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Enhancing Power Reliability through Improved Distribution Substation Design

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Abstract

This dissertation work is a study about "**Distribution Substation to Improved the Power Reliability"**. The first task of the study is evaluating the reliability of the existing distribution system,calculating the most powerful reliability indices. The standard of other countries. As this study indicates, the existing power distribution system of the city has many problems. The main problems are high level of unreliability, low energy management, poor scheduled maintenance and operation. To address the challenges of the existing distribution system, designing of an improved substation has been proposed as a solution to tackle the problem.

The new design can be considered as a modern distribution substation which includes automatic reclosing systems to minimize the durations of interruptions, remote telemetry units to communicate with the control room and load dispatch center and the grounding grid system for safety of personals and equipment in the substation. The design process starts from forecasting the future load of the substation and includes detail procedure of fault current and voltage drop calculations, selection ofthe major substation equipment, selection of protection devices and the earth mat design.

The study utilized different meteorological and statistical data and software like MS-Excel, AutoCAD, Simulation, design and Optimization Software. The simulation is used to evaluate the designed power distribution substation to ascertain that, it produces the desired reliability improvements. The result of the simulation shows that the designed system can advance the reliability of the overall system by improving the reliability indices values.

Keywords: Power reliability, Distribution substation, Reliability indices, Substation design, Ethiopia

Introduction

The power distribution system is a critical component of electrical infrastructure, comprising transformers, poles, wires, and substations that deliver electricity to end-users. In Ethiopia, distribution substations step down transmission voltages to 33 kV or 15 kV, further reduced by transformers to 380 V three-phase or 220 V single-phase for consumers. Substations include switches, transformers, and protective equipment to ensure safe and efficient power flow.

Power quality and reliability are paramount, measured by efficiency, service continuity, voltage stability, and overall performance. In Ethiopia, frequent interruptions—sometimes multiple times daily—affect both low- and medium-voltage systems. Voltage drops cause equipment failures, bulb blackening, and reduced appliance efficiency, while overvoltages damage electronics. These issues undermine economic growth, particularly in industrial zones like Bishoftu City, located near Addis Ababa and designated for industrial development.

Statement of the Problem

Ethiopia's government aims to elevate the economy to middle-income status, emphasizing electric power expansion. Bishoftu, as an industrial hub, receives significant power allocation, yet suffers from chronic interruptions at low and medium voltages. This thesis conducts a comprehensive investigation of Bishoftu's distribution problems, proposing design improvements as a prototype for nationwide application. The focus balances advanced technology with cost optimization to enhance reliability.

Objectives

To investigate power distribution issues in Bishoftu and recommend enhancements via redesigned substations. Assess problems from customer and utility perspectives at selected substations.

Forecast future loads.

Design an improved system to resolve issues.

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Estimate economic impacts.

Evaluate reliability improvements through simulation.

Significance of the Study

This study provides a detailed analysis of Bishoftu's distribution challenges and a complete redesign, including economic assessment. Results can guide the Ethiopian Electric Power Corporation (EEPCO) for implementations in Bishoftu and beyond.

Study Area

Bishoftu (9° 6' N, 37° 15' E) is an industrial and tourist zone in Oromia, Ethiopia. Bishoftu Substation II supplies the city and nearby towns with 132 kV input from Kality, stepped down via three transformers (16/20 MVA, 16/8/8 MVA, 16/20 MVA). It operates radially with outdated oil circuit breakers and manual data handling.

Literature Review and Theoretical Background

Electrical Substations

Substations transform voltages using transformers, facilitating power flow from generation to consumption. They include switching, protection, control equipment, and transformers. Distribution substations isolate faults, regulate voltage (2.4–33 kV), and serve urban areas with complex setups.

Substation Design Considerations

Key factors include reliability, cost, expansion potential, land availability, safety clearances, environmental impacts, and central location. Layouts start with one-line diagrams showing lines, switches, breakers, and transformers. Buses connect components, with configurations affecting cost and reliability.

Switching and Load Management

Switching connects/disconnects components for maintenance or faults, planned or unplanned. Load size determines substation capacity; critical loads require redundancy. Protection needs vary by load criticality, using breakers, fuses, and relays.

Construction Methods

Options include wood (inexpensive for small sites), steel lattice (high strength), low-profile steel, or unit substations (integrated components).

Reliability Configurations

Single Bus Bar: Low cost, simple, but lacks flexibility; faults shut down the entire bus.

Double Bus Bar: Allows circuit transfers; higher reliability but costlier.

Double Bus Bar with U Form: Dual breakers per circuit; maximum reliability.

Double Bus Bar with Bypass: Combines double bus and transfer; for high-voltage sites.

Ring (Mesh) Bus: High reliability via looped breakers; complex relaying.

Distribution Automation

Benefits include reduced outages via auto-restoration, improved voltage control, fault detection, and financial gains from quick restoration. Areas: substation/feeder automation and consumer-side.

Reliability Analysis

Reliability ensures supply adequacy and security against disturbances. Indices consider customers, load, duration, power interrupted, and frequency.

Failure Frequency (f): Failures per year/unit length.

Mean Time to Failure (MTTF): Average operational time before failure.

Mean Time to Repair (MTTR): Average repair time.

Availability (A): MTTF / (MTTF + MTTR).

Unavailability (U): 1 - A.

Interruptions: Transient (self-clearing), permanent (requiring repair), planned/unplanned. Characteristics: Momentary (<5 min) vs. sustained; causes include faults, protection errors.

