Enhancing Resilience: Analysis and Prevention of Trip caused by bush fire on Transmission Lines in North Eastern Regional Grid of India

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Abstract— **The long last bush fire, causing the failure of transmission lines auto-reclosing, repeated trips or inability to restore the network quickly, poses a significant threat to the safety, reliability and stability of power systems. This paper analyzes the statistics of bushfire events affecting 132 kV and above transmission lines in the North Eastern Region (NER) of the Indian Power Grid from January 2016 to May 2024, examining the frequency of trips caused by bushfires and summarizing their characteristics and impacts. Besides, this paper also analyzes how bushfire causes transmission line trips with the help of live fault tracks and finds the paths through which transmission line discharge when trips happen and highlights critical preventive measures that led to a 35 % reduction in bushfire related tripping incidents. The strategies outlined in this paper offer valuable insights into mitigating the impact of bushfires on power transmission systems ensuring improved grid stability and reliability.**

Keywords—*Auto-reclosing, bush fire, Disturbance Recorder (DR), Right-of-Way (ROW), Transmission lines (TL), Trip out.*

I. Introduction

Transmission lines are the most widely spread part of the power system and overhead lines are subject to different environmental conditions such as fires, lightning and even faults caused by birds. The resulting outages not only affect the line but also affect the equipment in substations. Transmission line wildfires pose a serious threat to the power grid [1].

California has also a long history of wildfires, with their frequency and intensity rising in recent years due to factors such as climate change, drought and electrical infrastructure failures. Key incidents like the Camp Fire (2018),Woolsey Fire(2018)and Silverado Fire(2020)highlight the vulnerability of the state's power grid. Similarly, while less frequent than in California, wildfires in Southern China occur, particularly in rural and forested areas, driven by agricultural practices and dry conditions. Recent decades have seen several wildfires affecting rural communities and farmland.

The increasing incidence of wildfires and bushfires across the regions like California and Southern China highlights the critical need for robust precautionary measures to protect overhead Extra High Voltage (EHV)lines. In order to minimize the damage to overhead lines, precautionary measures like infrastructure upgrades, vegetation management, early warning systems and community engagement have been adopted by California, USA and Southern China.

The vision-based technologies including the use of cameras, sensors, and machine learning algorithms have emerged as powerful tools in monitoring systems globally, their adoption in wildfire detection for transmission lines in NER remains limited. Such technologies offer the potential to detect fire-related anomalies early, enhancing preventive measures. However, the feasibility of implementing these technologies faces several environmental, technical and processing challenges.

The North Eastern Region Grid within the Indian Power System encompasses 07 states and 12 Inter-State Generating Stations (ISGS). Presently, it caters to a maximum demand met of 3764 MW, supported by a total installed capacity of 5131 MW. The grid infrastructure includes 42 numbers of 400 kV lines, 50 numbers of 220 kV lines, and 315 numbers of 132 kV lines. Additionally, the North Eastern Region is interconnected with the Northern Region Grid of India through the +/- 800 kV Biswanath Chariali – Agra Bi-pole Multi-terminal HVDC link.

Some of the Overhead transmission line corridors in NER widely pass through mountain and forest areas with frequent human activities. They are affected by fire customs such as burning land, agricultural production and life. The month of March is particularly prone to a high incidence of bush fire.

Overhead transmission line trips caused by wildfires account for a considerable proportion of all kinds of trips and power outages [2-7]. Based on the Grid Operational experience in the NER over the past 8 years, bush fires have been a significant cause of transmission line tripping and power supply interruptions. According to statistical outage reports, bush fires are responsible for 3% to 4.5% of power system outages in NER, resulting in substantial economic losses to the national economy.

