety incidents particularly level crossing accidents take the next coverage. Within the equipment failures signaling equipment's failures take the next level in the contribution of interruption of the operation. Rolling stock failures and other equipment failures will exhibit less effect in the operation one after the other.

Finally the researcher would like to recommend that the maintenance center should give a high attention to the identified equipment failures which are categorized according to their level of sensitivity. They can improve their trend of maintenance by increasing the level of preventive maintenance and preparing spare parts for frequently damaged spare parts i.e.:- axel counter and signaling equipment's. Some spares which are not compatible to the system might fail frequently so that preparing genuine and compatible spare parts will dramatically improve the maintenance efficiency.

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Reliability Assessment of Power System Network: A Detailed Review

Abel Ehimen Airoboman*

*Department of Electrical/Electronic Engineering, Faculty of Engineering & Technology, Nigerian Defence Academy, PMB 1209, Kaduna. (airobomanabel@nda.edu.ng)

‡ Postal address, Tel: +234 7032186403

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Abstract

Due to an increase in technological advancement and population, there is also a corresponding increase in the demand of electrical energy within Nigeria. Utility is presently characterized by suppressed demand due to the poor reliability inherent in the system. Utility, therefore, considers load shedding as a way out to ensure that the available power from each of the feeders from a network gets to its respective customers at any giving time they choose for the customer while the time the customers choose for themselves remains immaterial. However, in recent times, increased in downtime has been observed as a result of various faults and failures noticeable on the network and this has led to outrage by the customers who only considered protests as the only way out in expressing their dis-satisfaction with the system. This anomaly, therefore, arouses the interest for this study to carry out a detailed approach to carry out a review on the state of the reliability of the power system network in Nigeria and juxtaposing it with what is tenable outside the country with a view to determine the present state of the network and how it has fared with respect to time.

Keywords Network, Nigeria, Power Systems, Reliability, Utility.

1. Introduction

Electrical energy plays a vital role in the economy of any nation; hence, there is need for an increase in the quality and quantity of power supply in order to cater for the load requirement and create a competitive advantage for the nation [1,2].The Nigerian Power Sector (NPS) in the 80's was highly formidable and efficient. Then, electrical power supply was unconditionally provided meeting the numerous demands and needs of the populace. This may be attributed to the following facts: the sector as at then was still nascent, there was a low advancement in technology, moderate population growth and the mindset of the populace who as at then may see electric power as a mirage. But a lot has happened over the years: increase in population size, significant improvement in technology and the mindset of the populace who now see power supply as a necessity. These factors thereby, contributed to the unreliability in the NPS and this may be due to the fact that there was no proper planning in place or in cases where it exists, there were no data to plan with by the concerned authorities. According to [3-4], the global figure of persons without electricity is approximately 1.6 billion and with such a huge number, one may say that sector is characterized by poor reliability globally is poor. In recent times, customers and consumers took to rioting along the street expressing their disappointment and lack of credibility in the sector, the effect of this is that it places the lives of the system's operator at risk and could also lead to possible vandalization of power equipment [5]. Reliability analysis has gained attention in many areas of engineering like subsea compression system [6] and in the determination of strength of materials [7] etc. Reliability is closely associated with outages, interruptions, failure, availability etc. and reliability is also closely associated with switchgear, protection, and control. Absolute 100% reliability and availability of generating systems, transmission and distribution systems cannot be guaranteed. However, a very high level (about 99.9%) is aimed at and is being achieved in developed countries consequently, high reliability is possible when there are availability of generation, transmission and distribution systems, adequate reserve capacity (margin) between installed capacities and expected maximum load, the system is properly designed and when there is an effective operation and maintenance plan in place [8]. Reliability is the chances that an unsatisfactory event which is a function of system adequacy and system security will not occur at any giving point in time [9 – 12]. In addition, [13-14] asserts that reliability is the chances that a given item, equipment or system shall yield results that are similar irrespective of the number of outcomes of the variables involved. Furthermore, Prada [15] postulated that for a system to be reliable, it must meet its required function within a stipulated time period. Consequently, [16] asserted that for a system to be reliable, it must ensure continuity of supply under increasingly stressed condition. Also, Kueck, [17] affirmed that reliability is not all about error in design as postulated by Hakon *et al.*, [18], but sag, swells, impulses as well as harmonics can also affect the load connected to the system. Consequently, Miryousefi *et al.*, [19] defines reliability as the design of a system to conform to aappropriate standard while Billinton and Allan, [20] asserted that reliability is ensuring continuity of supply under a standard voltage and frequency. In their articles, Cadini *al.* [21] and Larsen *et al.*, [22] lamented on the need to improve on customer's expectation to meet a stable power supply, while Yaghlane and Azaiez, [23] declared that the power system network is affected by environmental and political menace; hence, system's survivability study is paramount. .Borges & Cantarino, [24] and Jayachandran [25] defined reliability as a decision making tool and a scheme for power management by managers and operators of the system respectively meanwhile IEEE defines "reliability as the ability of an item to perform a required function, under given environment and operational conditions and for a stated period of time" (ISO8402) [26]. From the foregoing, it can be concluded that there is no general definition for reliability; however, it can be seen that irrespective of any chosen definition, the term "continuity of service" appears virtually in all cases. Hence, reliability is eventually defined as the chances of a system, equipment, network etc. to ensuring that continuity of service is sacrosanct beyond a period of time.

