A study of temporal dynamics and spatial variability of power frequency electromagnetic fields in Saint-Petersburg

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Abstract. This paper studies spatial distribution and temporal dynamics of power frequency electric and magnetic fields in Saint-Petersburg. It was determined that sanitary-protection and exclusion zones of the standard size high-voltage transmission lines (HVTL) do not always ensure maximum allowable limits of the electrical field depression. A dependence of the electric field strength on meteorological factors was defined. A series of sources create a city-wide background for magnetic fields. That said, the heavier the man-caused load is, the higher the mean values of magnetic induction are. Abnormally high values of magnetic induction are explained by the influence of underground electric cables.

1. Introduction.
Electromagnetic fields are still an insufficiently studied and poorly controlled environmental factor. Influence of electromagnetic fields on a human body is associated with the induction by a field of electrical currents of various strength and frequency inside the body, which may lead to both positive and negative consequences. People exposed to electromagnetic fields of increased intensity suffer from cardiovascular system malfunctions, metabolic disorders, as well as disorders of endocrine, immune, and reproductive systems, which is widely discussed in numerous sources ([1-3] et al).

In Russia, the protection of people from the exposure to electromagnetic fields is assured by sanitary-protection and exclusion zones created along HTVL, as well as by hygiene certification of household and commercial appliances and devices. However, Sanitary Norms and Regulations SanPiN 2971-84 [4] and SanPiN 2.2.1/2.1.1.1200-03 [5] define sanitary-protection zones only for HVTL 330 kV (20 meters wide), HVTL 500 kV (30 meters wide), HVTL 750 kV (40 meters wide), and HVTL 1150 kV (55 meters wide). Sanitary-protection zones shall be differentiated from exclusion zones, which are established not for the protection of people from the exposure to electromagnetic fields, but for the protection of high-voltage transmission lines. The width of exclusion zones is 20 meters for HVTL 110, 25 meters for HVTL 220, and 30 meters for HVTL 330 and HVTL 500 calculated from the projection of outermost phase conductors. That said, maximum exposure limits are 1 kV/m for residential zones and 5 kV/m for populated areas outside residential zones. Procedure [6] outlines the rules applicable to the exclusion zones of HVTL. A number of restrictions is applied to the territory of exclusion zones, for example, it is prohibited to arrange any events that involve mass gatherings. The paper does not consider the question of a possible dependence of electric fields of HVTL on weather conditions, and the question of mix and interaction of fields from various sources, a phenomenon known as electromagnetic smog in the scientific literature.
National health organizations in most countries of the world are considered negative influence of low-frequency electromagnetic fields (including power frequencies 50 and 60 Hz) to be not proved. So, in most part of the world there is no permissible exposure limits for low-frequency electric and magnetic fields. Now it is a subject of investigations, in particular by Scientific committee on the new and again revealed risks for health (SCENIHR) – advisory organ at the European commission on safety issues of consumers, public health and environment. Risks of a leukemia, damages of DNA and infringement of immune system are considered as possible effects of low-frequency electromagnetic fields [7]. Approximate safe limit of magnetic induction [7] is 0.4 μT (400 nT), that 10 times less most rigid among hygienic norms operating in Russia (5 μT for premises, children's, preschool, school, general educational and medical institutions according to Hygienic norms GN 2.1.8/2.2.4.2262-07 [8]).

2. Materials and Methods
The study of the power frequency electromagnetic fields in Saint-Petersburg was carried out from October 2016 through June 2017 by means of Gigahertz Solutions ME 3830 B M/E Analyser.

This meter can measure the strength of an electric field between 1 and 2000 V/m and the intensity of a magnetic field (magnetic induction) between 1 and 2000 nT. In several cases, the upper measurable value of 2000 V/m was not enough and it was possible only to state that this value was exceeded and to determine dimensions of a related zone. The below three types of measurements were taken:

- profile monitoring measurements, taken under wires in places of maximum sag and at a distance of 10, 15, 20, 25, and 30 meters from these places (from 19 to 32 series of measurements for 4 profiles);
- point monitoring measurements, taken to determine the stability of characteristics of electric fields with regard to the series of sources for these fields in residential areas (from 32 to 61 measurements in each of 4 points);
- point single measurements, taken at separate points of the city (approximately 300 measurements).

The measurements were taken in the places of maximum wire sag 1.8 meters above the ground. Information about weather conditions was taken at the Internet-service http://rp5.ru/Weather in Saint-Petersburg.