II. STATISTICS OF BUSH FIRE EVENTS IN 132 KV AND ABOVE TRANSMISSION LINES

From January 2016 to May 2024, there are 118 numbers of trip events in 132 kV and above transmission lines as shown in Fig.1 which is caused by the bush fire. Among the trip events, the number of trip events in 400 kV transmission is 30 accounting for 25.42 % and that in 220 kV and 132 kV transmission lines is 14 and 74 respectively, accounting for 11.88% and 62.7% respectively. In Fig.1, the tripping of transmission line due to bush fire reached a peak of 34 numbers in the year 2017, followed by a declining trend in subsequent years. Currently, 132 kV transmission lines are still weak in responding to bush fires. The discharge of transmission line affected by bush fire will cause poly-phase fault, while the success rate of poly-phase fault reclosing is low [8]. Under the severe environment of burning bush fire and dense smoke, the recovery condition of discharge channel is very poor. This results in frequent consecutive tripping within a short span of timeframe, thereby imparting substantial strain on the power grid.

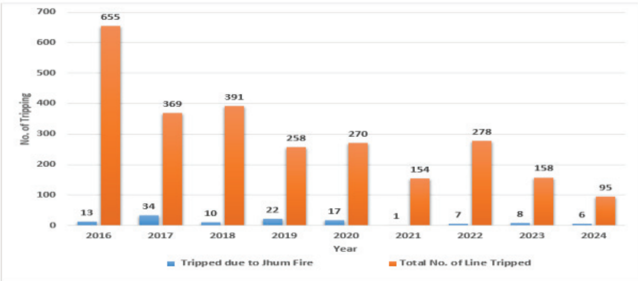


Fig.1. Bush fire incident statistics in 132 kV and above transmission lines in NER Grid from 2016 to May 2024

Fig.2 shows the monthly distribution of bush fire-related transmission line trip-outs from January 2016 to May 2024, highlighting the pattern of occurrences during this period. The peak trip-out times occur between January to April and October, constituting 6 %, 64 %, 8% and 5 % of the total trip out times respectively. There are mainly two reasons for the high incidence of bush fires in these months. One is the low moisture content of winter vegetation in this region and the frozen vegetation in winter is easy to ignite and spread after being dried in spring. On the other hand, the Spring Festival and other customs, as well as the spring ploughing and burning waste and the autumn harvest burning straw led to increase fire sources.

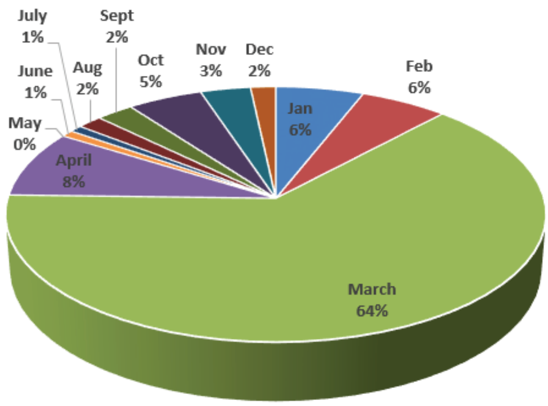


Fig.2. Monthly bush fire trip-out times in 132 kV and above transmission lines in NER Grid from 2016- May 2024

As shown in Fig.3, the number of bush fire trip-outs has decreased each year. Specifically, the 132 kV transmission line has experienced 74 bush fire trip events, averaging about 8 times per year. This region is frequently impacted by strong winds, which can easily carry foreign objects into the transmission lines. Moreover, the large forest and hilly areas pose a significant threat to the entire transmission line network.

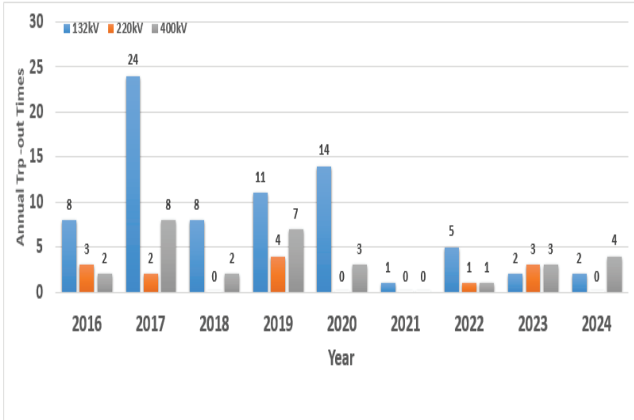


Fig.3. Voltage level wise trend chart of bush fire trip-out times from 2016-May 2024

