Original Research Article

Quantification and Analysis of Human Errors across the Life Cycle of Electrical Installations

ABSTRACT

The modern power system has different installations and as they are manmade, their consistency and security are dependent on human intervention. This research study has been carried out to analyse different types of faults in Electrical Installations according to life cycle and human related intervention in the various stages of the life cycle of an electrical installation. Secondary data has been collected to derive the results regarding the electrical faults in Electrical Installations according to life cycle and human intervention in the various stages of the life cycle of an electrical installation. It is found that electrical failures majorly occur in transformers, switchgear and rotating machines. By categorizing electrical faults into its life cycle, the different human errors were realised. The stages of machine life cycle found are design, assembly, inspection, operating and maintenance. By constructing a network and combining it with the life cycle of the installation, different human involvements have been recognized that leads to faults and accidents.

Key Words: Electrical Installations, Electrical Equipment, Component, Life Cycle, Error, Human Intervention

1. Introduction

The modern power system which utilizes electricity for fulfilling various purposes has different installations in it like transformers, cables, switchgear, motors, generators etc. The wear and tear of electrical installation and equipment is common because of their continuous usage, and this progression starts as soon as the installation is set up. If wear and tear is not controlled, it can cause electrical catastrophes, breakdowns, power outages and accidents.

Electricity is used to power machinery, produce lighting, broadcast electromagnetic waves for telecommunication, cool or heat the air, propel transportation vehicles, etc. The electricity industry is generally divided in four processes, first, electricity generation, Second, Electricity transmission, third, Electricity distribution and fourth, Electricity retailing.

Electricity generation is the process of producing electrical power. It can be generated from non-renewable sources of energy like coal, oil or natural gas. It is also generated from renewable sources of energy such as water, sun, wind, nuclear fission etc. The transmission and the distribution network together are known as the power grid or simply grid. Electricity retailing is the final selling of electric power from generation to the end-user. Electrical equipment is an apparatus designed, installed and utilized for conducting, controlling, generating, transmitting or distributing electrical power. It typically comprises of an enclosure, a collection of electrical components, and often a power control mechanism to turn on or turn off the equipment.

With the expansion in industrial activity there is a boost in the electricity demand. Rising population along with growing electrification and per-capita usage is another reason for the consumption of electrical power. As a result, large-scale projects and investments across the value chain have given an impetus to the industry.

India is the third major producer and third leading consumer of electrical power in the world, with the installed power capacity reaching the mark of 344 GW (Non-renewable energy) as of February 2019 (BP Statistical Review World Energy 2018). The nation also has the fifth highest installed capacity in the world (Power Industry Report, May 2019).

2. Literature Review

2.1 Types of Electrical Installations and Critical Faults in them

The maintenance and testing of electrical power equipment is explained in this book. It elaborates all types of major electrical installations used in industries, commercial buildings and residential buildings and the various types of faults occurring in them. The operation of electrical equipment has been explained from the human point of view as humans are the users of them (Gill, 2008).

2.2 Concept of Human Errors and Accidents

Quality management and reliability engineering philosophies were acquired that apply to error reduction. Researcher proposed a hands-on solution to operators that offers proposals, instruments and a plan that any electrical utility can implement to decrease the probability of errors in its control centres, power plants and out in the field (Terry Bilke). The problem of human errors had been divided in two ways, the person method and the system method. The person method concentrates on the mistakes of individuals: absentmindedness, inattentiveness, or ethical drawback. The system method focuses on the situations under which persons work and tries to shape defences to prevent mistakes or lessen their consequences. High-integrity companies, which have rarer accidents, have identified that human inconsistency was the method to prevent mistakes, but concentrated on inconsistency, and were inattentive with the likelihood of failure (Reason, 2000). Heinrich's Accident pyramid has created an awareness to comprehend the order of grave accident happening and consequently the companies have designed their accident prevention agendas. Yet, quick and differentiated industrial actions rose and consequently the risk of grave accidents rose. The study on post Heinrich suggestion recommended revalidating the theory and companies to redesign their hazard prevention programs (Penkey & Siddiqui, 2015).

