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Energy Management of Transmission Line by Optimizing Fault Condition and using Line Maintenance Techniques

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ABSTRACT

Maintenance of EHVAC power transmission line is essential to maintain continuity of supply. Various maintenance techniques are practiced on EHVAC Transmission lines to manage continuity of supply for the grid. This paper presents a thorough investigation of various factors found important in the maintenance of transmission systems. This shows application of inspecting equipment as a condition monitoring equipment for failure prediction.
Basic requirements of maintenance procedure for transmission lines under various conditions are studied and briefly analyzed.. All the practical implementation of various possible transmission line works discussed. A 400 kV lines case study during fault situation presented here to enhance the acquaintance of the subject. Live maintenance work for most of the common problems for continuous energy supply and its management is discussed which may help researchers to get practical exposure.

Keywords: *Energy Management, Maintenance Techniques, Transmission lines, Condition Monitoring*

1. INTRODUCTION

India is having a substation network of 81716 Circuit MVA with nominal EHV lines of HVDC ± 800 kV, ± 500kv, with an AC lines of voltages 66 kV, 110 kV, 220 kV, 400 kV and 765 KV with transmission lines of 23621 circuit km. In India, live-line maintenance started on medium voltage during year 1976 and in year 1998 for HV lines (80 kV). Various electricity generations are added to the electricity grid unevenly to spread the power supply at a cheaper rate. The substation consists of smart equipment closely monitoring all the exchange of power at Control Centers of Energy Management Systems (EMS). It is essential to deal with increasing costs and requirements as per regulatory [1].

Following steps required for Energy Management System.

a) Data collection & metering consumption of energy.
b) To save energy finding and quantifying opportunities.
c) Opportunities targeting for saving energy
d) Pursuing on improving energy saving
e) Effectively managing the consumption of energy is a continuous process.
f) Energy management reduces carbon emissions, costs and environmental damage [1][2].

2. PROPOSED METHODOLOGY

To apply maintenance on transmission system, there is need to study

a) Various types of faults
b) Reasons for line occurrences
c) Reasons for line/equipment failure, type of maintenance required.
d) Condition monitoring of substations, lines, insulators & hardware etc.

All above gives economic benefits & extension of life to apparatus, contributes new ways for energy management applying live line technologies improvement [1].

Propose methodology of energy management consists of
A. Design of energy management
B. Selection of Maintenance Techniques.
C. Role of Inspection
D. Equipment’s used for Patrolling
E. Type of maintenance applied
F. A Case study
G. Result & Conclusion

A. Proposed Design for Energy Management

The Indian transmissions grid system with energy management equipment in the substation with intelligent equipment and controllers. Transmission lines monotonous maintenance is needed for continuity of supply with security, quality and safety. Yearly maintenance work planned and chalked out sooner as per technical availability through shutdown or by live line maintenance [1].Fig. 1 shows the steps required for Energy Management.

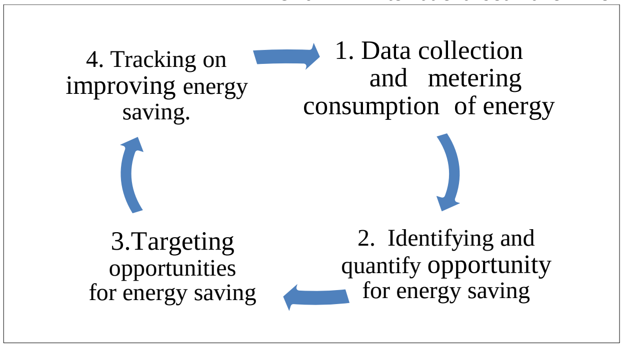

Fig.1. Steps Required for Energy Management

Advance monitoring techniques are used for preventive maintenance like Dynamic Contact Resistance Measurement (DCRM), Response Analysis of frequency (FRA), Detection of Puncture Insulation (PID), scanning, with Thermo-vision Dissolved Gas Analysis (DGA), Resistive Current Measurement of Third Harmonic (THRCM) etc.[1][3].The purpose of writing this research paper is to consider the benefits of adapting live maintenance and various other works that may be carried out in the transmission, continuous energy supply management system without disruption through the application of various maintenance techniques.Fig.2 shows diagnostic techniques for preventive maintenance [1].