2. Status of Electric Power in Nigeria

The Nigerian power utility company is lagging in the energy business [27]. The utility company, PHCN, as it was called before its privatization, is yet to meet the people's demand for electric energy satisfactorily. It is evident that the generated power is inadequate and so, the utility company considers load shedding and restricted demand as a way out [28]. Also, some DISCOs reject power due to payment constraints from their customer. Figures 1 and 2 are examples of dilapidated and over-loading conditions with which the network is operated. One may ask, how reliable can a system be? as well as assuming that its effect can be visible to the blind and audible to the deaf. In order to meet up with business activities that require availability of power, commercialists resort to small generating sets as shown in Figure 3 thereby solving the problem of power shortage only on a short-term basis.

Figure 1: 33kV Distribution Network [29]

Figure 2: 0.415kV Distribution Network [29]

The electricity generation in Nigeria takes place under a high proportion of in-operational generating plant capacities, overloaded and overstretched transmission lines. In addition to these problems are hydrological inadequacies in hydroelectric plants particularly during the dry season, and vandalization of electrical equipment and these have resulted in: very low voltage, power outages at alarming frequencies and illegal electricity consumption practice.

The determinant for the effectiveness and sustainable efficiency and growth for any electrical power system operated by either a public utility, a monopoly wholesaler, a monopoly supplier, an independent private supplier, or a distribution company, is its ability to operate safely, and within timelines i.e. adequacy of facilities to be essentially supported with appropriate planning, operational protection and control methods, adequate maintenance to mention but a few.

Figure 3: Commercialists Distributed Generation Scheme [30]

The utility, therefore, should meet their first requirement of a reliable service which is to provide and maintain adequate generation capacity to meet the load demand. The specific objectives of an electric power supply system (or utility) are: to generate adequate power for both the present and future need, to ensure safety and reliability in the transmission of electric power, to distribute electric power in a quality and effective manner to specific users. At the consumer end, the level of performance of the utility and/or the customer's satisfaction index is measured by the ability of the utility to provide a continuous and uninterrupted supply of electric power, provide high-quality electricity, i.e. one with good voltage regulation, cause minimum disturbance to the environment including electronic and communication interference and maintain and operate the system in the most efficient way [31].

3. Effects of series and parallel connections on system's reliability

The series arrangement of the various feeders shown in Figure 4. F_1, F_2, F_3, and F_n represents feeder1, 2, 3 and the n^{th} feeder respectively. For the chain to succeed then all the blocks in the network must succeed [32]. The reliability of the network is represented in equations (1 – 2)

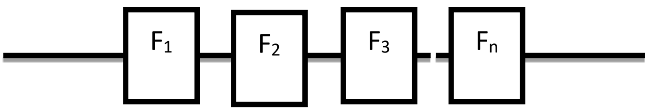

Figure 4: A representation of feeders in Series Connection

$$R(t) = P(T > t) \quad (1)$$

$$= R_1(t) * R_2(t) \quad (2)$$

Because each of the probabilities of (2) is less than one therefore, their product will be less than the smaller of the two probabilities. i.e If $R_2(t)$ is less than $R_1(t)$, then multiplying $R_2(t)$ by a number less than 1, their product will be less than $R_2(t)$ and vice versa. If this is true, then the reliability is less than or equal to the minimum of either $R_1(t)$ or $R_2(t)$ which leads to a poor reliability. Hence, series connection will always leads to a poor reliability. In Figure 5, the block diagram of a parallel network is represented with six different feeders in connection. Giving that $f_1, f_2, f_3, f_4, f_5, and\ f_6$ represents feeders 1 to 6. Figure 5 can be simplified to Figure (6) using equation (2)

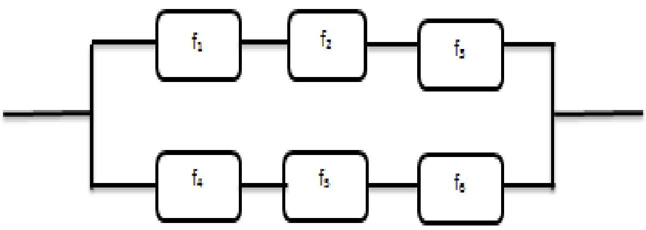

Figure 5: A representation of feeders in Series and Parallel Configuration

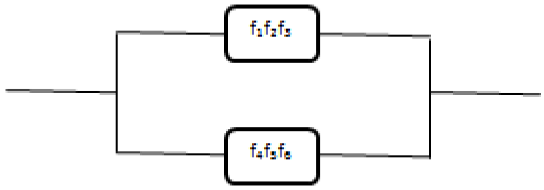

Figure 6: Equivalent Feeders in Parallel

Hence, the probability of success and failure of the system can be given as:

$$\Pr(success) = f_1 f_2 f_3 + f_4 f_5 f_6 \quad (3)$$

$$\Pr(failure) = (1 - f_1 f_2 f_3) * (1 - f_4 f_5 f_6) \quad (4)$$

Given that $f_1 f_2 f_3$ and $f_4 f_5 f_6$ function independently then the reliability can be computed as:

$$R(t) = P(T > t)$$

$$\text{Then } R(t) \geq R_1(t) \times R_2(t) \quad (5)$$

According to El-Dameese [97], systems connected in parallel have the merit of improving the reliability of the said system. Hence, (5) gives the mathematical equation that can be used to solve for systems in parallel. Generally, a system composed of components functioning independently in parallel will have its reliability higher than the reliability of the individual component connected in series.

