

IMPACT OF SEASONAL VARIATION ON CORONA DISCHARGE AND OVER ALL POWER WHEELING EFFICIENCY OF OVERHEAD TRANSMISSION LINE WITHIN WESTERN REGION OF INDIA.

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ABSTRACT

India experiences diverse climatic conditions ranging from tropical in the south to temperate and alpine in the Himalayan north. As the EHV transmission network of India is spread across the length and breadth of the country, it is quite natural that the national grid too is subjected to different climatic conditions. Even different parts of the same overhead 765 kV or 400 kV long line experience different weather conditions at the same time, as the line passes through different weather zones. Depending upon the season, the transmission network is exposed to different extreme weather conditions.

Though the overhead lines are well designed to endure these diverse weather conditions while maintaining reliability margin, but their performance is to some extent influenced by the climatic condition. One of the performance indices is its loss. The ohmic loss is dependent on affecting corona are discussed. In section III effect of weather on corona loss variation within various parts of eastern region of country is studied. Section IV describes operational practices to minimize corona loss and finally Section V draws the conclusion

Keywords— EHV, WR, Corona, SIL, Critical disruptive voltage and HVTL

I. INTRODUCTION

Increasing the rated voltage for long distance power transmission has several well-known advantages. But with increase in voltage level, corona loss also increases [1]. The air molecules around the conductor of HVTL (high voltage transmission lines) get ionized, leading to partial discharges

II. THEORETICAL BACKGROUND OF CORONA

A. Mathematical Model of corona power loss

Formation of corona in EHV transmission lines is accompanied by some power loss. Peek has given an empirical formula [4] to calculate this power loss as follows:

$$P_c = \frac{K}{\delta} (f + 25) \frac{\sqrt{R}}{\sqrt{a}} \left(\frac{V_L}{\sqrt{3}} - E_{dcv} \right) \times 10^{-5} \text{ KW/km/phase} \quad \dots\dots\dots (1)$$

the power flow and not much affected by weather. But corona loss which takes place in EHV transmission network is greatly influenced by the weather condition and seasonal change in the country.

This paper aims at identifying the area in the eastern grid of the country where corona loss variation is more in different season. Some measures to minimize such loss are also suggested.

Where

- f=Supply frequency in Hz
- V_L = Line voltage (rms) in kV
- E_{dcv} = Disruptive voltage (rms) per phase in kV
- R = radius of the conductor in meter
- d = Spacing between conductors in meter
- K = Fixed constant
- δ = Air density correction factor
- V_{ph} = Phase voltage (rms) in kV

This formula holds well when the ratio of phase voltage to critical disruptive voltage is more than 1.8. But if this ratio is less than 1.8, Peterson’s formula is used for calculating the corona loss.

The formula is as follows: Equation (2) when the applied voltage in an insulation system exceeds a critical voltage. When the voltages become greater than the

$$P_C = \frac{(21 \times 10^{-6} f v^2)}{\log_{10} \frac{d}{R}} \times F \frac{\frac{KW}{km}}{phase} \dots \dots \dots (2)$$

Where,

critical voltage value, corona starts but the conduction area is not large enough to cause breakdown or electrical arcing to the other area nearby[2]. Ozone gas is produced when corona occurs on transmission line its smells like chlorine but has a metallic touch in it[3]. The corona effect has no clear indication before it occurs. The special symptoms of corona are hissing sounds, radio interference, and production of ozone that can be easily observed in high voltage transmission lines. The electric conductor can be affected by irregular shape, unstable voltages, acidic rain (only in industrial area). The dielectric breakdown of air most often occurs due to corona because it deteriorates the insulation but it is basically a slow process. The effects of corona are primarily studied here for contrasting weather condition in different part of the eastern region of India.

This paper is organized as follows: In Section II Theoretical back ground of corona is described and various factors

F= Multiplying factor

v= Phase to neutral voltage

Dependence of corona loss upon various factors like system parameters, transmission line physical parameters and weather is clear from the above formulas. Weather effect is taken into consideration by the factor δ appearing directly in the Peek’s equation. In Peterson’s formula though there is no direct weather related term but as critical disruptive voltage changes with weather condition so weather effect is taken care of by the multiplying term F. The typical variation of F with V_{ph} and E_{dcv} as found in literature is indicated below:

V_{ph}/E_{dcv}	0.6	0.8	1	1.2	1.4	1.6	1.8
F	0.012	0.018	0.05	0.08	0.3	1	3.0

Table 1: Variation of F with V_{ph}/E_{dcv}

δ also appears indirectly in the formula for disruptive voltage as shown below:

$$E_{dcv} = 21.1M_0\delta R \log_e \frac{d}{R} \text{ kV} \dots\dots\dots (3)$$

Where,

M_0 = Surface irregularities factor

M_0 is 1.0 for polished conductors and varies in the range 0.87-0.80 for stranded conductors.

