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REPORT OF FAILURES DUE TO ICE, WIND AND LARGE BIRDS EXPERIENCED ON THE 420 kV LINES OF TURKEY

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Abstract

The paper describes the mechanical failures due to ice and wind, which caused the collapse of 114 towers of the 420 kV Turkish lines in 14 separate incidents, during the first 5 years of operation. It also discusses the temporary electrical faults caused by ice and wind.

Referring to a previous report [1], the paper gives further information on the severe problems resulting from the droppings of the Egyptian vultures, which caused several hundred temporary faults.

A statistical record of all the faults is presented.

The tower failures and faults experienced are evaluated in relation to the mechanical loading assumptions and design criteria. A brief summary is given of the countermeasures being adopted.

Keywords

Transmission. Line. Ice. Wind. Birds. Fault. Tower. Failure. Design.

1. Introduction

Turkey's 420 kV transmission system was put into operation in 1974, as a radial network overlaying an extensive 154 kV grid.

From the electrical point of view, system design proved sound. In spite of the transmission distance – up to about 1000 km – the system was stable; voltage and reactive power control, and the containement of overvoltages were satisfactory. The failure rate of 420 kV station equipment, and the malfunctioning of the protection system have been less than reported for other 420 kV European systems. For the 420 kV lines, the operating results were unsatisfactory, the failure rate being an order of magnitude higher than reported for 420 kV lines in Europe; there were various reasons for this.

To exploit the hydroelectric resources of the Euphrates river, some of the lines are routed across the highlands of Central Turkey, at an elevation of 2000 m above sea level. These regions are uninhabited, vegetation is absent, and there was no prior operating experience with HV lines. Thus, no quantitative information was available on ice and wind overloads, which later experience showed to be among the most severe reported anywhere in the literature.

Because of the great length of lines involved, loading assumptions less conservative than in many European countries were accepted, to reduce cost. In the regions exposed to ice, the design assumptions regarding the longitudinal loading of suspension towers proved inadequate; this resulted in the cascading failure of many towers in several incidents. In certain regions, resistance to combined ice overload and transversal wind and, occasionally, to the vertical overload, were also found to be insufficient.

The electrical failures caused by the Egyptian vultures were unexpected, because no such troubles had occurred on the 154 kV lines during many years of operation in the same regions, and there had been no previous reports on the presence of considerable numbers of such birds. Noteworthy aspects of this phenomenon are the very large number of faults (certainly more than 600), the great length of lines involved, and the complexity of the bird antiperching devices that had to be added.

The Turkish Electricity Anthority has decided to publish details of the failures that have occurred, so that others might be spared the same troubles.

2. Main design characteristics of the 420 kV lines

The single-line diagram of the initial 420 kV system, which was put into operation in 1974, is shown in Fig. 1. The system involves 2530 km of single – circuit lines.

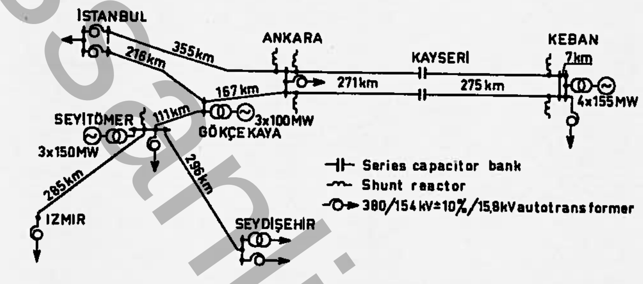

Figure 1 – The 420 kV Turkish grid in operation since 1974

The two Keban - Ankara - Istanbul lines were specified in 1965-66 according to American design criteria and generally with the loading assumptions stipulated in the Turkish regulations in force at that time [1]). The other lines shown in Fig. 1 were specified a few years later by TEK, who also decided to apply the same design so as to ensure uniformity of tower manufacture.

The main design features common to all the lines are as follows:

- *Conductors:* twin bundle ACSR code Rail; total section: 2 x 517 sqmm; diameter: 29.59 mm; Aluminium/Steel sections ratio: 14.5; spacing 45.7 cm; normal phase–to–distance: 8.7 – 9.1 m; EDS at + 15 °C: 20%.
- *Shield wires:* two EHS galvanized steel cables; section: 72 sqmm; diameter: 11.1 mm; shielding angle of outside phases: 20°; shield wires are insulated on the Keban – Ankara – Istanbul lines.
- *Tower configuration:* steel lattice type self-supporting towers, horizontal design. Suspension towers have rectan-

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[1]) The coauthor consultant to the Turkish Electricity Authority started his duties in this capacity in 1969, after this work had been completed.

gular base with ratio of the two sides of 2.06. The outline of the normal suspension towers is shown in Fig. 2.

