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Application and Importance of use of RAS (Robotics and Autonomous System) Overhead Line (OLE) and Power Transmission maintenance

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***Abstract*: Railway maintenance involves high unsafe conditions due to the high operational voltage levels which Railway operations utilize (that is 25KV, 50KV, 750VDC). Maintenance is critical for safe, reliable, quality, precise and cost effective service which plays a paramount role for railway operations. In order to achieve these desired aspects use of Robotic and Autonomous Systems (RAS) in Railway maintenance has been suggested and in the same cases implemented. In addition most of the power losses in railway operations are contributed by the pantograph interaction with the contact wire and quality of maintenance on the wire to provide smooth passage of the pantograph. This paper aims to evaluate the importance (in energy consumption reduction and safety) and feasibility of use of RAS, and the extent of maintenance it can provide based on RAS application case studies and possibilities. The paper also suggests the need to increase the percentage of RAS implementation in overhead line and power transmission maintenance from the recorded 5%. The growing need for electrical locomotives and vehicles brings in the need to manage electrical consumption of the EMUs (Electric Multiple Units) or locomotives while in operation. One of the ways to manage or reduce cost of consumption is to provide adequate Overhead (OCS) maintenance and power transmission maintenance. Poor maintenance will eventually result in increased power losses which are reflected on the cost of power. Introduction of RAS in railway electrical maintenance would be an ideal solution for achieving expected cost benefits, corrective, periodic and preventive maintenance including high safety implementation.**

Keywords— EMU, OCS, Pantograph, Power Transmission, Power Losses, RAS,

I. INTRODUCTION

With the increase in traffic, getting a block to maintain the different Railway assets is increasingly becoming more and more difficult. To carry out the optimum maintenance (in right quality and quantity at the right moment in time) condition monitoring techniques are favorable. By application of condition based maintenance techniques the disadvantages of ‘scheduled maintenance’ & ‘breakdown maintenance’ can be avoided. The employed maintenance can be planned at the time it is necessarily required avoiding failures and also saving the precious block maintenance difficulties and time.

Most railway systems in the world use 25 kV AC single phase, 50Hz traction supply system. These systems require various equipment and infrastructure in Power System Inspection and Over Head Electrical line maintenance to keep the system working efficiently. Generally it has been experienced that significant numbers of failures of Power System equipment and Overhead Electrical line are caused by failure and lack of maintenance due to non-availability of power block. With the increasing trend of traffic it is desirable to reduce maintenance time by applying modern instruments (RAS) in the field of maintenance. It is significantly considered that condition based maintenance instruments should be used core jointly with the TRD (Traction Repair Department) maintenance staff. These instruments may play a significant role to improve maintenance quality of work, safety and with least block time to improve system reliability and availability.

To minimize outages caused by equipment failures, modern condition based maintenance techniques need to be implemented in maintenance of TRD assets to predict deterioration of components.

BENEFITS OF CONDITION MONITORING

- Reduction of un-planned outage
- Minimize the severity of damages.
- Increase the system stability.
- Predictable maintenance schedule
- Prevention of costly failure.
- Helps to plan future renovation.
- Use of equipment for maximum economic efficiency.

II. BACKGROUND

Maintenance can be defined as a task or series of tasks that protect or reinstate the anticipated condition of a system, and these tasks include technical, administrative, and managerial actions taken [1,2]. In railway industry, proper maintenance of infrastructure, rolling-stock, and other resources are vital in providing a safer, reliable, efficient, and resilient output. In Swedish railway, about 30% of all rail and track related incidents and accidents that took place between1988 to 2009 were due to maintenance related causes [3]. Additionally, it has been revealed that among 700 accidents reported over 23 countries, 37% were due to rolling-stock faults and 36% were due to failures in infrastructure [4]. Further, by referring to

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Pareto graph, it can be realized that maintenance contributes to most 80% of the rail and track related accidents [4].
In addition, by referring to the Pareto graph, it is evident that rolling-stock and infrastructure faults contributed almost 80% of accidents summarized by the D-RAIL FP7 project.

