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RESEARCH ARTICLE

Design of Faulty Switching Detection and Alert System to Prevent Fatality of Servicemen During Transformer Maintenance

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ABSTRACT Enriching electric safety feature is the foremost concern for reducing fatality. Recent power system installations have been equipped with all safety features by employing modernized technological innovations. However, the age-old equipment installed long before lacks safety features. One of the critical safety feature issues that cause a threat to human life due to lack of safety features is the malfunction of the air break isolation switch which is caused by thermal effects. Similarly, fatality during the maintenance of distribution of the transformer is of significant concern. Globally, air break switches have been utilized to isolate power lines and transformers in the distribution premises. Facilitating the transformers with safety features is a highly complicated and expensive task. Consequently, severe fatalities have been recorded due to the lack of accident preventive techniques. In this perspective, the proposed work is to develop a Faulty Switching Detection and Alert System (FSDA) to alleviate the life-threatening issues. The FSDA mechanism is an integrated actuator setup configured beside the transformer switches and operating rods and the malfunction of switches is detected and alerted. The Programmable Logic Controller (PLC) module is used to integrate the detection mechanism with alert and display system. The system generates an alarm to alert the workmen to avoid fatality.

INDEX TERMS Switch malfunction, fatality during transformer maintenance, detection of faulty switching, PLC-based smart alert, fatality prevention technology.

I. INTRODUCTION

Despite the infrastructures of power sectors having been established long before, switching protection technologies are still outdated and ineffective. The authors of [1] have narrated various causes of fatality in electrical sectors and emphasized the significance of adopting protective and preventive devices. The impact of climatic change on Electrical Accidents and Risk has been predicted and analyzed [2]. Performance monitoring and survey are mandatory requirements for identifying circuit breakers and disconnecting the circuit or bolster conditions to prevent fatality [3]. A detailed causation model comprising 24 models covering 100 years has been developed by [4]. The work outcomes have enabled people to pay more attention to 'safety culture' in accident prevention. The electrical installations and equipment have to be verified and inspected periodically for their accident preventive features [5]. The workmen need to be educated and trained about all the safety aspects of handling electrical equipment during maintenance to reduce the risk of an accident [6]. The equipment failure and malfunctioning drastically influence the reliability of distribution substations [7]. An integrated asset performance monitoring cum diagnosis topology has been suggested by [8] to enhance the overall safety and reliability of the system. In 2014, accidents were recorded and analyzed due to false action of differential

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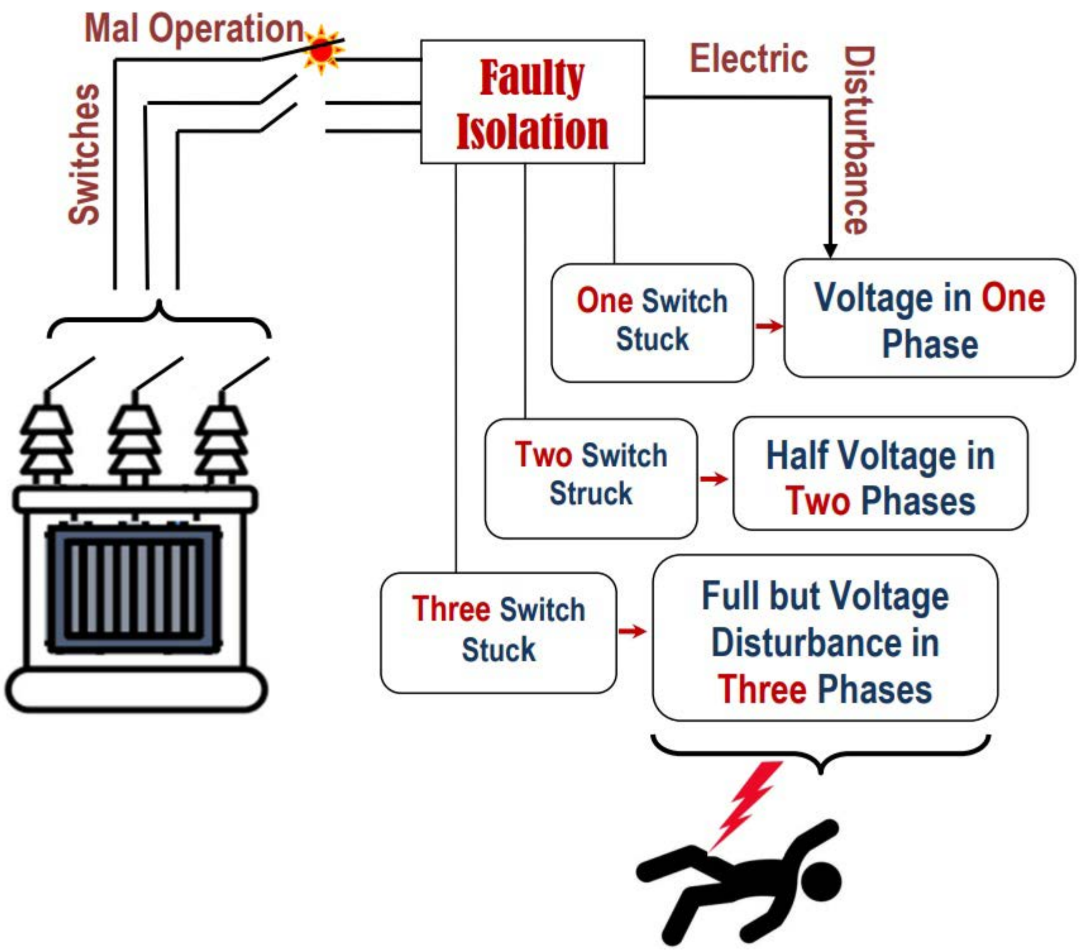


FIGURE 1. Graphical representation of consequences of the isolation switches malfunction.