4. Reliability indices

Indices of Reliability (IoR) are statistical tools used for reliability assessment of a component, system or network with respect to available data. The IoR basically used in power systems studies are either with respect to the customer or the load which serves the customers [33]. IoR are veritable tools because they assist in telling how reliable a system, equipment, component or network is thereby assisting in determining the weak links. In equations (6-15) the mathematical interpretations of the IoRs are presented.

- **Reliability Function R(t)**

The chances of a system, equipment, network etc. to ensuring that continuity of service is sacrosanct even beyond a period of time and can be represented mathematically as presented in equation (6) [34], [102], [103].

$$R(t) = \frac{Total\ Operating\ Hour - Downtime}{Total\ Operating\ Hour} = \frac{\sum_{i=1}^{n} T_{OHi} - T_{DTi}}{\sum_{i=1}^{n} T_{OHi}} \quad (6)$$

- **Failure Rate (FR)**

Failure rate could increase, decrease or remain constant and that depends on the context of operation. Generally, the FR of equipment for exponential distribution can be given in (7) Centikaya, 2001 [96].

$$\lambda = \frac{Total\ Number\ of\ Failures}{Some\ Measure\ of\ Operational\ Exposure} = \frac{\sum_{i=1}^{n}\sum F_{oi}}{\sum_{i=1}^{N} T_{OHi} - T_{DTi}} \quad (7)$$

- **Mean Time Between Failures (MTBF)**

This index relates to repairable item consequently, when a failure is observed in a system and such failure is cleared the duration between these periods is known as MTBF. MTBF can be calculated mathematically using (8) [35].

$$\text{MTBF} = = \frac{\sum_{i=1}^{n} T_{DTi}}{F_{Oi}} + \frac{\sum_{i=1}^{n} T_{UTi}}{F_{Oi}} \quad (8)$$

- **Mean Time To Repair (MTTR)**

The interval at which failure cleared from a network in order to restore it back to its full operating state. A low MTTR implies a good maintainability. MTTR can be represented mathematically as presented in (9) [36].

$$\text{MTTR} = = \frac{\sum_{i=1}^{n} T_{DTi}}{\sum_{i=1}^{n} Fo_i} \quad (9)$$

- **Availability (A)**

The chances that a system would continue to carry out its required function at a given period of time in order to meet the set objectives of the system's operator

$$\text{Availability} = \frac{up\ time}{uptime + downtime} = \frac{\sum_{i=1}^{N} T_{UTi}}{\sum_{i=1}^{N} T_{UTi} + \sum_{i=1}^{N} T_{DTi}} \quad (10)$$

where T_{UT} is the total uptime of the feeder; T_{DT} is the total downtime of the feeder; T_{OH} = total operational hour; F_0 is the number of feeder outage; MTBF = mean time between failure, MTTR = mean time to repair; MTTF is the mean time to failure; λ is the failure rate of the feeder; A is the availability and R is the reliability

Generally, these basic parameters that are used to assess the reliability of a power system network can also be termed the Load Point Indices (LPI) and they are used to identify the weak link in a system. Consequently, the Customer Based Indices are used to determine system's reliability from the customers' position.

The indices are now represented mathematically as seen in equations (11 – 15) in accordance with [37-38]

- **System Average Interruption Frequency Index (SAIFI)**

This is an index that deals with the average frequency of interruptions experienced by customers over a giving time within a giving locality.

$$\textbf{SAIFI} = \frac{\sum_{i=1}^{n} FR_i CLP_i}{\sum_{i=1}^{N} CLP_i} \quad (11)$$

- **System Average Interruption Duration Index, (SAIDI)**

This index is used to determine the average number of time a customer is out of supply of energy supply

$$\textbf{SAIDI} = \frac{\sum_{i=1}^{n} AOT_i CLP_i}{\sum_{i=1}^{N} CLP_i} \quad (12)$$

- **Customer Average Interruption Duration Index (CAIDI)**

This is the average number of time required to restore supply to customer per interruption that is sustained.

$$\textbf{CAIDI} = \frac{\sum_{i=1}^{n} AO_i CLP_i}{\sum_{i=1}^{n} FR_i CLP_i} \quad (13)$$

- **Customer Average Interruption Frequency Index (CAIFI)**

This is an index that shows trends in customers interrupted and assists to indicating the ratio of customers affected per a given customer base.

$$\textbf{CAIFI} = \frac{\sum_{i=1}^{n} NCi_i}{NAF} \quad (14)$$

- **Average System Availability Index (ASAI)**

This measures the average availability a system that serves a giving customer. It is represented as follows

$$\textbf{ASAI} = \frac{\sum_{i=1}^{n} CLP_i \times 8760 - \sum AOT_i CLP_i}{\sum_{i=1}^{n} CLP_i \times 8760} \quad (15)$$

where FR = failure rate , CLPi = number of customers of load point i., AOT_i= annual outage time and Ni is the number of customers of load point I, NCi= Number of Customer Interrupted, NAF = Number of affected customers, section titles are italic.