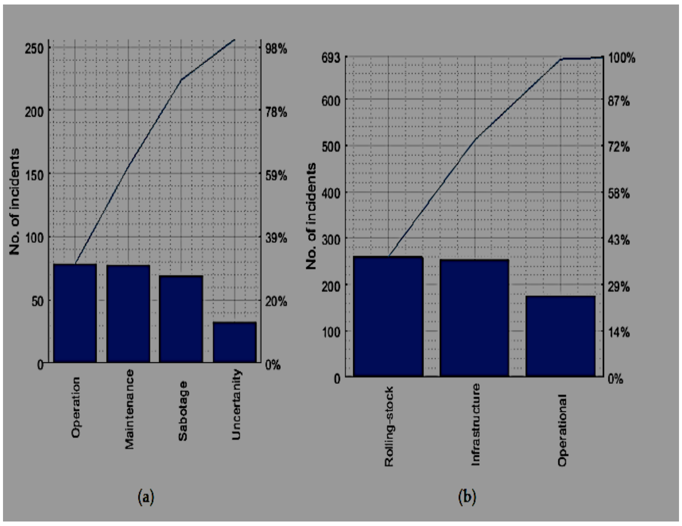

Figure 1: Summarized causes of accidence statistics by D-Rail FP7 Project

For decades, researchers have conducted extensive studies to introduce RAS into railway maintenance tasks. Through these studies, conclusions made were that there is only limited potential for improving the productivity of the rail workshop through RAS and it will remain modest until equipment and technology became economical [5]. However with the growing technology industry, electrical advances have become economical feasible to implement in various robotic applications. Distinct research and developments of RAS in railway maintenance domain have been summarized and analyzed. It has been identified that majority of examined developments are related to rolling-stock maintenance and inspection, which is about 56%. About 28% developments are related to rail-track maintenance and inspection tasks, followed by power transmission maintenance, which is around 5%.
RAS in the railway bridge and tunnel maintenance accounted 4% and 3% of total developments, while other maintenance applications, such as automated condition monitoring of grade crossings and cleaning of stations and platforms accounted for 4% of the total developments [5]. Further, it has been found that the majority of RAS implemented are limited to inspection and monitoring tasks, which are about 62%. The remaining 38% of RAS perform physical manipulation for a detailed breakdown by area of application [5].

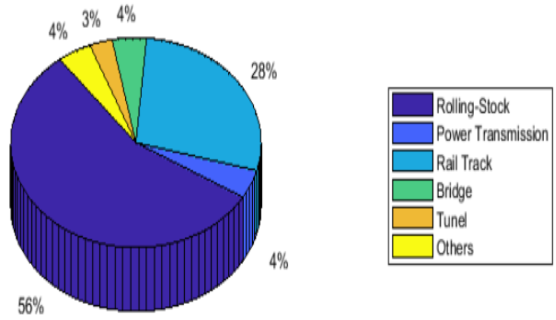

Figure 2: Percentage Development of RAS usage in Railway

The use of railway networks and installation of electrical trains is projected to increase by 40% due to demand for electrified rail operations and its benefits to environment as a mass transportation system for both freight and passengers. As the need and demand increases the necessity for maintenance and inspection will also increase with usage. Therefore, optimizing inspection and repair of the rail electrical network and facilities, in a cost-effective manner, whilst preserving or enhancing the safety, quality, and reliability of the service remains a key challenge [6]. Over the years, much focus in RAS development has been channeled to rolling stock maintenance, railway track and infrastructure in relation to accident prevention and causes [11]. However with the growth in electrical train usage the need for RAS in overhead and power transmission maintenance has inherently increased. In addition, railway maintenance technicians risk own safety to assure the safety of passengers and to keep trains operating. In most occasions, these railway employees perform their jobs in unfavorable and unergonomic environments. For instance, railway electrical maintenance technicians encounter risks while working on active live power transmission lines/rails in the vicinity during switching operations, working at heights, or in unergonomic postures for prolonged periods [7,8]. Switching accidents may occur resulting in loss of life and/or expensive railway equipment due to maintenance human error or inaccurate maintenance or inspections.

