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Evaluation of Systems Performances and Systems Reconfigurations

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Abstract— **The paramount interest in any reliability study is ensuring a good quality of service to customers defined as a combination of availability of the energy supply and the quality of the energy available to the customers. This paper discuss on the reliability of the power supply for three kinds of situations. This will show how reconfiguration and alternative sources improve the reliability of the power system. The aim of this paper is to evaluate power system reliability analysis improvements with distributed generators (also known as Distributed Resources) while satisfying equipment power handling constraints and energy sustainability technology thereby eliminating the frequent rate of power interruption or outage to the consumers.**

Keyword: Power system reliability, energy sustainability, distributed generator, segment, circuit traces.

I. INTRODUCTION

The economic and social effects of loss of electric service have significant impacts on both the utility supplying electric energy and the end users of electric service. The cost of a major power outage confined to one state can be on the order of tens of millions of Naira. If a major power outage affects multiple states, then the cost can exceed 100 million Naira.

The power system is vulnerable [1] to system abnormalities such as control failures, protection or communication system failures, and disturbances, such as lightning, and human operational errors. Therefore, maintaining a reliable power supply is a very important issue for power systems design and operation.

A Flexible AC Transmission System (FACTS) controller is a system based on power electronic equipment that enables control of one or more AC transmission system parameters [2]. In an effort to increase the reliability of the distribution system, FACTS controllers should be introduced and deployed in our system as a means of controlling the flow of power between the source and the loads.

Carefully studying failure scenarios in power system allow the placement of FACTS devices in certain locations in order to prevent the failure from happening. The installation of the FACTS devices should therefore increase the overall reliability of the power system.

This paper presents the research efforts and the software implementation of a reliability analysis algorithm for electrical power distribution systems. This algorithm is used to study reliability improvements due to the addition of distributed generators. This algorithm also takes into account system reconfigurations.

A. *Distributed Generators*

Distributed generators come in many forms including gas turbine driven synchronous generators, wind powered induction generators, fuel cells with inverter circuitry, and others. The use of distributed resource generation is projected to grow. This growth is due to cost reductions available with distributed generators. The cost reductions may be the result of released system capacity or reductions in generation costs at peak conditions.

B. *Definition of Power System Reliability*

The function of an electric power system is to satisfy the system load requirement with a reasonable assurance of continuity and quality. The ability of the system to provide an adequate supply of electrical energy is usually designated by the term of reliability. The concept of power-system reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. There is a reasonable subdivision of the concern designated as “system reliability”, which is shown in Figure 1.

Reliability study introduces concepts aimed at improving awareness among distribution system planning and operation personnel in reliability issues and application. Reliability studies were developed by a wide range of practitioners in the power distribution industry and are particularly useful to:

1. Distribution system planning operation engineers;
2. Distribution system economists and risk manager; and
3. Decision makers on system expansion, refurbishment and rehabilitation.

At system planning time, there are three fundamental reliability related design considerations adequacy namely:-[3].

1) Transient performance adequacy;
2) Reserve adequacy; and

Capacity adequacy.

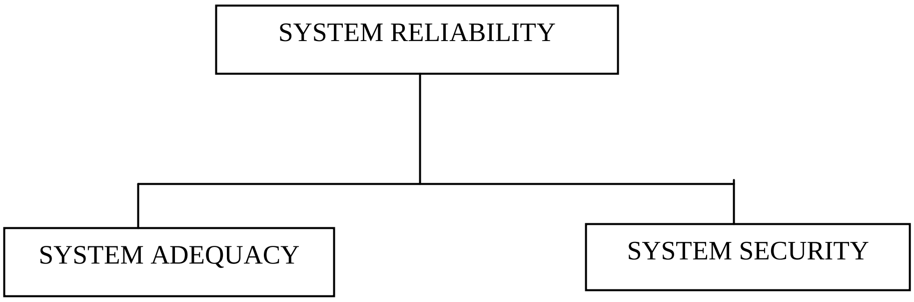


Figure 1 Subdivision of System Reliability

Figure 1 represents two basic aspects of a power system: system adequacy and security. These, Adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points and the reserved. Security relates to the ability of the system to respond to disturbances arising within that system. Security is therefore associated with the response of the system to perturbations [4]. Most of the probabilistic techniques presently available for power-system reliability evaluation are in the domain of adequacy assessment. The techniques presented in this paper are also in this domain.

C. Reliability Assessment Techniques

Both qualitative and quantitative tools are used in order to review issues concerning the continuity of electricity service experienced by customers. Reliability analysis has a wide range of applications in the engineering field. Many of these uses can be implemented with either qualitative or quantitative techniques. Qualitative techniques imply that reliability assessment must depend solely upon engineering experience and judgment.

