A Novel Design to Prevent Electricity Theft from Pole Mounted Distribution Boxes

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***Abstract*— In India, distribution losses are substantial from pilferage of distribution lines and connected equipment like energy meters, distribution boxes and various connectors. Few SEBs (State Electricity Boards) have started using Arial Bunched cables for prevention against theft by direct hooking on conductors but it has been observed that maximum power theft occurs through distribution box which makes distribution box most vulnerable component against power theft. Further, burning of distribution boxes happens due to overloading and improper connection system which results in high Ohmic loss. To prevent this, development of a theft proof distribution box with reduced Ohmic loss is needed which gives reliable operation throughout its life span with ease of installation and maintenance. In this paper focus is towards development of novel approach to avoid theft from pole mounted distribution box which is imperiled to major share for electricity theft among all equipment used in distribution system.**

Keywords*— *Anti-theft, Contact Resistance, Distribution Box, Electromagnetic Actuator, Finite Element Analysis

I. INTRODUCTION

In a power distribution system, Revenue and performance of distribution utilities are largely affected by Aggregate Technical and Commercial (AT & C) losses as distribution utilities completely depend upon retail consumers who expect electricity without power cut. AT & C losses also indicate health of a distribution system, billing system and vigilance system. In short, AT&C losses are one of the most important aspects of a distribution network and need to be maintained at the minimum possible level to ensure technical and financial sustainability of utilities. Power theft by illegal connections is chief contributor to commercial losses that is unaccountable and affects the revenue severely. Hence, in order to reduce commercial losses, utilities have to focus more on curbing power theft.

In commercial losses power pilferage is a critical issue faced by Discoms and Utilities in India along with that problems related to energy meters like faulty meters & meter tempering are also common [1]. Several solutions both technical and administrative are being adopted to detect and minimize power theft. Replacement of bare overhead conductors with covered conductors, laying conductors underground, increasing vigilance and power accounting are few measures being embraced [1-3]. Although power theft from overhead lines has been arrested substantially through adaption of covered conductors, power pilferage is still rampant from distribution boxes (DB) mainly pole mounted DBs. Distribution boxes are the junction points through which the power connections are made to domestic consumers [4]. Traditionally distribution box is a simple enclosure with a door either of steel or plastic and with metal bus bars enclosed within which is used for electrical connections. This simple structure is highly susceptible to vandalism and the bare metal bus bar is easily accessible for illegal/unauthorized connections [4]. Several incidents of burnout of distribution boxes and human fatalities are attributed due to tampering of Distribution boxes. In addition to economic losses to utilities, the power quality is also severely affected due to illegal and substandard connections [4].

Currently there are many solutions available for preventions of theft from the distribution box by various manufacturers. Mostly Anti-Theft arrangements are done to prevent opening of enclosure door. Some special shapes of screw heads with keys are used for opening of distribution boxes. Some utilities use specialized sealing of the boxes to prevent or identify power theft. Once seal is broken, concerned person from Distribution Company can understand that power theft has happened from the box and can take further action. Efforts are going on towards wireless theft detections devices using GSM & Zigbee communications systems for Distribution lines [5]. These systems are just detections of electricity theft but not towards stopping or reducing theft.

In this paper, a novel enclosed anti-theft bus bar assembly and metallic flush mounted enclosure along with an electrical pulse operated electromagnetic lock has been proposed to prevent electricity theft from distribution box which is mounted on distribution lines poles. First theory of electrical contact between busbar and conductor has been explained and it is used to develop design of busbar assembly with low contact loss. In the proposed distribution box, bus bar assembly is not exposed which in turn makes power theft difficult. Moreover, password protected electromagnetic lock prevents unauthorized opening of distribution box. In subsequent sections design and assembly of anti-theft distribution box has been discussed in detail followed by thermal analysis of busbar assembly and testing of actual proto type.

II. DESIGN

A. Anti-Theft Distrubution Box

There are two modes by which theft happens in a distribution box. First mode is direct tapping from bus bar and second mode is by piercing the cable sleeves in the distribution box. A distribution box used in 440 volts overhead cable network is shown in Fig. 1. It is used to take power from main lines and distribute power to residential and commercial consumers. Apart from receiving & delivering power, this novel design also avoids electricity theft. It is designed to allow quick and easy electrical connections using low voltage copper and aluminum conductors in residential and commercial consumer power lines.