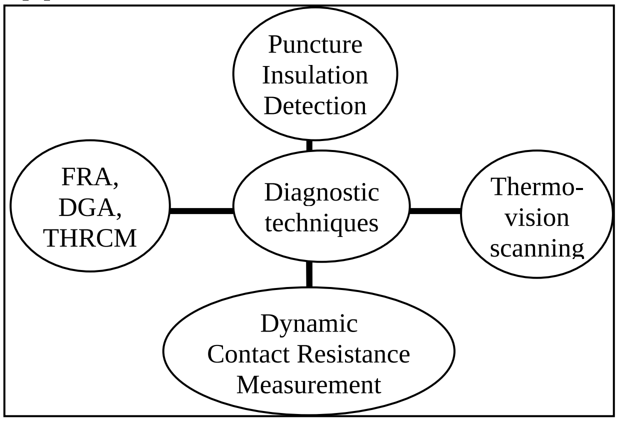

Fig.2. Diagnostic techniques for preventive maintenance

The above study improves the efficiency of live-work technology which facilitates the following advantages over cold line methods [1][3]

a) Avoid outage, so continuity of supply to consumers.
b) Switching cycles of switchgear may be reduced.
c) Avoids emergency outages; it can help to reduce incident risk.
d) Reduces penalties during the downtime of utilities.
e) No revenue loss.
f) Problems can be attended immediately.
g) The Less manpower and time required for maintenance as compared to the cold line method.

Transmission Company aims to control Maintenance work with planning and execution [4].

a) Optimizing costs of maintenance,
b) To confirm maximum availability of asset
c) Prolonging life of assets
d) Safeguarding sufficient supply quality,
e) Confirming protection of staff and the public,
f) Ensuring company sustainability for long-term
g) Improving quality service,
h) To reduce operating cost of the grid, maintain regular service and operation.

B. Selection of Maintenance Technologies

The choice of technologies will be based on their application & on accomplishing technical and organizational conditions. Best suitable choice of these technologies will decreasing costs and increase efficiency. Following criteria shall be considered for technologies selection [4][5]

a) Operating Criterion (Q1)
b) Climate Criterion (Q2)
c) Technological Criterion (Q3)
d) Organization Criterion (Q4)
e) Technical Criterion (Q5)
f) Functional Criterion (Q6)
g) Integrated Management(Q7)
h) Economic Criterion (Q8)

a) Operating Criterion (Q1)*:*

It gives details regarding grid operation, annual & monthly maintenance programming, unscheduled installations & apparatus for discontinues from service.

b) Climate Criterion (Q2):

It considers working meteorological conditions, temperature, wind speed, humidity, etc. It is to be quantified with instruments (hygrometers, thermometers, antilog or digital anemometers, etc.).

c) Technological Criterion (Q3):

Its objective is to provide technique to use in electrical installation with equipment, tackles and their application in supply of power, gauges and its access, etc.

d) Organization Criterion (Q4*):*

Organization of economic operators, technical characteristics of material, technological criteria and quality criteria.

e) Technical Criterion (Q5):

It depends upon the characteristics of equipment, climatic conditions (Q2) execution unit of technical equipment (Q3),work organization (Q4)[3].

f) Functional Criterion (Q6):

Such criteria should be determined and established in advance by an expert on the basis of the application. These must be as official documents as per contract. It should refer the available facilities, automation, positioning, cancellation, etc.

g) Integrated Management (Q7):

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Criterion refers to technology, quality at work with environmental protection, occupational health, and safety conditions.

h) Economic Criterion (Q8):

These criteria identifies completion cost organizational requirements with technology, system conditions, network efficiency, energy loss, congestion and their additional costs (damages, additional costs), etc. The total cost is given by equation (1)

$$Ct = Cs + Cl + Cee \qquad (1)$$

Where:
Ct - Total cost,
Cs - Additional costs (compensation, etc.)
Cl - Cost of applying technology, according to estimate offer,
Cee - Cost of energy loss and congestion,

The additional cost, includes the cost of access to the amenity, the cost of the equipment, the tools needed, the transport modes, their application and other concerns necessitating costs (procurement, etc.)[3] [4] [5].