Quantitative methodologies use statistical approaches to reinforce engineering judgments. Quantitative techniques describe the historical performance of existing systems and utilize the historical performance to predict the effects of changing conditions on system performance. In this research, quantitative techniques combined with theoretical methods are used to predict the performance of designated configurations. The systems considered in this research are radially operated [5] with respect to substations, but are reconfigurable.

II. RELIABILITY INDICATORS FOR MEASURING SERVICE

A. Quality Performance

A basic problem in distribution reliability assessment is measuring the efficacy of past service. A common solution consists of condensing the effects of service interruptions into indices of system performance. The Edison Electric Institute (EEI), the Institute of Electrical and Electronics Engineers (IEEE), and the Canadian Electric Association (CEA) have suggested a wide range of performance indices [7]. These indices are generally yearly average of interruption of frequency and duration. They attempt to capture the magnitude of disturbances by load lost during each interruption.

These reliability indices are among the following:-[6]

Customer Average Interruption Duration Index (CAIDI) is an indicator of average interruption duration, or the time to restore service to interrupted customers. CAIDI is calculated by dividing the total system customer minutes of interruption by the number of interrupted customers.

2. *System Average Interruption Frequency Index* (SAIFI) is an indicator of average service interruption frequency experienced by customers on a system. It is calculated by dividing the number of service interruptions by the number of customers served.
3. *System Average Interruption Duration Index* (SAIDI) is a composite indicator of outage frequency and duration and is calculated by dividing the customer minutes of interruptions by the number of customers served on a system. Mathematically, SAIDI is the product of SAIFI and CAIDI. Thus, a SAIDI of 100 may be achieved by a SAIFI of 1 and a CAIDI of 100, or by a SAIFI of 1.25 and a CAIDI of 80.
4. *Momentary Average Interruption Event Frequency Index* (MAIFIe) is an indicator of average frequency of momentary interruptions or the number of times there is a loss of service of less than one minute. MAIFIe is calculated by dividing the number of momentary interruption events recorded on primary circuits by the number of customers served.
5. *Customers Experiencing More Than Five Interruptions* (CEMI5) measures the percent of customers that have experienced more than five service interruptions.

These are the five key reliability indicators recently introduced for the purpose of assessing distribution reliability performance. These are the reliability indices used by the Florida's Investor–owned electric utilities (IOU) for assessing and auditing their performance in electricity distribution system. Such reliability indicators are listed below:

i. Customer Average Interruption Duration Index (CAIDI);
ii. System Average Interruption Frequency Index (SAIFI);
iii. System Average Interruption Duration Index (SAIDI);
iv. Momentary Average Interruption Event Frequency Index/Indicator (MAIFI);
v. Customers Experience More than Five Interruptions (CEMI5).

The mathematical computation is as follows:

$$\text{CAIDI}_{ik} = \frac{\text{Sum of all customers minutes interrupted } (CMI_{ik})}{\text{Total number of customers interruptions } (CI_{ik})} \quad \ldots \tag{1}$$

$$\text{SAIFI}_{ik} = \frac{\text{Total number of customer's interruption } (CI_{ik})}{\text{Total number of customers served } (C_{ik})} \quad \ldots. \tag{2}$$

$$\text{SAIDI}_{ik} = \frac{\text{Sum of all customers minutes interrupted } (CMI_{ik})}{\text{Total number of customers served } (C_{ik})} \quad \ldots \tag{3}$$

$$\text{MAIFIE}_{ik} = \frac{\text{Sum of all customers momentary interruption events } (CME_{ik})}{\text{Total number of customers served } (C_{ik})} \tag{4}$$

$$\text{CEMI5}_{ik} = \frac{\text{Customers experienced more than 5 interruptions } (CEM5_{ik})}{\text{Total number of customers served } (C_{ik})} \; x \;\; 100\% \quad \ldots \tag{5}$$

i = 1, 2, 3 ………………………… m

k = 1, 2, 3 ………………………… n

where i denotes year and

k denotes kth district

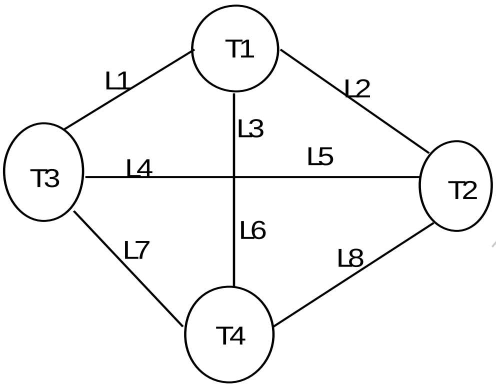
These five performance indices express interruption statistics in terms of system customers. A customer here can be either feeder, or an individual, firm, or organization who purchases electric services at one location under one rate classification, contract or schedule. If service is supplied to a customer at more than one location, each location shall be counted as a separate customer.