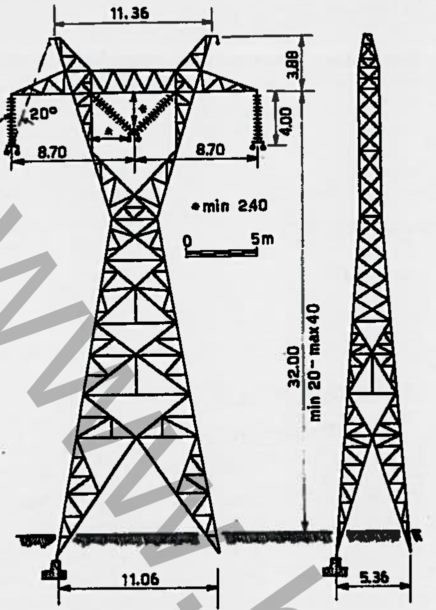

Fig. 2 – Ouline of normal suspension tower type 4A1.

- *Insulation:* "V" strings in the intermediate phase, with minimun net air clearance to tower of 2.4 m; vertical strings in the outside phases; toughened glass standard insulators (ϕ = 245 mm, s = 146 mm) in strings of (20) – 22 – 24 units depending on elevation.
- *Foundations:* mixed type lattice steel–armoured concrete slab (see Fig. 2).
- *Loading assumptions* for tower design:
  - *Transversal load:* pressure of 67.5 kg/sqm on conductor projections, and 90 kg/sqm on insulators and on 2.6 times of one face of the towers (corresponding to wind speed of 118.5 km/h), combined with vertical loads, without ice. Safety factor 1.8.
  - *Vertical load:* ice, without wind. Three zones were considered with ice overload of $0.2\sqrt{d}$, $0.3\sqrt{d}$ and $0.5\sqrt{d}$ kg/m, respectively (d = conductor diameter in mm), i.e. for Rail conductor 1.1 kg/m, 1.63 kg/m and 2.7 kg/m. Safety factor 1.8.
  - *Longitudinal load* with torsion: for suspension towers, pull in any one phase of 2.43 tons, equivalent to 50% of maximum tension of one Rail cable, or 1.81 tons on shield wires, combined with 1.8 times the vertical ice load, without wind. Safety factor 1.

  In addition an assumption of longitudinal wind on towers and conductors was made.
- *Weight of towers:* the above loading assumptions, with application of 11 different types of towers and use of St. 37, St. 42 and St. 52 steel, resulted in an average weight of towers of 15.5 tons/km, including the foundation steel members embedded in the soil. Average span is 380 m. All tower prototypes were tested to destruction before starting mass production.

3. Records of line electrical faults and mechanical failures

Table I summarizes the many faults which occurred on the 420 kV lines in operation in the 5–year period 1975-79 (see Fig. 1). Faults are classed as ϕ-G: single-phase to ground; ϕ-ϕ: double-phase, with or without ground (no breakdown is available); 3ϕ: three – phase. Most 3ϕ faults were in fact cases of

Table I   Faults record of the 420 kV lines of Turkey in operation in the 5-year period from 1975 to 1979.