C. Role of Inspection

Role of inspection in maintenance

Inspection of Overhead Line (OHL) carries out by taking actions that consist of an assessment of conventionality through measurement, monitoring, evaluation with standard equipment & installations. The inspection goal is to check and asses state of all types of line equipment [1, 6, 7, 8].

Line patrolling for OHL consisting:

a) Ground patrolling: foot patrol - Observation by a walk.
b) Monkey patrolling - examination by climbing on the tower, up to upper cross arm level, keeping safe body clearance.
c) Standard patrolling – It can be done simply by digital photography and inspection using a helicopter.

Inspection work that can be done:

a) Checking of foundation state & its related work.
b) Inspecting condition of the tower state (cross-arm, main legs, insulator strings); tower structure & related work.
c) General study of line, line components, checking sag, and localization of hot spots.
d) Cutting vegetation on the line crossings.
e) Conductor's state, various hardware's connected to conductor and coronal activity.
f) State of the earthlings; revision of earth connections.

A modern technical inspection appliance facilitates focusing the inspecting - maintenance activity on the defective electrical joints, avoiding undesired maintenance, locating faults & saving time [7]. Preventive maintenance is always better than disaster management.

Equipment's used for Patrolling

Equipment used for patrolling is determined by the application of technologies [7].

a) Thermo-graphic scanning.
b) UV Image (Corona) Inspection
c) Cable height Measurement Meter
d) Punctured insulator detection using a positron instrument by electric field measurement and voltage measurement method using Ritz's instrument
e) Tower footing resistance (Impedance)
f) Tan delta measurement for CT, PT, CVT) Transformer, Reactor, Grading Capacitor etc.

a) Thermo-graphic scanning

Thermo vision scanning is conducted to detect hot spots which are formed due to high contact resistance. Hot spots are developing on the jumpers & other hardware.

Figure 3 shows Hot Spot developed on top of Lightning Arrestor.

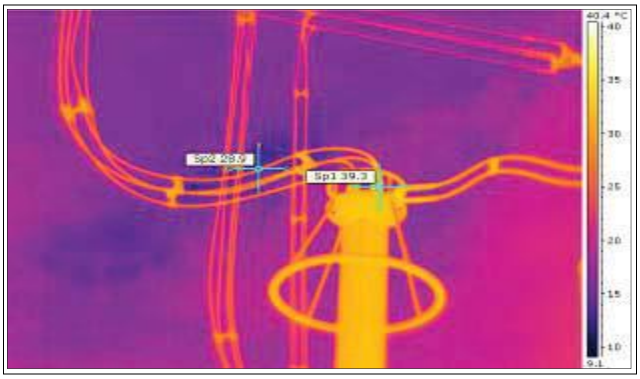

Fig. 3. Hot spot on Lightning Arrestor

The temperature at the hotspot is between of 90°C to 200°C temperature variation depends on system loading. To perform the work safely, detailed analysis should be conducted before starting repair work.

b) UV Image (Corona) Inspection

When the insulating property of insulator is decaying due to pollution, contamination like chemicals, salt or dust Corona indicates of developing a conductive layer. A line may suffer tripping, if property of insulator is not maintained. Corona can be detected by using corona camera for UV inspection.. Figure 4 shows Corona inspection of 400kv lines.

