Damageability of Overhead Lines During Ice Storms in Ukraine

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***Abstract* — In Ukraine the main problem of overhead transmission line (OHL) reliability during winter period is icing in combination with high winds. The greatest failures in Ukrainian overhead transmission network were in November 2000 during broad scale icing storm. Some statistical data of this icing event, its meteorological description and damageability of OHLs were proposed in comparison with older icing storms.**

I. Climate Changing and its Influence on OHL Reliability

The end of the twentieth century was characterized as technical time. The humanity exerts influence practically on every climatic process in the world. The great number of disasters in the world confirms this fact during last ten years.

The increasing of mean annual temperature on 0,7 ^{0}C was observed in Ukraine from 1961 to 2000. The changes in mean season temperature for the different parts of Ukraine are proposed in Table 1.

TABLE I
TRENDS OF MEAN TEMPERATURE IN UKRAINE, ^{0}C [1]

Part of Ukraine	Trend of mean temperature, ^{0}C			
	Winter	Spring	Summer	Autumn
Northern part	+ 3.4	+1.1	0	-1.1
Central part	+2.8	+0.6	-0.5	-1
Southern part	+1.2	0	-0.6	-1.2

But the temperature trends are not smooth. In winter months and in November the temperature in most cases was between +2^{0}C and – 5^{0}C, that's why the frequency of icing increases. In summer the temperature trends is 15-17^{0}C per day and night. The frequency of thunderstorms in July and August increases from 9-14 days per season to 20-30 days.

During the last 20 years the mean value of annual maximal mass of icing was lover than in previous period practically in two times. These trends are recorded practically for each of 204 weather stations in Ukraine. The most intensive decreasing of ice and wind with ice loads was fixed in the Eastern part of Ukraine, that was characterized as the most icing region (see fig. 1). But in some Southern and Western parts of Ukraine especially on the Black Sea coast the situation is quite different. These regions were characterized as low icing and in nature there were some peaks of ice loading (see fig. 2). The most widespread peak was fixed in this region in November 2000.

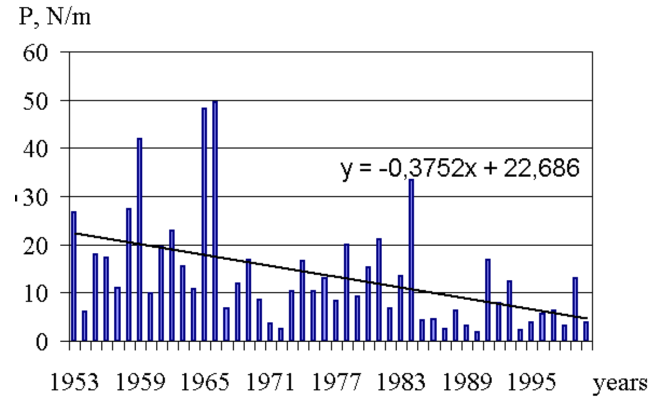

Fig. 1. Maximal annual mass of icing for East of Ukraine and its trend (weather station Dar'evka)

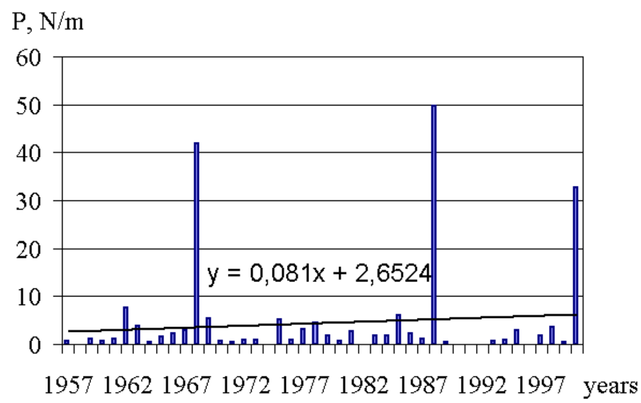

Fig. 2. Maximal annual mass of icing for South of Ukraine and its trend (weather station Odessa)