It consists of three levels of protections to avoid electricity theft. The first level of protection is electromagnetic lock inside the enclosure which is operated by a password protected tool. The second level is anti-theft plate arrangement inside enclosure which is opened by specialized screws. In third level a unique anti-theft key is required to connect/disconnect cable conductors. In underground cables system, armoured cables are used which requires earthing of cable armour. In this distribution box specially designed connection system shown in Fig. 1 is used which serves dual purpose of earthing as well as mechanical holding of cables to avoid additional stress on contact region of cable conductors.

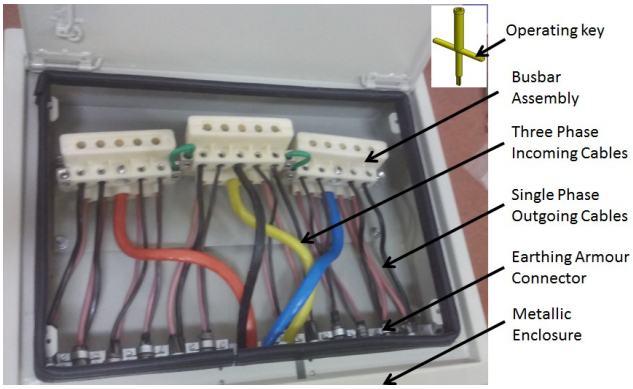

Fig. 1. Distribution Box with cables connections

A unique key is required for connections and disconnections of incoming as well as outgoing cable conductors. The key has a unique design which makes it very difficult to copy. It is designed in such a way that one single key can be used for all the operations of distribution box.

The bus bar housing is enclosed in a metallic box which has a flush door which makes it unsusceptible to sharp objects like screw drivers, spanners etc. In addition to door, an antitheft plate is also provided which covers inner space of the box. The antitheft plate has to be first opened by line man using the same special tool and then only the line man can start installation of cable in enclosed bus bar. The enclosed busbars are fixed in the metallic box protected by electromagnetic locking arrangement. In the conventional distribution boxes major problem is earthing of underground cable armours. To resolve that exclusive design of clamping arrangement develop which not only providing earthing but also holding cable properly as a mechanical support.

B. Busbar Assembly

Low I^2R losses and theft free connections system are the two major requirements from the busbar assembly. I^2R losses are highly affected by poor connections systems like conductor binding, loose bolts and improper conductor preparations etc. Also environmental conditions leads to increase contact resistance and then increase in I2R losses due to that life and performance of distribution boxes highly affected and increase chances of burning.

Parameters affecting connections system:

1) Contact Resistance

An electrical contact is a make and break junction between two conductors of any conductive material suitable to carry continuous electric current without overheating throughout its working life. The amount of charge transfer from one conductive body to another depends on electrical contact resistance between two surfaces. In ideal condition, electrical contact resistance remains constant irrespective of large number of connection and disconnection of circuit under no load as well as loaded conditions [5-6].

Fig.2 shows electrical contact between current carrying conductor and highly conductive busbar. It is assumed that pressure applied to current carrying conductor and busbar remains constant. In microscopic view it is observed that surface of conductor and busbar are not smooth and there are multiple peaks and valleys. Actual real contacts between two surfaces are very small and also there are oxide film between some of the real contact and in some contact are area with broken oxide film. Contact pressure plays very important role which breaks oxide film and makes actual contact through which maximum current flows [4-6].

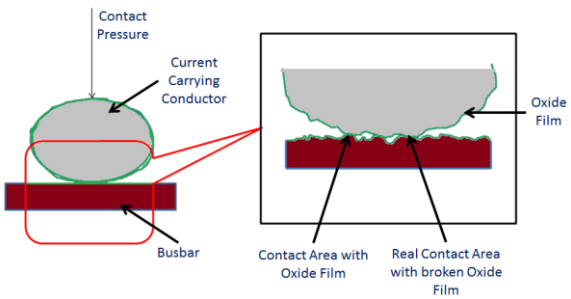

Fig. 2. Electrical Contact Topology

The flow of current depends upon contact resistance which can be mainly classified as 1) Constriction resistance 2) Film resistance 3) Bulk resistance. Due to oxide film and less contact area current constricts towards real contact area and resistance offered by that area is considered as constriction resistance whereas resistance offered by oxide layer is called film resistance [5-6]. Inherent resistance of busbar and conductor are resistance offered throughout current path which is called bulk resistance of connector. Sum of these three resistances equals total contact resistance [5-6].