3. Results and Discussion

Strength of electric fields
Table 1 contains statistical characteristics of a series of observations over strength. Strength values exceeded 2 kV/m in all cases when measurements were taken directly under wires. Going away from the wires, the repeatability of exceedance of the given value was gradually diminishing, but it was not enough to determine statistical characteristics.

The study results show that electromagnetic fields with strength more than 1-2 V/m (maybe regarded as a city-wide background or a measurement error) were observed only in the vicinity of HVTLS, not farther than 100-120 meters. However, according to data contained in Table 2, the width of zones with high values of the strength of the HVTLS electric fields varied and did not always fall within the limits of the above-mentioned dimensions of sanitary-protection and exclusion zones.

In case of HVTLS 110 kV near the crossing of Blyukher and Kondratyevskiy avenues, the values higher than maximum allowable limits of the strength at the boundary of the exclusion zone (20 m) were observed in 11 instances out of 24 (45.8%); in case of HVTLS 330 kV near the Devyatkin subway station, the values higher than maximum allowable limits of the strength at the boundary of the sanitary-protection zone (20 m) were observed in 27 instances out of 32 (84.4%), and at the boundary of the exclusion zone (30 m) – in 20 instances out of 32 (62.5%). In case of two remaining HVTLS, the values higher than maximum allowable limits of the strength were not observed at the
boundaries of sanitary-protection and exclusion zones. Strength values in the nearby residential houses were lower than the maximum allowable levels in all instances.

Table 1. Statistical characteristics of intensity measurement results in case of profile monitoring

| Monitored locations                                                                 | Number of measurements | Mean value, kV/m | Root mean square deviation ($\delta$) | Coefficient of variation, % |
|------------------------------------------------------------------------------------|------------------------|------------------|--------------------------------------|----------------------------|
| HVTL 330 kV near the crossing of Blyukher and Kondratyevskiy avenues, 20 meters from wires | 30                     | 525              | 261.6                                | 49.8                       |
| HVTL 330 kV near the crossing of Blyukher and Kondratyevskiy avenues, 25 meters from wires | 30                     | 194              | 124.2                                | 64.0                       |
| HVTL 330 kV near the crossing of Blyukher and Kondratyevskiy avenues, 30 meters from wires | 30                     | 104              | 33.5                                 | 32.2                       |
| HVTL 110 kV near the crossing of Blyukher and Kondratyevskiy avenues, 15 meters from wires | 30                     | 1257             | 489.4                                | 38.9                       |
| HVTL 110 kV near the crossing of Blyukher and Kondratyevskiy avenues, 20 meters from wires | 30                     | 808              | 334.6                                | 41.4                       |
| HVTL 330 kV near the Devyatkin subway station, 30 meters from wires                | 32                     | 1221             | 426                                  | 34.9                       |
| HVTL 330 kV near the Devyatkin subway station, 50 meters from wires                | 32                     | 688              | 189.9                                | 27.6                       |
| HVTL 330 kV near the Devyatkin subway station, 70 meters from wires (the nearest building) | 32                     | 68               | 114.4                                | 168.2                      |
| HVTL 220 kV near the Devyatkin subway station, 20 meters from wires                | 32                     | 819              | 257.2                                | 31.4                       |
| HVTL 220 kV near the Devyatkin subway station, 25 meters from wires                | 32                     | 685              | 199.5                                | 29.1                       |

Table 2. Width of zones where values of the strength of the HVTL electric fields exceed 1 kV/m (maximum exposure limits for residential zones) and 2 kV/m

| Monitored locations                                                                 | Number of measurements | Over 1 kV/m, m | Over 2 kV/m, m |
|------------------------------------------------------------------------------------|------------------------|----------------|----------------|
| HVTL 330 kV near the crossing of Blyukher and Kondratyevskiy avenues                | 21                     | 18             | 20             |
|                                                                                    |                        | 19             | 14             |
|                                                                                    |                        | 18             | 16.5           |
| HVTL 110 kV near the crossing of Blyukher and Kondratyevskiy avenues                | 21                     | 0              | 23             |
|                                                                                    |                        | 17.5           | 0              |
|                                                                                    |                        | 14.5           | 9.1            |
| HVTL 330 kV near the Devyatkin subway station                                     | 19                     | 26             | 50             |
|                                                                                    |                        | 41.6           | 13             |
|                                                                                    |                        | 30             | 20.9           |
| HVTL 220 kV near the Devyatkin subway station                                     | 19                     | 14             | 22             |
|                                                                                    |                        | 18.9           | 11             |
|                                                                                    |                        | 17             | 14.8           |