	Type of fault	January	February	March	April	May	June	July	August	September	October	November	December	Total 1975-79 *)	Percent of types of faults	N. of faults per 100 km of circuit per year
Keban - Ankara - (Northern line) 550 km	ϕ-G	24	5	6	26	47	44	33	40	20	6	1	19	271	77.9%	12.65
	ϕ-ϕ	14	6	10		1	–		1	–	–	14	15	61	17.5%	
	3 ϕ	1	–	1	3	2	–	2	–	3	–	–	4	16	4.6%	
Keban - Ankara - (Southern line) 550 km	ϕ-G	36	10	8	29	44	29	16	45	23	4	6	26	276	81.2%	12.36
	ϕ-ϕ	27	1	11		–	–	–	–	–	–	12	9	58	17.0%	
	3 ϕ	–	–	1	1		1	3	–	–	–	–	–	6	1.8%	
Ankara - Istanbul - 355 km	ϕ-G	5	4	24	16	23	25	15	19	8	–	–	8	147	93.0%	8.90
	ϕ-ϕ	2	1	–	3	–	–	–	–	–	–	2	–	8	5.1%	
	3 ϕ	1	–	–	1	–	–	–	–	1	–	–	–	3	1.9%	
Ankara - - Gökçekaya 167 km	ϕ-G	1	–	11	20	20	25	15	11	5	–	–	2	110	93.2%	23.55
	ϕ-ϕ		–	–	–	–	–	–	–	3	–	–	–	3	2.6%	
	3 ϕ	–	–	1	1	–	–	–	–	3	–	–	–	5	4.2%	
Gökçekaya - - Istanbul 216 km	ϕ-G	7	1	6	5	5	6	1	7	–	–	–	5	43	78.2%	6.36
	ϕ-ϕ	1	1	–	–	–	1	–	1	1	–	–	–	5	9.1%	
	3 ϕ	–	1	3	–	–	–	–	1	–	1	–	1	7	12.7%	
Gökçekaya - - Seyitömer 111 km	ϕ-G	1	–	5	12	20	16	6	5	–	1	–	–	66	66%	18.02
	ϕ-ϕ	1	12	11	1	–	–	2	–	–	–	–	4	31	31%	
	3 ϕ	–	1	2	–	–	–		–	–	–	–	–	3	3%	
Seyitömer - - Izmir 285 km	ϕ-G	3	–	2	7	17	3	1	2	5	1	3	1	45	88.2%	3.58
	ϕ-ϕ	–	–	1	–	–	1	2	1	–	–	–	–	5	9.8%	
	3 ϕ	–	–	–	–	1	–	–	–	–	–	–	–	1	2%	
Seyitomer - - Seydischir 296 km	ϕ-G	2	–	–	5	5	1	10	1	–	1	11	1	37	86%	2.90
	ϕ-ϕ	–	–	1	–	–	–	–	1	–	–	–	–	2	4.7%	
	3 ϕ	–	1	–	–	–	2	1	–	–	–	–	–	4	9.3%	
Summary of all the 420 kV lines	ϕ-G	79	20	62	120	181	149	97	130	61	13	21	62	995	81.9%	10.04
	ϕ-ϕ	45	21	34	4	1	2	4	4	4	–	28	28	175	14.4%	
	3 ϕ	2	3	8	6	3	3	6	1	7	1	–	5	45	3.7%	
(aggregate lenght 2530 km)	all faults N	126	44	104	130	185	154	107	135	72	14	49	95	1215	–	
	all faults %	10.4	3.6	8.6	10.7	15.2	12.7	8.8	11.1	5.9	1.2	4.0	7.8	100	–	

*) Total and monthly number of faults, refer to a 5-year period (1975 - 79), but for line Ankara-Gökçekaya they refer to a 3-year period (77 - 79) and for line Gökçekaya - Istanbul to a 4-year period (76 - 79).

line tripping due to power swings in the early days, when the Ankara – Gökçekaya line was not in service.

Although the system is equipped for high-speed single-pole and three-pole selective reclosure, this was not applied until 1979. As a rule, reclosure was performed manually a few minutes after line trip-out. The vast majority of reclosures were successful, permanent faults being usually due to mechanical failures and to the conductors approaching the ground due to large ice overload.

The fault rates are reported separately for each line and for each month, since this provides a clearer insight of fault causes. Lumped figures are given for the 5 years concerned, because the yearly failure rates were not much different.

The main points which are shown by the fault records are the following:

- The average failure rate for all lines in 5 years has been 10 faults/100 km/year; however rates vary from 1.3 to 33 faults/100 km/year considering individual lines on a year by year basis.
- The ϕ-G faults (81.9% of total) are more frequent in the spring and summer months, April through August, owing to flashovers caused by bird droppings.
- Most ϕ-ϕ faults (14.4% of total) occur in the winter months, November through March, the major cause being telescoping between conductors due to wind and ice.
- Only a very small percentage of all recorded faults were caused by lightning. In fact, lightning performance of lines was good, as expected.
- There were no records of faults due to pollution of insulators and/or dew.

The mechanical failures involved the towers in almost every case. Foundations were never affected, apart from one occasion when an earthslide damaged the legs of two towers. Conductor failure was never reported as an original cause of failure. In two cases, the insulated shield wires fell owing to prolonged arcing on their support insulator and hardware. In two cases the conductors of an outside phase fell owing to fatigue breakage of suspension hardware, probably caused by repeated wind gusts.

In 5 years of operation, 114 towers were destroyed, out of a total number of 6658 towers, in 14 incidents, as summarized below:

number of incidents	1	1	5	4	3
number of towers destroyed per incident	36	17[1]	8 or 9	3 or 4	1 or 2
cause of incidents	rime ice + wind	heavy wind (tornado?)	rime ice + wind	rime ice + wind	ice or snow, and sometimes wind

[1]) Affected two lines on same right of way in July.

4. Analysis of failures caused by ice and wind

All the winter incidents involving tower destruction were caused by ice, generally with superimposed wind load.

In the literature, ice on transmission lines is classed in four categories: rime ice, glaze, hoarfrost and wet snow. The type that usually occurs in Turkey is hard rime-ice of average or high density, ranging from 0.3 to more than 0.6 gr/cm^3. Snow does not cause problems, because it is dry and thus considerable amounts cannot stick on the conductors.