2.3 Life cycle of electrical installations

Total quality maintenance, bearing in mind that to attain maintenance efficiency improved manufacturing procedures proficient of manufacturing quality products without disruption must be available (Al-Najjar, 1996). The general purpose of the maintenance procedure is to augment the profitability of the operation and improve the total life cycle budget without conceding security or ecological issues. The paper offers a new practice for risk-based maintenance. The proposed procedure is detailed and measurable. It includes three main elements: risk approximation, risk assessment, and maintenance preparation (Khan & Haddara, 2003). The major part of the report evaluates the factors that may influence inspection act and explains the applicable results from the literature. The report completes with a reiteration of the importance of inspection research and a brief of the major suggestions for refining inspection performance (Judi E, 2012). An automatic diagnostic system was projected by the paper for preventive maintenance (Chou & Yao, 2009). This paper is useful to people employed in the area of maintenance engineering (Dhillon & Liu, 2006). Electrical safety by design and maintenance is serious in order to help avert or lessen electrical accidents due to catastrophe of electrical equipment (Neitzel, 2016). Guide to Health and Safety by Design (2018) shows that designers have a central role in handling health and safety dangers. There are important principles of Health and Safety by Design that designers should follow. There are specific things to consider when designing structures, plant or substances. The guidelines begin with general notions that cover the Health and Safety at Work Act 2015, then it looks at the ideologies of Health and Safety by Design and it describes Health and Safety by Design.

2.4 Human interventions in electrical industry

Researcher has proposed a study of the questions prevailing in substation equipment care and restoration and offers the well-targeted countermeasures (Yuan, 2016). Researcher has conducted a study in an electricity distribution company (with rotational 12-hour shift work) in Iran during an 8-year period to review explanatory factors of wounds and damages. Workplace hazards are accidental events that cause damage. The socio-economic effects and human costs of accidents are huge around the world. Many fatalities happen every year in electricity distribution companies. Some electrical injuries are electrocution, electric shock, and burns (Rahmani et al., 2013). **I**nformation about the occupational characteristics of the wounded person, the instant at electrocutions that occurred in 1992-1996 to workers in the power sector of Greece, and its consequences are contemplated. The approximation of the accident rate per 1,000 workers, with sole attention to fatal accidents, is estimated. Also, the formation of an information system for accidents is proposed (Batra & Ioannides, 2002). Several diverse physiognomies of human blunder in maintenance held valuable for the factories are well thought-out, together with substantiations, numbers, and events; happening of faults in equipment lifetime, components of a maintenance person's time, maintenance condition and the motives for the presence of maintenance fault, kinds of errors, regular design mistakes and valued design rules to diminish equipment faults, maintenance guidelines, and fault scrutiny methods (Dhillon, 2014). A general outline is explained that categorizes design error according to people and organization. The paper suggests that people have the highest tendency to reduce mistakes through the procedure of set learning. This is because the work atmosphere offered by a company and the procedures used to give construction projects impact the nature and skill of people to accept tasks. Subsequently, there is a variety of policies that need to be accepted to reduce design mistakes so that safety and project implementation are improved (Lopez et al., 2010). Human faults Studied in nuclear-power-plant systems in combination with common-mode failures. The blunders evaluated are inapt testing, lacking maintenance plan, and calibration mistakes. The technique utilized, characterizes a positive input to power stations systems quickness by knowing common-mode failure when operating functions are involved. It is also pertinent to other complex manmade, man-machine system (Lisboa, 1988). Many plant power failures and accidents including personal injury are a product of human error rather than incompetent or faulty equipment. The paper studies the effect of operating errors on industrial power systems. The viewpoint and key fundamentals of confirmed systems and plans which add to system consistency are studied (Floyd, 1986). The techniques for pre-maintenance and post-maintenance are well thought-out for prospective failure states. For each condition, human fault prospect is computed for each case using the Success Likelihood Index Method (SLIM). Results are also calculated in this methodology (Noroozi et al., 2013).