5. Review of Literature

A study on the framework of simulation and modeling of power transmission grid considering failures that are cascaded was carried out by Cadini *et al.*, [21], the data, as well as the model of the detailed environmental conditions were collated from literatures. The authors eventually discovered that environmental condition is a major factor to be considered when carrying out reliability studies. Furthermore, Hua-Dong *et al.*, [39] carried out a study on systems framework in communication systems using the continuous Markov chain method. The authors were able to determine that degraded communication network can affect the system's performance, thereby increasing the system's operational cost. Rather than just sticking to the feeder routing approach as a means of enhancing reliability as proposed by Kumar *et al.*, [40] which was purely theoretical, Canizes *et al.*, [41], undertook a study on the enhancement of reliability using a Pareto Front Technique (PFT) and the Fuzzy Method (FM) in a radial distribution network through the identification of new investments in the system. An improvement on repair time and failure rate was however observed in the system although the work according to the authors was still in the experimental stage due to the problem of reconfiguration.

A study on the modeling of reliability in power system network using Stochastic Automata Network (SAN) in conjunction with Markov chain was carried out by Snipas *et al*., [42]. However, the authors were skeptical about the results obtained from the work owing to the fact that other techniques might yield better result due to the inability of the SAN in specifying functional deficiencies within the automata. In order to enhance the system's efficiency and effectiveness, Dehghanian and Fotuhi-Firuzabad, [43-44] proposed an algorithm; Common Load Point (CLP) and Reliability Centered Maintenance (RCM) which can be used to detect critical components in a system ,thereby using the obtained result to issue out maintenance order for an improvement in the performance of the system. If the weak link in a system can be identified and removed from the system, then there can be an improvement in the system owing to the fact that it can help to save cost; this was the assertion of Canizes *et al*., [41] Eventually, the Particle Swam Optimization (PSO) technique was used to achieve their aim. However, more work still needs to be done by looking at the system as a whole rather than dwelling on cost effectiveness only. Also, Lvov *et al*., [45] carried out a study assessing varying power line from the viewpoint of maintenance, clearing of faults along the line as well as construction for the purpose of enhancing reliability in medium voltage line in Latvia. The results showed that in practice, it is more economical to use other types of transmission line in addition to overhead line for network enhancement and effectiveness when considering not only the cost of utility but also the customer's reliability. Furthermore, Okada *et al*., [46] stated that transmission network planning for reliability improvement for a long-term is important for sustainability in the system in an electricity market. In order to improve on the maintenance strategy of a system, Pan *et al.*, [47] proposed a method that can be used to estimate failure in a given system using Failure Statistical Method, (FSM) the results obtained were tested on a transformer, transmission line, circuit breaker and cables and was found to be okay.

In carrying out the reliability assessment of large infrastructure, Tien and Kiureghian, [48] proposed the Bayesian Networks Method (BYM) to be used when the system becomes large and when it becomes difficult to use existing techniques. Due to the fact that correlated failure can be hazardous to a system, Li *et al*., [49] in an attempt to improve system's performance proposed a method to measure the impact of correlated failure on the system. However, the method suffers from a drawback that it was unable to prioritize the correlated failure for a sound judgment. Consequently, in order to identify these critical item(s) or equipment in a system that is to be prioritized, Samuel *et al.*, [50] did a study using the fault tree analysis to determine equipment that are more sensitive in the system. Also, Yahmadi *et al.*, [51] in an energy storage study to determine the causes and the method of enhancement, proposed the Tree Analysis (TA), which can aid in identifying equipment that are critical in the system for the purpose of priority.In order to improve on system's performance and reliability, [52 – 53] are of the opinion that once a Network is Reconfigured (NR) taking into cognizance ecological, environmental, topological as well as the active power loss in the system, then there can be a significant reliability improvement. However, [53] asserts that the meta-heuristic technique is used frequently because it converges easily.