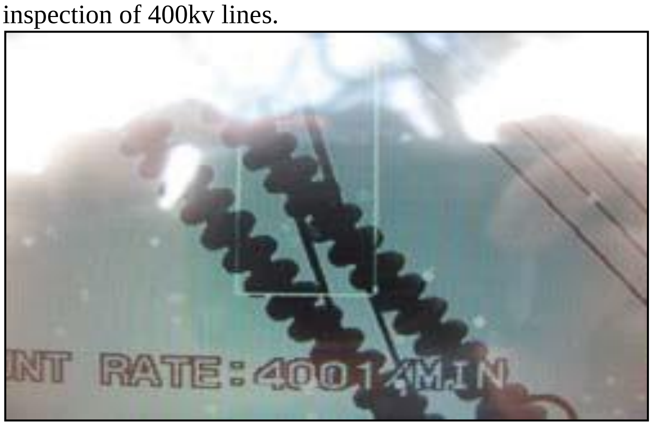

Fig. 4. Corona Inspection of 400kv lines

C) Cable height Measurement Meter

This unit measures line sag, which relates to the thermal constraints of the conductor. Line sags are an arc between a structure, ground, or vegetation and a transmission line. This is caused due to exceeding the thermal limits of transmission lines which may result in a transmission line fault. To protect terminal equipment from serious damage, line protective component disconnects line service during line fault condition. To manage the transfer of rated power lines, to ensure reliable operation of systems, to maintain thermal operating constraint(as per specifications for real power). This control forms an upper level of a line's transfer capacity [3, 4]. Table 1 and Fig. 5 shows the number of inspection and testing work conducted in a 400 kV Line Maintenance Unit of Maharashtra, India.

TABLE 1

Inspection & Testing work conducted on a 400 kV Line Maintenance Unit of Maharashtra, India.

Work carried out	No. of inspection & testing			
	Year 2016	Year 2017	Year 2018	Year 2019
PID Test on 400kV Circuits.	115	126	110	104
Tower stub inspection	376	416	432	367
Tower inspection	376	416	432	367
Tower Footing Resistance	41	37	28	48
Patrolling work	89	79	94	75
Sag Measurement.	85	74	97	75
Signature Analysis Test	28	35	29	31
Leakage Current Measurement	37	42	51	45
Partial Discharge Test	31	29	37	34
Thermoscaning work	115	126	110	104
Tower joint inspection	23	19	31	29

Fig.5 shows graphs of inspection & testing work conducted on a 400 kV Line Maintenance Unit.

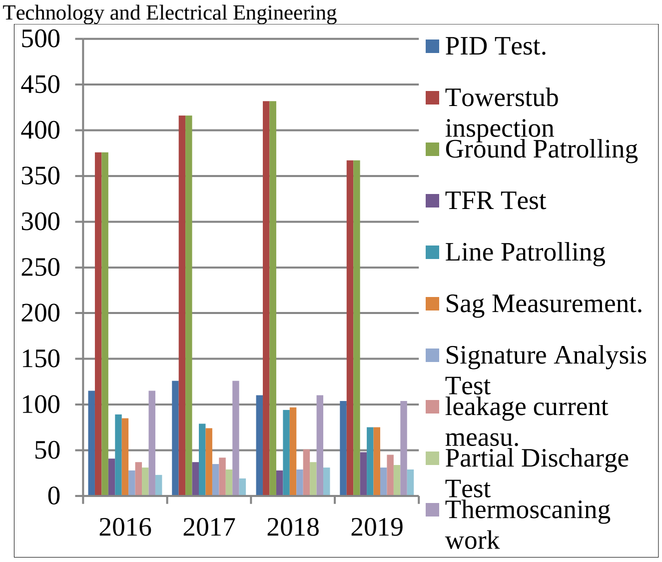

Fig. 5. Inspection & testing work conducted on a 400 kV Line Maintenance unit of Maharashtra, India.

D. Type of maintenance applied

To minimize operational risks formed due to bad environment, best suited preventive and predictive OHL transmission line maintenance needs to be applied as suited [8].

Major works in transmission line outage management are

a. To inspect the condition of line equipment replaces if faulty. Conduct preventive maintenance as tension, adjustment, tightness, jumper's adjustment and wear of all fittings.

b. Check the surrounding of tower structure, pole foundation, and hill fire, etc. to see and check position of spacers and dampers.

c. Maintain cleanliness and replace insulator, lightning arrestors if cracks.