A lot of researches noted increasing of natural catastrophes in recent years, in particular windstorms. In Ukraine and Russia the frequency of windstorms increased in 1,6 – 2.5 times during the last few years by the data of different researches. These aspects influence on overhead lines reliability (see fig. 3), which gives a classification of failures depending on damage cause for OHL by voltage 35-750 kV, during 1971-2000 in Ukraine. Thus the main reasons of OTL failures are broad-scale ice and windstorms (more then 50% of damages), so the lessons of these events must be investigated.

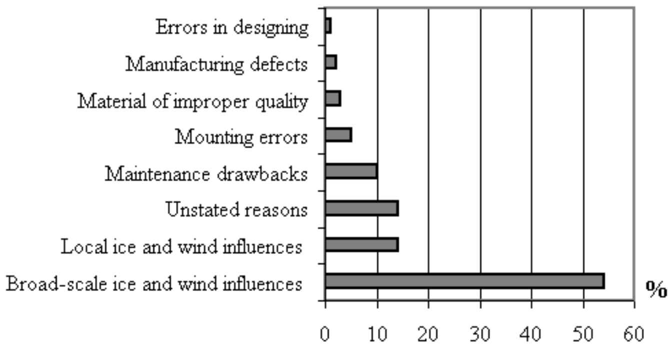

Fig. 3. Distribution of the quantity of failures depending on a cause

II. Synoptic Situation During Ice Storm in November 2000

Intensive icing in southeastern part of Ukraine was a consequence of interaction between cold Arctic air from north-east with the warm and moist air from southeast. Icing was from freezing rain and fog.

The most part of icing deposits was grown during 10-12 hours, and during next 4-5 days little increasing of icing was observed. The intensity of icing growth was 2-4 times more than have ever been observed in Ukraine. The air temperature was – 0 to – 2 ^{0}C, practically without daily trends.

Icing covered the territory over 226 000 square kilometers (near 118 800 square kilometers with broad-scale damages of trees, winter crops, conductors of OHL and transport), see fig. 5. Maximal thickness of icing in November 2000 was observed on ice measurement devices in Ukrainian weather stations Zatish'e – 197 mm and in Khmel'nitsky – 61 mm. In the southern part the situation was worse because of winds with the mean speed 14-17 m/c. The height of measurement device used in Ukraine is 2 m above the ground level. So the icing thickness on conductors of OHL was more than 1,5 – 2 times. The density of icing deposits was over 800 kilograms per cubic meter.

Recalculation of measured icing values in November 2000 with taking into account the previous recorded icing cases showed the return periods of icing. For two weather stations Khmel'nitsky and Zatish'e return period is more than 100 000 years. For weather station Pervomaisk, return period is about 760 years. For 7 weather stations the return period is about 200 to 400 years, and for the next weather stations (more than 20) the return period is from 5 to 50 years.

During the inspections the mass of icing from 3 kg per linear meter to 17 kg per linear meter (fig. 6) was observed.

The considerable distinctions of icing mass during inspections and recalculated with using weather stations data were determined. For example, icing mass 17 kg per meter was measured on OHL 750 kV "Dneprovskaya - Yuzhnoukrainskaya" conductors, but recalculated mass with using data of weather stations equaled 6 kg per meter.

