



GIS technologies in icing on power lines analyses

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Abstract— Icing, strong winds and permafrost are the main factors affecting normal OHL functioning in Western Siberia. Better understanding of physical and spatial characteristics of these events could help to raise reliability and stability of power supply in this region. Authors experience in GIS technologies application regarding this range of problems is shown in the article.

Keywords— *Icing, permafrost, wind, Western Siberia, Russia, GIS*

I. INTRODUCTION

The Western Siberian plane is one of biggest planes on the Earth (third after Amazonian and East European). This vast territory is rich of natural resources, but is characterised by severe climatic and natural conditions. Low temperatures during winter (abs. min -56°C, January avg. temp. -21,7°C), long cold season and short summer, strong winds (especially at the north of region), permafrost and icing make this land very difficult for living and economic activity (Fig. 1).



Fig. 1 Typical West Siberian landscape (May 2019).

Many developed oil and gas fields in this region has caused the fact that from late 70s till now has formed huge system of oil and gas pipes and overhead transmission lines (OHL). The total length of OHL of all voltage rates exceeds 10.000 km. Very precise and expensive oil-producing equipment raise the need of reliable power supply.

The rise of the dangerous weather phenomena (wind, ice and rime deposits, thunderstorms, etc.) due to the general climate warming in the Northern areas of the West Siberia cause multiple damages of the OHL.

There is a need for geological, climatic, permafrost and other natural hazards and their spatial distribution assessment in order to increase reliability of the power supply.

It is necessary to conduct spatial data analysis for it, namely, the process of the searching for the geographical patterns and spatial relations among objects by means of the geographic informational systems (GIS), which contains the following main stages: to create a digital map of the territory under usage, to map the research subjects to it (including OHL with their technical characteristics, and to analyse the patterns of their spatial distribution.

II. THE SPATIAL ANALYSIS OF THE DATA

For the assessment of the technical condition of OHL 110-220 kV spatial analysis was done with the following steps:

- data was collected for each overhead line (passport information, the records of defects and the operation logs, including the measures of the ground resistivity and grounding towers, tower setup coordinates by OHL lines, operating experience data);
- OHL operation experience was collected, including information about accidents with geographical coordinates;
- Overhead lines with their technical characteristics and operating experience were uploaded to GIS;
- There was done comparison of design loads used for every OHL construction (more than 30 year ago) with modern ice and wind load values.

The fulfillment of the above works let us conduct the spatial analysis of the operating experience data with the aim of finding correspondences between the current accident incidence rates and the current environment data, and their correspondence (or incorrespondence).

The authors developed a GIS-project which has the spatial database in its basis (based on SQL Server) (Figure 2). For visualization of the spatial information was used ArcGIS. Moreover, there was developed the software application in the project to put technical information and operating experience into the database.

Figure 1 shows a scheme of the interaction between users and the system developed in the GIS-project. The whole information (spatial, technical and the operating factors) is stored in one relational geographical database, located at MS SQL Server. ArcGIS ArcMap was used for the spatial data analysis (the substations location, towers and spans of OHLs). The technical characteristics of a line (passport information, design loads, the parameters of the wires, cables, nonconductors, towers, and other elements of OHL), together with operating data (accident records, types of defects, etc.) are written into the database in the developed application. The statistical assessment and data analysis of the OHL was done in separate application.

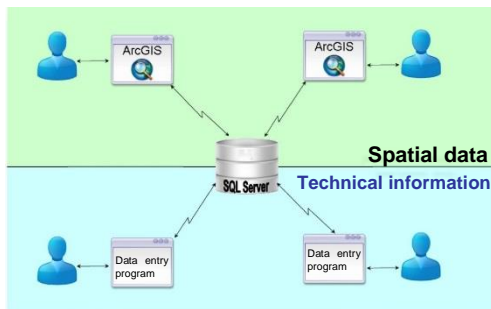


Figure 2 – Scheme of GIS-project

The database includes two types of tables: the ones which content spatial and technical information and the others which content only technical information. The main tables which content spatial and technical information are:

linOHL - the table for the storage of the spatial (in the form of lines) and technical information **on the overhead transmission lines**;

pnt_Towers - the table for the storage of the spatial (in the form of dots) and technical information **on the OHL towers**;

pntSubstations, *polSubstations* - the table for the storage of the spatial (in the form of points and -polygons correspondingly) and technical information **by substations**.