protection of the main transformer [9]. It is deduced that the false action event has occurred due to the un-synchronism of sampled data. In 2017, through the results, it had been inferred that the remote control availability for disconnectors (Smart Grid Technology) contributed more to the increased the failure rate than the device aging [10]. Preventive maintenance services have shown a positive sign of accident reduction [11]. The transformer operation is highly affected by the faulty disconnector switching devices, and further, the power line operation is disturbed [12]. The early fault diagnosis is crucial for preventing unexpected fault occurrence of power transformers [13]. The air break disconnector switches are opened before reaching the transformer for servicing, maintenance and many others. On some instances, one or more switches remain unopened. This issue might have been caused by degradation due to ageing or deterioration. Hence, one or more phases of the transformer remain connected to the supply terminals. Subsequently, when the substation worker climbs over the transformer for servicing, the worker encounters a fatal accident. Such incomplete disconnection-based fatalities occur commonly in distribution sectors [14]. Due to this factor, nearly thousands of workers have lost their life in electric accidents globally, and the count has been continuing [15] and [16]. In addition, there is no prompt technology to avoid such fatality to date [17]. Further, the switch malfunction leads to severe power disturbance in the High Tension (HT) and Low Tension (LT) sides of the transformer. The consequences of the isolation switch malfunction has been represented graphically as shown in Fig. 1.Therefore, enhancing the existing isolation system with safety features becomes crucial and challenging. Besides, a written request has been sent to Right to Information (RTI) and collected the details about the fatality events at the distribution transformers. The details have been included to insist on the severity of the issue. A detailed electric injury survey report has been presented in [18], it has been suggested to improve the safety features and alert the mechanism to avoid electric accidents and reduce fatality. The lack of a prompt technique to identify the switching fault results in the growing rate of fatal accidents and power line disturbances. Hence, the scenario emphasizes the importance and necessity for a remedial technique. In this regard, the Faulty Switching Detection and Alert system (FSDA) has been proposed. It is a novel electromechanical coordinated system exclusively developed

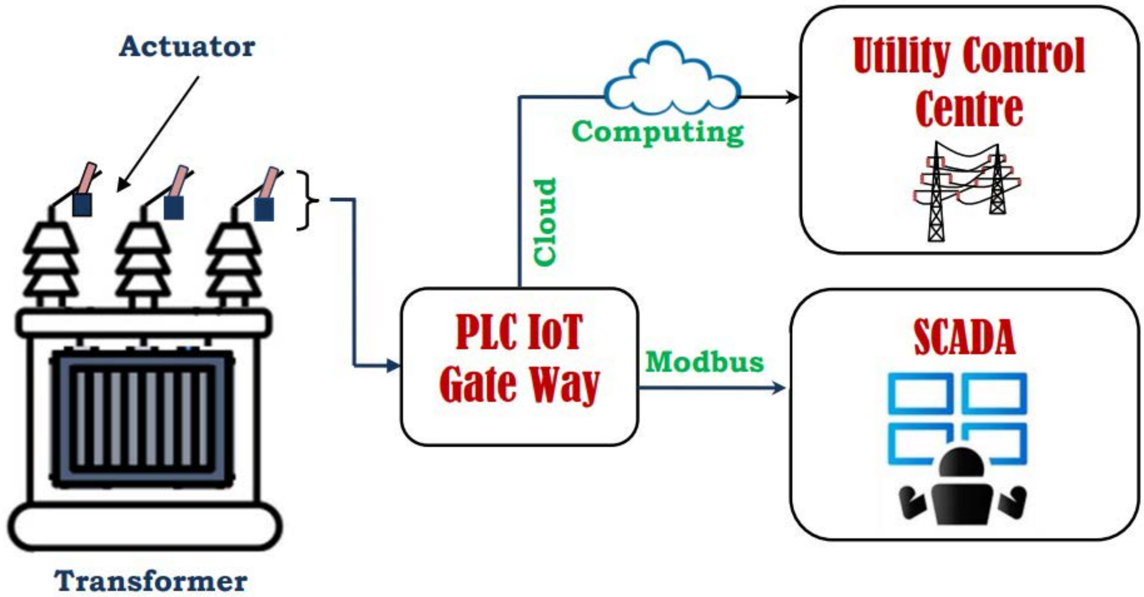


FIGURE 2. Remote monitoring and data acquisition features of the FSDA system.

for sensing the position of the switches and displaying the status of the isolation process. The spring rod type actuators are used to sense the position of the switch and it is integrated to PLC for detecting the switching system and produce alert signals.

Consecutively, a PLC IoT gateway can be integrated and it has the feature to provide cloud computing and integrating the system into the Supervisory Control and Data Acquisition (SCADA) system using a serial communication protocol such as MODBUS, which has been illustrated using a schematic sketch as shown in Fig. 2. Such advanced features facilitate the utility personnel to rigorously monitor and take immediate action during fault and malfunction. Further, the events can be recorded for data acquisition.

Section II deals with various state-of-the-art in isolation mechanisms and their limitations. Further, the power line isolation system used in various countries has been discussed. Section III highlights the major root causes of fatal accident occurrence possibilities. The proposed FSDA strategy has been illustrated in Section IV. The execution aspects of the system have been elaborated in Section V. The importance of executing the proposed strategy for safeguarding workman life has been emphasized in the conclusion of Section VI.

II. POWER LINE ISOLATION SYSTEM

The power system network emerged as an intelligent system with the penetration of advanced technology by installing highly protective and secured equipment. High voltage overhead lines and transformer isolation have been carried out with automatic circuit breakers in recent years.

A. STATE-OF-THE-ART ISOLATION SWITCHING DEVICES

The modern power line isolation system includes advanced safety features such as telemetry, monitoring, and control. The vacuum circuit breaker or Sulfur hexafluoride (SF6) Circuit breaker has been used for network isolation. However, the installations of such advanced technology are expensive and frequent maintenances are required for proper operation. In the distribution network, numerous switching points are required for isolating a particular portion of the network during maintenance. Hence, Air Break Switch (ABS) is commonly used as an isolation switch. The ABS switchgear uses air as a dielectric medium, and it is equipped with special horns to quench the arc during the current interruption. Globally, an ABS has been used as a switching point in the distribution network, especially to isolate the specific portions of the overhead lines, and transformer isolation during maintenance and services.

The modern air break switch is an electrical assembly set comprising a fuse block and a disconnect switch. The fuse protects the switch from over current. Hence, the possibility of hotspot formation and switch failure can be avoided. Moreover, the disconnect switches are interlocked with the door of the housing unit. As a result, the power supply must be terminated before opening the door of the unit. This modern ABS setup provides safety for operation. Besides, such a system is applicable for an individual sector or the transformers connected at the private premises, whereas in the distribution network, the power supply cannot be terminated for the entire network when the maintenance is required at a small region or sector. Further, the earlier installations have been done with conventional air break switches [19].