Critical disruptive voltage means the voltage at which voltage gradient at the surfaces of the conductor exceeds the breakdown strength of the air.

B. Factors affecting Corona loss

For 400 kV and above voltage levels, corona loss is influenced by various design considerations of line physical parameters as corona loss is dependent on system parameters, line physical parameters and weather condition. Though the main focus of this paper is to study the effect of the weather on corona loss in overhead EHV lines of the Eastern Regional power system of India, but the effect of other parameters are also discussed briefly.

Various line physical parameters influencing corona loss are as follows:

i) **Spacing of conductors:-** As spacing between conductors increases the corona loss decreases. If spacing can be made very large then corona loss can be made absent but that will not be economical. So spacing is chosen such that corona loss is as minimum as possible.

ii) **Size of the conductor:-** in Peek’s formula both

$$(\sqrt{R}/\sqrt{d}) \text{ And } (VL/\sqrt{3} - E_{dcv})$$

Terms are related to the conductor size. As radius of

Conductor increases the term (\sqrt{R}/\sqrt{d}) increases, but the same time E_{dcv} also increases so $(VL/\sqrt{3} - E_{dcv})$ term decreases. The overall effect is dominated by the $(VL/\sqrt{3} - E_{dcv})$ term

Hence with Surrounding air of the conductor does not increase much and corona loss reduces.

Influence of weather on corona loss is accounted in Peek formula by the term δ air density correction factor which appears directly and indirectly in the E_{dcv} . A lower value of δ causes higher corona loss as it is inversely proportional to the δ and the disruptive critical voltage also decreases as the δ decreases. Hence with decrease in air density correction factor, corona loss increases. Air density correction factor depends on weather condition. During bad weather condition like rain, snow, hailstorm air density decreases leading to decrease of critical disruptive voltage and increases of corona loss.

This is due the fact that water droplets on conductor surface form sharp edges which increases the electric field. Hence the disruptive corona voltage reduces and the corona loss increases. During foggy winter as well as high humid weather also moisture can accumulate on the conductor surface. This will lead to increase of corona loss. Load current plays an important role in minimizing the effect of corona loss as it heats up the conductor and hinders the formation of water droplet on the conductor surface. But during light load condition, load current can’t sufficiently heat up the conductor and similarly during heavy rains load current cannot prevent formation of water droplets. Hence increase of corona loss cannot be avoided during such climatic and power system conditions. Other weather parameters that influence the corona loss are height above sea level, temperature and pressure etc. At higher height from mean sea level the number of ions per unit volume of air is more hence corona loss is more in hilly region than on plane land. The dependence of corona loss on air density correction factor is already described. Value of this

factor is dependent on pressure and temperature at a particular height and is expressed as follow: Increase in conductor radius the corona Losses reduces [5]

i) **Surface condition of conductors-** rough or uneven surface increases the corona loss as this reduces the breakdown voltage.

Where,

$$\delta = \frac{3.92b}{273+t} \dots\dots\dots (4)$$

Various system parameters that influence the corona loss are as follows:

i) Line voltage:- corona losses are absent at lower voltage level, but as the voltage of the line become more than the critical disruptive voltage corona loss starts. The major transmission system backbone in India is at 400 kV level and in the last five years a huge growth of 765 kV transmission systems in India have taken place. So corona loss as a percentage of total system loss has increased considerably.

ii) System frequency:- As evident from the Peek's formula, corona loss is directly proportional to frequency, as our system is already designed for 50 Hz and its daily variation is tightened to a very narrow band that's why its effect on corona is almost constant.

iii) Load current:- load current sets the temperature of the conductor and this in turn hinders the formation of dew, snow on the conductor surface, Therefore conductivity of the
 $b = \text{Barometric pressure in cm of Hg}$
 $t = \text{temperature in degree C}$

Corona is also affected by the physical state of the atmosphere. In stormy weather conditions, dusty and rainy conditions, the number of free electrons and ions are more than that in fair weather condition. Hence the disruptive voltage reduces under adverse weather condition. This in turn increases the corona loss considerably.