III. RAILWAY ELECTRICAL MAINTENANCE (REA)

The electrical sector plays a crucial role in the technological and industrial progresses of a country. There are great possibilities for the application of robotic systems in the field [9].
Maintenance tasks on live lines involves a limited risk, despite worker skill. The risk appears with the occurrence of unexpected events. The most frequent tasks to be carried out in electrical networks include the following:

- Changing insulator sets,
- Opening and closing switches,
- Establishing new connections,
- Changing line equipment,
- Inspecting line equipment.

Ideally, all these types of tasks are executed manually by highly qualified electricians. They use techniques from maintenance schedules that have been carefully studied and designed to avoid workers' risks. It is also meant to increase efficiency and minimize task execution time. The two widely spread techniques used in manual live-line maintenance are:

- Distance works (working indirectly),
- Potential works (working directly).

In the first technique, the worker manipulates the line using different kinds of insulated hot-sticks. The operator works close to the line, tying up to the perfectly insulated pole. In the case of the second technique, workers remain in touch with the line. Certain areas are covered in advance with insulated accessories in order to prevent electrical shocks, and the contact with different line elements is executed with the appropriate rubber gloves. This technique can also be done with the worker in an insulated bucket placed on the top of a boom and close to the line. [11]

IV. RAS APPLICATION

With the developed testing equipment for live line maintenance it is possible to develop robotic applications based on the same working principles. Advanced robotic functions can be applied as a combination of testing equipment functionalities coupled into one smart device. The following testing equipment reveal the adequate possibility of a starting point for electrical RAS development for Railway electrical maintenance.

V. TESTING INSTRUMENTS DEVELOPED FOR OVERHEAD EQUIPMENT

- **Contact Wire Spark Checking**

Sparking occurs when there is unsmooth contact between the pantograph and the contact wire. The spark is developed on contact wire mainly due to kinks that develop on the contact wire. It is then however important to attend the kink roughened surface of the contact wire to avoid further rapid deterioration, with successive passage of pantographs resulting in reduced lifespan of the wire. It is necessary to carry out periodic tests and inspections to detect points at which contact between the contact wire and pantograph is unsatisfactory resulting in sparking.

- **OLIVIR-G PLUS**

The OLIVIR-G Plus was developed to assist Over Head Equipment (OHE) spark detection using a video camera. The hardware units consist of a GPS receiver which can track the current position of the locomotive in which the 'OLIVIR-G plus' is mounted. The OLIVIR mate RT software supplied with the unit identifies sparks in real time and saves them as images with locations, at the same time continuous video film is also recorded in the hard drive. These images can be analyzed to recognize the type of spark with their locations. [12]

Application: OLIVIR-G Plus was generated with two types of reports: Graphical Report and Text Report.

Accessories:

1. FOCUS LIGHT OPERATED AT 110V AC/DC SUPPLY.
2. CAMERA AND LIGHT
3. GPS ANTENNA
4. PROCESSING & LOGIN UNIT
5. GPS UNIT
6. SERIAL CABLE
7. BATTERY CHARGER
8. TRACK FEATURE COLLECTION UNIT

Advantages:

- It can show total number of images recorded during current collection test.
- The category of spark can be adjusted as per customer requirement.
- It gives the correct position of spark with its location.
- The size of spark value can be adjusted during current collection.
- It automatically saves all recorded data in the laptop date-wise.