2) Constant & uniform connection system

As shown in Fig. 3 compression springs are used to store force during connections and holding outgoing cable conductors. For incoming cable conductors unique studs are used which provide better connections suitable for carrying higher current. This type of contact exerts continuous pressure on the contact which results in uniform contact resistance throughout its life. Various experiments are performed using different values of spring pressure to find out optimum value suitable for low contact resistance. Pre-compressed spring concept is used to get required pressure in compact structure of busbar assembly. Spring loading test is performed on compression springs to check its pressure bearing capacity for life time.

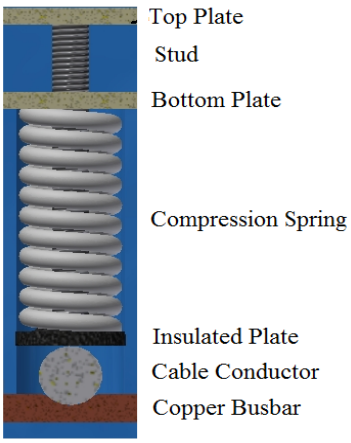

Fig. 3. Compression spring loaded connections system

This type of cable connection system is user friendly and it offers additional safety to line man owing to its completely insulated arrangement. The connection is not any person dependent as contact resistance remains same and its reliability does not change with installations practices [4].

3) Anti-Theft arrangement

In existing distribution box, the busbars are exposed and prone to theft. In antitheft distribution box the bus bar is enclosed in a thermally conducting and mechanically strong plastic housing. It is completely invisible to line man also. The line man has to use a special tool supplied with the product to insert the cable and to develop electrical contact between busbar & cable. A hybrid technology is used for connections system which includes Compression springs for outgoing connections and specially designed stud for the incoming cable conductors. To reduce addition of bimetallic resistance in overall contact resistance, tinned copper busbar is used in busbar assembly which also gives flexibility of usage of copper as well as aluminum cables. For proper fixing of busbar assembly in to the distribution box there are arrangements of fixing screws which are also tightened so that unauthorized person can not detach busbar assembly from the fixing. This busbar assembly can be used for 200A incoming connection up to 95 sqmm underground as well as arial bunched cable. Total 4 nos. of 25sqmm outgoing connections can be used for supplying residential consumers. There are possibilities of various combinations for three phase as well as single phase consumers. The busbar assembly consists of multiple busbar arrangements of phase and neutral in the same casing so that minimal bending required for the connections of incoming as well as outgoing cables as shown in Fig. 4. This system can be extrapolated in to more nos. of outgoing connections as per customer requirements.

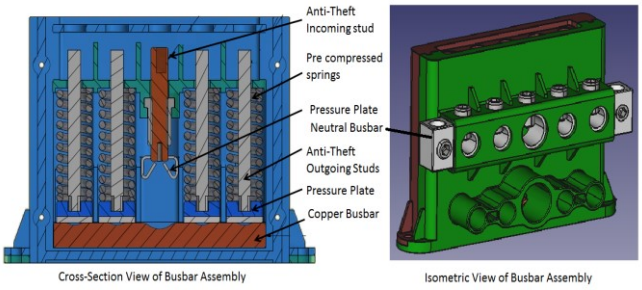

Fig. 4. Busbar Assembly of Anti-Theft Distribution Box

C. Electromagnetic Locking System

In present distribution box the locking of the door is done by simple nut bolt or mechanical holders. In some cases normal lever type locks are also used. These arrangements are prone to theft. To make the opening antitheft an electromagnetic actuator is used as locking arrangement in distribution box. First the required force from the actuator is calculated and design is made to generate same amount of force. The force generated by actuator is calculated analytically using reluctance network method and the same is validated by finite element analysis (FEA). The FE model contains a fixed core and a moving core (plunger) made of mild steel and a coil made of copper wounded on center limb of fixed core as shown in fig.5.

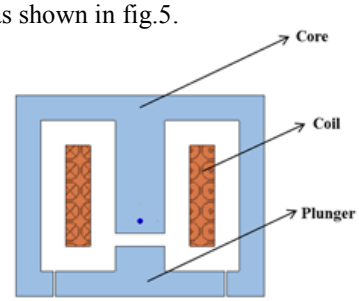

Fig. 5. FEA Model of Electromagnetic Actuator

2D magneto-static analysis of the actuator is done and flux plot is shown in Fig 6.