III. SEASONAL VARIATION OF CORONA LOSS IN DIFFERENT PARTS OF EASTERN REGION

Before we quantitatively analyze the variation of corona loss in different parts of eastern India and how it is guided by the climatic behavior of that part, it is necessary to discuss a few other points related to power system behavior in the ER.

A. Seasonal variation of load and generation pattern and grid characteristics in WR

Western region comprises the states Maharashtra, Chhattisgarh, Madhya Pradesh and Gujarat. The western region is connected to Northern region by bipolar 800KV HVDC link from Champha Polling Station Chhattisgarh to kurukshetra Haryana.

WR is connected to the Thermal Power Station Chandrapur by Bipolar 400KV HVDC link Padghe (Thane). To meet the deficit in power requirement and to share excess generation of western region is connected to Southern region by various links. v. z HVDC Bipolar link is under construction between Rajgarh Chhattisgarh to Pugalur Telangana State.

Also another link between Southern regions to Western Region is Solapur (MH) to Raichur Karnataka by 765 KV link. Also there is Wardha to Hyderabad by 765 KV link. Also another link of 400KV HVDC quad line is under construction From Xelam (Goa) to Narendra. Southern region is connected with the Northern Region by $\pm 500 \text{ KV HVDC Bipolar Link}$ between (ADANI Power) MUNDRA to Mahendragarh Haryana. Also there is link between BHUJ Polling Station Gujarat to Chhattisgarh (Rajasthan) by 765 KV Line. and also there is Quad link between Kanaksari (Gujarat) to Kankroli PG by 400KV link. And also Western Region is Connected to the Eastern region by Dharmrajgarh (Madhya Pradesh) to Ranchi by 765KV line, and also by 400KV line from Raipur (PS) Chhattisgarh to Ranchi (Zarkhand) with Triple line.