- **CONTACT WIRE HEIGHT & STAGGER MEASUREMENT**

Any change in alignment due to slewing of tracks will evidently affect the setting distance and the stagger of the contact wire [12]. Change in rail level due to variation in ballast cushion or packing down of the track would result in a change in contact wire height. Though provision exists in the cantilever assembly for adjustments of the stagger and height, such adjustments are not to be made unless absolutely necessary. It is best to maintain the position of Overhead line and tracks as in the SEDs (Standards). [12]

- **Rail Rod Ultrasonic Height & Stagger Gauge**

Rail Rod Ultrasonic Height & Stagger Gauge measures the height of contact wire and catenary wire without power block both on meter and broad gauge tracks. Rail Rod Ultrasonic Height & Stagger Gauge is used for measurement of height of contact wire & catenary wire on horizontal track gauge variable 1.0 m. to 1.7 m using a two wire stagger display with a variable gradient measurement option [12].

- **LIVE LINE Contact Wire Monitoring**

Following locations on the line are generally prone to higher wear rate of contact wire:

I. Stop Signal
II. FOB (Foot Over Bridge) / ROB (Road Over Bridge)
III. MEMU (Mainline Electric Multiple Unit) Locations
IV. Starter signal

It is therefore pertinent to monitor diameter of contact wire continuously at these locations. Present existing system in some railway networks checks diameter at one location per km once a year during Tower Wagon checking. However annual checks once have proven to be inadequate since it is observed that new locations with diameter less than the standard crop up at intermediate location and during intermediate time. [12]

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- **25 kV Live Line Contact Wire Wear Monitoring**

To have better and continuous monitoring of contact wire wear Jig was developed which gives measurement of contact wire diameter at eye level without need of power block [12].

Technical Specifications

Material High insulated fiber glass epoxy Telescopic rod (Jaw on top & Vernier calipers at eye level) with a Length of 5.15 m, pipe diameter 39mm outer, 30mm inner and a weight of 5 kg. Electrical Type tested at 100 kV at ERDA BRC and capable with constant high voltage up to 30 kV perfect in wet condition water absorption is only 0.2 %

Advantages:

i. The contact wire locations having higher wear rate can be monitored more frequently.

ii. The number of locations to be checked per km. can also be increased.

iii. It can help in better monitoring of health of contact wire and consequent reduction in contact wire parting cases.

- **LIVE LINE Insulator Cleaning**

The Overhead Line insulators require regular cleaning for ensuring uninterrupted traction supply. The periodicity of cleaning varies from one area to another depending upon pollution level and proximity to the sea. Where pollution is heavy, the cleaning has to be done more frequently [12]. This cleaning is essential as the insulators are affected by dust/ smoke particles, industry/ chemicals deposits, accumulation of coal/ cement particles which would form conducting layers on porcelain thereby causing Circuit Breaker tripping during night hours/ foggy weather/ drizzling. The insulators in light/ non- polluted zone are cleaned twice in a year that is pre-winter [11]. To overcome the problem of power block at aforesaid locations, a "Live Line Insulator Cleaning Jig" was developed.

- **Live Line Insulator Cleaning Jig**

The jig consists of light weight "Two Insulated Rod" (Each rod comprising of 2 to3 detachable sections of 1.85 m / 2.0 m length each with push button locking arrangement) provided with cotton pad on top. The cotton pad is fixed on one end to first to rod & clamped to other rod after inserting on insulator through hook arrangement. [11]

Application: With the increasing trend of traffic on Railway system, the construction of power block is likely to worsen further in near future; resulting insulator cleaning will adversely affect reliability of Overhead supply causing traffic dislocations [12]. The jig consists of two light weight insulated rods provided with cotton pad on top & clamped to other. Rod after inserting on insulator through hook arrangement. [12]

Technical Specifications

i. Material highly insulated fiber glass epoxy telescopic rod.
ii. Assembled length 6.0 (3 positions of 2.0m length two rods)
iii. Diameter of rod 39mm outer, 30mm inner
iv. Weight 6.0 kg
v. Electrical specification: Type tested at 100 kV at ERDA BRC and capable to withstand high voltage up to 30kV feet/ per ft. in wet condition water absorption is only 0.2%
vi. Cotton pad 2 feet long and 5 inch wide pad made of woolen cloth & sponge material.