Generally, there can be a substantive improvement in reliability if the planning of the energy storage system is done optimally Saboori *et al*., [54]. In order to achieve this task, a situation assessment reliability level was encouraged by Zou et *al.*, [55] i.e reliability study of any system should always be up to date. In addition, Hasanvand *et al.*, [56] proposed a Redesign of Distribution System (RDS) in a microgrid environment to enhance reliability, while Zhou *et al*., [57] is of the opinion that since the world is moving towards the use of renewables, reliability assessment, evaluation, study and improvement in that area is necessary. Reliability analysis of distribution transformer in Sokoto State, North-West Nigeria was carried out by Sulaiman & Ali, [58] and the result showed that the network was subjected to load beyond their identified limit, leading to poor reliability in the system and if the distribution network reliability is not optimized there is a tendency for the system to become scraps and no longer useful. Accordingly, Onime and Adegboyega, [27] carried out a research on the reliability analysis in Ekpoma, South-South Nigeria and the results obtained showed that the constant power outage in the system was as a result of the poor system's reliability. Hence, the researchers suggested that reliability improvement is sacrosanct for the system. In a related study by Okorie and Ibrahim, [59] in North-West Nigeria, the authors concluded that environmental condition accounts for 50% of the total problem on reliability.

Furthermore, Popoola et *al.*, [60] carried out a work on reliability in all the six states in South West geopolitical region in Nigeria and the results showed that the reliability and availability of the NPSN is seasonally dependent on an improved availability during the rainy season and a poor availability during the dry season. Hence, the obtained results, therefores, validates the results obtained by Izuegbunam *et al.*, [61] that it's not the generating station alone that requires attention but also the distribution arm for an overall reliability improvement. Further results showed that there were variations in the power supply in the region, hence the researchers concluded by stating that the system was not reliable. A study on the prediction of reliability in Port-Harcourt Rivers State, South-South Nigeria was carried out by Uhumnwango and Omorogiuwa, [62] by collating data for six months and using the NEPLAN software. The obtained results showed that a means of isolating faulty part in a particular feeder should be adopted instead of shutting down the entire feeder which eventually leads to poor reliability. A reliability assessment study in Kaduna State, North-West Nigeria was carried out by Jibril and Ekundayo, [63] and it was recorded that high forced outage is one of the major factor militating against an improved system performance. The results further showed that there is a violation of the IEEE standard of 0.9999. Accordingly, Ale and Odesola, [64] carried out reliability assessment of electric distribution system in Ondo State South-West Nigeria and declared that the system's reliability is porous with value of 23.48%.

According to Odior *et al.,* [65] the problems affecting sustainability in power supply in Nigeria can be grouped largely into two classes: the lack of sustainable policy as well as external forces. The authors further asserted that power supply to GRA injection substation is more regular when compared to Siluko substation.A study on the investigation into reliability assessment using Fault Tree Analysis (FTA) was carried out by Samuel *et al.,* [50] and the result showed that FTA offers significant improvement (about 51%) in the improvement of the line. in addition, Musa *et al.,* [66] carried out an investigation on the analysis of power outages in low voltage feeders in Maiduguri, Borno State, Nigeria. The analysis was based on monthly outage data collected for a period of about two years. Tables and graphs were used in the analysis of the work. It was discovered that some of the feeders under investigation performed appreciably well during a particular time of the year. It was also discovered that outages in the network were due to aging of equipment and defects, lightning, vandalizing of equipment, poor maintenance etc. Consequently, Okakwu and Oluwasogo, [67] undertook a research on reliability evaluation in Lagos State, Nigeria using 11kV feeders to estimate the reliability of the primary and secondary distribution network. The failure rate (λ), the Mean Time between failures (MTBF) and reliability of the network using MATLAB program, which were the objectives of the research were achieved. The data collected for the analysis were number of outage and down time losses. The results showed that the frequency of faults were extremely low for all the months on the 11kV lines and thus makes for an improved reliability which is good for the system. The submission of Okundamiya *et al.,* [68], revealed that for a good voltage profile to be recorded by customers tied to the Guinness feeders, then the distance from the transformers to the point of consumption should not exceed 400 meters.

A study on the development of reliability Indices-Markov Model for an electric power distribution prediction for future years reliability was carried out by Ogujor and Kuale, [69]. The model was fine-tuned with 2003 power outage data and validated using 2004 data from the then NEPA,now privatized and called Ugbowo Injection Substation under Benin Electricity Distribution Company BEDC. The results predicted worsening figures unless drastic and conscious measures are put in place. A maximum error in prediction of -0.12% was obtained in Eguadiaken feeder, while a minimum error of -5.5% was obtained in Ugbowo feeder. Due to the findings and low error margins, the model can be confidently and adequately recommended. .In the same vein, Ogujor and Kuale, [70], undertook a study using Pareto Analysis to reduce faults in distribution system. In the work, causes of faults and its reduction in relation to higher reliability was discussed. An exploratory case study consisting of four (4) feeders were investigated. Data collated was managed using Microsoft Access database. Results obtained from the study showed that elimination of load shedding in the Nigeria Power System will lead to having reliability with a "9" in its first decimal place. Furthermore, Okakwu *et al.,* [71] worked on reliability improvement through identification of few significant faults in a distribution feeder. In the paper, an up to date analysis of the substation was actualized and implemented using Pareto and Anti-Pareto principle. The researchers were able to analyze the current state of the case study and recommended improvement due to Pareto analysis.The reliability evaluation and improvement of the Ajele Injection Substation which was the case study of the work was successfully identified and necessary recommendations were given. It also showed that Pareto Principles performed better than the anti-Pareto principles. The elimination of 20% of faults on the distribution will lead to a reliability of at least
"8" in its first decimal place.