There are the following tables for the storage of the auxiliary information:

tbOrganisation, *tbFilial* - are designed for the storage of the information about the owner of the power facility (a substation or a OHL);

tbPerson is designed for the storage of the contact information about responsible persons;

_WindRegionsREF, *_IceRegionsREF*, *_IceWindRegionsREF* - informational tables of the climatic loads in accordance with normative documents of different years.

The other table set is designed for the operating experience storage:

tbIncident, *U4Prizn*, *klVidOborud*, *klPriznOrg*, *klPriznTexn*, *IncTypeREF*, *EventTypeREF* - general data about incidents (shut-downs, etc.), including date, time, the investigation documents number, record and classificational mark, etc.;

TextAkt is the full text of an investigation document of a technological breakdowns (according to the directive

document 34.20.801-2000 "Instruction for investigation and record of technological breakdowns in the operations of the power systems, stations, boiler-houses, power and heat lines");

Obor, *klMarka*, *klUzel*, *klIzOb*, *klMater*, *klPrPov*, *klOtOb*, *klNapr*, *klTypuz*, *klUslRab*, *klSostN*, *klHar*, *klObst* -detailed information about the case of a technological breakdown and the broken facility in accordance with the cumulated classifier if the electrical part of the power stations, power and heat nets.

WindEvent, *IceWindEvent*, *GrozaEvent*, *PucenieEvent*, *GalopingEvent*, *OtherEvent* - tables for the storage of information about the place and the characteristics of the incidents connected to the impact of wind, ice (with wind), storm, frost heave, galloping and other phenomena.

III. ACCIDENCE RISK ANALYSIS

There were more than 3000 incidents analysed on overhead lines 35-500 kV on the territory of West Siberian plane for the period from 2010 to 2016. The collected data was processed and entered into the GIS-project database for the mapping and spatial analysis conduction.

The shutdowns with successful and unsuccessful automatic reclosing were included into the OHL shut-downs analysis. The causes of OHL shutdowns are divided into the following groups:

1. Storm shutdowns of OHL (atmospheric overvoltage) caused by the lightning hit at the wire rope, towers, and also phase wires.

2. The wind impact, accompanied by the unpredicted wind flaws and the contact movement of the insulator strings to the tower body or transverses, with the following closure of the air gap, and also damage of the towers.

3. Ice and wind impact emerging due to the adhering to the wires and wire ropes ice deposits (air hoar) which after the local cut-offs and in the presence of strong wind cause to the shut-offs of different types: wire rope-wire, phase-phase, etc. The shut-downs due to the ice and ice deposits and the shut-downs due to the wind loading during the icing were merged.

4. Conductors (wires) galloping caused by the wind are stable low frequency oscillations of a wire. As a rule they are accompanied by the inter-phase faults and cut-downs of the wires due to the relocation of the wires of the phases and storm wires vertically with a great amplitude under ice and wind loadings.

5. Extraneous effects - shutdowns of the lines due to the third party impact. The most of the cut-downs were caused by the transit of the out of gauge vehicles, unsanctioned works conduction in the exclusion zone, wires surge, isolators buntions, etc.

6. Constructional defects - the OHL cut-downs due to the manufacturing defects of the OHL elements, and also due to the hidden manufacturing defects.

7. Construction and assembly defects.

8. OHL shut-downs caused by birds. The isolation break-downs by the birds excrement and other products of their activity: nesting on the towers leads to the fire emergencies, faults, and other damages.

9. Ground frost heaving - the OHL shut-downs due to the inclinations or falls of the towers as a result of base polling

frost heaving, and as a consequence inter-phase closings and wire breaks.

