Ain Shams University
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RELIABILITY EVALUATION OF DISTRIBUTION SUBSTATIONS USING ANALYTICAL TECHNIQUES

M.Sc. Thesis

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STATEMENT

This Thesis is submitted to Ain Shams University in partial fulfillment of the requirements of M.Sc. degree in Electrical Engineering.

The included work in this thesis has been carried out by the author at the department of electrical power and machines, Ain Shams University. No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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ABSTRACT

The focus of this research work is on the reliability evaluation of distribution substations using an analytical approach. Basic load point reliability indices are to be evaluated at various load points in a substation taking into account both passive and active failures, malfunction of normally closed circuit breakers, and scheduled maintenance. Then, additional system reliability indices for the whole substation are to be evaluated, which can be used in comparing substation designs based on their reliability. Besides, this research work allows developing a reliability model for distribution substations to be utilized in HL-III adequacy assessment.

This thesis recognizes the need for an appropriate modeling for various components used in substations. This permits the inclusion of all the realistic component failure modes in the reliability prediction, and appeared through two categories of minimal cutsets; basic and non-basic. The analytical approach utilized here for reliability evaluation is based on a Failure Modes and Effects Analysis (FMEA) which employs the technique of minimum cutsets to compute the frequency and duration of a fault with respect to the criterion of continuity of electric service.

In addition, a computer program is described for generation of minimal paths, generation of minimal cutsets, and evaluation of reliability indices. The application of this program is illustrated by considering a practical substation example.

LIST OF PUBLISHED PAPERS

[1] A. R. Abul'Wafa, M. A. Mostafa, A. H. Gad, "**A Heuristic Technique For Generating Minimal Paths Of Networks With Bidirectional Elements**", Ain Shams Journal of Electrical Engineering, Vol. 2, pp. 187-199, Dec. 2008.

[2] A. R. Abul'Wafa, M. A. Mostafa, A. H. Gad, "**A Computer Program For Generating Minimal Cutsets Used In Substation Reliability Evaluation**", Ain Shams Journal of Electrical Engineering, Vol. 2, pp. 263-270, Dec. 2008.

[3] A. R. Abul'Wafa, M. A. Mostafa, A. H. Gad, "**Reliability Evaluation Of Distribution Substations Using An Analytical Approach**", Ain Shams Journal of Electrical Engineering, Vol. 3, pp. 281-300, Jun. 2009.

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LIST OF ABBREVIATIONS

HL	Hierarchical Level.
FMEA	Failure Modes and Effects Analysis.
MCS	Monte Carlo Simulation.
SCE	Southern California Edison company.
LOLE	Loss Of Load Expectation.
MELL	Mean Evaluation of Lost Load.
LCC	Life Cycle Costs.
PRINDAT	Predecessor Input Data technique.
BPM	Backwards Predecessor Method.
TF	Total Failure.
AF	Active Failure.
M	Maintenance.
S	Stuck breaker.
BMCS	Basic Minimal Cutset.
NBMCS	Non-Basic Minimal Cutset.
$\mathcal{U}$	Up state.
$\mathcal{D}$	Down state.
$\mathcal{S}$	Switching state.
TLOC	Total Loss Of Continuity.
PLOC	Partial Loss Of Continuity.
SAIFI	System Average Interruption Frequency Index.
SAIDI	System Average Interruption Duration Index.
CAIDI	Customer Average Interruption Duration Index.
ASAI	Average Service Availability Index.
ASUI	Average Service Unavailability Index.
EENS	Expected Energy Not Supplied.
AENS	Average Energy Not Supplied.
ASCI	Average System Curtailment Index.
DG	Distributed Generation.
NSW	New South Wales.
MP	Minimal Paths matrix.

LIST OF SYMBOLS

N	A set of nodes in a general network
C	Interconnection matrix
N_c	Number of components
N_b	Maximum number of branches leading to a node
λ	Total failure rate
r	Repair time
U	Annual outage time
λ_a	Active failure rate
s	Switching time
P_c	Stuck probability
λ'	Maintenance rate
r'	Maintenance duration

CHAPTER 1: INTRODUCTION

1.1. INTRODUCTION

The increasing dependence of modern society on electrical energy puts a heavy pressure on electric power utilities to provide an energy supply of acceptable quality with reasonable assurance of continuity [1]. It is not economical and technically feasible to attempt to design a power system with one hundred percent reliability. Power engineers, however, attempt to achieve an acceptable level of reliability within existing economic constraints.

Attempts have been made over the last four decades to resolve the dilemma between the economic, operating and reliability constraints, by developing a wide range of techniques. The criteria and techniques first used in practical application, and in use even today, are deterministically based. The basic drawback of deterministic criteria is their inability to consider the probabilistic or stochastic nature of system behavior, customer demands or of component failures.

The need for probabilistic evaluation was recognized many years ago but these techniques were not widely used in the past due to lack of data and computational resources, etc. A wide range of probabilistic techniques have now been developed which attempt to recognize the severity of an outage event, its impact on system behavior and operation, together with the likelihood (probability) of its occurrence. The data required to support these techniques are generally available and computational resources are not a problem.

1.2. POWER SYSTEM RELIABILITY AND RELATED CONCEPTS

The word reliability when used in the context of power networks is generally defined as the concern regarding the ability of the power system to provide adequate supply of electrical energy [2]. The term reliability has a wide range of meaning and cannot be associated with single specific definition. In general terms, it is related to the existence of sufficient facilities within a system so that the system is capable of supplying electric power to its customers under both static and dynamic conditions, with a mutually accepted assurance of continuity and quality [3]. It is necessary to recognize the extreme generality of the term and therefore to use it to indicate, in a general rather than a specific sense, the overall ability of the power system to perform its function.

A simple but reasonable subdivision of the concern designated as system reliability can be made by considering the two basic and functional aspects of the system, adequacy and security [3]. System adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand or system operational constraints. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the consumer load points. Adequacy is therefore associated with static conditions which do not include system disturbances. System security relates to the ability of the system to respond to disturbances arising within it. These include the conditions associated with both local and widespread disturbances and the loss of major generation and transmission facilities etc. This thesis is restricted to the adequacy assessment of electrical power systems.