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To

My Grand Parents

(Late Mr. Babu Nandan Ram & Late Mrs. Dasi Devi)

My Parents

(Mr. Ghurbhari Ram & Mrs. Kamla Devi)

and

My Wife

(Mrs. Nidhi)

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Sachin Kumar

Abstract

This thesis provides a thorough examination of the electrical power system's reliability assessment. The investigations include the generation of natural lightning waveforms to evaluate the reliability of the power system by analysing the effects of the Lightning Impulse Voltage (LIV) waveform. Further, the integration of Distributed Energy Resources (DER), such as Conventional Generation (CG) and Renewable Energy Source (RES), including wind, solar, and battery storage systems, has also been accomplished, and the electrical system's reliability has been analyzed.

Incorporating the renewable energy sources into the distribution network offers some benefits with drawbacks. However, the advantages outweigh the disadvantages since it provides limitless, accessible, and cost-effective information in comparison to traditional sources. According to recent studies, the uncertainties of electrical power sources lead to probabilistic and reliability assessments of electrical systems. The system includes components that are prone to failure, such as offshore and onshore wind farms, microgrids, energy storage systems, and other high voltage networks. As a result, it's critical to talk about how to deal with uncertainty factors in the generating, transmission, and distribution systems. As a result, this thesis discusses use of such conventional energy, wind energy, solar energy, and battery storage technologies for reliability assessments.

When uncertainties are taken into account, integrating wind energy into the conventional grid poses a number of significant difficulties. To evaluate the dependability and performance of the Doubly Fed Induction Generator (DFIG)-based Wind Integrated Power System (WIPS), the uncertainties, such as the occurrence of a three-phase failure and lightning fault, are taken into account. As a result, the power system precondition research was conducted, which included Wind Farm (WF), Voltage Source Converter (VSC), and lightning voltage and current phenomena. As a result, this thesis considers the realistic equivalent circuit to generate lightning envelopes of impulse voltage and current as well as rectangular pulse current. The resulting

lightning fault impulse voltage is then applied to the 3-phase terminals of grid-connected DFIG-based WIPS. To compare the output responses of the DFIG-based WIPS, a 3-phase short circuit fault is implemented. The controller gain values are used to monitor the system's behaviour under both faults. The gains of a sixth-order transfer function for Wind Turbine Generator (WTG) are calculated using an optimization technique, which included proportional (k_p) and integral (k_i) gains. The Monte-Carlo (MC) simulation technique is used to evaluate the power system's reliability, with the LIV being a major source of VSC failure. The DFIG-based WIPS is discovered to produce significant responses under both kinds of failures by finding the optimum controller settings. It has also been discovered that the decrease in the number of failures in VSC during the lightning strike increases the system's reliability.

The thesis work has been extended further on the reliability assessment of renewable energy interfaced EPDN considering the Electrical Power Loss Minimization (EPLM). EPLM aims at minimizing the detrimental effect of real power and reactive power losses in the distribution system. Some techniques, including integration of RES, network reconfiguration, and expansion planning, have been suggested in the literature for achieving EPLM. The optimal RES integration (also referred to as Distributed Generation (DG)) is one technique to minimize electrical losses. Therefore, the locations to accommodate these RESs are obtained by implementing two indexes, namely $index_1$ for single RES and $index_2$ for multiple RESs. Then, the optimization technique is applied to obtain an optimal sizing(s) of the Distributed Generations for achieving the EPLM. The reliability assessment of the distribution system is performed using the optimal location(s) and sizing(s) of the RESs (i.e., Solar Photovoltaic (SPV) and WTG).

Moreover, a Battery Energy Storage Device (BESD) is also incorporated optimally with the RESs to achieve the EPLM further and to improve the system's reliability. The result analysis is performed by considering the power output rating of WTG-GE's V162-5.6MW (IECS), SPV-Sunpower's SPR-P5-545-UPP, and BSS-Freqcon's BESS-3000 (i.e., Battery Energy Storage System (BESS) 3000), which the corresponding manufacturers provide. According to the study outcomes, the results are found to be coherent with those obtained using other techniques that are available in the literature. These results are considered for the reliability assessment of the electrical distribution system. reliability assessment is further analyzed considering the uncertainties in reliability data of WTG and SPV, including the failure rate and the repair time. The reliability assessment of optimally placed Distributed Generations is performed by considering the electrical loss minimization. It is inferred that the reliability of the EPDN improves

by contemplating suitable reliability data of optimally integrated RESs.

This thesis thoroughly explores the reliability assessment of DG interfaced Distribution System (DS)s based on power loss minimization. The work has been performed on IEEE 33 bus and IEEE 118 bus Distribution Systems with 1CG, 1CG+1WTGs, and 1CG+2WTGs for several Power Factor (pf), including Unity Power Factor (UPF), 0.9, 0.85, and 0.82. Firstly, the optimal siting(s) and sizing(s) of DG/DGs is/are obtained based on loss of power minimization. An optimization technique is implemented to find the DGs' optimal sizing(s). The locations to accommodate these DGs are obtained by implementing the two indexes, namely, $index_1$, $index_2$, and $index_3$ for single and multiple DGs. The results obtained are coherent with the results obtained by using other techniques available in the literature. Then the reliability assessment of DS is accomplished considering uncertainties in DG reliability data, including failure per year (λ_p) and outage duration or Repair Time (RT). Various types of loads, including commercial, industrial, and residential, have also been considered to analyze the reliability. The reliability assessment of optimally placed DG integrated DS is performed for 1CG, 1CG+1WTGs, and 1CG+2WTGs, and it is observed that the DS's reliability improves with the increasing number of DGs and lower uncertainty in reliability data.

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Appendix A

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List of Abbreviations

AENS	Average Energy Not Supplied
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
BESD	Battery Energy Storage Device
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
CG	Conventional Generation
CF-PSO	Constriction Factor-based Particle Swarm Optimization
DER	Distributed Energy Resources
DFIG	Doubly Fed Induction Generator
DG	Distributed Generation
DS	Distribution System
ECOST	Expected Interruption Cost
EDNS	Energy Demand Not Supplied
EENS	Expected Energy Not Supplied
EIR	Energy Index of Reliability
ENS	Energy Not Supplied

EPDN	Electrical Power Distribution Network
EPLM	Electrical Power Loss Minimization
ESS	Energy Storage System
EV	Electric Vehicle
IEAR	Interrupted Energy Assessment Rate
LIV	Lightning Impulse Voltage
LI	Lightning Impulse
LOEE	Loss of Energy Expectation
LOLE	Loss of Load Expectation
LOLF	Loss of Load Frequency
LOLP	Loss of Load Probability
MC	Monte-Carlo
PDF	Probability Density Function
pf	Power Factor
PI	Proportional Integral
PSO	Particle Swarm Optimization
RES	Renewable Energy Source
RPCG	Rectangular Pulse Current Generation
RT	Repair Time
RTS	Reliability Test Systemm
SPR	Surface Plasmon Resonance
SPV	Solar Photovoltaic

SG	Spark Gap
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
UPF	Unity Power Factor
VSC	Voltage Source Converter
WECS	Wind Energy Conversion System
WF	Wind Farm
WIPS	Wind Integrated Power System
WT	Wind Turbine
WTG	Wind Turbine Generator