3. Problem Statement

The World Bank said in the report that India lost a whopping $86.1 billion, or around 4% of its GDP because of distortions in the power sector. Estimated at 1.42 per cent of GDP per year, the impact of power shortages on downstream rural households and firms is the second largest economic cost for India. The electrical failures majorly occur in transformers, switchgear, relays, buses, cables and rotating machines. The faults can occur in different components of the installations. The mode of fault identified as electrical, mechanical and thermal. All the three modes of failures have a direct relation with human involvement as the equipments installations are manmade. These faults in turn can create grave accidents and fatalities. Hence, the problem statement is to identify every possible human mistake that can occur in electrical equipment and Electrical Installation.

4. Research Objectives

4.1 To study human related intervention in various stages of life cycle of an electrical installation

4.2 To analyse different types of faults in Electrical Installations according to life cycle

5. Research Methodology

The research contains the exploratory design as it helps to assist to segregate key human errors and its relationship with the electrical faults for further scrutiny. Secondary data has been collected to derive the results regarding the electrical faults in Electrical Installations according to life cycle and human intervention in the various stages of the life cycle of an electrical installation. The external data collected from books, government standards and published research papers and material of various research scholars associated in the field of electrical industry and quality management.

6. Analysis and Major Findings

The electrical failures majorly occur in transformers, switchgear, relays, buses, cables and rotating machines. The faults can occur in different components of the installations. The mode of fault can be electrical, mechanical or thermal. All the three modes of failures have a direct relation with human involvement as the equipments and equipment installation are manmade.

6.1 Types of failure in Electrical Installations

Breakdowns can occur in any electrical installation at any time. The key power equipment taken for consideration are transformers, switchgear, switchgear buses, electromechanical relays, cables, and rotating machines. This equipment makes up the whole power system and any problem in this equipment can put the system integrity and reliability at stake. A failure can occur in any part of the installation such as enclosures, insulation, or an insulation system, connections, internal parts etc (Gill, 2008).

Following table gives a list of components of different electrical equipment where there is a possibility of failure.

Table 1: List of components of electrical equipment where fault can occur

Installation	Components
Transformers	Enclosure, Coils, Core, Electrical Connections, Insulating Oil, Terminals, Tap changers.
Switchgear	Enclosure, Frame, Mechanical components, Lubricants, Contacts, Electrical control circuits.
Switchgear relay	Enclosure, Coil wire, Coil spool, Coil coating, Contacts, Slip bearings, Cams, Timing Diaphragms.
Switchgear Bus	Conductor, Enclosure, Insulators, Electrical, Connections.
Cables	Insulation, Jacket, Conductor, Shield, Sheath.
Rotating Machines	Insulation, Windings, Girth Cracking, Bearings.

6.2 Types of Errors

There is a rising consciousness that unless all fundamentals in the electrical installation's life cycle are enhanced, there may not be optimal safety. The primary step is to comprehend the entire electrical setting that occurs within this life cycle. Electrical safety may be influenced either positively or negatively in each phase of the life cycle. The following figure shows the classification of human errors in the various stages of the life cycle of an electrical installation (Dhillon & Liu, 2006; Gill, 2008).

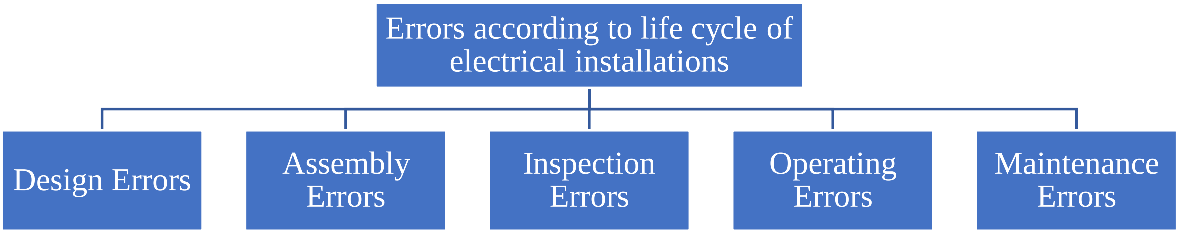

Figure 1: Errors according to life cycle of electrical installations

(Source: Dhillon, B. S., & Liu, Y. (2006). Human error in maintenance: a review. Journal of Quality in Maintenance Engineering, 12(1), 21–36. https://doi.org/10.1108/13552510610654510

The design procedure in the electrical setting includes assessing system notions, making equipment plan and arrangement diagrams, applying thorough designs for the service, acquiring hardware and apparatus, executing human wants in the design, assigning fitting role to personnel and Ensuring the efficiency of the man and machine interface.