The major factor influencing the strength of electric fields is a load of HVTL. However, characteristics of the same lines vary depending on meteorological conditions. Dielectric properties of the air depend on its humidity, and not so much on relative humidity, as on the absolute one. Table 3 provides correlation dependences.
Table 3. Coefficients of correlation between strength measures in the HVTL monitoring range and meteorological characteristics

| Monitored locations | Coefficients of correlation considering measures: | Absolute humidity | Relative humidity | Air temperature | Atmospheric pressure |
|---------------------|-----------------------------------------------|------------------|------------------|----------------|---------------------|
| HVTL 330 kV near the crossing of Blyukher and Kondratyevskiy avenues, 20 meters from wires | 0.681 | -0.145 | 0.652 | -0.573 |
| HVTL 330 kV near the crossing of Blyukher and Kondratyevskiy avenues, 25 meters from wires | 0.737 | -0.061 | 0.617 | -0.564 |
| HVTL 110 kV near the crossing of Blyukher and Kondratyevskiy avenues, 15 meters from wires | 0.762 | 0.579 | 0.353 | -0.602 |
| HVTL 110 kV near the crossing of Blyukher and Kondratyevskiy avenues, 20 meters from wires | 0.732 | 0.370 | 0.453 | -0.526 |
| HVTL 330 kV near the Devyatkino subway station, 50 meters from wires | 0.629 | -0.149 | 0.511 | -0.272 |
| HVTL 220 kV near the Devyatkino subway station, 20 meters from wires | 0.726 | 0.518 | 0.760 | -0.565 |
| HVTL 220 kV near the Devyatkino subway station, 25 meters from wires | 0.736 | 0.461 | 0.829 | -0.503 |

As it was technically impossible to measure strength values higher than 2 kV/m, we managed to calculate correlations with meteorological characteristics only in the monitoring points relatively remote from the wires. Therefore, an additional calculation was done to determine the correlation ratio between the width of zones with values exceeding 1 kV/m and 2 kV/m and meteorological characteristics. Table 4 provides the calculation results.

Table 4. Coefficient of correlation between the width of zones with values exceeding 1 kV/m and 2 kV/m and meteorological characteristics

| Monitored locations | Coefficients of correlation considering measures: | Absolute humidity | Relative humidity | Air temperature | Atmospheric pressure |
|---------------------|-----------------------------------------------|------------------|------------------|----------------|---------------------|
|                     | Coefficients of correlation considering measures: | < 1 kV/m | < 2 kV/m | < 1 kV/m | < 2 kV/m | < 1 kV/m | < 2 kV/m | < 1 kV/m | < 2 kV/m |
| HVTL 330 kV near the crossing of Blyukher and Kondratyevskiy avenues | 0.620 | 0.749 | 0.537 | 0.473 | 0.313 | 0.578 | -0.382 | -0.573 |
| HVTL 110 kV near the crossing of Blyukher and Kondratyevskiy avenues | 0.688 | 0.761 | 0.501 | 0.502 | 0.310 | 0.483 | -0.504 | -0.631 |
| HVTL 330 kV near the Devyatkino subway station | 0.687 | 0.461 | 0.522 | 0.244 | 0.740 | 0.551 | -0.539 | -0.411 |
| HVTL 220 kV near the Devyatkino subway station | 0.741 | 0.631 | 0.596 | 0.508 | 0.693 | 0.638 | -0.638 | -0.652 |
Correlation coefficients shown in Tables 3 and 4 are indicative of the average and strong dependencies existing between the strength of an electric field and meteorological characteristics. An absolute humidity is the major meteorological characteristic, which directly influences the result. Moreover, the closest correlations, as a rule, are obtained for the same factor. The influence of remaining characteristics is indirect and is manifested as factors forming the absolute humidity. Atmospheric pressure and temperature hardly influence the strength of an electric field directly; however, the increase of temperature leads to higher evaporation, which, in its turn, results in higher absolute humidity (direct relationship), while the pressure increase (anticyclonic weather) is associated with lower humidity (inverse relationship). The correlation sharply decreases along the borders of zones of HVTL influence, up to insignificant values.

**Magnetic Fields**

Magnetic fields, characterized by measures of magnetic induction, do not produce such sharp maximums under high-voltage transmission lines as electric fields do, and can be described by a less rapid decrease with the increase of distance from HVTL (Figure 1), as well as by higher and omnipresent city-wide background.

![Figure 1](image_url)

**Figure 1.** Mean values of strength and magnetic induction at various distances from HVTL 330 kV near the Devyatkino subway station.

Legend: E – strength of an electric field, V/m; M – magnetic induction, nT; along the horizontal axis which shows the distance in meters from the outermost wire.