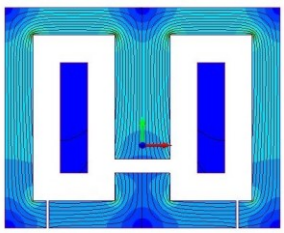

Fig. 6. Flux Plot of Electromagnetic Actuator

A prototype is developed based on the design and tested in the lab. for 1000 nos. of mechanical operations. The experimental setup is shown in Fig. 7. This electromagnetic lock is opened by a separately provided lock opening tool which is password protected.

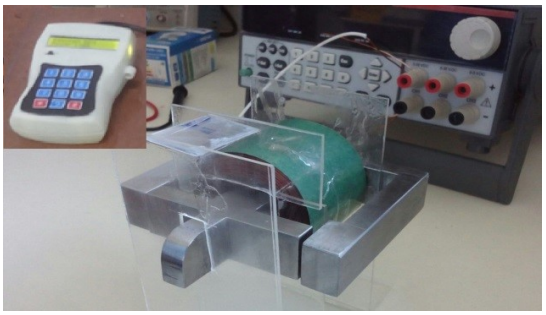

Fig. 7. Experimental set up of Electromagnetic Actuator

D. Password protected Opening Tool

The main purpose of opening tool is to give protections against unauthorized access of distribution box. The opening tool consists of LCD and other electronic components with cord for the connections to electromagnetic lock as shown in the inset of Fig.7. There are specially selected batteries placed inside the tool which are connected in series with relay whose main functions is to make or break contacts as per signals from the microcontroller. Microcontroller is programmed in such a way that password can be changed as per requirements. Internally programmed timer allows opening distribution box in specified time durations if it is not opened in stipulated time duration then it will again close. The main purpose is to provide a timer to restrict unauthorized opening of box by randomly putting password and trying to open box for electricity theft.

III. Performance Verifications Using Analysis

Multi-physics FEA investigations has been done to find out following parameters,

1) Heat generations/Energy loss due to heating
2) Temperature Distribution
3) Current Density
4) Electrical Field Intensity

Actual service conditions i.e. 200A from incoming cable and 50A from all other outgoing cables is considered for analysis purpose. Outer plastic body is considered as a convections boundary with below assumptions,

1) Natural convection present within box
2) Convections surface are smooth
3) Surface are corrosion free without oxide layer
4) Ambient temp. remains constant during analysis

Maximum heat is generated at the main incoming contact point of conductor with busbar. The busbar is at the bottom of the cable housing and the heat flows from busbar to outer housing surface through conduction. This analysis helps to identify hot spot locations as well as temperature distribution which directly affect performance reliability of busbar assembly.

IV. Performance Verifications Using Experiments

Busbar assembly is heart of the distribution box where high current is distributed in nos. of outgoing connections. Mostly there are stranded Al cables used for incoming and outgoing connections which are connected to tinned copper busbar. This connection results in contact resistance build up which increases temperature in all contacts of connections. Thus, it is very important to measure contact resistance. Four terminal method is used for the measurement of contact resistance between two conductors. There is not any standard procedure for the measurement of contact resistance for these kinds of busbar assemblies, but analysis of contact resistance values gives us better picture about performance of distribution boxes in the field conditions [6]. The arrangement for contact resistance measurement is shown in Fig.8. There are four junctions and each junction consist of two conductors connections with single busbar as indicated in Fig. 8.

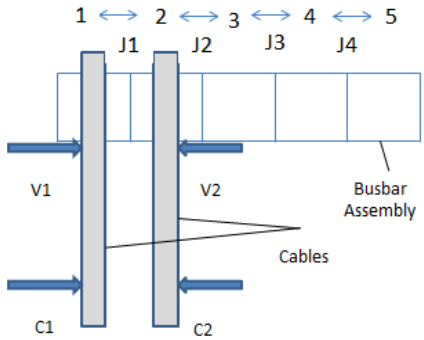

Fig. 8. Connections arrangements for Contact Resistance Measurement

It's also very important to measure contact resistance considering various sizes of cables are considered to measure contact resistance.

In this test full load current is supplied through its main incoming cable and all outgoing connections are shorted with other busbar assembly to generate closed loop circuit. The test continues for at least 24 hours and temperature of all contact regions are noted down every hour.

V. Conclusion

A novel and innovative design of distribution box has been proposed with three layer of theft protection. Also to enhance performance of distribution box hybrid concept introduced and analyzed with experiments and FEA.

In future same distribution box can developed communicable type which communicate tempering of enclosure and also electricity theft.

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