Amuta *et al.,* [72] work was centered on the scheme of protection in recent Nigeria practice. An exploratory case study of Abule-Egba Business unit under Ikeja Distribution Zone having nine (9) injection substations of 33/11kV transformers with 32 outgoing feeders was used in the actualization of their research. Data was collected using the site logbooks and analyzed. The analysis on the work was on relay, which is the main protection device in any power system protection scheme. In view of this, reliability analysis was carried out on the case study but no software justification of results was implemented. According to Eti *et al.*, [73] the authors proposed a RAMS Risk Analysis as a tool to enhance performance of generating stations in Nigeria. The authors were of the opinion that there can be significant improvement on the system if their proposed method is taking cognizance of, owing to the fact that it can help to reduce risk within the system. Adoghe *et al.,* [74] asserted that a system is reliable if it has a minimum of two 9's in its first and second decimal places. According to Cotaina *et al.,* [75] the researchers presented the application of RCM to several industries. Hence, providing the analysis, model of risk, and the various computer program that can be used when carrying out the computerized tools of implementation of RCM taking into cognizance the risk studies. However, of the many industries listed in the work, the power industry was primarily neglected but was rather made secondary. The fact that adequate and reliable power supply in a given nation is proportional to its level of development should have made the power sector one of the primary industry for RCM implementation.

Hilber, [76] established a process method for the definition of the purpose of priority. The method proposed by the researcher clearly stated that in carrying out reliability studies and in order to obtain an optimized solution in maintenance both in the transmission and distribution network, that priority must be given to certain but not all equipment in the network. Hence, prioritizing the power systems component was made the priority leading to an important model. This will aid in achieving the said purpose and this was in accordance with the system's maintenance and potential and reliability importance. The index was eventually used for the evaluation of maintenance actions with the aim of achieving an optimal maintenance plan. Subsequently, Morais *et al.,* [77] developed a Reliability Centered Maintenance model based on the experience of maintenance crew for instrument transformer. This was done by carrying out statistical analysis of failures with the aim of taking into cognizance the available failure possibilities. A discrete five level matrix model was developed that will aid in showing the consequences of the severity of a failure. However, according to the author, a similar model could only be applied to current transformer and voltage transformer only. In order to improve on the maintenance strategy of PHCN, Ewulum, [78] proposed a Utility Availability Centered Maintenance Strategy (UACMS) model that combined various maintenance techniques in addition to the work authorization. Hence, the entire strategy was eventually connected to a database support for the purpose of managing information. Enofe, [79] laid emphasis on the effect of poor training and how poor training of system's operator and maintenance personnel has contributed in hindering maintenance action. The work further stressed that the then PHCN staff were not regularly and effectively trained to meet up with the current maintenance trend practiced globally in industrialized nations. Although, the work was primarily aimed at addressing poor training of maintenance personnel and neglected maintenance of equipment; it failed to recommend the best maintenance action for this purpose. For the purpose of comparison for decision making, Kutlev, [80] proposed a model in choosing the right configuration type of substation for various customers. The criteria used by Kutlev, which has maintenance and operation as one of its indices, was achieved using the Life Cycle Cost (LCC). Accordingly, Georgescu *et al.*, [81] developed a preventive maintenance model that was based on RCM and as such, the model has the tendency of restoring the system's performance in the presence of technical limitations. However, RCM component comprises preventive, predictive, reactive and proactive maintenance. Hence, practicing strictly a preventive maintenance in isolation of these other components could be very costly and as such the model developed here could be very costly to implement.

Furthermore, Sule, [82] looked at the system's capacity with respect to the three arm of the power sector in the Nigerian power network,and laid emphasis on poor maintenance culture as one of the major factors responsible for the poor supply of electricity in Nigeria. Furthermore, the work was able to create awareness to the appropriate authorities on the need to address the nonchalant approach that has bewildered a good maintenance and maintenance strategy of the system. In Afefy, [83] the researcher used RCM to identify basic information as it concerns equipment criticality based on several errors and use the information gathered to propose and develop an algorithm for calculation of equipment Failure Mode Effect Analysis (FMEA), Root Cause Failure Analysis (RCFA), as well as the Failure Mode Effect and Criticality Analysis (FMECA), the result showed a reduction in the downtime cost when compare to the Run-To-Failure maintenance. According to Igweonu and Joshua , [84], their work was aimed at the development of a model for the purpose of improving the maintenance of the power system network. The model produced was a five-stage algorithm that involved the planning, organizing, directing, operating and controlling of the system's network and the overall aim was to achieve a soft landing policy for the 21stcentury utility. From the presentation, 80% of the model's functionality was assigned to preventive maintenance, while 20% was assigned to corrective maintenance. Although the high percentage of preventive maintenance practice could help reduce the frequency and severity of unplanned failure; however, it could be ineffective and costly since it is majorly the only maintenance strategy practiced.