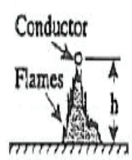
III. ANALYSIS OF SHORT CIRCUIT CAUSED BY BUSH FIRE

According to the analysis, it was found that the distance between the discharge point and hanging point ranges from 6 to 35 meters, while the distance between transmission line and earth wire ranges from 9 to 15 meters. And this is where line is in close proximity to the earth wire. Steep topography helps free air path come into being. Therefore, discharge path can be easily formed.

Based on the observation of the convection motion of free air, it was found that the formation of a discharge path is more likely in either the upper or lower path. Besides, three-phase line in vertical or triangular configuration can cause inter-phase short circuit more easily. Side line and earth wire are in up and down position and as such, discharge path can be easily formed as well.

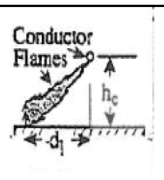
In TABLE I. the minimum clearance distance is given for the case where the fire burns directly under the conductor for five nominal phase-phase voltages.

TABLE I. MINIMUM CLEARANCE DISTANCE SUGGESTED IN THE CASE WHERE THE FLAMES ARE IMMEDIATELY UNDER THE LINE CONDUCTORS (FROM LANOIE & MERCURE, 1997)

Nominal phase-to-phase voltage levels (V_{rms})	Configuration	Minimum clearance distance h suggested. (m)
735		35
315		15
230		11
161		8
120		6

In TABLE II, the minimum cleared ROW distances are given as lateral distances from the conductor along with the practical minimum height clearing for each of the nominal phase to phase voltages. This deals with the case where the flames are blown towards the conductor by a cross wind. It is to be noted that these distances only pertain to phase to ground flashovers. For lower voltages, somewhat longer distances are suggested in order to account for flash tree-top fires that may occur where tall trees are present next to the ROW.

TABLE II. MINIMUM CLEARED RIGHT-OF-WAY DISTANCE, GIVEN AS LATERAL DISTANCES FROM EACH LINE CONDUCTOR (FROM LANOIE & MERCURE, 1997)

Nominal phase-to-phase voltage levels (V_{rms})	Configuration	Minimum line clearance height h_c. (m)	Lateral distances d_l suggested (m)
735		13.6	25
315		6.5	11
230		6.1	8
161		5.8	8*
120		5.5	6*

*taking in account the height of tree tops

IV. ANALYSIS OF FORMING OF FREE AIR PATHS

On average, the concentration of charged ions in the air is approximately 1000 ions per cubic meter. Meanwhile, transmission lines are insulated by the air. Therefore, air is considered ideal and cheap as material. Under such conditions, minimum distance of 1.3 Meters for 400 kV transmission line is enough for insulation. However, when bush fire occurs, high temperature caused by the burning can reach up to 1000 °C and this leads to atoms rapid stimulation and dissociation.

Learning from trip surroundings, it’s the mixing burning of crown fire and earth fire that results in trips. In other words, when earth fire is dissociated up to the treetop, air is burned to dissociate again. Besides, trips can be caused by climbing fire as well. As climbing fire's flame is higher, while dip head fire's flame is lower, charged ion and electron neutralize, making it hard to cause transmission line trips. The forming of fire discharge path agrees with the theory of flow column.

The existence of a discharge path, once formed, is typically transient and lasts only for a brief period due to the prolonged duration of bush fires. Discontinuation of the path can occur when the intensity of the burning weakens or when the fire's direction undergoes a change. And this is why auto-reclosing fails or tripping occurs repeatedly.

V. EVENT ANALYSIS USING DISTURBANCE RECORDER OUTPUT

Disturbance recorder output data obtained from the field has been used to observe the waveform characteristics to suggest possible cases of tripping of lines due to bush fire. Case studies on tripping of 400 kV Silchar-Byrnihat Line on 10.04.23, 400 kV New Kohima-Mariani-2 Line on 06.04.2024, 220 kV New Mariani-Mokokchung Line on 14.03.2019 and 400 kV Silchar-Imphal-2 Line on 05.01.2021 has been done for the analysis and is illustrated in Fig. 4, Fig.5 and Fig.6.