B. POWER LINE ISOLATION USING AIR BREAK SWICTH

Air break switches are used to open the power feeder line for maintenance. A schematic representation of air break switch setup is shown in Fig. 3. Three air break switches are provided in each phase and are commonly connected to a horizontal

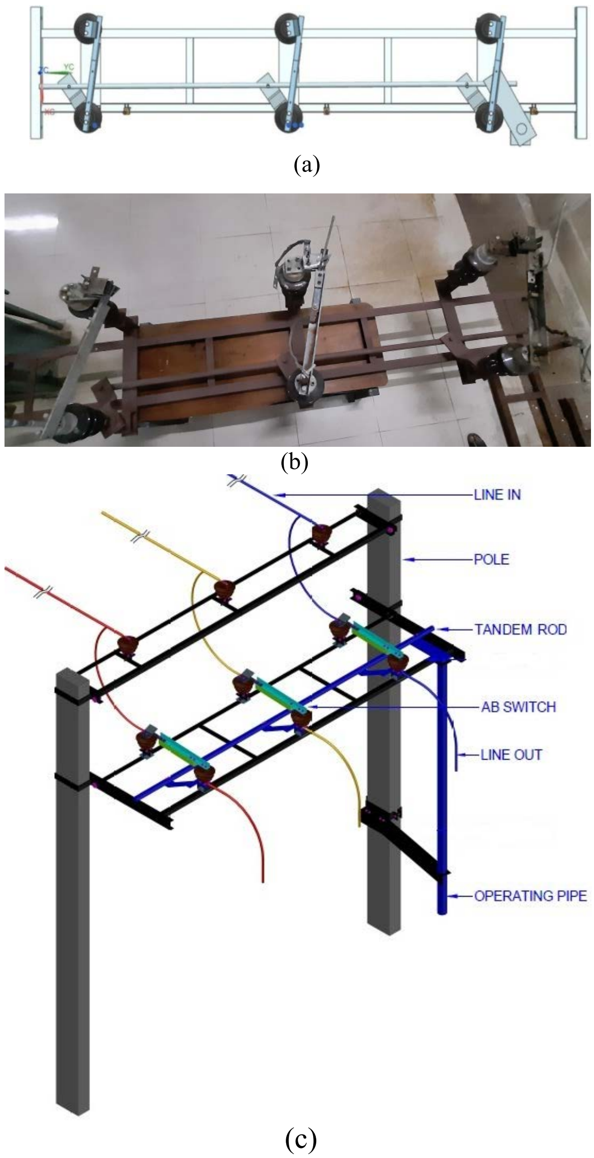


FIGURE 3. a) Schematic structure of distribution transformer with isolation switching setup b) Actual picture of a switches setup in a prototype model of a transformer C) Top view of the isolation switches in three phases.

lengthy lateral tandem rod fixed beside them. On operating the tandem rod in to and fro movement, all the three air break switches can be opened and closed simultaneously.

This process of opening the power line switch is known as gang operated air break switching. Since the tandem rod is in top surface of the transformer, a vertical rod (operating rod) is coupled to tandem rod from the bottom to access them. The operating rod is rotated a quarter rotations to perform the isolation process. It is made up of insulating material such as wood or fiber.

C. GLOBAL ASPECTS OF POWER LINE ISOLATION TECHNIQUE

A worldwide utility survey has reported an extensive description of the failure rate of the power system equipment [15]. Most of the countries use the same type of air break switches

TABLE 1. Gang operated air break switches used globally.

SN	Countries	References
1	United States	[20]
2	United Kingdom	[21]
3	China	[22]
4	India	[23]
5	Japan	[24]

in their distribution network. The possibility of accident occurrence is more in gang-operated air break switches compared to the single pole type. In the United States, a single-pole air break switch has been mainly used for isolation. Isolation is accomplished manually by the servicemen using an insulated handle. However, in some parts of the United States, gang-operated units are installed. Similarly, the gang-operated air break switches are used in the United Kingdom, India, China, and Japan, where the possibilities of an accident are higher. According to the field conditions, some changes may take place in physical installation but not in the technique. However, the gang-operated air break switches experience higher switches' malfunction issues due to hot spots and corrosion after prolonged usage. The gang-operated air break switches are used globally, and a few names of the countries are depicted in Table 1 with references.

III. FATAL ACCIDENT OCCURRENCE POSSIBILITIES

The fatal accidents due to direct electrical contact are 25 times greater than those involving accidents due to other means of electricity such as leakage, equipment blast etc [6]. Several studies have reported that a higher possibility of accidents is attributed to unsafe operations. In such a scenario, unnoticed failure of the disconnect switch may cause fatality [14].

Generally, during maintenance of transformer the switches in the three phases are opened for isolation. Once the three-phase switches are opened for disconnection, one or more switches get stuck within and remain connected. A graphical illustration of malfunction of the isolation switch has been furnished in Fig. 4. Without knowing this problem, if the workman climbs up for servicing faces fatal accidents.

Several such fatal accidents are reported on the electricity board [16]. Information about such accidents is not disclosed by any electricity authorities globally. Hence, by sending an information request to the RTI (Right to Information Act) board, the details of isolation-based accidents have been collected. The responses from several substations of a single state have been received in written format, and the details are depicted in Table 2. It provides information about the number of accidents from 2008 to 2018 in the state of Tamil Nadu, India.

A. GLOBAL SCENARIO OF ACCIDENTS DUE TO SWITCH MALFUNCTION

In the United States, a single-pole air break switch is used for isolation [25]. For a three-phase circuit, three single

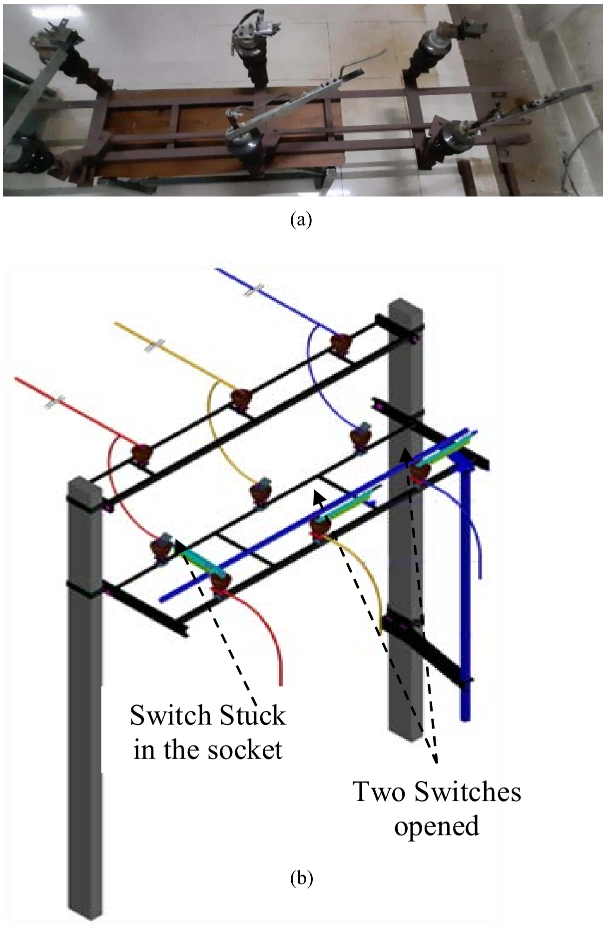


FIGURE 4. a) Actual picture of a switch stuck model b) Schematic representation of switch stuck event.