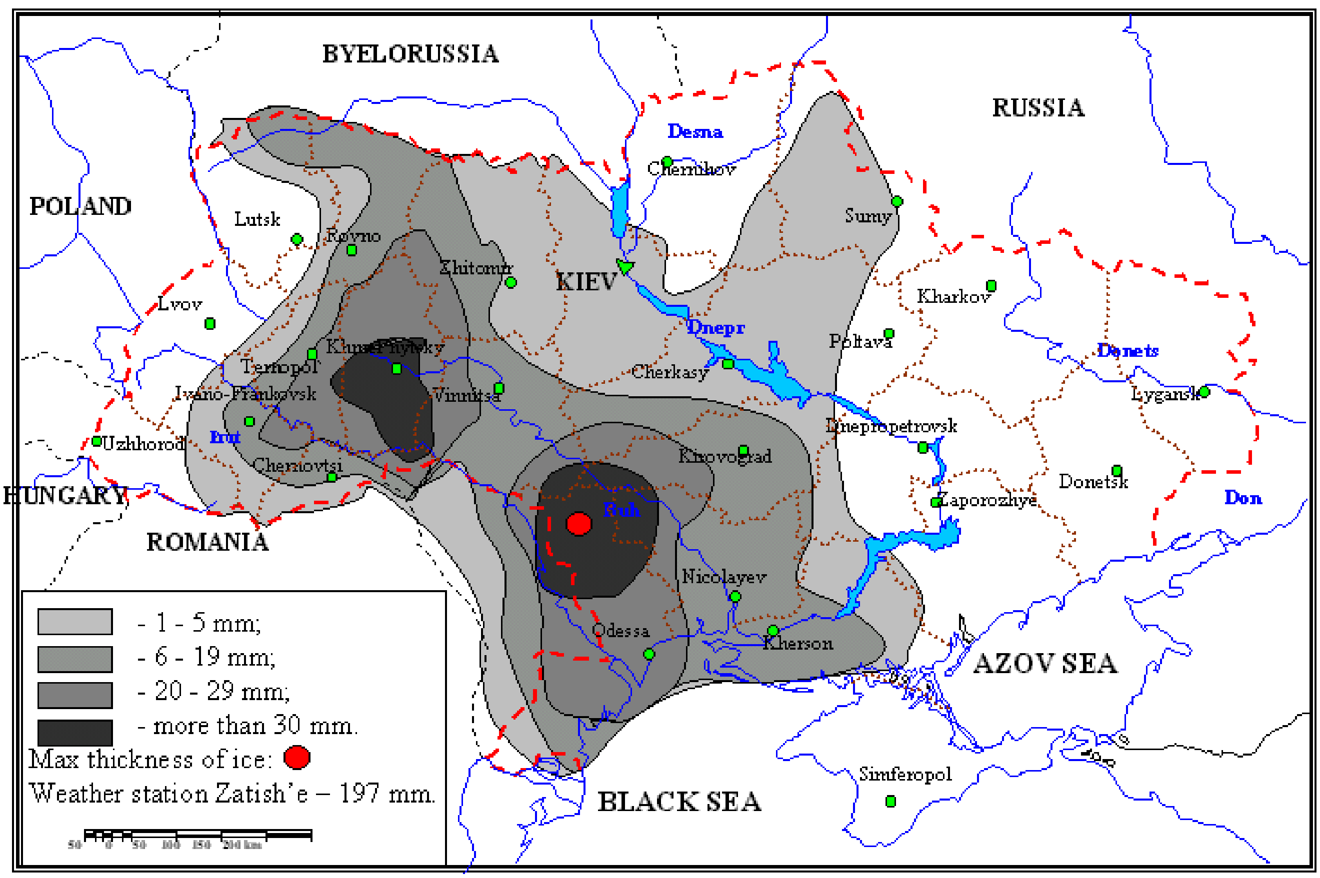

Fig. 5. Diameter of icing on ice measurement devices on Ukrainian weather stations

Fig. 6. Icing on OHL 750 kV conductors:
a) Isakcha - Yuzhnoukrainskaya b) Dneprovskaya - Yuzhnoukrainskaya

III. Damages of OHLs During Ice Storm in 2000

At the end of November 2000 the icing had led to the damage of 20931 OHLs, more than 270 thousand reinforced-concrete and over 20 000 metal towers failed, more than 3420 t conductors became unfit for further service. The greatest in the last century natural catastrophe that struck Ukraine has paralyzed the activity of nearly five thousand settlements in 12 regions of this country. In November 2000, almost four million people found themselves under the extreme conditions living with no electricity and heat, gas and water supply for a week and in some places for 4 months.