10. Fire is an often result of the extraneous effects. There was defined a distinctive point from the cases connected to the fire in the gas pipe line under the line, forest fire and other reasons.

11. Ageing and facilities exhaustion - line shut-downs due to the aging destruction of the elements of the OHL, or defects emerged during the operation.

12. Unidentified causes - line shut-downs which cause was not defined during the investigation. In the most cases it was impossible to identify the damaged areas, both because of the absence of the visible damages and difficult accessibility of the areas under lines.

Figure 3 shows the distribution of the technical break-downs by their causes.

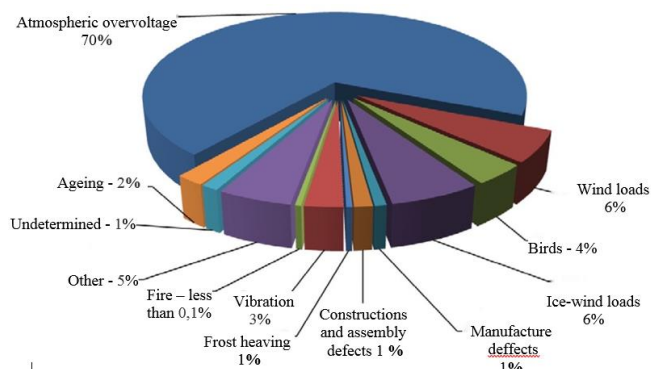


Figure 3 - Distribution of the technical break-downs by their causes

As one can notice in the figure 2, the main reason of the lines cut-downs is lightning overvoltage. Their number in this territory reaches 70% of all the cases under investigation. It's worth noting that although ice heaving caused only 1% of all the cut-downs, it does not mean that this issue is not relevant for the area under investigation. The analysis of the examination records, records of damages and the records of work done at overhead lines revealed 3582 cases of the heaving of the base tower polling from 2010 to 2016.

In this article main focus done on ice-wind loads and permafrost (frost healing).

IV. THE COMPARISON BETWEEN THE DESIGN CLIMATIC LOADINGS OF THE OPERATING LINES AND THE NORMATIVE REGULATIONS

Developed GIS-project was used to make comparison of design loads used for every OHL during design and construction (more than 30 year ago) with modern ice and wind load values.

The overhead lines were mapped in the GIS-project onto relevant regional climatic maps. Then, a comparison of the climatic loads used during the design and construction with modern normatives was done.

Figure 4 shows the comparison of the design climatic loads of the operating lines 110-220 kV with the modern requirements. As one can see from the figure 4, some parts of the line correspond modern requirements (in green), and some

parts had a considerable rise in climatic loads (depending on the level of the loading rise, these parts are marked in color ranged from yellow to red). The specific level of ice and wind loads rise can be found in the corresponding tables.

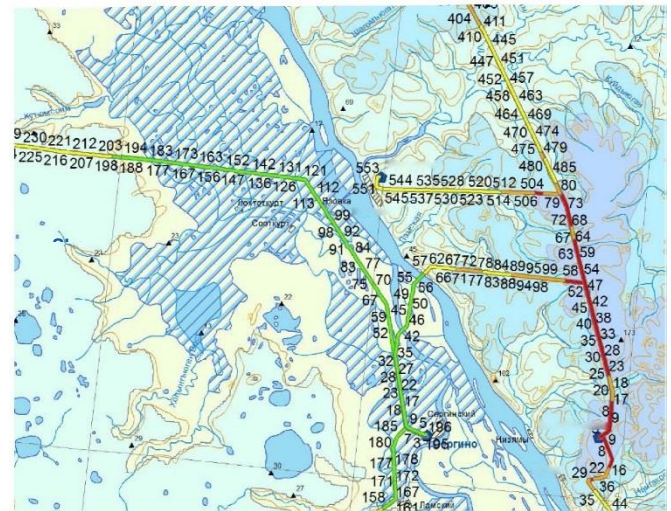


Figure 4 - Comparison of the design climatic loads of the operating lines 110-220 kV with the requirements of modern climatic maps.