6.3 Classification of faults in Electrical Installations according to life cycle

The life cycle of electrical equipment is the series of changes and development it passes from its inception till its scraping. By classifying electrical faults into its life cycle, the different human errors can be found out. The stages of machine life cycle found are design, assembly, inspection, operating and maintenance.

Below table shows the Classification of all faults into various phases of life cycle of an electrical installation. By doing this the quality of the equipment can be taken care of in every stage of the life cycle of that equipment.

Table 2: Classification of Faults in Electrical Installations according to life cycle

Installation	Design	Assembly	Inspection	Operating	Maintenance
Transformer	Windings Electrical Connections	Mechanical stress on the enclosure during transportation Moisture in core Loose connections Dirt/humidity in oil Corroded and contaminated terminals	Corrosion of enclosure due to moisture Dirt/humidity in oil Corroded and contaminated terminals	Degradation of coil due to overload/ overcurrent Transients due to switching Mechanical stresses due to inrush current Mechanical stress on terminals Arcing in tap changer	Corrosion of enclosure due to moisture Degradation of coil due to overload/ overcurrent Loose connections Dirt/humidity in oil

Switchgear	Cracking of insulation due to arcing	Misalignment of contacts Loose connections Loosening of Connectors	Corrosion of enclosure due to moisture Damage to anti-corrosive paint Electrical overload on contacts	Mechanical stress on latch, spring and racking assembly Electrical overload on contacts Physical damage to control circuits Resistors/Relays/Switches overload	Corrosion of enclosure due to moisture Damage to anti-corrosive paint Drying out of lubricant Deposition of dirt and contamination Loose connections
Relays	Error in trip setting Programming error in numeric relays	Mechanical stress on the enclosure during transportation Misalignment of contacts	Corrosion of enclosure due to moisture Loosening and aging of coil spool Corrosion of slip rotor Bearings	Cracking of coil wire due to high temperature Heating up of contact carriers Overloading of capacitors	Corrosion of enclosure due to moisture Loosening and aging of coil spool Twisting of contacts Corrosion of slip rotor bearings Corrosion of damping magnet
Switcgear Bus	Cross-sectional design defect Improper terminal	Damage to conductors during transportation Loose connections	Corrosion of enclosure due to moisture Deposition of dirt and contamination on Insulators	Heating of conductors by overloading Physical damage	Corrosion of enclosure due to moisture Deposition of dirt and contamination on insulators Loose connections
Cables	Low grade material	Breakage/Damage Damage in transportation to jacket Loosening of connectors	Corrosion of cable sheath due to alkaline environment	Heating up of cables Degradation of cable shield	Wetting of cables Degradation of cable shield Corrosion of cable sheath due to alkaline Environment
Rotating Machines	Calculation error in design, Cooling system	Open machines leading to abrasive material attack which can puncture insulation	Moisture in windings Reduce electrical and mechanical strength of insulation leading to puncture; increased sensitivity to mechanical vibration Clogging in	Insulation breakdown due to high temperature causing delamination, partial discharge and short circuit High temperature causes reduction in physical strength, shrinkage, reduced conductivity High mechanical stresses which	Insulation breakdown due to high temperature causing delamination, partial discharge and short circuit High temperature causes reduction in physical strength, shrinkage, reduced thermal

			filters and air ducts	loosens bracing and can puncture insulation Overheating due to unbalanced supply voltage	conductivity Clogging in filters and air ducts

6.4 Classification human related intervention in the various stages of the life cycle of an electrical installation

Along with the hierarchy the situation/setting in which the personnel work also must be considered as it straight away influences the functioning of the individuals. Another factor that must be well-thought-out is the man machine system of the electrical installation. This system is important as the interface between man and machine can also give onset to grave errors.