A high rate of concrete tower damages is the result of rather high percentage, i.e. till 70% of 35-110 kV OHL are suspended by using concrete towers. However, the quantity of concrete tower damages under the superdesign loads as calculated for 100 km OHLs is 7 times larger than that for metal towers.

During icing events in November 2000 17 OHL by voltage 330 – 750 kV were damaged. There were damages of 507 towers, 127 conductor spans, 71 ground wire spans, 22 insulator strings and 3 foundations (fig. 7). There were 268 damages of reinforced concrete towers, 235 metal towers; over 80 percent of the damages were cascade. In dependence from failure parts there were detected for metal towers:

-167 tower collapses,

- 56 damages of cross-arms (fig. 8),
- 16 peak damages;

for concrete towers:

- 96 tower collapses,
- 65 inadmissible displacements of concrete poles,
- 21 damages of cross-arms,
- 86 peak damages.

Together with defined damages of OHL during storms there was a great number of indefinite imperfections of OHL elements such as relaxation of tension in guys and conductors, tower top displacements and so on.

The statistical data of OHL damages by voltage 0,4 – 154 kV during ice storm in November 2000 are shown in Table 2.

Fig. 7. Foundation failure of OHL 330 kV “ LadTES – DsGRES ”

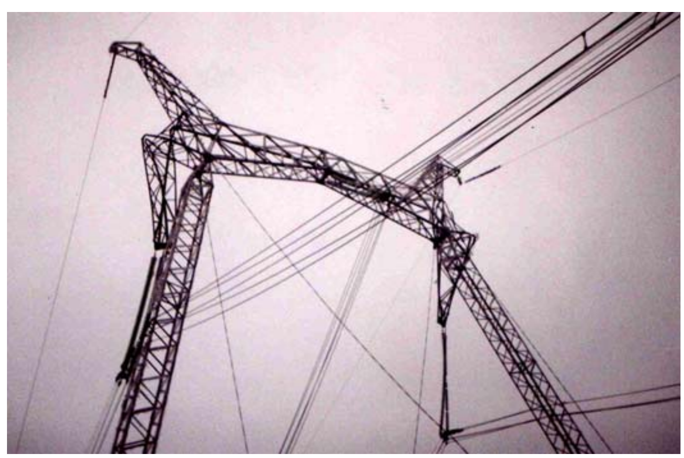

Fig. 8. Cross-arm failure of OHL 750 kV “Isakcha- Ujzhnoukrainskaya”

TABLE II
QUANTITY OF DAMAGED TOWERS IN PERIOD 26 - 27 NOVEMBER 2000

Region	OHL voltage, kV							
	154-110		35		10		0.4	
	Quantity	%*	Quantity	%*	Quantity	%*	Quantity	%*
Vinnitsa	200	1,7	240	12,7	39225	13,6	405250	5,1
Zhitomir	-	-	-	-	492	0,2	472	0,1
Kirovograd	20	0,3	40	1,4	12000	5,5	10000	2,1
Nikolayev	2	0,0	260	7,6	4000	1,9	6000	1,5
Odessa	337	3,6	112	3,0	52860	17,5	112662	17,4
Khmel'nitsky	30	0,4	25	1,5	1809	0,8	2361	0,4
Cherkasy	-	-	50	2,1	2674	1,3	3798	0,6
In total:	589	1,2	727	4,5	113060	7,8	175818	5,0

Ref.: * In percentage to all exposed towers

Table 3 shows the quantity and percentage of damaged OHL towers by voltage 0.4 – 150 kV during icing and wind with ice storms from 1975 till 2000. During icing events in November 2000 OHL towers were damaged much more than during previous icing events.