I. Predictive Maintenance (PdM)

The Main intension of predictive maintenance is to use the policy of 'predict and prevent' instead of extension (or cancellation) of repair and replacement periods. The Main reason for system failures is non-availability of data regarding preventive maintenance process and inspection, schedule plans. Non availability of data on short/medium term operational schedule or machinery performance [9].

II. Transmission line maintenance works

Transmission line maintenance works needs special technique and preparation.

a. Conductor re sagging
b. Conductors replacement
c. Tower erection, commissioning etc.

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3. METHODS OF MAINTENANCE

Maintenance method applied are depends on fault, location of fault and equipment to be repair or replaced.

a. Cold line maintenance
b. Live line Maintenance
c. Washing Technique.
d. Deteriorated tower stub strengthening.

a) Cold line maintenance

Work Performed with Cold line Maintenance [8]. 30% of faults in the line are due to bird pollution, bird streamer and flashed over insulator string need be replaced regularly.

Following maintenance work can be performed by Cold line method

I. Insulator string replacement, changing cross-arm, changing of single with double strings.
II. The majority work of preventative maintenance is spacer/damper replacement. Most of the transmission lines have (2, 3, 4, and 6) bundled conductors.
III. Works on the tower foundation; installation of warning plates and numbering plates.
IV. Repairing works on the cross arm; lining of suspension PAS towers.
V. Clamps and joint replacement.

Below Table No.2, shows the inspection, testing work conducted by a 400 kV Cold Line Maintenance Unit of Maharashtra, India in the year 2016,2017,2018,2019.

TABLE 2
Maintenance work conducted by one of 400 kv line operation and maintenance unit of Maharashtra, India.

Work carried out (Supply disconnected)	No. of Cold line work conducted			
	Year 2016	Year 2017	Year 2018	Year 2019
Repair of hotspots, joints	68	84	92	82
Changing of bus bar, clamps	54	34	75	67
String Replacement	24	19	27	4
Removal of foreign objects	89	74	99	69
Tower stub strengthing	15	21	32	38
Tightening of nut bolt & hardware.	58	39	48	64
Insulator Washing	32	28	42	29
Refixing of earth wire.	39	42	53	49
Tightening of jumper	65	52	49	68
Tree cutting	178	154	183	137
Dead end & conductor	43	51	39	47
Fixing of spike guards, Bird guards	112	137	147	129
Replacement of broken spacer-dampers	53	38	49	61
Line Signature Test	79	83	68	52
Insulator Meggering	75	49	53	69

Fig. 6. shows no. of maintenance work conducted by one 400kV Line O&M Unit of Maharashtra, India in a year

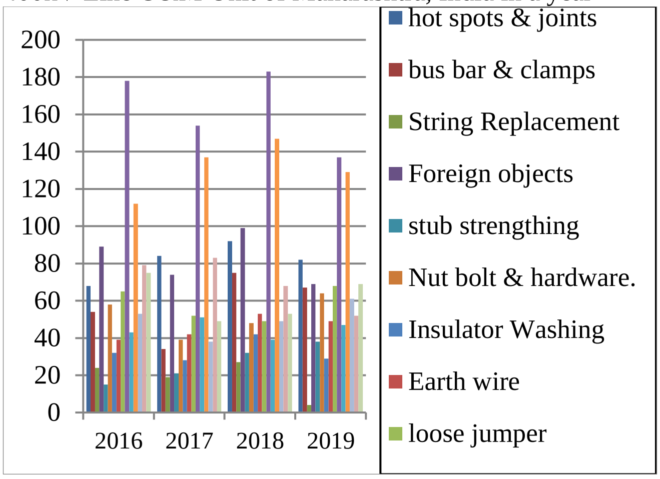

Fig. 6. Maintenance work conducted on one 400 kV Line by Operation and Maintenance unit.

b) Live Line (LLMT) Maintenance

Using live line maintenance techniques insulators replacement work on 400kV and 220kV lines is an important activity. Recently advanced maintenance techniques were developed for the installation of monitoring systems, anchors, lightning arresters, replacement of ground wire etc. [7, 9]. In live line maintenance, safety is at the highest priority of team members. Proper training with safety procedures, technical skills needs to monitor. Improvement in the working environment and safety features are needed, which can be achieved by regular training and exchange of skill and experience from experts [10, 11]. Some work that is possible with live line but cannot be done due to proper tools and expert manpower [12].