Table 3: Classification of Human Errors in Various Stages of Life Cycle

Error Factor	Design	Assembly	Inspection	Operating	Maintenance
Personal	Attention Knowledge & Skills Experience Negligence Reasoning Mistaken Assumptions Violations Lack of Specific Knowledge	Attention Knowledge & Skills Experience Negligence Human anatomy & Anthropometrics Motor Skills Reasoning Habit Mistaken Assumptions Violations Lack of Specific Knowledge	Attention Knowledge & Skills Experience Negligence Beliefs & Perception Memory Habit Mistaken Assumptions Recognition Failure Lack of Specific Knowledge	Attention Knowledge and Skills Experience Negligence Human anatomy & Anthropometrics Motor Skills Beliefs & Perception Memory Decision making ability Habit Mistaken Assumptions Recognition Failure Violations Loss of Biorhythm Lack of Specific Knowledge	Attention Knowledge and Skills Experience Negligence Human anatomy & Anthropometrics Motor Skills Beliefs & Perception Memory / Reasoning Decision making ability Habit Mistaken Assumptions Recognition Failure Loss of Biorhythm Lack of Specific Knowledge

Team	Leadership Role awareness Resource Management Participation Information Delivery	Leadership Team co-ordination & Integration cohesion Role awareness Supervision	Availability of communication Quality of communication Leadership Role awareness Supervision Standardization in instruction	Availability of communication Quality of communication Leadership Team co-ordination & Integration cohesion Role awareness Resource Management Supervision Standardization in instruction Information Delivery	Availability of communication Quality of communication Leadership Team co-ordination & Integration cohesion Role awareness Resource Management Supervision Standardization in instruction Information Delivery
Organization	Staff & its quality Recruitment Training & its quality Management Efficiency Vendor Management Quality of Resources Organization structure Policies & Processes Quality Management Documentation	Staff & its quality Recruitment Training & its quality Management Efficiency Organization Structure Policies & Processes Documentation	Staff & its quality Recruitment Training & its quality Management Efficiency Organization Structure Policies & Processes Documentation	Availability of communication Quality of communication Leadership Team co-ordination cohesion Role awareness Resource Management Supervision Standardization in instruction	Staff & its quality Recruitment Training & its quality Management Efficiency Maintenance Culture Organization Structure Policies & Processes Documentation
Situation	Task Load Stress Time Pressure Telework Fatigue Complexity	Task Load Stress Time Pressure Design of working time/Shifts Fatigue Complexity Illumination /Dark Lighting Temperature variations Adverse	Task Load Stress Time Pressure Design of working time/Shifts Fatigue Bad procedure Illumination/Dark Lighting Inadequate design of workplace Task Characteristic	Task Load Stress Time Pressure Design of working time/Shifts Fatigue Bad procedure Complexity Alcohol/Drugs involvement Noise/Vibrations Illumination/Dark Lighting Temperature Variations	Task Load Stress Time Pressure Design of working time/Shifts Fatigue Bad procedure Noise/Vibrations Illumination/Dark Lighting Temperature Variations Adverse Behaviour Inadequate design of workplace Movement Constriction

		Behaviour Inadequate design of workplace Movement Constriction	Frequency of task Movement Constriction	Adverse Behaviour Inadequate design of workplace Task Characteristic Frequency of task Movement Constriction	
Machine	Human-System Interface Tools & Equipment Design Deficiency Miscalibration	System Response Tools & Equipment	Tools & Equipment Information not visible	Human-System Interface Tools & Equipment Panel/Screen Layout & Arrangement Panel/Screen Visibility Panel/Screen coding/labelling Convenience to operate Handle/Lever/Switch	Tools & Equipment Housekeeping Convenience to operate Handle/Lever/Switch

7. Summary of Major Findings

The life cycle of electrical equipment is the series of changes and development it passes from its inception till its scraping. By classifying electrical faults into its life cycle, the different human errors found out. The stages of machine life cycle found are design, assembly, inspection, operating and maintenance. By building a network and combining it with the life cycle of the installation, 64 different human involvements has been identified which can lead to electrical faults and accidents. These interventions can be addressed specifically for mitigating their effects. In further research in future the process of Kaizen continuous improvement can be applied to maintain the quality of electrical installations by eliminating human errors.

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