TABLE 2. Fatality details received through RTI.

Year	No. of Accident
2008	7
2009	6
2010	9
2011	8
2012	8
2013	12
2014	14
2015	14
2016	13
2017	17
2018	18
Total	126

switches are installed in each phase correspondingly. During the maintenance of the transformer, these switches are carefully disconnected manually by a serviceman [26]. Hence, the malfunctioning of a switch can be identified initially, and immediate action can be taken. Hence, the electric injuries and fatalities in the United States are lesser when compared in other countries. However, gang-operated air break switches are used in some parts of the United States [20], where the accident possibilities are high. It is reported in [15] that in the United States, the fatality due to over headline contact is 42%, and transformer is 26% of the total electric injuries. The electric accidents occurred during transformer servicing are mainly due to improper isolation whereas the electrical injuries due to carelessness and human errors are significantly increasing [16]. The literature [27], [28] demonstrated the characteristics of electrical injury and conveyed that contact with overhead lines has caused several electric injuries and fatalities. The rate of electric accidents is about 0.04% to 5% in developed countries, and it is 27% in developing countries, whereas the global average is 4.5%. In contrast, the electric accidents in China account for more than the global average and are reported in [29]. Globally, distribution transformers use air break switches for line disconnection. The standards, namely IEEE C37.30.5-2018, and IEC 62271-1:2017 have been used for high voltage air break switches [30], [31].

Though the manufacturers use the standards, the switch's lifespan depends on the range of temperature evolved due to current flow and environmental effects. Since temperature rise and environmental conditions are highly non-linear, the lifespan of the ABS is unpredictable. Hence, the predictive maintenance or replacements of the switches cannot be accurately established. Further, it is difficult to identify the switch malfunction.

B. WAYS OF SWITCH MALFUNCTION LEADING TO FATALITY

The transformer-based fatality occurs mainly due to stuck up in air break switches and the following are the possible ways of switch malfunction causing fatalities:

- When one or more switches are stuck up, it causes no disconnection
- If the switch is partially open, an arc is established, and it leads to improper disconnection
- When the operating rod is stuck due to corrosion, all the switches remain connected
- Damaged switches are replaced with jumpers temporarily, and they remain connected when the disconnect mechanism is activated.

C. CAUSES OF SWITCH MALFUNCTION

The air break isolation switches are in an open atmosphere, and it is exposed to all climatic variations. Hence, corrosion forms on the surface of the switches and sockets due to the oxidation reaction. It grows laterally over the entire surface as a discrete crystal appearance called as a-spot, and its schematic diagram has been shown in Fig.5.

In any electrical contact junction, the electric current flows through fine spots called a-spots. It is a materials' Surface micro-roughness phenomenon. The spots are highly discrete in bulk conductors, and the current flow lines are bundled

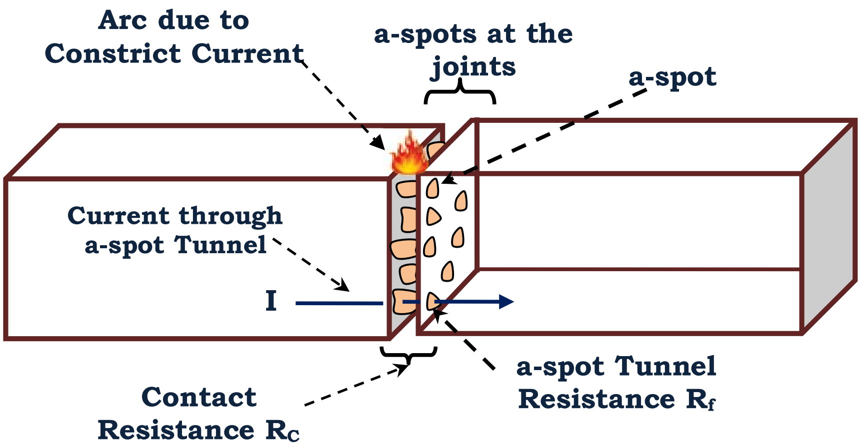


FIGURE 6. Constrict current flow through a-spot and arc formation.

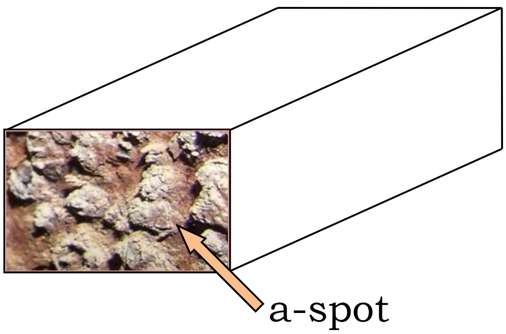


FIGURE 5. A-spot formation in the metal surface due to corrosion.

together to pass through the a-spot contact spots. A schematic sketch has been depicted in Fig. 6 to illustrate the phenomena.

The electrical contact area of a-spot is lesser than the mechanical contact area, resulting in constriction to current flow, known as constriction resistance. Contaminant films would often form around the a-spots and further constrict current flows due to increased resistance. The constriction resistance and the film resistance are collectively defined as contact resistance. The contact resistance is determined by several a-spots and cluster resistance (Holm resistance). In bulk conductors, the contact resistance is given as

$$R_c = \rho\left(\frac{1}{2na} + \frac{1}{2\alpha}\right) \tag{1}$$

where

a- Mean of a-spot radius

n- Number of a-spots

α- radius of the cluster (Holm)

ρ - Resistivity of the conductor

In a a-spot the current flow is restricted through a narrow uneven and irregular path known to be tunneling resistance. Consecutively, film resistance is exhibited through a quantum tunnel. The resistance due to tunneling of an insulating film of the metallic conductors is given as

$$R_f = \rho\frac{d}{A} \tag{2}$$

where d and A are the thickness and surface area of the film, respectively. The heat formed in an a-spot has to be dissipated through the conducting portion of the metal body. Since the conduction portions are restricted, the entire heat and the current flow in a narrow path. Hence, a high potential difference is produced around the a-spots. The voltage developed at the contact area is given as

$$V_c = IR_c \tag{3}$$

When the a-spot increases, the contact area decreases. Hence, the contact resistance Rc increases. Subsequently, the contact voltage increases and increased ionization in small gap, i.e., high voltage between small air gap ionizes the air molecules and a conduction path will be established for electron flow. Thus, arc is produced in the contact spot of the switch. The prolonged arcing leads to deformation in the contact structure and the switch stuck in the socket and further operation will become complex. This issue might result in a complete stuck up of switch where it cannot be opened or partially operable. At such a partially operating condition, the arc establishment possibilities are much higher.