Advantages:

i. It can save wastage of manpower for discharge Rod/ Power block/ E-socket/ Ladder etc.
ii. It can increase productivity.
iii. It gives better quality of insulator cleaning/ resultant reduction in CB transient tripping

iv. Transmission Line Inspection Robot Developed by EGAT Research Program

Inspection of transmission lines usually consumes workforce to achieve the required routine tasks by ground patrolling alongside the transmission line paths. Minimization of man-hour is essential in order to improve capability while the precision of data is still needed to be conserved. For this reason, completely/partially utilizing robotic technology into the standard line- inspection working method is of great importance [14]. Current means of routine power line inspection have been dealing with helicopters and Automated Vehicles to minimize cost of manpower. However it demands costly capital and high operation budget whilst the latter suffers with many constraints, such as short battery lifetime, relevant laws, dependability in operation, and so forth. Therefore, application of an innovative inspection robot rolling along an Overhead line can play a significant role in transmission line inspection improvement [14].

The maintenance robot that travels along an Overhead line can be practically upgraded to an inspection robot. The previous developed robots showed the ability to travel just one single span. To significantly improve inspection efficiency, a new autonomous robot negotiating and crossing successive obstacles automatically must be developed [15]. Crossing through each span end pole is the key challenge for the robotic transmission line inspection. When the robot encounters a pole, personnel needs to climb to each pole and then manually transpose the robot to another side of span. It would be more efficient to use if the inspection robot can automatically navigate through termination points. Nevertheless, autonomous crossing of obstacles repetitively requires huge efforts on advanced technology because equipment installed on the overhead structures have a lot of variety. Regarding mentioned constraints, a design was developed as an approach to develop a new mobile robot which could travel through a series of obstacles and earth wire cross arms with automatic navigation as well as feature of gathering high-quality visual information, e.g., damaged equipment and right-of-way vegetation data [15]. The aim of the development was to create a novel transmission line section robot that could roll along Overhead lines with autonomous crossing of obstacles. The work developed approach improves more efficiency than the existing approaches, such as ground patrols or helicopters. Provides photo and video via both offline and online (real time) providing a new means to improve more accurate inspection than the conventional practices and improved data capture and analysis. As a special feature, in the event of an outage event, the robot can be sent out swiftly to search for an outage cause in mountainous regions, minimizing the service interruption. The feature is essential for inspection or fault detection outside SCADA inspection or fault detection reach.

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VI. CONCEPTUAL DESIGN OF TRANSMISSION LINE INSPECTION ROBOT

The overhead power line inspection robot was designed to work with autonomous features and use a communication network for tele-operation. The conceptual design of the inspection robot provided a control portion which was divided into 3 key portions systematically connected: moving control, communication control, and remote control parts. The three units were linked together as operations for the entire system and link with operators through an Application on a handheld equipment in the field that would track data of the robot transmitted via the cloud network system. [15]

Robot motion-control part

The Robot movement was controlled by a microprocessor, which is the core duty for moving the robot towards a desired location precisely. The inner subsystem included a system of battery power supply which energizes power to all parts and feedback-control that could work with a communication control part closely for sensing the state of the robot for judgment and receiving information to command motion control for each movement.

- **Communication control part**

It included an embedded microprocessor which had the role of communicating with each equipment including sensors which transmit feedback information to the movement part that identify the state of movement or a camera record function during the robot roll along each path.