Weather records show that the "ideal" conditions for rime-ice formation did actually occur in all the winter incidents. The phenomenon was caused invariably by a combination of three factors:

- thick fog or clouds, formed of small droplets;
- wind, generally strong, moving the fog across the line;
- temperature below freezing, usually lower than - 5 °C.

It was observed that wind always plays an adverse role, because: (i) it continuously brings new droplets into contact with the conductors; (ii) it carries away the latent heat of fusion, thereby permitting further freezing of droplets; (iii) it causes a pressure drop downstream side of conductor, which may favour condensation. The faster the wind, the greater and faster the formation of rime-ice.

A number of incidents occurred on a 60 km portion of the two Keban – Kayseri lines, in Eastern Turkey, crossing highlands 2000 m above sea level, where a strong wind blows and winter temperatures are extremely low (a diurnal temperature of – 35 °C was recorded when the line was under repair). Generally the towers destroyed were located on the crest of mountains. Fewer disasters occurred on the lines in North–Western Turkey at an elevation of 1100 and 1500 m.

Figs 3 and 4 show typical formations of ice on conductors. The ice build-up is usually circular in form, very rarely does it occur as pennant. The prevailing circular form indicates that, in spite of bundle arrangement, the conductors rotate somewhat during ice formation.

In the case of Fig. 4, the average diameter of the ice sheet was 23 cm and density was 0.4 gr/cm^3, with a resulting average ice overload of 16.4 kg per meter of cable. On one occasion a line repair team reported an ice sheet 45 cm in diameter!

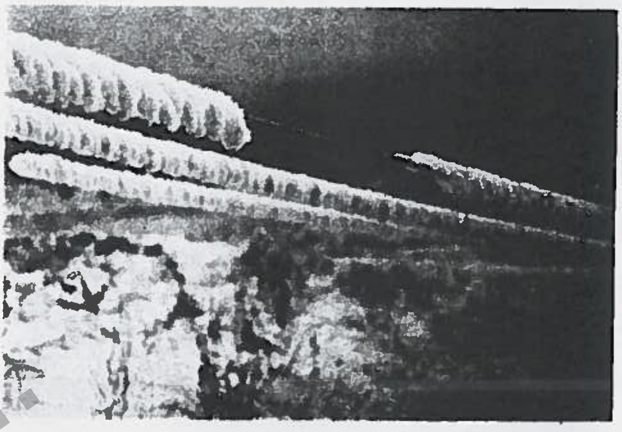

Fig. 3 - Typical ice formation on Rail conductors, Gökçekaya - Seyitömer line.

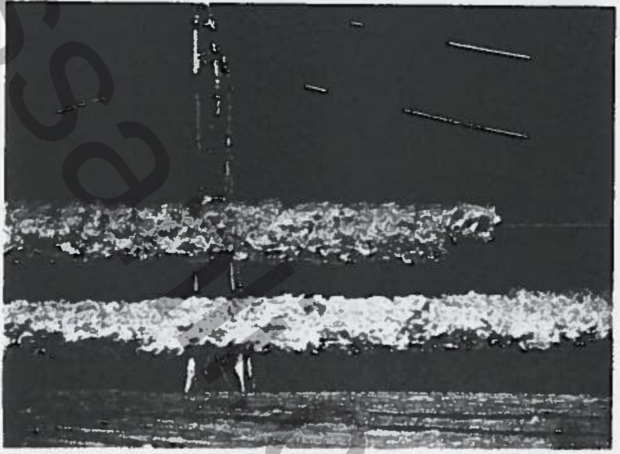

Fig. 4 - Typical ice formation on Rail Conductors, Keban - Kayseri line.

Experience has confirmed that, with severe rime-icing, as encountered in Turkey, conductors of different sizes usually end up having the same diameter of ice sheet. The two conductors of the bundle are generally surrounded by independent sheets.

It can be seen from Fig. 4 that the conductors of the second line (in the background) are not covered with ice. This is explained by the fact that the line was carrying a current of about 750 A.

Ice formation on conductors was usually observed to be much greater than on tower members, and on the branches of trees of similar diameter, where it rarely exceeded 5 cm of thickness.

The ice sheets shown in Figs 3 and 4 cause a vertical overload of 3.5 to 6 times the specified ultimate towers resistances to ice overload; the surface exposed to wind is about 8 times greater. It is obvious that the design loads are exceeded by far and towers are liable to collapse owing to vertical, transversal, and also to longitudinal overload due to ice imbalance.

The only practical remedy against such severe rime-icing is the use of a single large-diameter conductor, instead of twin or triplet bundles, in order to reduce the ice and wind overloads to about one half or one third, respectively. This solution has already been applied in other countries, and is being applied in Turkey on the Bosphorous 420 kV crossing and on the critical portions of the new lines.