The extensive analysis about the corrosion formation and the related expressions (1) to (3) gives a clear insight about the reason for switch stuck-up issue and its consequences. A periodical maintenance such as cleaning the dust between the contacts, wiping out the surface with cleaning aid will help in reducing the corrosion formation. A periodical and prior maintenance had shown an excellent sign of accident reduction [11]. Further, by maintenance services the own out and out dated switches can be identified initially and accidents occurrence can be avoided.

D. POWER LINE DISTURBANCES DUE TO

FIGURE 7. Representation of jumper connected between the switching terminals.

SWITCH MALFUNCTION

Generally, the transformer's HT (High Tension) side is isolated (opened) by an air break switch for maintenance or servicing purposes. During power line isolation process, following issues arises due to switch malfunction:

- ➢ Case I: One switch is stuck, and two switches are opened.
- ➢ Case II: Two switches are stuck and one switch is opened
- ➢ Case III: Three switches are stuck
- ➢ case IV: Damaged switches are replaced with jumpers

In the first case, two phases are open, and one remains stuck. The LT side will not receive any power. However, if the workman climbs and unknowingly comes in contact with the non-isolated live terminal, then fatal accidents would occur since the excitation will be present in one terminal. The possibilities of such accidents are less in this case.

In the third case, all the three terminals on both HT High Tension and Low Tension LT sides remain live. Since the isolation process is initiated and the switch open mechanism is executed, some switches may be stuck completely and some switches may disconnect partially. If the distance between the switch and hold is lesser, an arc is formed and supply tends to exist. There is no mechanism to indicate such a condition. Consequently, the LT side experiences voltage disturbance. Consecutively, the possibilities of fatal accidents are high in this case.

The fourth case deals with connecting jumpers at the place of damaged switches. The jumpers are conducting wire temporarily used to directly connect switching terminals to replace the damaged switches during emergency situation when the switches are not available to replace. In many occasions the jumper wire are left unnoticed. During next isolation process the jumper connected power line cannot be isolated. Hence, accidents are inevitable in this case. A jumper connected terminals has been depicted in picture shown in Fig.7.

In the second case, in addition to the possibility of fatal accidents, the LT side of the transformer undergoes severe power disturbances.

During one phase open situation, on the LT side, one phase experiences actual full voltage, and the other two phases exhibit half the value with 180° out of phase, the transformer LT side winding diagram has been shown in Fig. 8. The concerning supply voltage is given as

$$V_{\omega Y} = V_{YB} \tag{4}$$

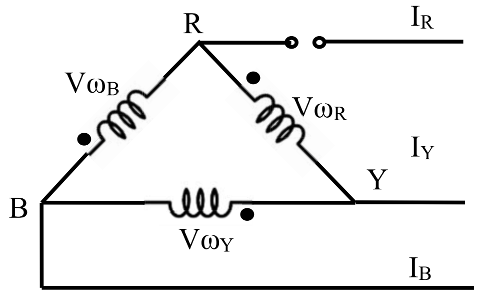


FIGURE 8. Transformer LT side winding setup during one phase open.

$$V_{\omega R} = V_{\omega B} = -\frac{1}{2}V_{YB} = \frac{1}{2}V_{YB}\angle 180^{\circ} \tag{5}$$

$$I_R = 0;\; I_Y = -I_B \tag{6}$$

where

$V_{\omega R}$, $V_{\omega Y}$ and $V_{\omega B}$- Voltage across the phase winding of the phases R,Y & B, respectively.

I_R, I_Y and I_B - Line currents of the line R, Y & B, respectively.

V_{YB} - Line voltage between the phases Y and B.

The variation in the phase voltage and the line current leads to drastic disturbance in the transmission line in the distribution network. The efficiency of the line reduces, and it can be deduced from the expressions (7) and (8). The line current is given as

$$I_l = \frac{P}{\sqrt{3}\, V_s \cos\phi} \tag{7}$$

where

P= Output power

V_s = Supply Voltage

Resistance of the conductor is given as

$$R = \frac{\rho l}{a} \tag{8}$$

The under-voltage and the line drop consequently increase the line current. It can be inferred by the phasor diagram as shown in Fig. 9.

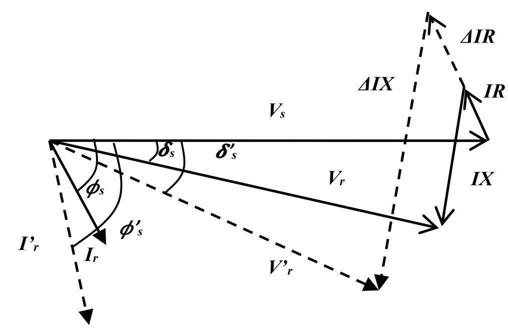


FIGURE 9. Impact of line voltage drop.