This includes working on the maintenance of transmission line corridor; some types of work are stated as follows:

a) In Indian Transmission system 90% of live line maintenance work consists with inspection, replacement of faulty insulator, a damaged insulators string of all types, removal of unwanted object from conductor and insulator string.
b) It includes inspection of clamps, installation of suspension clamps, and maintenance of the armor-rod; oiling of nut bolts, liquid spray for contact cleaning.
c) It includes inspection, maintenance, replacement of vibration dampers, arching devices, warning spheres, and spacers, etc.
d) Replacement of damaged isolators jaw in live conditions. Maintenance of isolator, opening, and closing of isolator's blades, wherever the isolator blades get stuck up.
e) Jumpering of two live bus sections on both sides of the gantry, attending red hotspot that occurs on lines.
f) Provides bypass jumpers to the isolators, tightening of nut bolts of tension string jumpers.

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g)Providing a bypass jumper or repair sleeve on the damaged part of the live conductor.

h)Measurement of the line to ground clearance, working on the ground.

i) Insulator washing.

The Engineer should take permission and follow the laid down procedure before starting the execution of work. The team leader should present & explain all the work that they have to complete, to all team members. He explains the working procedure and task to be performed by each member [13].

The hot spots maintenance work conducted by applying a bare hand method or hot stick method, depending on the available clearance [10][14].

Table 3 and Fig.7 shows Live-work and testing work conducted by a 400 kV Line maintenance unit of Maharashtra, India in a year.

TABLE 3

Live line work & testing work conducted by a 400 kV Line Maintenance Unit of Maharashtra, India

Work carried out	No. of Live work conducted			
	Year 2016	Year 2017	Year 2018	Year 2019
Patrolling work	89	79	94	75
Tower leg inspection.	376	416	432	367
PID Test	115	126	110	104
Hot spot Repair	78	96	89	69
Work on conductors, clamps	65	68	70	76
Removal of foreign objects	5	3	7	4
Tower leg angle fixing	18	24	19	27
Jumper & Nut-Bolts etc.	76	68	59	84
Stub strengthening	11	17	12	19
TFRMeasurement Test	41	37	28	48
Replacement strings	47	59	78	85
Replacement CC Ring etc.	27	34	29	38
Refixing of copper bond	12	16	18	19

Fig. 7. shows no. of Hot line work & testing work conducted by a 400 kV Line Maintenance unit of Maharashtra, India in the year 2016, 2017, 2018 & 2019.

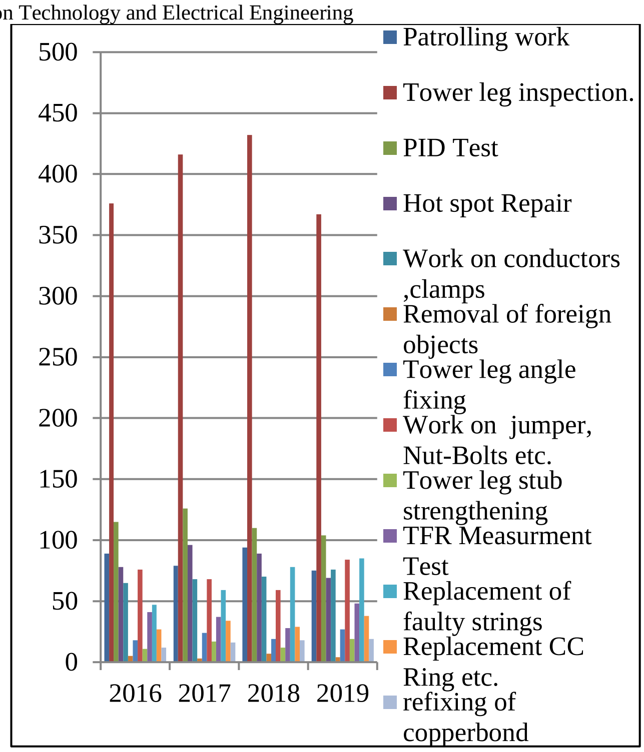

Fig.7. Testing work & Hot line work conducted on a 400 kV Line by Maintenance Unit in a year.