TABLE III
QUANTITY OF DAMAGED TOWERS IN PERIOD 1975 – 2000 IN UKRAINE

Year	OHL voltage, kV			
	150-110	35	10	0.4
1975	-	-	35000	2000
1977	-	-	600	400
1978	2	48	6888	-
1985	-	-	1000	808
1988	221	249	18661	11149
2000	589	727	113060	175818

IV. MAIN REASONS OF OHLS DAMAGES

The main reason of OHL damages in Southern and Western parts of Ukraine is imperfection of Ukrainian codes and rules [2] for overhead lines designing. Under climatic loadings processing peaks are not taken into account (see fig. 2) so the basic level of ice and wind with ice loads is lower than real ones.

The main reason of the great number of OHLs 0,4 kV damages is using under their designing the climatic loadings with 5-year return period and reliability indexes 1,2 - 2.

The overloading took place in some local territories and in this case the absence of ice melting devices, emergency stocks of towers, cables, wires had led to catastrophic consequences.

In some cases the unsatisfactory technical state of Ukrainian OHL makes certain impact on damageability of OHL elements, but the shown results gave the qualitative picture of OHL elements behavior during icing and wind storms.

During icing storms the principles of ice load calculation used in Ukraine such as changing of ice thickness in dependence form height above ground level and from diameter of conductor give non-accurate results.

In some cases the unbalanced icing on conductors led to tower collapses. Cascade damages were possible because of absence of anti-cascade towers and devices.

During long exploitation of OHLs the coordination principles of its mechanical strength were changed. For example on fig. 9 the failure propagation on OHL 750 kV "Yuzhnoukrainskaya – Dneprovskaya" is shown. Cable breakage was in span 740 – 741. Tower 740 was without damages because of suspension string breakage. The cross-arms on towers 736 – 739 and 741 – 745 were damaged. This example illustrates that in some cases using prevention methods such as reduction of insulator carrying capacity may prevent the tower damage.

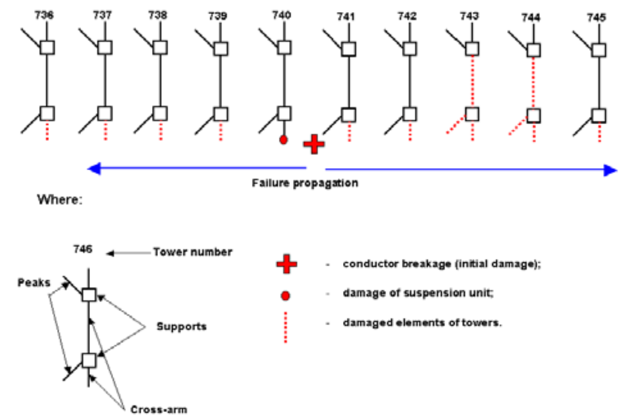

Fig. 9. Damage of OHL 750 kV "Yuzhnoukrainskaya – Dneprovskaya"

IV. CONCLUSIONS

The impacts and consequences of ice storm in November 2000 led to stirring up the scientific interest to problems of atmospheric icing and its impact on overhead transmission line reliability.

During the last two years new Ukrainian codes and rules for overhead lines designing, new climatic reference book with the data of 203 weather stations, Rules for OHLs exploitation were elaborated. In these documents practically all of overloading consequences were taken into account. Some Codes, for example, Principles of OHL technical state estimation and reconstruction are under elaboration.

Some enterprises of energy market began their activities of elaboration ice melting equipment, repair emergency stocks of towers, cables, wires and development new methods of fast recovery of broken OHLs using fast-erected towers.

And in conclusion, National Energy Company "Ukrenergo" as the largest Ukrainian company with Donbas National Academy of Civil Engineering and Architecture have elaborated automated icing monitoring systems for quickly prediction of icing and wind events.

V. REFERENCES

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[2] *Electric Installation Code.* Minenergo USSR. Moscow. 1987. 648 p.