Various major load and generation pockets are shown in the Fig.1

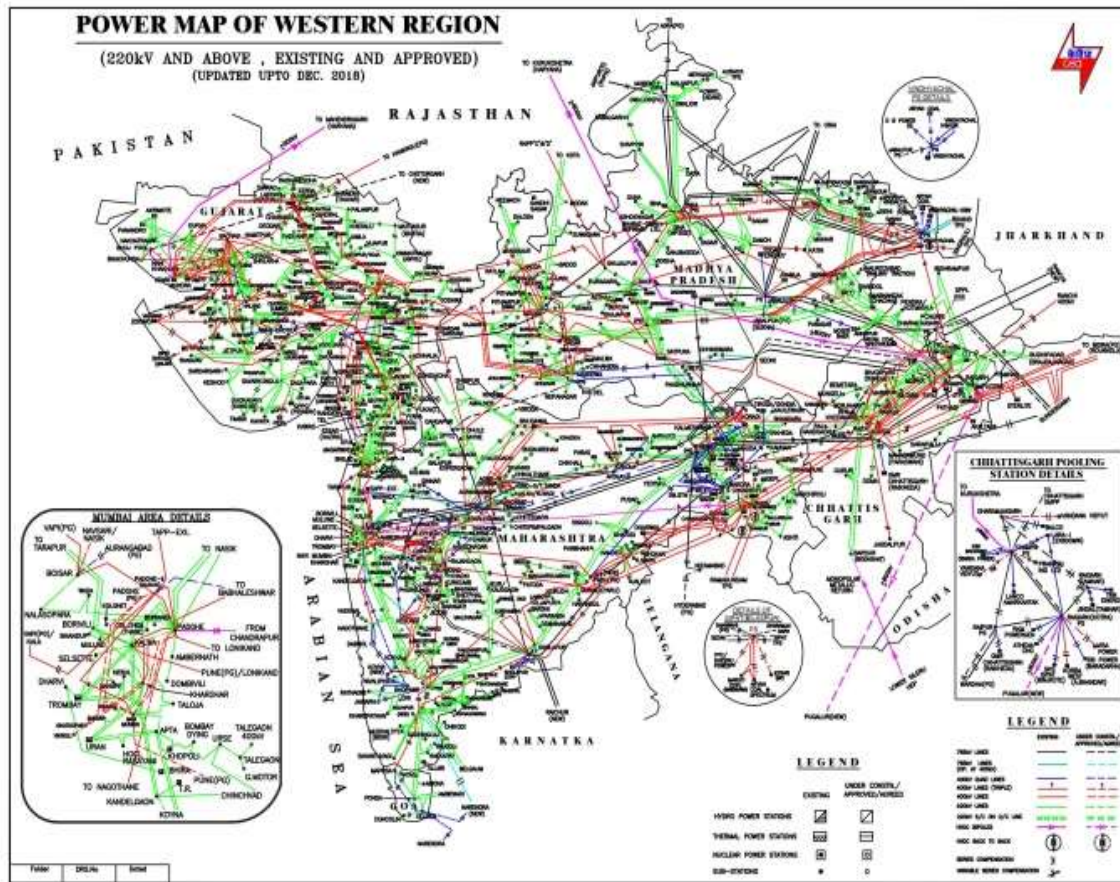


Figure 1: Power map depicting load generation pockets of WR

Peak load met during the evening peak of summer is around 20000 MW and during winter off peak hours the minimum load falls to around 10000 MW. In rainy season the difference between highest and lowest load met is occasionally much higher than that in other seasons as sudden load throw-off takes place due to storm and heavy rain. The main challenge that is faced during the winter off peak and sudden load throw-off is controlling the over voltage in the EHV transmission system. Reactive power control is exercised by generator excitation control and switching of bus reactors or switchable line reactors. During the above mentioned situation as network voltage profile increases, it influences the corona loss greatly. Corona loss is increased firstly due to formation of water droplets, dust accumulation due to bad weather and secondly due to low loading and consequent high voltage in the system. The effect of low loading and high voltage on corona can be explained as follows: corona loss depends directly on system voltage as already shown in Peek’s formula.

During the winter off peak, the whole WR grid faces high voltage problem as the loading of most of the lines remains below SIL, this increases the corona loss. Voltage profile along the line for different loading conditions is as shown in Fig.2.

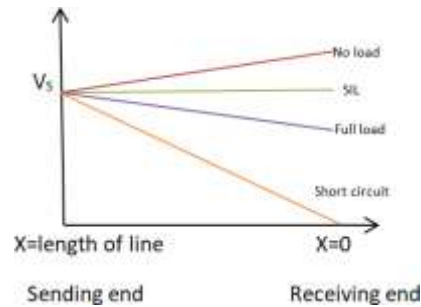


Figure 2: Voltage profile along the line when Loading is other than SIL

So, it can be seen that the voltage along the line is more than that at its terminal substations. So this in turn contributes to more corona loss. Also during the low line loading the load current cannot heat up the conductor enough to prevent formation of water droplets.

B. Characteristic weather condition in different parts of the WR during various seasons

The Western region of India lies in the humid-subtropical zone, and experiences hot summers from March to June, monsoon from July to October and mild winter from November to February. The states nearer from the sea coast have humid and slightly extreme climate, especially during the winter and summer, but the whole region receives medium as well as heavy, sustained rainfall during the monsoon month. Widespread fog formation occurs over Southern and middle states of India namely Madhya Pradesh, Maharashtra, Gujarat in Western Region, the phenomenon is nearly periodic starting from mid of December up to mid of January every year, since 1997[7]. Coastal belt of Maharashtra, Gujarat has a equable climate and the atmosphere is highly humid and sticky. Eastern part of Western region, being remote from the coast, experiences extreme weather in summer and winter.

It is observed that fog is prominent in Eastern part of Western region. There are many EHV lines - both intra and inter regional, that pass through this part of Western region. Corona loss of a few lightly loaded 765 kV lines located in the Western part of Western Region is greatly affected during the fog.



Figure 3: Fog affected area in WR

C. Seasonal variation of corona loss of different EHV lines passing through various part of WR.

Corona effect is very prominent in 765 KV line. Seasonal variation of loss in 765 kV inter-regional lines viz.

Solapur (MH) to Raichur Karnataka by 765 KV link and also Wardha to Hyderabad by 765 KV link. which are passing through different geographical area are examined.