Case 1: Tripping of 400 kV Silchar-Byrnihat Line on 10.04.2023

As per the disturbance recorder output from Silchar shown in Fig.4, fault was initiated at 13:47:57.581 Hrs and was cleared within 490 msec. The line tripped on distance protection in Z-1, BE with Ib:2.1 kA, In:2.1 kA, Vbe:189 kV, Vn:64 kV. It was observed that fault initiates at positive peak of the B-phase voltage waveform and phase angle between Ib and Vbe is -24 degrees.

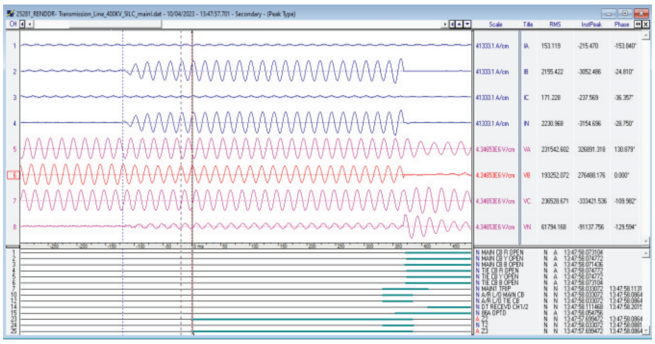


Fig.4.Tripping of 400 kV Silchar-Byrnihat Line on 10.04.2023

Case 2: Tripping of 400 kV New Kohima-Mariani-2 Line on 06.04.2024

As per the disturbance recorder output from New Kohima shown in Fig.5, fault was initiated at 12:53:56.933 Hrs and was cleared within 49 msec. The line tripped on distance protection in Z-1, BC with Ib:3.3 kA, Ic:3.3 kA, Vbe:113 kV, Vce:94 kV. It was observed that fault initiates at positive peak of the voltage waveform without neutral and phase angle between Ib and Ic is 180 degrees.

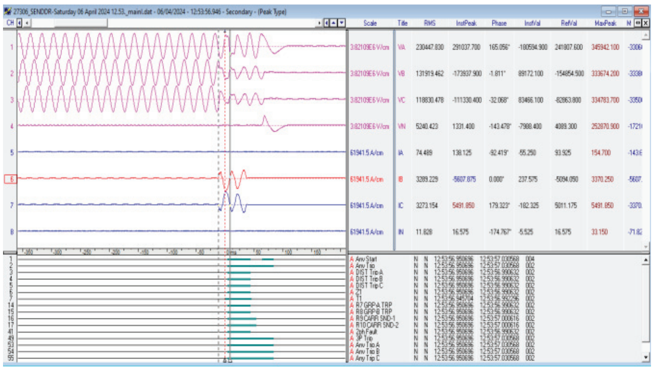


Fig.5. Tripping of 400 kV New Kohima-Mariani-2 Line on 06.04.2024

Case 3: Tripping of 220 kV New Mariani-Mokokchung Line on 14.03.2019

As per the disturbance recorder output from New Mariani shown in Fig.6, fault was initiated at 13:09:28.331 Hrs and was cleared within 60 msec. The line tripped on distance protection in Z-1, BC with Ib:2.2 kA, Ic:2.2 kA, Vbe:66kV, Vce:66 kV. It was observed that fault initiates at positive peak of the voltage waveform without neutral current and phase angle between Ib and Ic is 179 degrees (near to 180 degrees).

