

Meteorological conditions associated with the full-span galloping oscillations of overhead transmission lines

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ABSTRACT

The recorded phase-to-phase faults associated with the full-span galloping of CEGB overhead transmission lines over a 7-year period have been correlated in the form of histograms of number of faults as a function of wind speeds prevailing at the times of the faults. It is shown that, for bundled conductors, the results are in reasonable agreement with the theoretical predictions of Hunt and Richards for the minimum wind speeds necessary to cause phase-to-phase faults.

1 INTRODUCTION

In a recent paper, Hunt and Richards¹ presented a theory for determining the maximum energy input from the wind into the full-span galloping oscillations of ice-accreted bundled overhead transmission lines. The main assumption made was that the galloping motion could be represented by a vertical oscillation which was sinusoidal in time. One of the conclusions of the paper was that, for any particular conductor and tower geometry, there is a critical wind speed below which oscillation amplitudes large enough to cause interphase clashing cannot be maintained. The critical wind speed is found to be a function of the maximum lift coefficient of an iced conductor or bundle of conductors, which can only be estimated using wind-tunnel models of ice-laden conductors. This is the biggest unknown in the theory, and should be borne in mind when applying the theory.

At the time the paper was published, there was very little information available about the wind speeds prevailing at the times of full-span galloping of bundled conductors, and it was not possible to assess how close the critical wind speed was to the actual lower-bound wind speed found in practice. This paper presents data collected from the CEGB transmission system over a 7-year period, and is a first attempt at examining the meteorological conditions under which large-amplitude full-span galloping occurs on bundled overhead transmission lines.

2 NATURE OF THE DATA

The problem of determining whether or not galloping is occurring on an overhead line is not, in general, easy. The indication of galloping which has the greatest impact on a transmission system is the occurrence of phase-to-phase faults, with the consequent operation of the system protection equipment. This is not an infallible detector, as phase-to-phase faults can also arise following the sudden release of ice loads from one phase, but it has the advantage in the CEGB that the faults are recorded and may subsequently be analysed.

In this paper, we have used a list of phase-to-phase faults known to have occurred on the CEGB overhead-line transmission system in conditions of strong wind and/or ice and snow in the period 1965-72. The list gives the substations at each end of the offending circuit, and the date and fault time. No information was, in general, available concerning the precise location of the faults. (The problem of locating phase-to-phase faults is discussed by Wilton et al.²)

This list was examined, and faults clearly not associated with galloping were eliminated at this stage. Where a number of faults had occurred in quick succession on a circuit, this was only counted as one fault for the purpose of this analysis. The next step in the process was the determination of the relevant meteorological conditions. The lack of precise information on the location of faults, combined with the relative scarcity of hourly recording meteorological stations, ruled

out any great precision at this stage. The process adopted was to use the spot wind speeds (i.e. 10 min mean wind speed) and temperature from the meteorological station(s) nearest to the circuits on which the faults occurred.

There are obvious drawbacks to this method, but in the event, in most cases, the recorded meteorological conditions did not appear to be changing very rapidly from hour to hour at the fault times; so it was felt that the data used represented a fair guide to the prevailing conditions.

3 ANALYSIS OF THE DATA

Hunt and Richards¹ concluded that, for a bundled conductor, the necessary condition for galloping can be expressed as a relationship between oscillation amplitude a , wind speed U and circular frequency of oscillation ω , namely:

$$\frac{a\omega}{U} \leq 0.82 \quad (1)$$

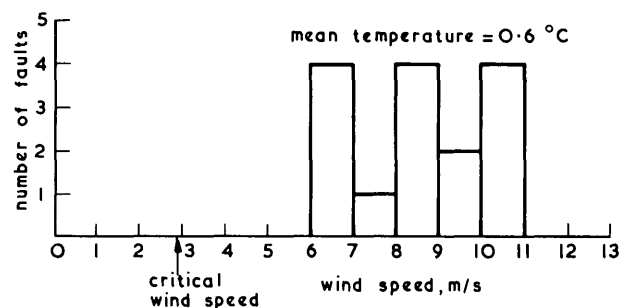


Fig. 1
132 kV BES L7

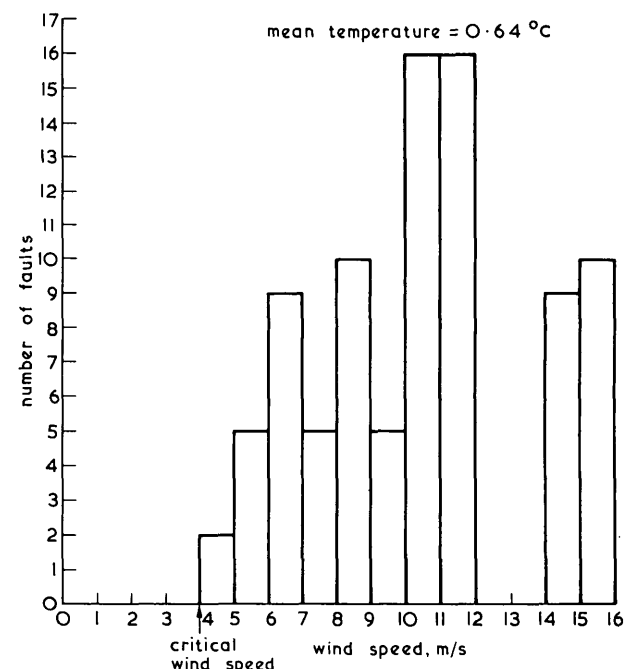


Fig. 2
275 kV BES L3

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Thus, given ω and the minimum value of a necessary to cause phase-to-phase clashing (assuming antiphase oscillations between adjacent phases), the minimum wind speed necessary to sustain this amplitude may be calculated. The CEGB employs four tower configurations with bundled conductors. All the constructions are twin bundled conductors, with the exception of BES L6 which employs a quadruple bundle.

The meteorological data are presented in Figs. 1-4 as histograms showing the numbers of faults plotted as a function of the wind speed prevailing at the times of the faults. The mean temperature at the fault times and the relevant critical wind speed are shown on each histogram.

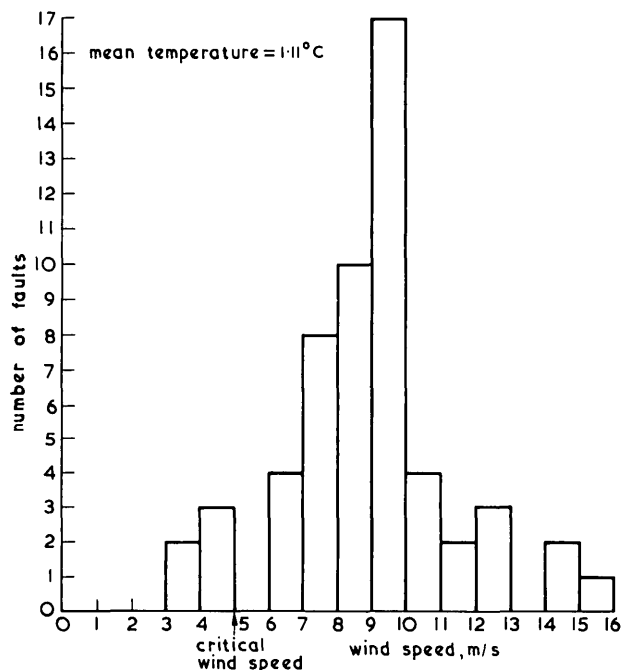


Fig. 3
275/400 kV BES L2

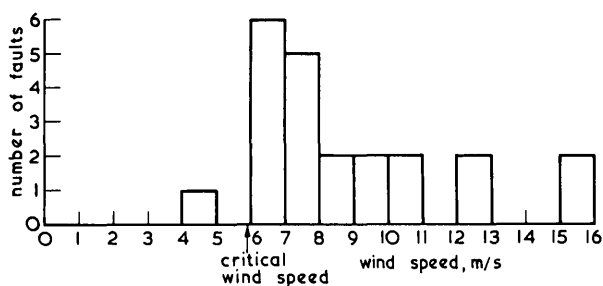


Fig. 4
400 kV BES L6

4 DISCUSSION

It can be seen that the results strongly support the theoretical conclusions concerning the minimum critical wind speed necessary to cause interphase clashing. In studying the histograms it must be remembered that:

- (a) The wind speeds quoted are only a general guide to the meteorological conditions prevailing at fault times, and exclude any effects local to particular stretches of line and any rapid changes in meteorological conditions which may have occurred.
- (b) The critical wind speeds are inversely proportional to span length, and the values quoted are only typical figures. The absence of precise data on the actual fault locations makes exact calculation of critical wind speeds impossible.
- (c) The calculations assume equal midspan sags on all phases. The inequalities which must occur in practice will affect the critical wind speed.