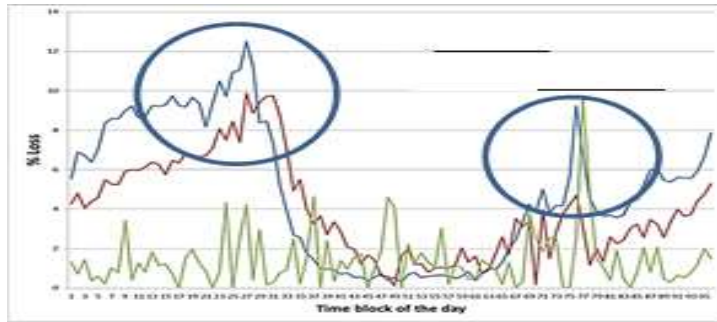


Figure 4: Variation of % line loss during a typical winter day of various 765 kV line

It is clear from the Fig.4 that during winter off peak hours, percentage loss in the 765 kV lines significantly increases. It is to be noted that lines Solapur (MH) to Raichur Karnataka by 765 KV link and also Wardha to Hyderabad by 765 KV link.

Where formation of fog during night or near dawn is quite common, when ambient temperature is normally very low. Together with high voltage condition due to light load, the corona loss in line increases significantly, thereby increasing the total line loss. Also sometimes there are some measurement errors of current and voltage transformer but these effects are constant throughout the day. So this may led to some higher value of loss but don't affect the loss pattern.

Figure 5. Variation of % line loss of various 765 kV and 400 kV line passing through fog affected area of Solapur (MH) to Raichur Karnataka by 765 KV link and also Wardha to Hyderabad by 765 KV link of Dec-2017

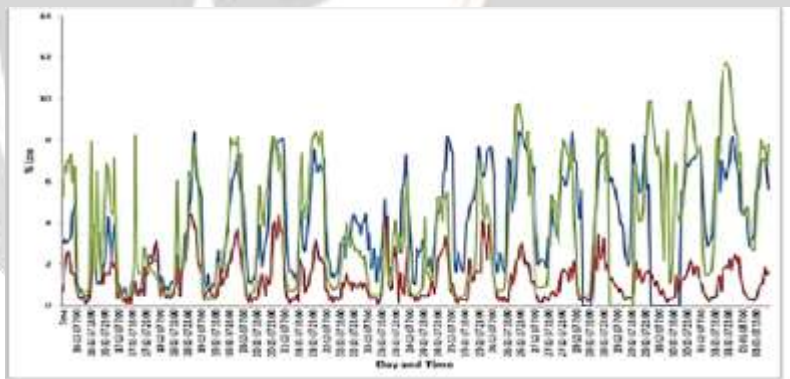


Figure 5. Variation of % line loss of various 765 kV and 400 kV line

From Fig. 5 it is seen that from mid of December as formation of fog during night and early morning hour starts % loss also increased during that part of the day. Similar pattern is seen for different year during the same period. This is consistent with the fact that corona loss increase due to fog.

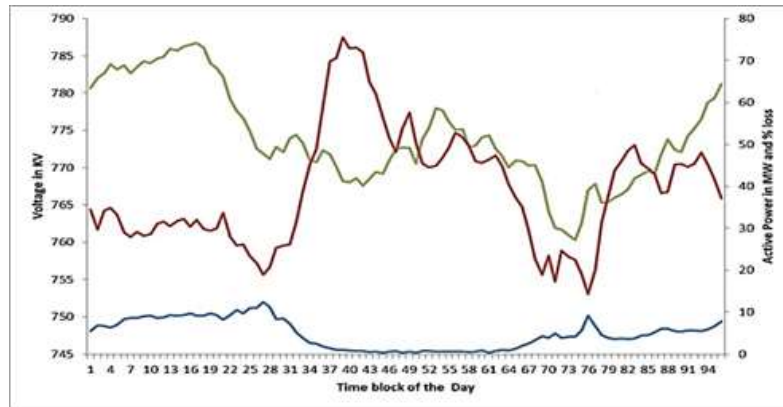


Figure 6: Voltage and Loss variation in a typical winter day

Figure 6: Solapur (MH) to Raichur Karnataka by 765 KV link and also Wardha to Hyderabad by 765 KV link, voltage and Loss variation in a typical winter day

From the Fig.6 it may be seen that during night lean load hour's voltage as well as percentage the loss increases. As low load current could not prevent the formation of water droplets and voltage also increases, so this increase of loss is solely due to corona effect. Further, during lean hours, corona loss dominates out of the total loss. So we may say variation of corona loss follows the same pattern as total line loss.