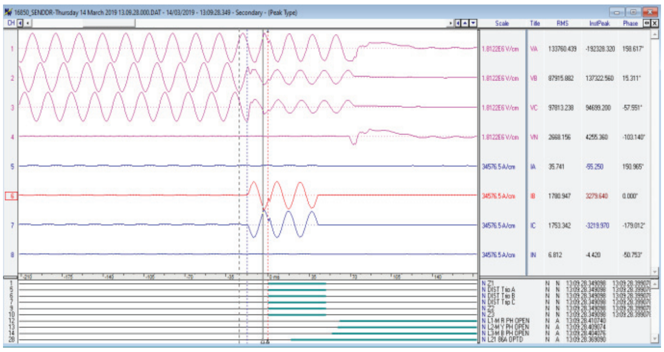


Fig.6. Tripping of 220 kV New Mariani-Mokokchung Line on 14.03.2019

Case 4: Tripping of 400 kV Silchar-Imphal-2 Line on 05.01.2021

As per the disturbance recorder output from Imphal shown in Fig.7, fault was initiated at 15:52:31.043 Hrs and was cleared within 51 msec. The line tripped on distance protection in Z-1, AC with Ia:2.7 kA, Ic:2.7 kA, Vae:110kV, Vce:110 kV. It was observed that fault initiates at positive peak of the voltage waveform without neutral current and phase angle between Ia and Ic is -178 degrees (near to 180 degrees).

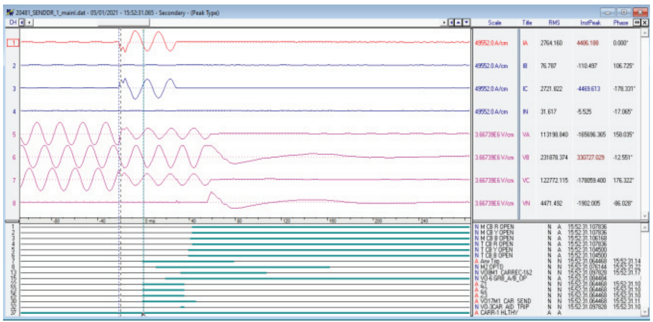


Fig.7.Tripping of 400 kV Silchar-Imphal-2 Line on 05.01.2021

From all the above tripping of lines, following characteristics are observed in bush fire related trippings. The cause being bush fire was subsequently ascertained from the outage report submitted by the transmission utility:

i) The fault current shall be phase to phase not involving ground. The fault currents in both phases shall nearly be in phase opposition (near 180 degree).

ii) The fault current shall be phase to Earth. The fault current lags the voltage in the faulty phase by small angle.

iii) Fault current may start at any phase angle of the voltage wave form.

iv) Fault initiates at positive peak of the voltage waveform

v) Fault current remains same during the fault period.

vi) Fault current may or may not be symmetrical.

VI. MEASURES AND SUGGESTIONS TO PREVENT TRANSMISSION LINE TRIP-OUT

After analyzing the various tripping caused by bush fire we conclude several methods to mitigate these issues as follows-

1. To reduce potential fuel sources and create unobstructed air paths, it is essential to promptly remove combustible objects such as dry trees, fallen leaves and grass from beneath the transmission line corridors. Additionally, the number of trees within the corridors should be minimized, maintaining a clearance of 45-50 meters around the towers and 15 meters around the lines. It is necessary to strengthen the close contact with forestry and forest fire control departments, establish a fire linkage notification system, improve the isolation safety measures, do contingency measures for emergencies [9].

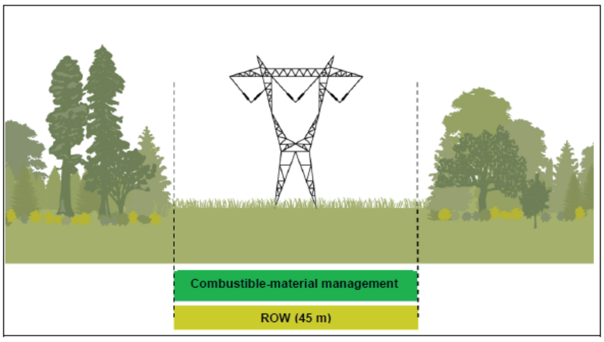


Fig.8. A schematic representation of the areas managed to prevent fires.