The line voltage drop is given as

$$V_d = I_l R = \frac{P}{\sqrt{3}V'_s \cos\phi'_s} x \frac{\rho l}{A} \tag{9}$$

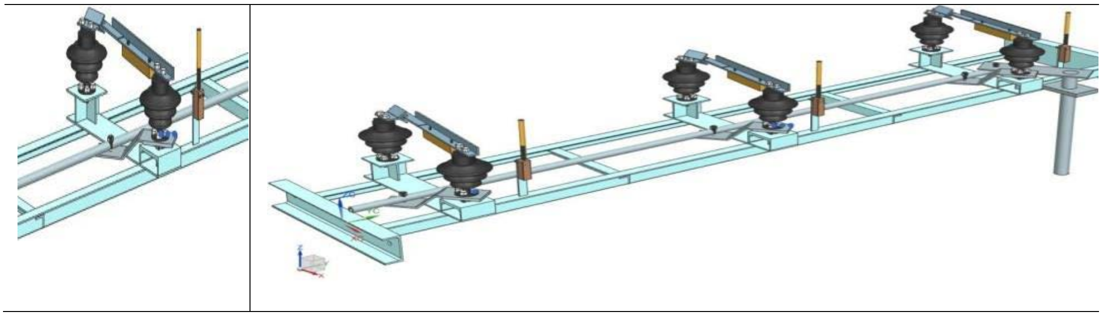


FIGURE 10. Pictographic model of the proposed actuator system.

where

V'$_s$ = Supply terminal voltage during mal operation

Cos'Φ = Power factor during malfunction

The reduction in line voltage leads to a rise in line current and hence, the transmission loss increases and results in increased temperature and heat dissipation. The dissipation loss is governed by Equation (10).

$$P_{loss} = 3\,(I_r+\Delta I)^2 R = 3 I_r'^2 R = \frac{P^2 \rho l}{V_s'^2 \cos^2 \phi_s' a} \tag{10}$$

The area of cross-section of the conductor is given as

$$a = \frac{I_l}{\delta} \tag{11}$$

where

δ - Current density

The faulty switching leads to voltage variation and deteriorates the performance of the line. The transmission line efficiency during malfunction of transformer isolation switches is given in Equation (12).

$$\eta_l = \frac{P_{out}}{P_{out} + P_{loss}} = 1 - \frac{\sqrt{3}\delta \rho l}{V_s' \cos \phi_s'} \tag{12}$$

The disturbance in the power network may last for a long duration and the performance of the line is affected until the fault is rectified. Hence, the malfunction of the switches leads to power line disturbance that is similar to a faulty line. The faulty switching leads to vast voltage disturbance and rise in current through the feeder line. Hence, it leads to exacerbate the other issues such as under voltage, load unbalances in the power distribution network.

The investigation about the electrical parameter variation using the expressions (4) to (12) during the faulty switching gives a clear insight about the consequences of a faulty switching.

IV. PROPOSED FSDA DESIGN AND ITS SIGNIFICANCE

A newer Faulty Switching Detection and Alert system (FSDA) has been proposed to address the issues due to malfunction of the isolation switches and alleviate the fatality rate. Embodiments of the present work focus on safety measures relating to high tension voltage distribution systems, particularly to monitor isolation switching operation in a distribution transformer. In a conventional approach, the switch isolation process is verified by visual detection before any operator undertakes the maintenance work. Suppose if the service personnel have overlooked the process and if any malfunction occurs in the switch, it might, in turn, lead to an accident of the maintenance operatives.

The proposed FSDA system uses an actuator to detect the malfunction of the mechanism. Further, it includes a double alert system, one using light indication and the other using a high alarming system. The structure of the proposed actuator-based model is shown in Fig. 10. The shown model has to be mounted near the switch rods of the transformer as a secondary source for actuation during switching operation.

The proposed design has been segregated into five functional elements to describe its operation.

Element A: This part comprises of a spring rod actuator setup configured adjacent to the transformer isolation air break switches. These actuator setups are used to identify the status of isolation switches. The movable actuating part of the actuator is fixed with a non-conducting rod-like structure fastened to it. Generally the actuators are in Normally-Open (NO) condition, it goes to a closed condition when the isolation switch strikes its surface mechanically during the isolation process and gets activated. The pictorial representation of the actuator setup has been depicted in Fig. 11.

Element B: This part comprises of an actuator setup configured adjacent to the operating rod as in Fig. 11. The operating rod is a mechanical structure used to open the three isolation switches of a transformer mounted overhead. It comprises of a small gear setup which would be rotated a quarter rotations which in turn operates the tandem rod. The tandem rod will convert the rotational movement into linear motion and opens the movable handle of the air break switches that are fixed in a fixture. Since the isolation mechanism is initially driven by the operating rod, an actuator is fixed adjacent to it. The actuator near the operating rod acts as a primary device to initiate the isolation monitoring

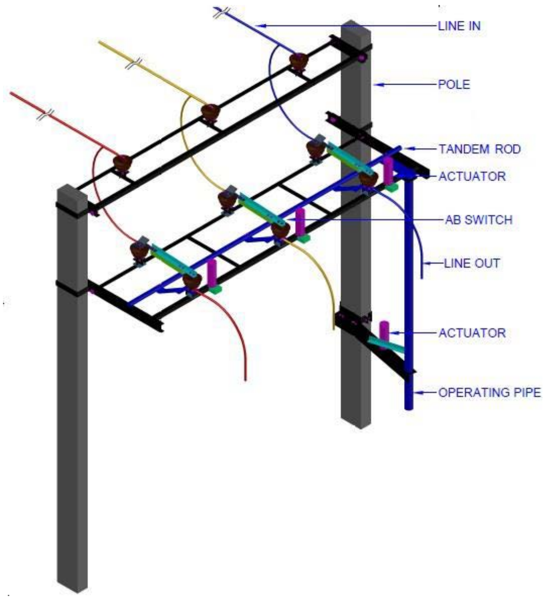


FIGURE 11. Pictorial representation of the actuator setup fixed in a transformer structure.

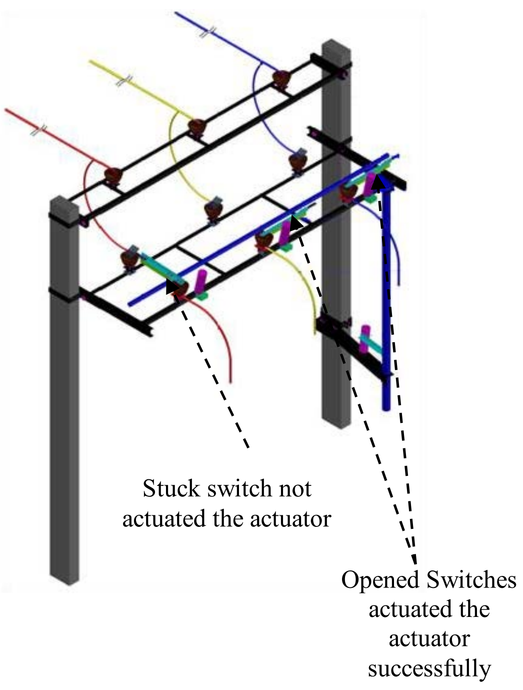


FIGURE 12. The pictorial representation of an isolation process and one of the switch stuck condition.

mechanism. The isolation monitoring and the alert mechanism are initiated when the actuator near the operating pipe is actuated. The pictorial representation of the isolation process and one of the switch stuck conditions has been shown in Fig. 12.