Values of magnetic induction equaling 1-2 nT, i.e. those within the measurement error, were observed only in the central part of Sosnovka park, at a distance more than 0.5 kilometers from the nearest possible sources. Measures of magnetic induction both HVTL and at the monitoring points of residential areas are less variable (Table 5) and substantially less dependent or independent altogether upon meteorological characteristics (Table 6).

As relatively stable characteristics, the measures of magnetic induction demonstrate a fairly clear spatial differentiation depending on the territory use pattern and housing type (Table 7). Abnormal values are related to the influence of cables and can be determined not only by statistical data, but also by sharp increase of values next to the ground or to the cable sheath. Comparing the characteristics of territories with different use patterns and housing types, it becomes obvious that the intensity of the power frequency magnetic fields depends on an overall man-caused environmental load.
Table 5. Characteristics of a set of measurements of magnetic induction taken at monitoring points in residential areas

| Monitored locations | Number of measurements | Mean value, nT | Root mean square deviation (δ) | Coefficient of variation, % |
|---------------------|------------------------|----------------|-------------------------------|-----------------------------|
| 15 Ushinskiy st., building 1 | 60 | 179.5 | 34.4 | 19.15 |
| 114 Grazhdanskiy avenue, building 6 | 57 | 84.6 | 20.4 | 24.1 |
| near the Grazhdanskiy prospekt subway station | 61 | 36.2 | 8.2 | 24.5 |
| near the Ulitsa Dybenko subway station | 34 | 18.3 | 5.9 | 32.1 |

Table 6. Coefficients of correlation between the measures of magnetic induction observed at the monitoring points in residential areas and meteorological characteristics

| Monitored locations | Coefficients of correlation considering measures: | Absolute humidity | Relative humidity | Air temperature | Atmospheric pressure |
|---------------------|-----------------------------------------------|-------------------|------------------|----------------|---------------------|
| 15 Ushinskiy st., building 1 | -0.368 | 0.233 | -0.413 | 0.125 |
| 114 Grazhdanskiy avenue, building 6 | -0.321 | 0.267 | -0.403 | 0.192 |
| near the Grazhdanskiy prospekt subway station | 0.355 | -0.281 | 0.399 | -0.187 |
| near the Ulitsa Dybenko subway station | -0.502 | 0.292 | -0.588 | 0.332 |

Table 7. Basic results of magnetic induction measurements at Saint-Petersburg’s territories with different use patterns and housing types

| Use pattern, housing type | Number of measurements | Mean value, nT | Root mean square deviation (δ) | Coefficient of variation, % | Number of abnormal values above 3δ limit | Mean value excluding abnormal values, nT |
|---------------------------|------------------------|----------------|-------------------------------|----------------------------|------------------------------------------|----------------------------------------|
| Densely built-up historical center | 136 | 279 | 310 | 95.4 | 4 | 271 |
| Including streets | 93 | 325 | 310 | 95.4 | 4 | 271 |
| Including yards | 30 | 228 | 211 | 92.4 | 1 | 195 |
| Including squares and other spare areas for housing development | 13 | 56 | 56 | 56 | |
| Mixed housing | 18 | 145 | 145 | 145 | |
| Modern housing | 94 | 90 | 90 | 90 | |
| Including streets | 61 | 68 | 67 | 99.2 | 1 | 63 |
| Including space inside city blocks | 33 | 134 | 205 | 153.2 | 1 | 97 |
| Parks, gardens | 30 | 9 | 10 | 109.2 | 1 | 7 |

4. Conclusions

Results of the study suggest that standard dimensions of sanitary-protection and exclusion zones are not sufficient to ensure the electromagnetic safety of people. The revealed dependence of the strength of electric fields of high-voltage transmission lines on meteorological conditions indicates that the dimensions of sanitary-protection zones shall be differentiated based on climatic parameters. The dimensions of sanitary-protection and exclusion zones of high-voltage transmission lines shall consider climatic factors, which influence dielectric properties of the ambient air. These zones shall be
widened in areas with a humid climate and narrowed in dry regions. There are grounds to believe that most problems with the strength of electric fields will be discovered in the territories with warm and humid climate; in case of Russia, this is, in the first place, the Black Sea coast of the Caucasus.

Measures of magnetic induction can be regarded as indirect indicators of the challenging ecological situation (geoindicators). Advantages of this bioindicator include simple and quick measurements and complete absence of dependence on previous conditions (inertia), while disadvantages include the need to take into account specific sources of fields leading to local anomalies.

References

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