Variations of total active power loss of some of the 400 kV lines passing through the same corridor are shown below (Fig.7).

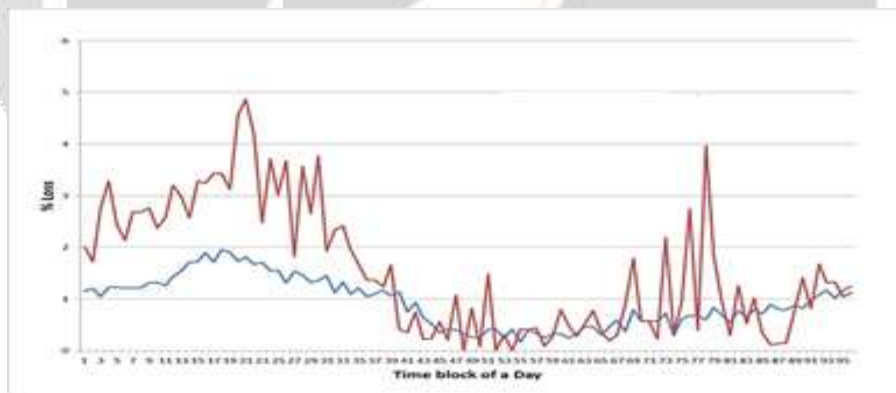


Figure 7: Variation of % line loss during a typical winter day of various 400 kV line in Western Region

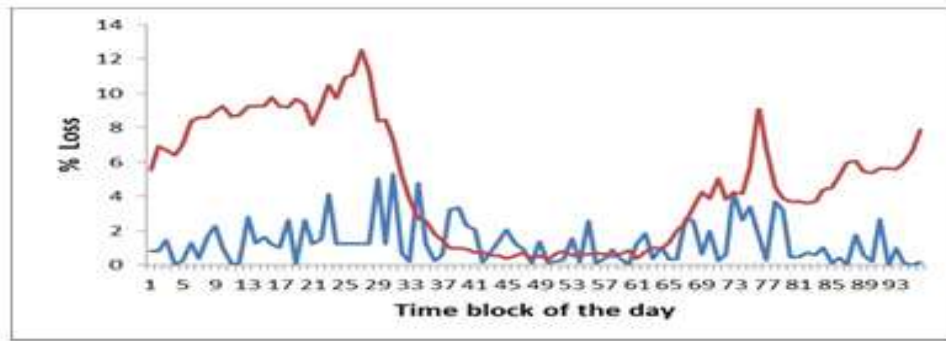


Figure 8 Variation of % line loss during typical summer and winter day

Figure 8 Variation of % loss during typical summer and winter day of Wardha to Hyderabad by 765 KV link and Solapur (MH) to Raichur Karnataka by 765 KV link. From plots of % loss shown in Fig. 8, it may be seen that the active power loss in summer is lower and almost constant throughout the day as opposed to high loss during night and early morning hours in winter season, for the same line.

During summer relatively flatter % loss is seen every year. So effect of fog on corona loss is clearly understood. In Marathwada, north Maharashtra, eastern Gujarat and some parts of Madhya Pradesh the area experiences slightly high voltage in winter due to low load condition.

The plot of % line loss of 400 kV Subhasgram-Haldia is shown below (Fig. 9) for both winter and summer (one day):

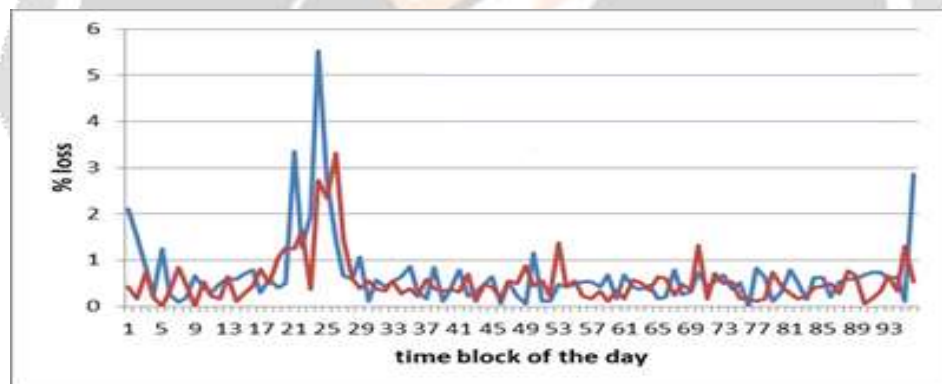


Figure 9: % loss of Bipolar 400KV HVDC link between Chandrapur to Padghe (Thane). During winter and summer