Element C: This is the isolation monitoring and alert mechanism unit. When the actuator near the operating rod is actuated, the system initiates a checking mechanism to ensure a successful isolation. Successful isolation will result in the glow of green light to ensure safe operation. Any malfunction of switches would result in a danger alert signal by the glow of red light and turns ON the alarm to alert the service personnel.

Element D: Programmable Logic Controller is used to sensing the actuation signal, monitor and generate an alert mechanism.

Element E: This is a power supply and backup unit. It consists of a power supply and battery backup units. The power supply is taken from the HT side of the transformer tapped before the isolation switch such that the power is not disconnected even during the transformer isolation. The battery setup is used to supply power during power outages. The complete structure of the proposed FSDA strategy is shown in Fig. 13.

Before developing this technique, an extensive literature search was carried out. The patent search has been conducted by considering the invention's key elements as disclosed by the inventor(s). The details of the patent are furnished in Table 3. Of the several references retrieved in the present search, it is evident that the identified references appear to disclose only a few critical elements of the invention, as shown in Table 4. The key elements B, C, and D do not seem to disclose any identified references. Therefore, the above-disclosed subject matter appears to be novel since none of the references discloses all the key elements together.

TABLE 3. Patent relatedto the key elements of the FSDA design.

Patent	Description
[32]	This technique is to perform the connection and the disconnection between the control terminals of the main body and the cradle of the air circuit breaker automatically and reliably.
[33]	This technique increases the separation speed of the power contacting with a gas blast circuit breaker. The power contact of the movable contact piece is operated via a switch actuated by the drive lever assembly or a rack and pinion.
[34]	The invention relates to the observing and control device of the composite electric power electron breaker.
[35]	An alarm circuit provides an alarm warning if the circuit breaker or fuse in series with a load is opened for any reason.

The principle of operation of FSDA has been discussed with exemplary cases from A to E.

A. TAN TERM ROD FAIL

In one exemplary situation, while operating the isolator by pipe, the tan term rod may fail to isolate the isolator mechanically because of less tightness between the operating pipe and

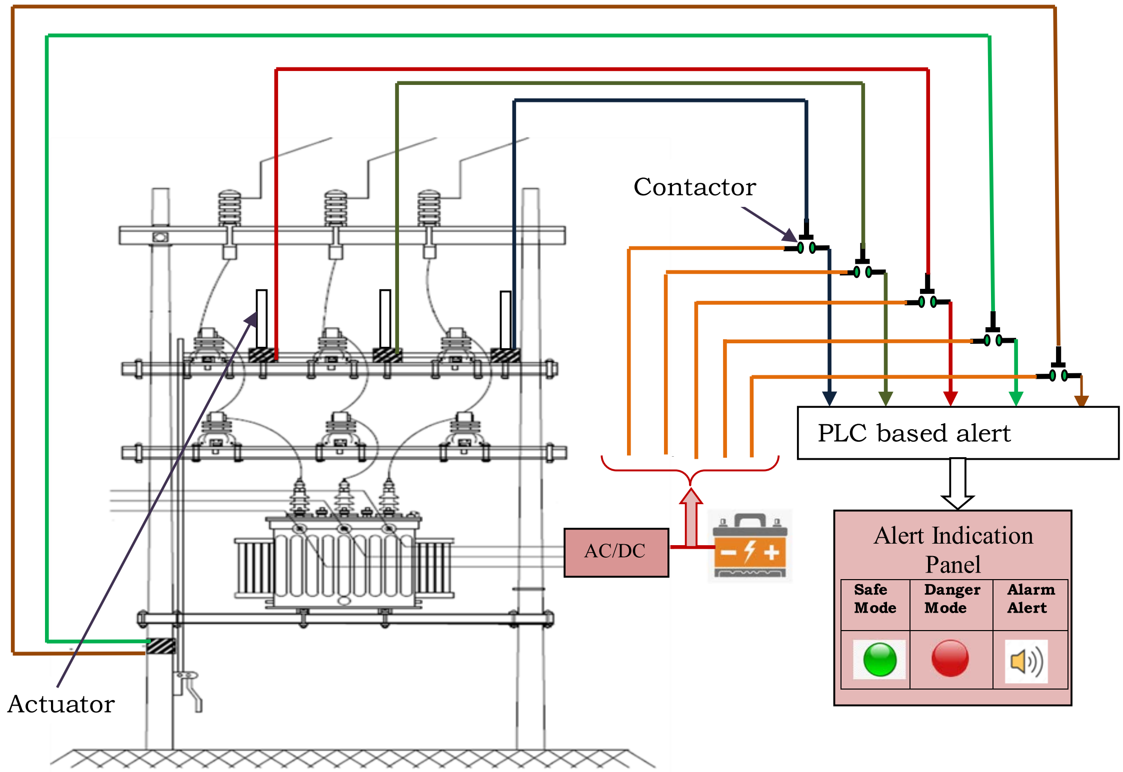


FIGURE 13. Transformer equipped with faulty switching detection and alert system.

TABLE 4. Mapping of key elements with references.

Elements	Patent reference			
	[29]	[30]	[31]	[32]
A	✓ (Partial)	✓ (Partial)	×	×
B	×	×	×	×
C	×	×	×	×
D	×	×	×	×
E	×	×	✓ (Partial)	✓ (Partial)

Note:
✓ Indicates that the element is disclosed in the literature
× Indicates that the element is not disclosed in the literature
✓**(Partial)** Indicates that the element is disclosed partially in the literature

the tan term rod. This issue may occur because of frequent switching operations. In such an exemplary situation, the actuator fixed near the operating pipe unit alone will be activated, but the actuator mounted near the isolator monitoring unit will not be actuated. Consecutively, the alert light and the alarm will be activated to alert the worker.

B. ISOLATOR STUCK UP

The isolator switches may be stuck-up with its fixing contact. This issue arises due to ageing or hotspot formation. In such a situation, the actuator at the faulty switch will not be activated.

C. ISOLATOR PARTIALLY OPEN

One or more isolators may partially open or may remain within arcing distance. In such situations, actuators at the respective phase will not be actuated.

D. BYPASSING ISOLATOR BY JUMPER

Suppose any open-circuit fault occurs due to the damage to the isolator switch. In that case, it is fixed by jumper wires for providing a power supply for emergencies due to the unavailability of isolator switches. During this situation, while switching operation for isolation is initiated without noticing the jumper wire, the isolation will occur only in other phases.