Analysis of the incidents shows that in some cases ice formation occurred only in very few spans, initially causing the collapse of one tower, due to vertical overload combined with transversal wind load. Several other tower then collapsed lengthwise, one by one, due to the longitudinal cascading effect. Sometimes the disaster stopped only at the first anchor tower. Fig. 5 shows examples of towers of the same type which collapsed in a winter incident transverswise and lenghtwise, respectively.

In other incidents it was clear that the first tower collapsed due to vertical overload, sometimes combined with longitudinal load as a result of ice imbalance.

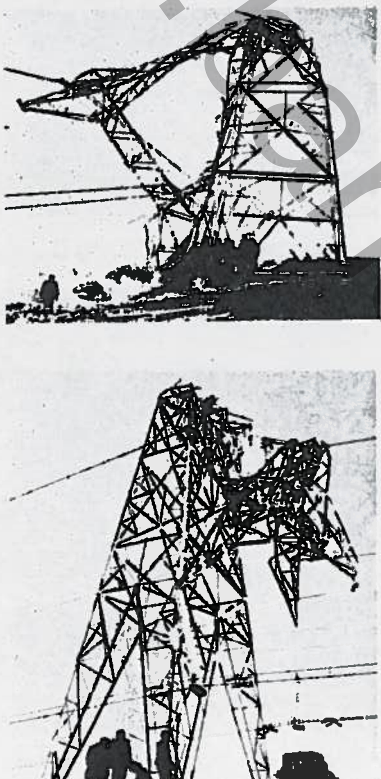

Fig. 5 - Collapsed towers, transverswise and lenghtwise, on the Keban - Kayseri southern line.

In a couple of incidents, severe rime-ice (see Figs. 3-4) built up continuously on several kilometres of line, when a strong wind was blowing. On one occasion 36 towers were destroyed, including an anchor tower. Fig. 6 refers to the latter disaster.

In the winter incidents, a large number of towers collapsed at the waist, where the delta shaped upper part is connected.

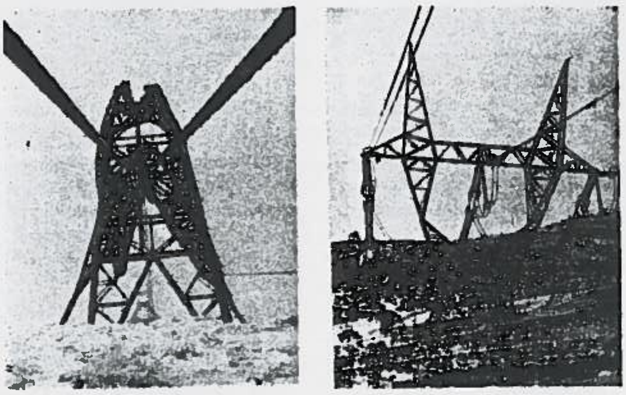

Fig. 6 - Collapsed towers on the Gökçekaya - Seyitömer line. Right: anchor tower; left: suspension tower.

In a summer incident, 17 towers were destroyed, not far from Istanbul due to what was probably an exceptionally intense whirlwind, near the sea. In the strip where it passed, centuries-old oaks were stripped of all their branches and long-established fruit-trees were uprooted; there were no houses in the area. It is estimated that the whirlwind exceeded a speed of 160 km/h; it crossed two 420 kV lines on same right-of-way (centre-to-centre distance between lines, 70 m) and caused the collapse of 9 towers on one line and 8 on the other.

A few towers which were directly struck by the wind collapsed transverswise, entirely from their base, as Fig. 7 (above) shows. Many other towers collapsed due to longitudinal pull and dynamic forces; usually this lengthwise collapse occurred at the tower waist, as shown in Fig. 7 (below).

Measures adopted to strengthen the damaged portions of the lines are those usually taken: reduction of spans by inserting additional towers; use of stronger towers of new design; change of line route or use of single conductors instead of bundles, if exceedingly heavy ice formation occurred on a long portion of line exposed to wind. In addition, a new line, about 80 km long,