It was found after the analysis of the line shut-downs connected to the ice and wind loads, in addition to the comparison of design climatic loads with modern requirements that the causes of many of 110 kV OHL shut-downs are connected to the climate change or to the fact of our better understanding of climatic conditions in that region.

There was composed a list of OHLs less qualified to modern ice and wind loads values or having big rate of ice loads incidents. It was recommended to the power company to examine the possibility of the complex reconstruction of these lines (or their parts) in order to strengthen their reliability.

V. ICE LOADS

As it can be seen from fig. 3 ice and ice-wind loads are the cause of only 6% of total accidents. This is because this region does not characterized by high ice loads. Wet masses from Atlantic "loose" their water supply in the European part of the continent. Remains of water are stopped by Ural Mountains. Indeed climatic maps created on the base of long-period meteorological observations shows that for the territories with the same absolute height and geographical conditions but located one in the European part, before the Ural mountains and second after Ural mountains in Asian part of the continent the maximum equivalent radial ice thickness having return period of 25 years differs two times (25-40 vs. 15-20 mm)! So, air masses, already poor of water, coming to this vast, open territory of West Siberian plane, from west or north do not face here any relief obstacle and do not leave here any considerable ice loads.

Our automatic monitoring station located in the north part of the region (59,598N, 29,737E) during all cold season 2018/19 has recorded only several times small hoarfrost loading with maximum equivalent radial ice thickness of 5

mm. Meanwhile strong winds (20 m/s and higher) were recorded more than 10 times.

It does not exclude the possibility of rare strong icings from upcoming wet air masses.

One of these episodes has took place in January 2016 when wet and relatively warm air masses from North Atlantic has reached this territory. Weight of hoarfrost icing was more than 1100 g per linear meter, which is 11,6 mm of equivalent radial ice thickness ($0,9 \text{ g/cm}^3$). For OHL constructed on equivalent radial ice thickness of 5 mm it meant exceeding design load of 2 times.

Some photos of that case are shown below (fig. 5, 6).



Figure 5 – Icing event on the north of the region on January 2016.

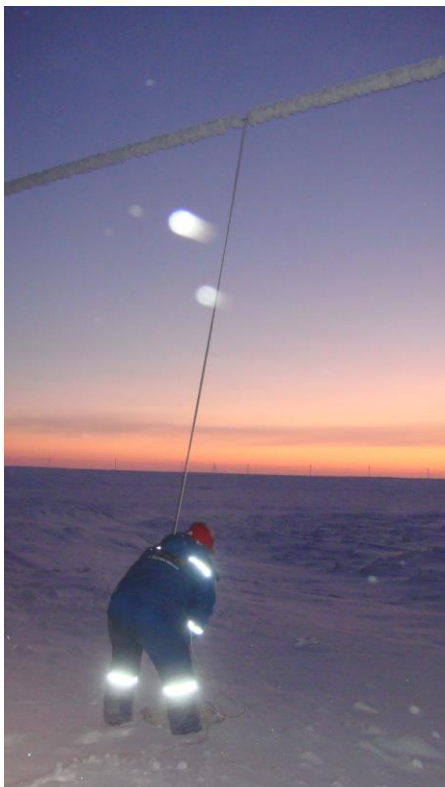


Figure 6 – Manual deicing on January 2016.

VI. FROST HEAVING

The biggest problems with the line operation are caused by frost heaving and the destruction of the towers' bases. The

point is that the degradation of the frozen ground in the bases causes the weakening of their fixation in the ground base, and in the light of the strong wind impact on the tower, which coincides with the seasonal melting the of top ground layer (usually in the autumn period), the bases loose their stability. It causes inclinations and deformations of the towers. Although according to the statistics, the number of the line shut-downs due to the frost heaving is very low (around 1 % of all shut-downs), they are the main causes of operating problems of the lines.