2.2 RELIABILITY AND SELF HEALING CONCEPT

Reliability is the characteristics of an item expressed as the probability that it will perform a required function under stated conditions for a stated period of time. It is an extension of quality into a time domain and is paraphrased as the probability of non failure in a given period.

On the other hand, self- healing is a mechanism through which a system, component or equipment communicate within themselves in terms of their functions. This function can simply be demonstrated by a system of transformers connected as shown below in Figure 2. As can be seen, there is a direct link between every pair of transformers. This provides redundancy. For a fully functional system, all 4 transformers $(T_1 - T_4)$ and all links (l_i) should be operational. However the system can still function well despite the failure of one or two of the links provided that a path still exist between any two transformers.

However, in this case, transformer failure is more harmful than link failure but it is possible for the system to temporarily remain functional despite the failure of one or more transformers. This is all what the self- healing entails about thereby promising self-healing. The acute reduction of the failure probability provided by the self-healing enhances the system.



Ti - Substation transformer all interconnected

Li - Line Transmission

Figure 2 Mesh S-H Network.

III. System Design to Achieved Higher Reliability

Of paramount interest in any reliability study is ensuring a good quality of service to customers defined as a combination of availability of the energy supply and the quality of the energy available to the customers (Medjoudj, 1994). In the following sections we will discuss the reliability of the power supply for three kinds of situations. We will show how reconfiguration and alternative sources improve the reliability of the power system.

A. Radial Distribution System

Figure 3 shows a simple Radial Distribution System. In this system a single incoming power service is received and distributes power to the facility.

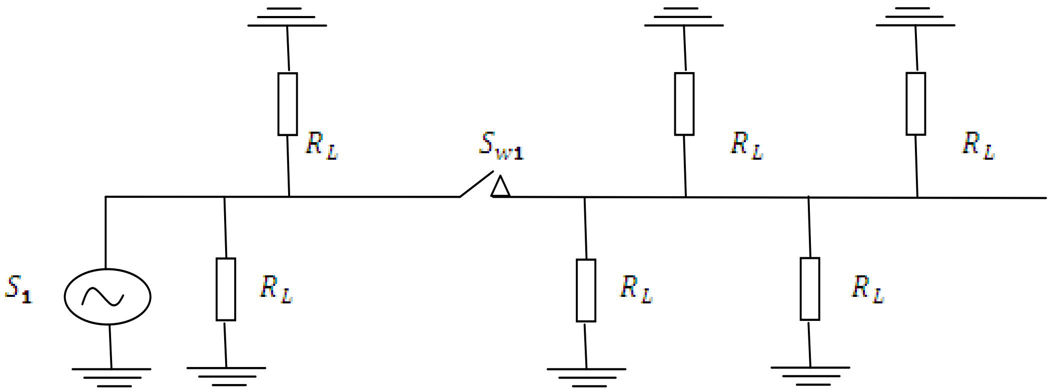


Figure 3 Simple Radial Distribution System

The circuits (one circuit fed by S1 and the other fed by S2) are tied together through a normally open tie-switch (TW), with both power sources energized. The electrical equipment is designed to accommodate 100% of the facility load. For instance, when a failure occurs in source S1, after the failure is isolated by opening the circuit breaker, the tie-switch is closed allowing the complete load to be served from a single source until the problem is corrected. Most customers can be restored immediately and don't have to wait until S1 is repaired. With this reconfiguration, it improve the reliability of the whole system thereby increased the customers satisfaction of the electricity services and minimize the total number of customers impacted.