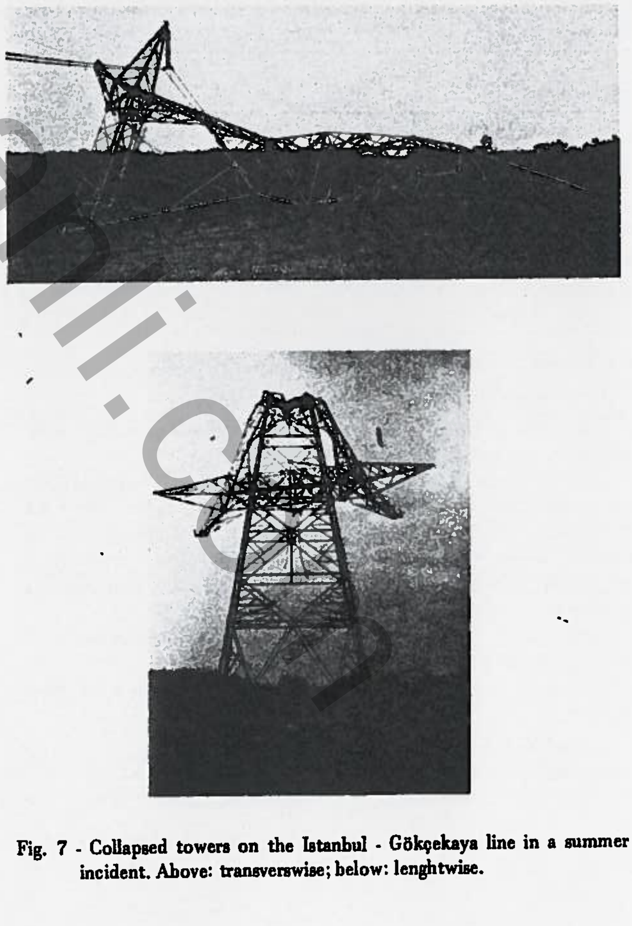

Fig. 7 - Collapsed towers on the Istanbul - Gökçekaya line in a summer incident. Above: transverswise; below: lenghtwise.

will be built, to be used as a stand-by for both of the two circuits on the 60 km portions of the Keban – Kayseri lines, where the largest number of incidents has occurred, and further failures are expected. A better route will be chosen for the stand-by line, at lower elevation, and different conductors and towers will be used.

Many phase-to-phase short circuits occurred in the winter months (see Table I), during windy periods when there were no thunderstorms. These faults were found to have been caused by the non-synchronous displacement of the conductors (telescoping) due to wind gusts, bringing the intermediate phase close to or in contact with an outside phase. This is something which can happen when the wind blows on irregularly ice-sheeted conductors. There were however several flashovers also on long ice-free spans struck by wind.

It is believed that telescoping of conductors may have been made worse by the non-symmetrical suspension of the three phases.("V" and "I" strings, see Fig. 2), and also by the large sag and relatively low weight of conductor Rail, that contains a very small amount of steel.

Remedies against telescoping are not easy and no action has been taken. Consideration has been given to the reduction of conductor sagging by increasing tension, or to stringing the intermediate phase with a smaller sag than the outside phases, thereby reducing the probability that the phases may approach flashover distance. Use of large-diameter single conductors would certainly reduce telescoping.

A number of ϕ-G faults occurred on the lines due to ice formation during the winter months (see Table I). There are two causes of these faults:

(i) Descent of conductors to flashover distance to ground, due to ice build-up in one span and very little on the nearby spans, or due to exceedingly heavy ice on several spans. This phenomenon of course constitutes a hazard for people and animals.

(ii) Descent of an earth wire highly loaded with ice, at or below the conductor level, and flashover due to the wire swinging under the effect of the wind. This phenomenom may occur when conductors are freed of ice overload before the shield wires, owing to the Joule effect, or also because of the larger increase in sag of the shield wire than conductors under comparable ice overloads. The phenomenon was favoured by the fact that the design sag of shield wires without overload was not sufficiently less than conductor sag, and also owing to the relatively small section of the shield wires.

Phenomenon (i) could be remedied by using conductors with a larger content of steel than Rail, or by increasing the tension parameter in critical zones, thus reducing sagging. Application of single large-diameter conductors instead of bundles, would provide a much better solution to this problem in the critical regions.

Phenomenon (ii) can be remedied by using much less sag on shield wires than on conductors in normal conditions, as is usual in many countries, and by applying shield wires of larger diameter (12.5 mm or more) in the critical zones. Of course one solution would be to eliminate shield wires in the critical zones.

As a last remark, it should be noted that span galopping of large magnitude was never observed, probably because of the circular form of the ice sheets. Sub-span galopping never occurred. The lines were never harmed by eolian vibrations.

5. Analysis of faults caused by the Egyptian vultures

Most of the 995 ϕ-G faults during the 5 years of record, occurred on the lines terminating in Ankara (see Table I) and were caused by the droppings of birds perching on the tower crossarm.

As already reported [1], it was difficult to trace the cause of the faults and this resulted in a 3 - year delay in applying countermeasures. Further information is given here.

Faults occurred generally in the intermediate phase of the lines, at night between 9 pm and 6 am, in the months from May to August. In general the line could be re-energized successfully a few minutes after trip-out. Weather was usually good and there were no switching overvoltages. Fault locators, even though not always operating properly, located faults at a distance between 15 km and 200 km from Ankara.

Fig. 8 is a photo taken early in the morning in an area with rocky terrain; it shows an unusually large number of birds.

The birds that mainly cause the troubles have been identified as Egyptian vultures (Neophron Percnopterus), although some other species of vultures may have contributed to some extent.