Live Line technology needs more cost and time. This is due to special equipment, protective dress, training, workers accommodation and use of vehicles. However, LLMT is economical compare to cost of loss of supply which is more due to transmission lines supply unavailable. The main reason of live line technologies improvement on transmission networks after cost assessment of various technologies tells that the loss of finance due to outage may main cause in spite the outages and penalties [2][6][15]. Fig.8.and fig. 9 below shows important activities performed by live line maintenance [16]. Fig. 8 shows the replacement of the insulator string by live line technology on a 400kV line.

Fig. 8. Replacement of insulator string

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Fig. 9 shows the Replacement of Jumper by live line technology

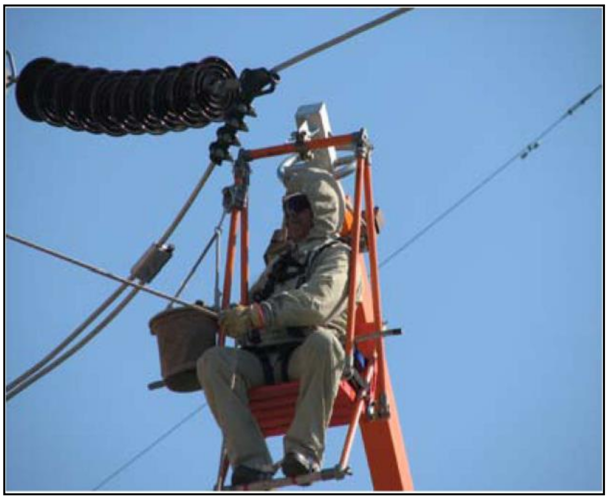

Fig. 9. Replacement of Jumper

4. A CASE STUDY OF INDIAN GRID

Transmission line shown of 400 kV with 272 km length for case study[1][17]. , Line tripped on dates 31/5/2018 as per Disturbance Report due to heavy rain at 4:06:33:128 pm. A tree branch falls on Y phase, hence occurred line (L2-N) fault. Information shown here of pre fault & fault with waveforms.

Disturbance report information given below is used to study faults, types its reason phase and location. This study is beneficial for application as inspection and monitoring of line. This record provides evidence about fault.[1]. Table 4 shows disturbance report data & Fig.10 and Fig. 11.show Disturbance signal of Line fault (L2-N) occurs on (Y phase)[1].

TABLE 4.
Disturbance Report Data

Sl. No.	Channel Name	Prefault RMS	Prefaul t Angle	Fault RMS	Fault Angle
1	Current R Ph	0.6 kA	68°	0.9kA	56.3°
2	Current Y Ph	0.6 kA	-53.5	9.2kA	44.6°
3	Current B Ph	0.6 kA	-174.8	0.4kA	165.6°
4	Current **N**	0.0kA	68°	9.9kA	47.6°
5	Voltage R Ph	239.4k V	-120.3	243.6k V	-116.8
6	Voltage Y Ph	241.2k V	119.1°	100.6k V	99.3°
7	Voltage B Ph	236.6k V	0°	248.6k V	99.3°
8	Voltage N	4.3kV	111.°	181.7k V	-47.8

In the above study, the fault was located at 14.8 km (5.4%). Proper action have been taken earlier to protect against this fault if system would have been inspected. Fig.10 shows line to ground fault disturbance signal (L2-N) occurs in Y phase [1].