B. *Alternative Feed Arrangement with DR*

We can improve the reliability further by adding a distributed resource (DR) into the circuit, as indicated in Figure 5. In case the failure occurs on the left hand side of SW1, we can open SW1 and close SW3, so that the DR can pick up the rest of the circuit, which was originally fed by S1. Without the DR, we have to draw the power from S2, this will result to overloading the system. Although this depend on maximum load demand by the system even if S2 can withstand. Such operation might violate system constraints or degrade the quality of the power supply, especially when the customer

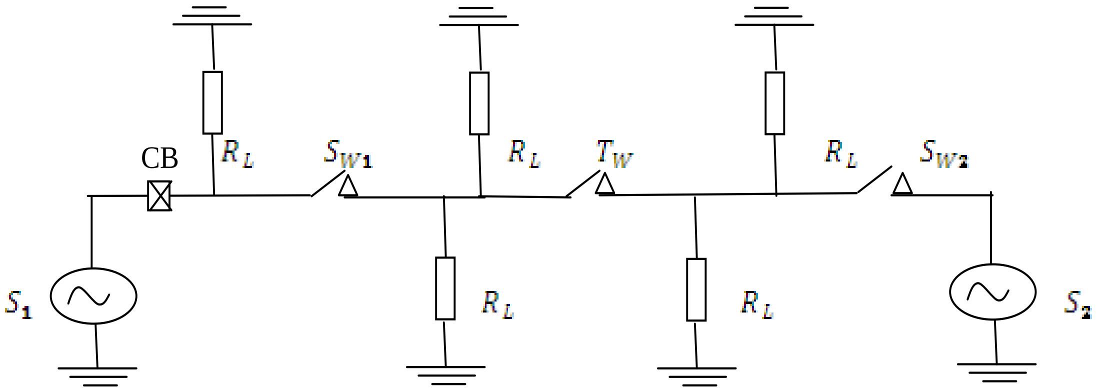


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Figure 4 Alternative Feed Distribution Arrangements

IV. SWITCHING OPERATIONS

Reliability analysis for a power system also leads to more reliable and cost-effective operation, since power restoration analysis is a subset of the calculations performed for reliability analysis. Here we assume switch operation time is less than repair time, so loads that have lost power may be restored faster by appropriate switching operations, or reconfiguration of the system.

There are two kinds of switching operations of interest. One is isolating the failure point so that a load point of interest which has lost power may be re-supplied from the original source. The other is to again isolate the failure point and to feed a load point of interest from an alternate source, if an alternate source is available. For example, in Figure 6, if a fault happens in component 4, we can open switch SW1 to isolate component 4 from the rest of the system. The original source S0 can still supply power to all the customers, except those on the downstream of switch SW1.

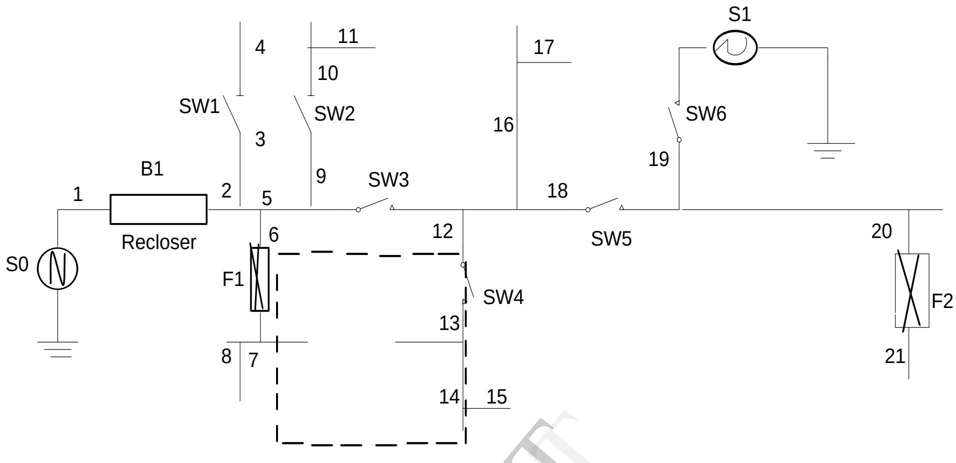

Figure 6 Sample Circuit

The second kind of switching operation isolates the failure point and interrupts the original power supply to the load point of interest. In this case we need an alternate feed to restore power to the load point of interest. For instance, if component 2 in the example circuit has a permanent fault, the fault can be isolated by opening B1 and SW3. In case there is no alternate source, all the segments downstream of the failed zone can only be restored after the fault is repaired. Since we have an alternate source S1 (assuming S1 can supply the power and the alternative feed path can carry the power), downstream of SW3 can be restored by closing SW6. The restoration time for this part of the system is shorter with switching operations than with the repair operation.

V. CONCLUSIONS

This work presented a reliability analysis, new reliability related index coupled with circuit traces which can be use to estimate or calculate the reliability of a given load point and even entire system. The placement of distributed generation and its effects on reliability is investigated. Three case studies were demonstrated, placing distributed generators further out on a circuit, instead of locating them in the substation, can help to enhance a system's reliability.

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