The maintenance dynamics for decades and their responses to changing expectation were reviewed by Adoghe *et al.*, [74] The work indicated the growing awareness of how equipment failure affects safety and environment considering their relationship with maintenance. It is in that wise that a model was proposed to link maintenance and reliability of deteriorating equipment with periodic inspections that will lead to available maintenance strategies. But the work only adopted reactive maintenance and preventive maintenance as part of the maintenance strategy and thus did not take cognizance of the other RCM components. Mathematical model in reliability studies could be best represented using polynomial functions obtained using curve fit tools because it gives a good relationship between a predictor and a response variable [85]. Similarly, Bishop, [86] and Weisstein, [87] opined that it is an effective way of replacing data that are missing. Furthermore, El-Hadidy and Helmi, [88] proposed a disturbance monitoring system as a tool for carrying out predictive maintenance management and operation with the aim of improving maintenance efficiency and reducing maintenance cost. Since this was the only type of maintenance practiced in the work it may not lend itself to all types of items and equipment failure. Subsequently, Jae-Haeng *et al.*, [89] proposed a Maintenance Priority Index(MPI) to be used as maintenance index in replacement of Time Based Maintenance. The model was therefore designed to apply the Load Effect Index (LEI) and Failure Effect Index (FEI). It did not only consider the physical state of the lines but also demonstrated the necessity of the system's reliability with a view to achieving effective cost implication. The work, however, was strictly applicable to transmission line only.

Ahmed, [30] proposed the concept of RCM modeling in generation, transmission and distribution stations as an appropriate tool for reliability enhancement in the Nigeria Power System network. The work suggested that for effective maintenance management scheme, RCM should be adopted in all tiers of the power sector. However, the work did not provide a detailed modeling of how to achieve this. It only gave some of the steps that is required to develop the model. In their submissions, Suthep and Kullawong, [90] set a priority for critical parts of equipment after which data on damage and risk level were analyzed by using FMEA for calculating the various parameters of the system's reliability. Finally, a preventive maintenance task based on RCM was selected using the Microsoft Excel simulation for the improvement of maintenance plan. The results showed the rate of failure of the plant was reduced and the machine availability rate of the plant was increased accordingly. According to Yssaad *et al*., [91], when carrying out a criticality analysis on a system or equipment, an existing failure data could either be used or experience from a crew who understands the system. Risk assessment and evaluation should, therefore, be included in reliability studies for the purpose of robustness as well as for a sound maintenance judgment [92]. Furthermore, Yang *et al*., [93] identified that the risk evaluation method found in the literature is not robust enough owing to varying conditions, these conditions according to Canizes *et al*., [94] are inadequacy and insecurity of the system and the obtained result may not be used for a general risk assessment of the system. However, Li,[49] affirmed that if the system indices was based on historical failure data then such analysis can be said to be adequate because it factors into consideration both adequacy and security. The (Pareto Analysis) PA is of the opinion that more concentration should be on the parts of the system that are critical, rather than on the less-critical segment and when the critical portion is resolved, an improvement in reliability can be recorded [95]. With respect to Power System Network (PSN), PA can be used to identify the weak link either in the generation, transmission or distribution arm of the sector i.e it can identify the 20% events that constitutes 80% of the problems emanating from the network. The PA is used to identify the vital few and trivial many feeders in a given network, therefore it could also be called the Vital Few Trivial Many (VFTM) technique. For the purpose of this research, the 20% feeders that cause 80% of the failures emanating from TCN Benin facility shall be determined.

6. Summary of Findings

In Tables 1 – 2, the summaries of findings for the reviewed works are presented. While Table 1 is a summary of related works outside the shores of Nigeria, Table 2 gives a quick glipse of works within Nigeria.

Table 1. Reliability studies other than Nigerian network

Author	Nature of Work	Network	Tools	Remark
Canizes *et al* [41]	enhancement of reliability	33-bus network	Pareto Front Technique (PFT) + Particle Swam Optimization (PSO) + Fuzzy Logic (FL)	Optimization
Snipas *et al*., [42]	modeling of reliability in power system	Ring bus configuration	Stochastic Automata Network (SAN) + MARKOV + minimal path set	Reduction in state spaces of a network
Tien and Kiureghian, [48]	reliability assessment of large infrastructure	Series parallel test system	Bayesian Network Method (BNM)	Size limitation in modeling large system
Yahmadi *et al.*, (2016	causes and the method of enhancement,	Battery System	Tree Analysis (TA)	Optimization of storage systems
Jae-Haeng *et al.*, [89]	maintenance index for replacement in System	IEEE 9-bus system	Load Effect Index (LEI) + Failure Effect Index((FEI)	Cost optimization
Suthep and Kullawong, [90]	a priority for critical parts of equipment	Hard Chrome plating plant	Failure Mode Effect Analysis (FMEA) + Reliability Centered Maintenance (RCM)	Reduction in Mean Time Between Failure (MTBF)
Hasanvand *et al.*, [101]	reliability enhancement	IEEE 34-bus distribution system	Network Reconfiguration (NR)	Designing mini-grid from an existing distribution conventional network
Sultana *et al.*, [53]	reliability enhancement	Review work	Network Reconfiguration (NR)	Propose NR for future work reliability improvement
Shareef *et al.*, [52]	reliability enhancement and power quality	47-Bus distribution network	Firefly algorithm	Network reliability significantly improved and optimization achieved
Afefy, [83]	reliability and maintenance	Process steam plant	Root Cause Failure Algorithm (RCFA) + Reliability Centered Maintenance(RCM)+Failure Mode Effect and Criticality Analysis (FMECA)	Savings in labour and downtime cost
Pan *et al.*, [47]	modeling of failure rate	Circuit breakers	Failure Statistical Method (FSM)	Outage prediction of systems and components
Dehghanian and Fotuhi-Firuzabad, [43]	Outlook on critical components on distribution system	BIRKA Nat distribution system, Sweden	Critical Component Algorithm (CCA)+ Reliability Centered Maintenance (RCM)	Achieving reliability benchmark in a distribution system
Selvik and Aven, [92]	Risk assessment	off shore oil & gas	Reliability Centered Maintenance (RCM)+ Reliability and Risk Centered Maintenance (RRCM)	Reliability improvement and maintenance reduction