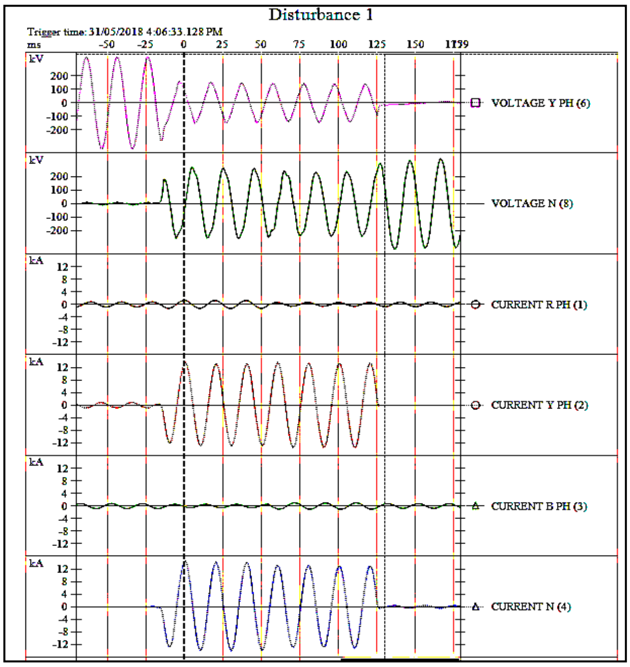

Fig. 10. Disturbance signal of the line to ground fault (L2-N) occurs on (Y phase).

To manage continuity & quality of supply without outage inspection & maintenance are the keys. Fig.11 show s total recording of disturbance signal during line fault (L2-N) occurs in Y phase [1].

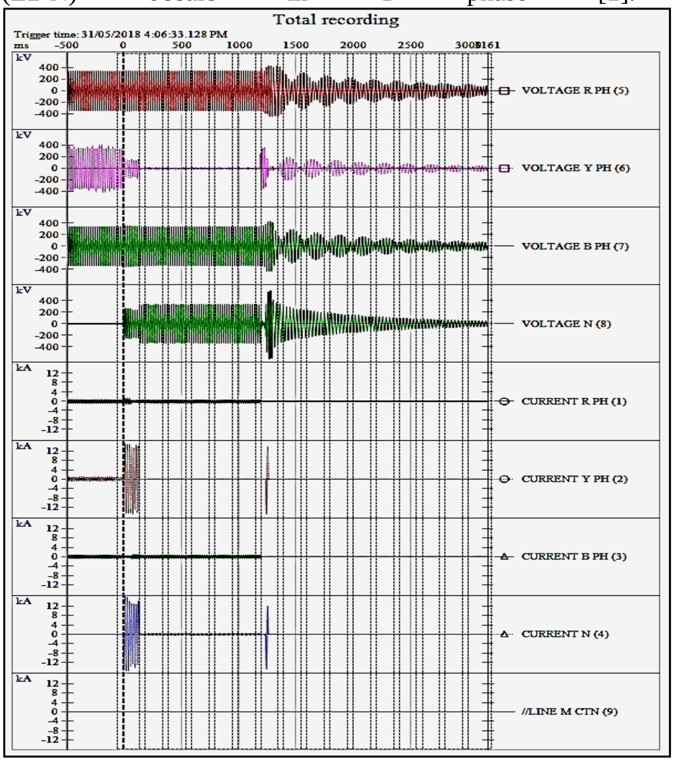

Fig. 11 Disturbance total recording signal of line fault (L2-N) occurs on (Y phase).

A study says that cost saved by live line maintenance is 70% greater than the income loss under fault condition as it depends upon fault type, duration & severity[1].

5. RESULT AND CONCLUSION

This paper presents various maintenance techniques applied to EHV AC Transmission lines for managing continuity of supply to Indian transmission grid. Paper show energy management of transmission system & outages saved by various maintenance works are related to each other. Paper shows application of inspecting equipment as condition monitoring equipment to decide the maintenance strategy. Case study shows 400 kV line under trip conditions whose tripping outage could have been saved by proper inspection and line maintenance to save energy during outage.

Some faults on the transmission system are difficult to manage by live line maintenance, then inspection under live line condition & maintenance under planned outage situation is the key of energy management to save the system from forced shutdown & related damages.

Live line maintenance technology has opened the way of energy management, cost-saving & life extension of the transmission system.

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