2. Transmission lines and locations where bush fire takes place should be identified by the Transmission utility. The utility has to ensure-

   Compatibility of vegetation with the corridors; Reduction of fire risk; Enhancement of the landscape and promotion of native species (such as oak, cork oak, holm oak and others);Stop the proliferation of areas of land with the same species of vegetation; Increase the intervention cycles; Ensure a shared responsibility with landowners; Cut maintenance costs.

3. Permanent educational campaigns needs to be conducted. Help from local administration needs to be taken to educate villagers to avoid bush fire which also can be fatal for locals.

4. Special drive arrangement should be taken in December and January months each year to remove bush from transmission line corridor.

5. Enhancement of forest fire use management and fire safety publicity in order to reduce the possibility of bush fire.

6. Carry out anti-fire inspections and firefighting. Put out any fire at its beginning.

7. Cut down the fire belts. Establish fire belts under the slopes for transmission lines, which traverse the wood, to prevent fire from spreading to transmission line paths.

8. The planting of alternative crops where fire is not used as a means of harvesting. Landowners were encouraged to cultivate of low-rise fruit bearing trees, horticulture etc. under the line corridor instead of bamboo /long trees.

Fig.9. Example of a managed Transmission line

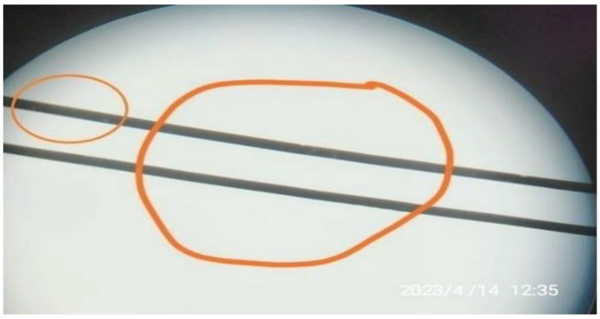


Fig.10. Bush fire flashover mark point

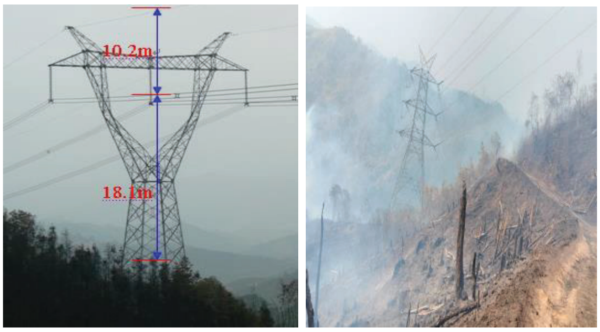


Fig.11. Bush fire Trip Tower

VII.PERFORMANCE ANALYSIS AFTER MEASURES TAKEN

TABLE III indicates a significant reduction in the total number of trippings and the percentage of bush fire-related trippings following the implementation of the aforementioned measures on these transmission lines.

TABLE III. PERCENTAGE OF BUSH FIRE FAULTS BEFORE AND POST MEASURES

Percentage of bush fire faults before and post measures					
Before measures taken			***Post measures taken***		
Total number of tripping	Tripping due to bush fire	Percentage of bush fire fault	Total number of tripping	Tripping due to bush fire	Percentage of bush fire fault
1943	**96**	**4.94%**	**685**	**22**	**3.21%**

Therefore, by implementing the aforementioned strategies to combat bush fire-induced interruptions, transmission lines traversing mountainous and forested terrain can mitigate the risk of unplanned power outages caused by bush fires.

VIII. CONCLUSION

According to the statistical analysis of operation data from the past 8 years for 132 kV and above transmission lines, bush fires are identified as one of the factor affecting the safe operation of these lines. Fault trips caused by bush fires account for 3-4.5% of the total fault trips in the North Eastern Region. The period from January to April has the most significant impact on transmission line reliability due to bush fires. Implementation of the above-mentioned measures in the transmission line has successfully reduced the outage rate to ensure uninterrupted power supply. Similar strategies can be adopted by the transmission utilities across the world where there were frequent tripping of line due to bush fire.

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