Some of the Egyptian vultures migrate from Africa, while some live permanently in Turkey. Their weight is 2-3 kg and their wingspan may exceed 2 m. Droppings form a continuous strip 1 - 1.5 m long and even greater, that is conductive. During the hours of daylight the birds fly about in search of food and are not seen around at all; by night, instead, they perch on trees or towers.

The reasons why faults occurred generally on the intermediate phase are thought to be as follows:

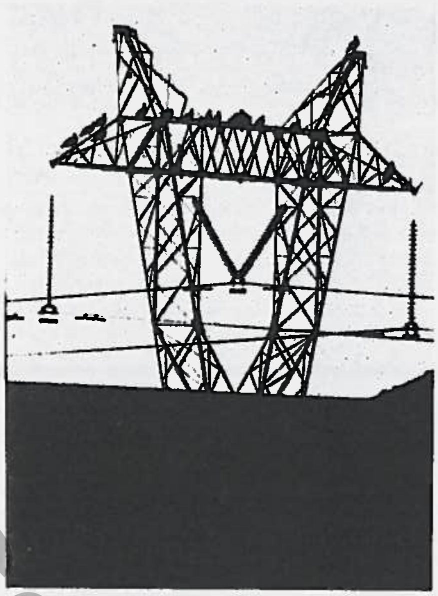

Fig. 8 - Early morning photograph of egyptian vultures.

- The air clearance between live parts and the lower face of the crossarm is about 2.4 m in the case of "V" strings (see Fig. 2). If this distance is to a great extent shunted by bird droppings, flashover may occur at normal operating voltage. The outside phases have a vertical air clearance of about 4 m from the tower crossarm, and thus partial shunting by bird dropping should not lead to flashover. The same situation holds good for the tension strings.
- In the long run, bird droppings had accumulated over some "V" strings and caused flashover in a few cases. Contamination was not found on the vertical strings.
- The vultures perch more frequently on the central part of the crossarm. i.e. over the "V" strings, because this portion is horizontal and more comfortable. Small antiperching devices had in fact been installed from the beginning over the outside phases, but this did not prove to be the reason why faults did not occur, because birds could perch nearby (see Fig. 8).

Birds were never killed by the flashovers they caused, since these occurred between the lower face of the crossarm and the line conductor beneath. It was reported that vultures often remain on the tower, heedless of heavy noise and flashes.

As the wild birds are protected by law in Turkey, the Ministry of Forestry recommended that no drastic measures should be taken which might harm the Egyptian vultures.

A proposal was made by ornithologists to plant rapidly growing trees along the line routes where there are no natural perching places. However this proved to be impracticable, because results would not be forthcoming for at least ten years.

It was decided to install antiperching devices on the tower crossarms, and the acceptable solution described below was worked out after three trials.

Each steel member of the upper face of the crossarm is covered by a row of vertical steel spikes, as shown in Fig. 9. The spikes are made of 5 mm diameter steel rod and are 20 cm long, with a sharpened tip. Distance between spikes is 10 cm. Weight is 25 to 35 kg per crossarm. With this solution birds perch for no longer than 10-20 minutes and thus become harmless.

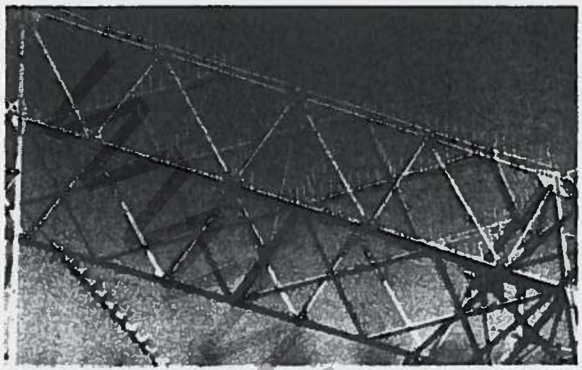

Fig. 9 - Antiperching spikes in the upper face of tower crossarm.

To prevent birds from entering inside the crossarm lattice structure, wire netting had to be placed on the upper face, on the two side faces and at the extremities of the central part of crossarm (not shown in Fig. 9). The netting is made of 2 mm diameter galvanized steel wire, with a wire—to—wire spacing of 20-25 cm.

Antiperching devices have had to be installed on many hundreds of towers. When the work is completed, some 3000 towers will have been protected. To reduce line time outage, an ad-hoc team of 60 labourers installs the protection on about 50 towers a day.

The effectiveness of these antiperching devices is proved by the fault records of the Gökçekaya — Ankara line, which was the first to be modified. The failure rate, that had never been less than 20 faults /100 km/year until 1979 (see Table I), declined to 2.4 faults /100 km in 1980, these residual faults probably being due to wind.