Still, the bypassed phase remains in connection with the supply source. In such a situation, the actuators at bypassed phase will not be actuated. As of the above-discussed cases, the processing system analyses the data through the actuators in real-time and activates the danger field buzzer and light indication. The output module would notify the user or any maintenance worker through the light and buzzer indicator.

E. SAFETY CONDITIONS TO CARRY MAINTENANCE

If the operating pipe and the isolators are appropriately operated during switching operation, such a condition is said to

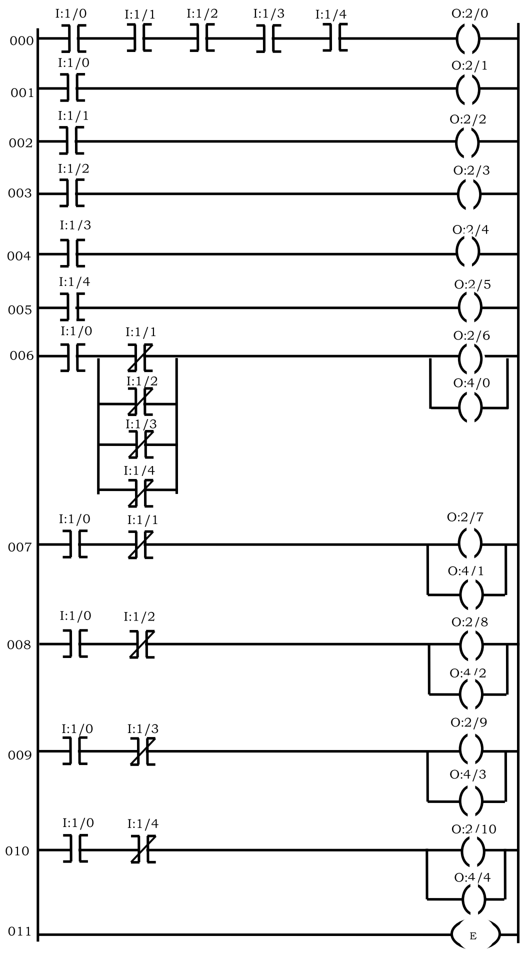


FIGURE 14. PLC ladder diagram for identifying and alert mechanism.

TABLE 5. PLC based transformer switching detection and indication details.

S.N	Actuator Signal I/P	Output Indication		Danger Alarm
		Safe Green	Danger Red	
1.	Overall	O:2/0	O:2/6	O:4/0
2.	I:1/0	O:2/1	-	-
3.	I:1/1	O:2/2	O:2/7	O:4/1
4.	I:1/2	O:2/3	O:2/8	O:4/2
5.	I:1/3	O:2/4	O:2/9	O:4/3
6.	I:1/4	O:2/5	O:2/10	O:4/4

be a safe operation. All the actuators at the isolator and the operating monitoring unit will be actuated in this normal operating situation. Then, the controller will analyze actuator inputs in real-time, and it will activate the safe operation light indication, which provides confidence to the service personnel.

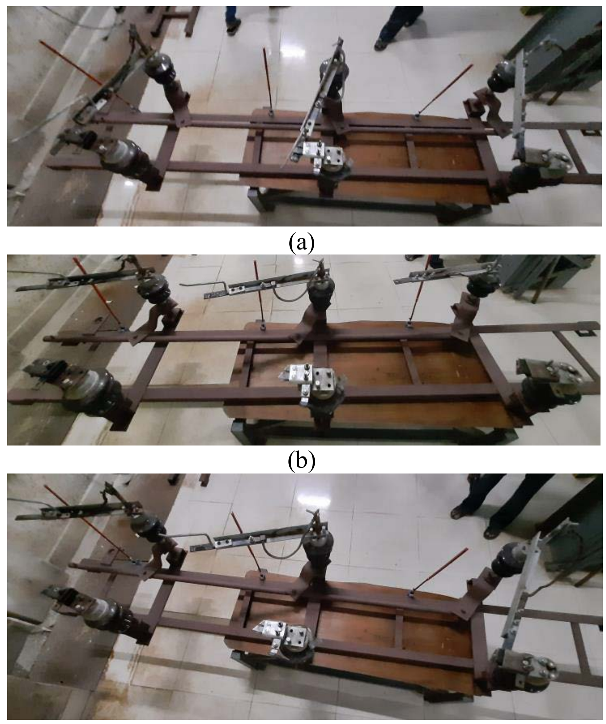
V. EXECUTION OF THE FSDA SYSTEM

The control logic of the proposed FSDA system has been designed and tested using a Programmable Logic Controller (PLC). PLC is an efficient approach for quickly identifying the actuator signal, generating an alert signal, and efficiently operating the display and alarm mechanism. The PLC logic of the proposed system is depicted in Fig. 14. The PLC contractor details of triggering the actuator for generating alert signals using a light display and the alarming mechanism have been depicted in Table 5.

A real-time model of the actuator has been designed and deployed in a prototype transformer switching setup. A spring

TABLE 6. Actuator details.

Description	Specification
Model	me-8169
Action	Momentary
Type	coil spring
Power	AC 250V 5A, DC 115V 0. 4A
Mounting Hole diameter	4. 5mm / 0. 18"
body dimension	85 x 28 x 25 mm / 3. 4" x 1. 1" x 1" (l*w*t)
Lever Length	85mm/3. 3 inch
Weight	60G



(a) (b) (c)

FIGURE 15. Prototype implementation of the actuator setup (a) position before actuation (b) position during actuation c) Switch stuck scenario.

rod type actuator has been chosen for experimentation, its detail is furnished in Table 6. The implementation setup is shown in Fig. 15.

VI. CONCLUSION

Most of the electric fatalities occur during transformer servicing in the power sectors due to mal function of contactor switches. Hence, several workers have died as well as the count has been continuing. Such kind of problem arises in the transmission line contactor switches as well. The root cause of the mal-functions of switches and their consequences have been elaborated. A novel faulty switching detection and alerting technique has been proposed to address the frequently occurring electric accident and the fatality. This proposed technique identifies the mal function of the switch and provides an alert signal. The setup comprises a double alert mechanism, one with light indication and the other with alarm. Installation of this device is simple, cost-effective, and requires no modification of the existing setup.

Furthermore, it provides safety to the workmen to carry out the maintenance service without fear. Incorporation of this technique will avoid life-threatening fatality and assures the safety compliance of the workers. The transformer and power line based accidents can be reduced by 26% by implementing the FSDA strategy. A prototype model of the proposed safety compliance technique has been designed and tested successfully.

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