While power flow through this line remains almost constant and even reduces during winter (due to planned outage of HEL units) it can be seen that the loss pattern during the winter does not vary much from that in summer. As formation of dense fog in this part of Eastern region is not that prominent, hence no major impact on account of corona is noticeable here. However, mild fog as well as smog is responsible increasing the total loss by additional 2-3% during night-lean / early morning hours. Actually the effect of fog is to reduce the air break down strength which is dependent on both air density and humidity. From weather point of view, only the effect of air density correction factor on corona has been elaborated so far. However, if we also consider the humidity correction factor, break down voltage of air further reduces [8]. In areas susceptible to fog, the relative humidity at night and early morning hours increase significantly during typical winter season, leading to formation of fog and dew. So the effect of fog is to increase corona loss and this affects mostly the EHV transmission line passing through the fog prone area of Western region. Also the effect is more in 765 kV lines than in 400 kV lines, though both the voltage levels follow the same pattern over the whole day.

III. CORONA LOSS REDUCTION STRATEGY

From the above results it is clear that in EHV lines the corona loss due to fog increases and this is prominent in lightly loaded 765 kV lines, theoretical background of which is already explained. As fog is predominant in the Western region, increase of corona loss in the EHV lines passing through this part of Eastern region is most prominent. Once a power line has been built, the only way to reduce the corona loss would be to reduce the voltage. There are situations when EHV lines are not heavily loaded and could be operated at a slightly reduced voltage. The corona loss changes as a power of the voltage, so for example, a loss reduction of 25% may be achieved with a voltage reduction of perhaps 5%. The 5% reduction in operating voltage increases the ohmic line losses by 10%. Therefore, reducing corona losses by decreasing the voltage could be implemented during periods of low line

Loading, if the benefits can justify the effort. The overall impact on efficiency would be climate-dependent. Now to reduce the corona loss the node voltage must be kept as close to nominal voltage as possible during the winter off peak lean hours. This could be done by proper reactive power management in the overall grid. In western part of Bihar, generators are very few in number. Thus, proper switching of the Bus reactors is the only way to bring down voltage. Also to control over voltage one of the lightly loaded parallel EHV lines can be opened. In such case, priority must be given to 765 kV line opening if that is otherwise permitted from system reliability point of view.

This helps to reduce corona in two ways, firstly it reduces the voltage hence corona loss reduce as it is directly proportional to square of the voltage and secondly with opening of one parallel line loading on the other line increases thus increasing the ohmic loss. The resulting increase in heat generation in that line indirectly helps to reduce corona by not allowing water droplet formation on the conductor. As corona effect is more in 765 kV lines so scope of optimizing taps of 765/400 kV ICT may be explored to reduce the 765 side voltage while maintaining 400 kV side voltages within acceptable limit.

IV. CONCLUSION

During power system planning the effect of weather is duly addressed from line load ability and tower design points of view. However during the operation phase weather also affects the transmission system performance from various directions. Increase of corona loss due to fog is one of them. Now neither the formation of fog nor the system designed could be changed. But some operational practices can help in reducing the corona loss as already discussed. Corona loss is dependent on system voltage and its effect is most prominent in fog prone region. So the fog prone areas need to be identified first and then detailed study may be carried out to assess how it is affecting the corona loss and overall loss. Subsequently, adopting operational practices as suggested would help in containing its effect to a minimum.

Overall Power Wheeling Efficiency of Overhead Transmission Line:

$$\text{Receiving End Power} = \text{Sending End Power} + \text{Transmission line losses}$$

Where,

$$\text{Total Transmission line losses} = I^2R + P_c \dots\dots\dots (5)$$

P_c = Power Losses Due to Corona Discharge
 I^2R = Transmission line Losses

From above Equation No.5, it is observed that Corona discharge greatly effect on the total power received at the load end.

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