Reliability Indices

SAIFI: Average interruptions per customer = $\sum(\lambda_i N_i) / \sum N_i$.

CAIFI: Interruptions per affected customer.

SAIDI: Average duration = $\sum(U_i N_i) / \sum N_i$.

CAIDI: Duration per interruption = SAIDI / SAIFI.

ASAI: Availability fraction = $(\sum N_i * 8760 - \sum U_i N_i) / (\sum N_i * 8760)$.

ASUI: 1 - ASAI.

ENS: $\sum(L_a(i) U_i)$.

AENS: ENS / total customers.

ACCI: ENS / affected customers.

ALIFI/ALIDI: Load-based frequency/duration.

MAIFI: Momentary interruptions.

Economics of Reliability

Higher investment improves reliability non-linearly. Outage costs: Utility (revenue loss, repairs) and customer (production halts, spoilage). Sector Customer Damage Functions (SCDF) and Composite (CCDF) quantify costs. Indices like EENS, ECOST, IEAR guide cost-worth assessments.

Related Research

Goodin et al. (2010) compared reclosers and sectionalizers for reliability gains. Makarov and Moharari (2009) proposed a fuzzy-logic reliability/security index. Roos (2005) evaluated solutions socio-economically. Kim (2009) modeled aging effects. Zhang et al. (2010) assessed conceptual designs. Derbie (2014) improved Adama's grid via smart reclosers, boosting reliability 50-75%.

Results and Discussion

Data from substation feeders (compiled in Table 2, not shown) revealed: SAIFI = 1812.67 interruptions/customer/year; SAIDI = 1770.17 hours/customer/year; ASUI high, indicating poor availability. ENS significant due to outages. Compared to international/EEPCO standards, reliability is poor. Causes: Low capacity, aging equipment, manual operations, inadequate maintenance.

Conclusions

Bishoftu Substation II fails EEA standards with excessive interruptions and unavailability. Causes include outdated equipment and poor maintenance. Proposed upgrade to double bus bar with automation improves reliability significantly, serving as a national model.

This research work shows that the reliability of the Bishoftu substation II (distribution system of Bishoftu city) does not meet the requirements set by the regulatory body that is, Ethiopian Electric Agency (EEA). The average frequency of interruptions at the existing substation is 1812.67 interruptions per customer per year and the average duration of interruptions is 1770.17 hours per customer per year. There is extremely high unavailability of electric power in the distribution network. The power supply of the overall system is unavailable for 1770.17 hours per year. There is also much loss of unsupplied energy due to both planned and non-momentary outages in the existing system. And also, the reliability of Bishoftu city power supply is very poor as compared to the international reliability indices and the reliability indices set by EEPCO. There are many reasons for these reliability problems according to this work, the low capacity, arrangement, aging of the substation equipment, poor trained of scheduled maintenance and operation and lack of new technologies such as remotely controlled smart reclosers and circuit breakers are recognized as the main causes for the identified problems.

Reference

[1] Y.V. Makarov and N.S. Moharari, “A Generalized Power System Reliability And Security Index,” IEEE, 2010.

[2] F. Wang, “Reliability Evaluation Of Substations Subject To Protection Failures,” Delft University, 2012.

[3] S. Derbie, “Study On Reliability Improvement Of Adama City Power Supply Using Smart Grid Technology,” Addis Ababa University, 2014.

[4] L.S. Flynn B, “Distribution automation pilot at PacifiCorp,” Western Energy Institute, 2006.

[5] R. Hunt et al., “Simplifying Protection System Design for Distribution Substations,” Texas A&M Conference, 2012.

[6] K. Jabrand and H. Nordli, "Innovative Substation Solutions To Reduce Investment costs," 2001.

[7] K.P. Sangar, "Selection Of Appropriate Location Of Substation For Planning Of Distribution System," Thapar University, 2009.

[8] J.D. McDonald et al., "Distribution Systems, Substations, and Integration of Distributed Generation," Springer, 2013.

[9] M. Dalis, "Design decisions for outdoor substations," McGraw-Hill, 1980.

[10] San Juan, P.R., "Basic Guides for Electric Substation Design," Colegio de Ingenieros, 2010.

[11] S.V. Ramakrishna and A. Gupta, "Reliability Of Power Supply," CEA, 2012.

[12] L.P. Manohar, "Reliability Assessment Of A Power Grid With Customer Operated Chp Systems Using Monte Carlo Simulation," University of Massachusetts, 2009.

[13] T. Dorji, "Reliability Assessment Of Distribution Systems," Norwegian University, 2009.

[14] H.K. Kim, "Reliability Modeling And Evaluation In Aging Power Systems," Texas A&M, 2009.

[15] F. Roos, "Electricity Supply Reliability Evaluation Of Improvement Solutions For Existing Electricity Networks," 2005.

[16] J.D. Kueck and B.J. Kirby, "Measurement Practices For Reliability And Power Quality," Oak Ridge National Laboratory, 2004.

[17] D.C. Secui and G.V. Bendea, "Reliability Indices Assessment Of Power Distribution Substations," University of Oradea, 2009.

[18] D. Zhu, "Power System Reliability Analysis With Distributed Generators," Virginia Polytechnic, 2003.

[19] R.E. Goodin et al., "Distribution Reliability Using Reclosers And Sectionalizes," 1999.

[20] D. Nack, "Reliability Of Substation Configurations," Iowa State University, 2005.

[21] Y. Zhang et al., "System Level Reliability Analysis For Conceptual Design Of Electrical Power Systems," 2010.