Experiments are planned to study if high — speed reclosure can automatically clear the faults caused by bird droppings, and, if this proves feasible, to determine the dead—time assuring a high probability of successful reclosure. If reclosure is found to be practicable, it may be applied instead of the antiperching devices for certain lines, where the failure rate due to birds is not too large and fairly frequent faults would not jeopardize stability.

6. Conclusions

The great number of electrical faults and tower failures that occurred during the first 5-years of operation of the Turkish 420 kV lines, has revealed some novel phenomena; it also confirmed, as regards other aspects (e.g. the longitudinal resistance of towers) the conclusions reached previously in other countries. The following are the main findings having reference to the environmental conditions in Turkey:

a) It is generally justified to specify a much higher longitudinal resistance for the suspension towers, sufficient to prevent cascading failure. In the mountainous line portions, where severe rime-ice is expected, any one tower should also withstand the load imbalance due to uniform ice on the upstream spans and no ice on the downstream spans. Lattice towers should have square base.

b) Ice, and ice + wind overloads need to be specified realistically, on the basis of careful site investigations, possibly involving some experimental stations. Identification of sites and overloads are the most difficult aspects of line design in Turkey.

c) Experience stressed the importance of choice of line route. It proves that the two major winter incidents might have been avoided or at least reduced in magnitude, merely if a better line route had been chosen.

d) Double-circuit lines forming part of an initial EHV radial system, should be placed on well separated routes in their portions exposed to severe ice and wind, in order to reduce probability of simultaneous failures.

e) The exceedingly large number of phase—to—phase faults due to conductor telescoping indicates that in the areas exposed to ice and wind, the span length should not exceed 500 m, and/or conductors should be chosen of types that permit sag reduction and, possibly, less sagging of intermediate phase. In the new lines use is made of ACSR cables with a ratio Aluminium/Steel sections of about 8.

f) The use of single conductors with a diameter of at least 50 mm is the best solution for improving the security of the short portions of the 420 kV lines exposed to severe rime-ice. Conductor tension with maximum ice (15 or 20 kg/m) should never exceed the yield strength. Single conductors appropriately tensionned may eliminate the risk of conductors approaching the ground due to ice overload, as well as risk of flashover due to telescoping.

g) The problem caused by large bird droppings was found to be more severe in the case of "V" strings involving a relatively small clearance to crossarm (min. 2.4 m).

7. References

[1] Iliceto F. and Türkoğlu G. — *Planning features of the extension of the 420 kV Turkish system* — (CIGRE Paper 31-12, 1980 Session).

Résumé

Le réseau de transport à 420 kV de Turquie a été mis en exploitation en 1974. Une partie des lignes traversent le hauts-plateaux (2000 m sur la mer) du Centre de la Turquie dont l'environnement s'est révelé très sévère pour l'exploitation, à cause de la formation de manchons de givre (poids parfois supérieur à 16 kg/m de câble) et de la présence en même temps de vent très fort. Des conditions très sévères ont été rencontrées aussi dans la Turquie Nord-Occidentale, à des altitudes entre 1100 et 1500 m.

Dans les premières 5 années d'exploitation d'un réseau composé de 2530 km de ligne à une terne, il s'est produit la destruction de 114 supports en treillis d'acier, en 14 différents incidents, dont 13 en hiver à cause du givre et du vent et 1 en été à cause d'un tourbillon de vent très fort.

Un phénomène typique à été l'affaissement en cascade de plusieurs supports, à cause du déséquilibre longitudinal des tensions des câbles produit par l'effondrement initial d'un ou deux supports, celui-ci à cause de la surcharge de givre et de vent. Ces incidents ont mis en évidence que les hypothèses de charge mécanique des supports étaient insuffisantes et aussi qu'en deux cas le choix du tracé de la ligne n'était pas le plus convenable.

Le rapport présente les statistiques de tous les défauts. Dans certaines lignes, le taux annuel a été supérieur à 20 défauts /100 km x an, la contribution principale (plus que 600 défauts) étant due aux court circuits monophasés à la terre, causés par les déchets physiologiques des vautours Egyptiens se perchant sur la partie centrale de la console des supports. Le rapport présente des renseignements sur le phénomène et sur les dispositifs mécaniques appliqués pour empêcher le stationnement des oiseaux.

Le rapport traite aussi des autres types de nombreux défauts qui se sont manifestés, tels que: défauts biphasés, causés par le téléscopage des conducteurs; amorçage entre conducteurs de phase et terrain en cas d'augmentation de la flèche provoquée par la surcharge de givre; amorçage entre câble de terre et conducteurs, à cause de la baisse du câble de terre surchargé de givre.

Les affaissements de supports et les défauts sont discutés en rapport avec les hypothèses de charge et les critères de projet.