- **Tele-monitoring control part**

The robot was equipped with a communication and network unit for transmitting states back to the cloud via a mobile cellular system for a tele-monitoring control part. M2M (machine to machine), which is a protocol commonly used as a format of Data streaming. It could work with reliability although the restriction of system bandwidth, i.e. sending data in the field to the cloud system via the Application for observing. [15]

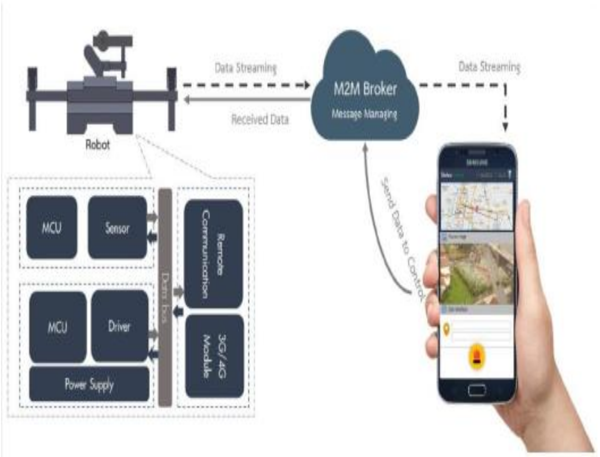

Figure 3: The conceptual design of the transmission line inspection robot

VII. PURPOSED DESIGN

The design concept was of an efficient robotic prototype for transmission line inspection with governing mechanism to transpose through obstacles on transmission lines developed by EGAT [15]. The model was designed and simulated using a special computer software. The robot consisted of 6 linear actuators with the maximum extension of 20 cm which was used to control the front or back wheel towards the desired position. When 3 linear actuators were connected together in a parallel mechanism to reach the required envelop. Moreover, the 3 wheels were required for driving the robot. Each wheel was installed with a driving motor which was installed inside the driving wheel set.

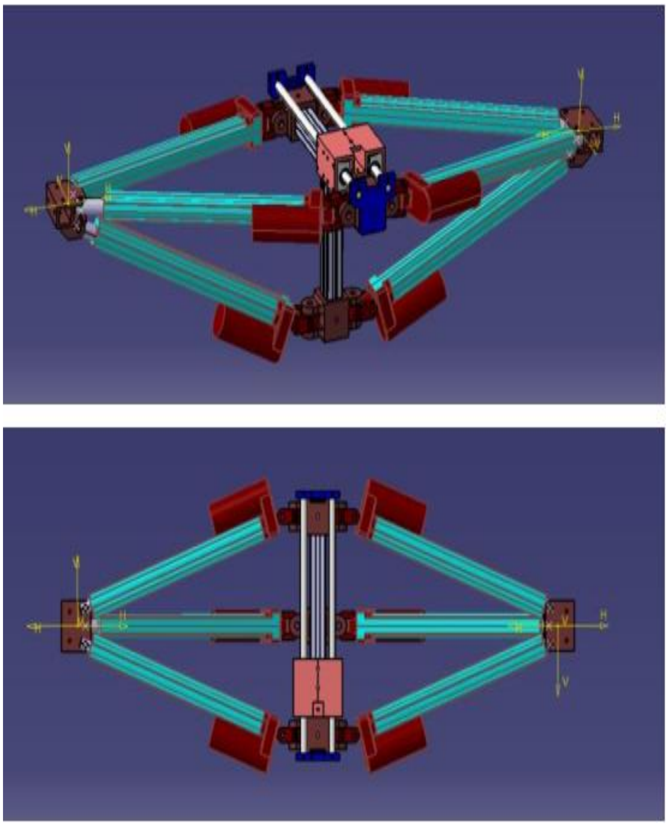

Figure 4: Design concept of the inspection robot

VIII. RESULTS

The invented pilot-line pulling robot for line tension adjustments was utilized to line pulling operations at many 115-kV transmission lines for different maintenance jobs during 2016-2019. The results revealed its capability on pulling the lead line/conductor along the Overhead line effectively and was accredited for real workings with no more harm to landowner and can operate with safety and reliability [15]. Examined results proved that the robot's performance on a pilot line pulling over the field was a success.