It is unfortunate from the point of view of the present analysis that the number of faults available for analysis is probably too small to enable reliable fault-probability/wind-

speed curves to be drawn. It is interesting, nevertheless, to speculate on the form these curves would take.

If we define $p(U) dU$ to be the probability that over one hour the wind speed is in the range U to $U + dU$ with temperature 0°C , and if $p_c(U) dU$ is the number of faults (per hour per km of line) when the wind speed is in the same range, then, if the probability that a conductor clashes (in faults per km per hour) is the same for all values of the oscillation amplitude $a > a_{\text{crit}}$ (the minimum amplitude required for clashing), $p_c(U)$ is given by

$$p_c(U) = 0 \quad U < U_{\text{crit}} \quad (2)$$

$$p_c(U) = \alpha p(U) \quad U > U_{\text{crit}}$$

where α is some positive constant. A typical histogram showing the distribution of wind speeds at Manston, Kent, when the temperature lies between -2 and $+4$ deg C is shown in Fig. 5. From this Figure, it follows that $p(U)$ is of the form used in Fig. 6a.

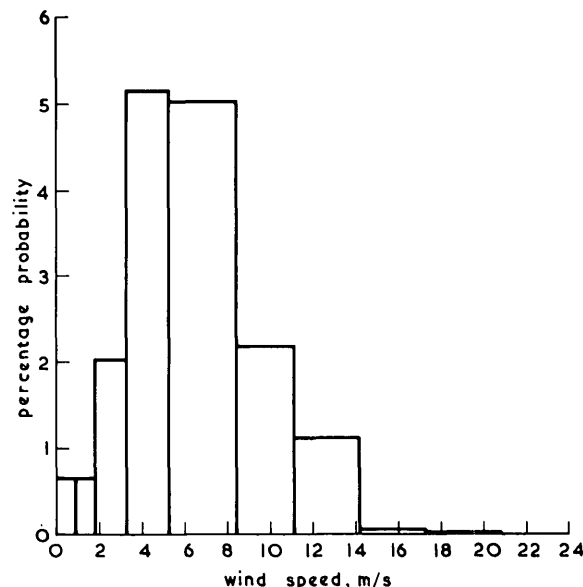


Fig. 5
Probability distribution of windspeed at Manston, Kent, for temperatures between -2°C and $+4^\circ\text{C}$

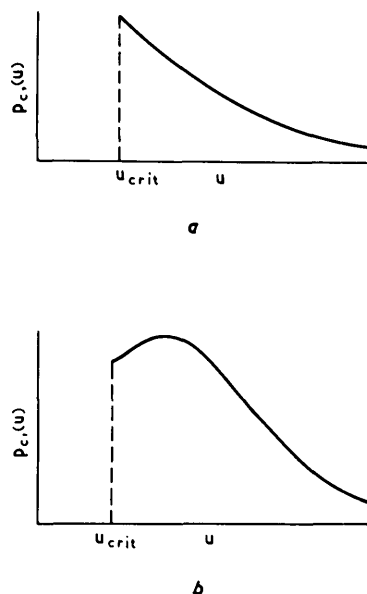


Fig. 6
Various sketches of the form of p_c as a function of windspeed

However, it is more likely that the probability of clashing increases as the difference $a - a_{\text{crit}}$ increases, and therefore as $U - U_{\text{crit}}$ increases, and thus p_c could have the form shown in Fig. 6b. This curve is not inconsistent with the histograms in Figs. 1-4.

We have produced a comparison between the meteorological conditions prevailing at the time of phase-to-phase faults on bundled-conductor lines and a theoretical estimate of the wind speeds necessary to sustain the oscillations. The results show that, in general, the predicted lower-bound wind speed for conductor clashing is a good approximation to the minimum wind speeds which give rise to faults in practice. This fact may enable meteorological data to be used more effectively in predicting the likelihood of clashing and in planning the routes of overhead lines. Further fault data are needed to enable assumptions regarding the nature of the fault-probability/wind-speed to be verified. However, real progress in understanding galloping and clashing will only come as a result of careful monitoring of overhead-line oscillations at the same time as the relevant meteorological data are recorded.

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