Table 2. Reliability studies within Nigerian network

Author	Nature of Work	Network	Tools	Remarks
Airoboman *et al* [98]	Stationary position of feeders	TCN, Benin 33kV network	Markov	Reduction of maintenance cost through the identification of stationary position
Airoboman *et al* [29]	Risk assessment of feeders	TCN, Benin 33kV network	Feeder Criticality Technique (FCT)	Feeders with risk are identified in the network
Airoboman *et al* [100]	Reliability assessment of feeders	TCN, Benin 33kV network	Reliability Indices (RI)	State of feeders reliability determined
Sulaiman and Ali, [58]	Reliability assessment	Distribution transformer (Sokoto State, Nigeria)	Reliability Indices (RI)	Reliability sate of the transformers were determined
Onime and Adegboyega, [27]	Reliability assessment	Ekpoma Network, Nigeria	Reliability Indices (RI)	Network reliability determined and needs improvement
Okorie and Ibrahim, [59]	Reliability assessment	Distribution network in North-West Nigeria	Reliability Indices (RI)	Network reliability determined
Jibril and Ekundayo, [63]	Reliability assessment	Kaduna distribution network, Nigeria	Reliability Indices (RI)	Forced outage identified as one of the causes of oor system's reliability
Okakwu and Oluwasogo, [67]	Reliability assessment	Idiaraba injection substation , Lago, Nigeria	Reliability Indices (RI)	Poor system reliability was identified
Ogujor and Kuale, [69]	Identification of events that are prone to failure	Ugbowo distribution network, Benin,Nigeria	PARETO	Feeders performance were identified and improved
Airoboman *et al*., [37]	Reliability assessment of transmission network	Maryland transmission network, Lagos, Nigeria	Reliability Indices (RI)	Poor network reliability identified
Ogujor and Kuale, [70]	Development of reliability indices model	Ugbowo distribution network, Benin, Nigeria	Markov model	Upcoming events in the network was predicted
Amuta *et al.*, [72]	Reliability assessment of protection scheme	Abule-egba distribution unit, Lagos, Nigeria	Reliability Indices (RI)	Poor reliability of protection scheme identified
Musa *et al.*, [66]	Reliability assessment	Low voltage feeders, Maiduguri, Nigeria	Reliability Indices (RI)	The network reliability is seasonally dependent
Uhumnwango and Omorogiuwa, [62]	Reliability assessment	Port-Harcourt distribution network, Nigeria	NEPLAN	Poor reliability identified due to the nature of shutting down feeders
Airoboman and Ogujor *et al*, [99]	Identification of failure prone feeders	TCN, Benin 33kV network, Nigeria	PARETO	Weak feeders in the network was identified

7. Identified Gap From Literature

It has been revealed from the reviewed literature and the summary presented in Tables 1- 2 that while most work on reliability outside the shores of Nigeria deals with instances of optimizing and enhancement of performance, outage prediction, risk analysis, reduction of size, achieving an appropriate standard etc. on components, equipment, facilities, system, majority of the work however on systems reliability using any arm of the Nigerian network as a case study mostly ended in the determination of how reliable a system is using reliability indices which could either be from the customer or load perspective. The results obtained however, from these research are quite helpful to the operators of the systems, research and scientific community, utility, regulators and policy makers at large because it has assisted in solving a problem by identifying where there is a problem. However, after identifying how reliable a system or network is, what follows? This is a research question that researchers should delve into especially as it concerns the Nigeria Power systems network. Meanwhile, only a few studies has ended up in either attempting to optimize the network, determine the effect of poor reliability on a giving network or even quantify the level of risk in the network or project future behaviour [104-105]. Researchers in this field are therefore encouraged to consider bridging the gaps as identified.

7. Conclusion

In this paper, a review on the comprehensive approach to reliability study especially on the Nigerian network was carried out. The paper asserted that more dimensions to reliability assessment is necessary with respect to an effective operation of system's network. Conclusively, the papers highlighted some gaps that were noticeable with various strata of the Nigerian network and therefore encourage researchers to consider bridging the identified gaps.

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Figure 1. Engineering technologies.

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