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Figure 5: Laboratory test for the prototype with the line model

The robot could cut the personnel cost up to 34 less people and save the payment for damage's properties. For an indirect output, the electrical transmission network would be safer and more dependable. The novel pilot line pulling robot was accredited as best practice by EGAT [15]. The standards for invention, working, and maintenance were archived as references for transmission line operation and maintenance units. The inspection robot for transmission lines was specially designed for inspecting overhead power lines, running via the Overhead line. Autonomous feature was a key challenge for developing the robot. Movement test was performed well on the simulated tower top for suspension type in the laboratory. After that, an actual field test was performed on July 2019 on suspension type and tension type towers of the real 115-kV power line [15]. The observed results showed that the prototype of robot can run and transpose through actual obstacles as tested in the laboratory. [15]

IX. OVERVIEW OF RAS IMPLEMENTATION

- **FEASIBILITY OF RAS IMPLEMENTATION**

One of the major draw backs in the development of RAS and implementation of advanced systems in RAS was the cost benefit results from such technology. Technology was expensive for such sophisticated robotics in such applications hence reduced efforts in Overhead Power Line inspections since Overhead maintenance was not directly linked to the main operation obstacle of Railway operators. With the industrial revolution turn around in technological advancements, tech implementation costs reduced, which offers the benefit of implementation of such sophisticated robotics. The growing demand in efficiency, cost reduction, safety and accuracy raises the need and desire to employ more RAS systems in overhead line maintenance.

- **RAS REAL TIME MONITORING**

Current Railway operations also demand the need for real time monitoring of Train movement and interactions of the Pantograph with the catenary wire. The Pantograph interaction is the key determiner of speed capacity utilization that is whether the maximum speed or line speeds can be attained or not. With uneven Pantograph interaction with catenary there is limited capacity to attain maximum rated speed of locomotive. The Pantograph dynamics and interaction improvements are the major obstacles of high speed capacity limitations. This raises the need to monitor the interaction in real time to access areas with smooth interactions and areas with uneven interaction. Such information is helpful to the maintenance as it will provide a guide line or basis of control measures. It will indicate if the unevenness or smoothness is linked to track topology or catenary topology, which is very essential for analysis and rectification of problem.

- **EFFECT OF POOR MAINTENANCE**

Poor maintenance would result in poor Power Collection, increased power losses which eminent as a bill of cost of energy and low power efficiency. A greater percentage of power loss is due to inefficient power collection which is caused by pantograph dynamics, offset of center line, inaccurate stagger and slack. These inspection parameters are supposed to be precisely with the standard range to avoid uneven interaction of Pantograph which may result to a reduced Mean time to Failure of the contact wire and pantograph contact brush. These inefficiencies are eminent on the cost of maintenance and materials procurement which can be vividly evident when cumulatively assessed.

CONCLUSION

There is evidence of different types of advanced testing equipment designed and built for the maintenance and inspection of high voltage transmission lines. The smart approach presently proposes the essential implementation of deploying innovative robots for approaches towards the smarter maintenance. The developed robots were successfully utilized to the actual transmission line in countries like Thailand, causing tasks achieved with safety and reliability and without customer's service interruption. [16] In addition, it helps improve effectiveness by saving manpower and be an effective approach rectifying inspection precision while comparing to the convention one, such as ground patrolling. By utilization with the smart robots, companies would save on routine line maintenance and inspection.

RAS implementation in Railway Line inspection and installation is essential considering the cost benefit, quality of inspection and ease of inspection implementation. With the increase in demand for electrical train operations and considering the length of such Railway lines for freight implementation, employing RAS can be time effective and easier to implement on long lines. However the currently developed RAS systems are mainly prototype developments which require more funding and support to actually have an impact in the Railway Industry. RAS has great potential on effective significance to inspection and maintenance of Overhead lines but require funding to achieve required performance and combat the current drawbacks of the designs [17]. With support RAS systems can grow to in campus a combined functional robot that can perform 80-90% of the required inspection on a single unit. Current technological advancements do permit and allow such high speed processing functions.

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