The impact of the frost heaving forces and the bases deformation worsen line operating conditions, cause damage to its constructional elements, and lead to high annual costs for the line elements repair works. The photos of the figure 7 show different cases of the tower bases heaving and their effects for the line operation.



Figure 7a – Tower fall with the bases plucking out of the ground (October 2016).



Figure 7b – Tower inclination by the two bases outsqueezing



Figure 7c – Lop-sided heaving of the bases under the tower, temporary fixed by the pedestal backing

The analysis of the tower bases frost heaving was conducted with line operation logs, and also with defect

registers. In particular, the cases of inclination and fixation of the towers by the line repair workers were recorded either with jacks by support rack installations (platings or pedestals) or by hammering the heaved pollings. These cases did not cause line shut-downs. In addition, the cases of emergency shut-downs were used for the analysis of the frost heaving of the bases pollings according to the technological breakdowns investigation documents.

During the line examination documents, defect registers and operating logs analysis of the line 110-220 kV in the region of HMAO-Yugra and YNAO, there were found 3582 cases of the tower polling bases heaving during 2010-2016.

The tower bases deformation due to the frost heaving forces can be caused by:

- the inaccurate engineering and geological investigation of the geological conditions;
- the mistakes in the polling depth calculation for the reliable bases fixation;
- deviation from design decisions during line construction;
- changes in the temperature characteristics of the permafrost during the operation due to climate change (progressing rise of the ground temperature which is accompanied by the degradation of their frozen condition).

The cases of the frost heaving were mapped onto geographical bases by means of the GIS-project for the spatial analysis conduction. Their biggest number was documented in the North of the region, specifically, on overhead lines near Yamburg and Noviy Urengoy.

For example, the figure 8 shows the spatial distribution of the frost heaving cases of the line 110 kV UGP-2V - Buran (in violet). The cases of the frost heaving are documented almost on all the towers during the period of 2010-2016 on the map. This is directly related to the continuous spread of permafrost in this region and the presence of a layer of seasonal thawing, in which the processes of frost heaving are developing.

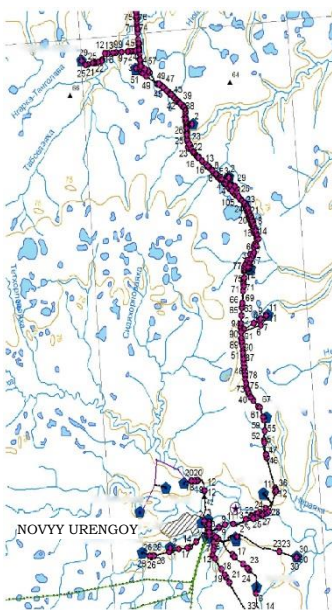


Figure 8 – Mapping of cases of frost heaving of piles of towers

Main measures in frost healing conditions:

- Rearrangement of towers to surface foundations on terrain with an even relief (without slopes, hills, etc.);
- Control of design length of the base (normal length should reach the layer which is not imposed to the seasonal melting);
- Reinforcement of towers by different methods;
- Use of bases of metal piles open profile cruciform section (Figure 9).



Figure 9 – Cross piles

The study of the dynamics of occurrence of frost heave cases by years showed that for some OHL, despite the use of the above measures, there is still a positive dynamics of their growth over the last year. This means that it is necessary to develop additional measures, for example, the use of special anti-frosthealing piles. Foundations on anti-stump piles can be installed on any surface, including a slope, with mandatory control over the achievement of the design depth of the dive.

VII. CONCLUSIONS

GIS technologies, along with data bases and special algorithms could give to a researcher powerful instrument for OHL operation data analysis and technical measures development for reliable OHL operation.

Spatial analysis based on GIS technologies give a possibility to determine “weak points” in power grid and prepare measures on reliability level increase.

In West Siberian region main causes of incidents on overhead lines are lightning, frost heaving, strong winds and icing.

Climate change caused in this region intensification of permafrost degradation and frost healing processes. In addition could be mentioned growth of frequency of strong wind and icing in this region.