University of West Hungary,
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PhD Thesis Summary

EXTERNAL ORIGIN VARIATION OF THE ELECTROMAGNETIC IMPEDANCE-TENSOR

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INTRODUCTION

The understanding and exact interpretation of the dynamic processes taking place in the subsurface and the external environment of the Earth can only be achieved by means of the diverse methods of geophysical exploration. Nowadays, application of electromagnetic (EM) geophysical methods became more important in the near surface exploration, archeological excavations, in the research of raw material and understanding deep-tectonic structures and processes. Authentic geophysical/geological information can only be achieved by aware processing and interpretation of the recorded EM data samples. In case of certain EM research methods -like the so-called magnetotelluric (MT) method- natural origin surface electromagnetic variations are recorded (Tikhonov, 1950; Cagniard, 1953). The linear relation between the surface electric and magnetic variations is characterized by the surface impedance function which is the target function of the MT exploration, holding information about the subsurface distribution of the EM parameters. In addition the MT response function also contains information about some attributes of the natural source of the surface EM variations. The practical MT data processing based on the simplification that these deviations are negligible. Well known fact that this assumption holds only in certain latitude range but lapses in equatorial and auroral latitudes. It neither stands on mid-latitudes at long periods, namely above hundreds of seconds. Pointing out the limitations of the routinish way of practical data processing and interpretation is an important duty of the theoretical geophysical research.

The candidate analysed the temporal stability of the EM surface impedance function assuming realistic magnetospheric/ionospheric source mechanisms and current systems operating in mid-latitudes.

He supplemented and verified the results of the exact theoretical approach with processing and interpretation of observatory recordings.

RESEARCH OBJECTIVES

The deviation of the surface impedance function originated from the geometry or extent of the source current field is called *source effect*. The main objective of the PhD work is to provide a quantitaive estimation of the source effect, arised under operation of well-known mid-latitude magnetospheric/ionospheric source mechanisms. Accordingly saving his theoretical approach well-aimed statistical processing of experimental data is required. Hence he worded the following objectives:

1. To provide general formulas of the surface EM field arising under operation of pulzation ionospheric source current system as a function of physically realistic geometrical parameter domain.
2. To specify the general formulas of surface EM field of the pulsation ionospheric source current system concerning the boundary conditions of the fields related to the geophysical/geological model of the local subsurface.
3. To provide the general formula of the Tikhonov-Cagniard (CT) impedance concerning the pulsation ionospheric current system. In addition numrical specification of the CT impedance regarding to the case of the subsurface model of the site, as a function of the source system parameters like extent, wavelength and frequency.

4. Spectral analysis of experimental CT impedance function series computed by means of four years (2000-2004) of telluric and geomagnetic recordings in order to demonstrate occurrent periodic modulations.
5. Comparison of experimental impedance curves fitted on individual values at characteristic frequencies of different source mechanisms.
6. To examine the occurrent effect of geomagnetic activity on the experimental CT impedance.

PERFORMED TASKS

The candidate has performed theoretical and practical probes as follows:

THEORETICAL WORK

The candidate has provided theoretical description of the surface EM field of a pulsation current system based on Price's approach (Price, 1950). He specified the general formulas by means of the geophysical subsurface model of the observatory site, in addition performed numerical determination of the local CT impedance as a function of the source extent, wavelength, frequency and the observer's relative position. Accordingly he provided theoretical estimation of the pulsational source effect.

The cadidate separated the distortion effect of the different source parameters and provided their adequate physical interpretation. He determined the complex relation of the primary and secondary horizontal surface geomagnetic field and presented its numerical determination concerning the local geoelectric model in the whole 4D parameterspace.

He provided a possible physical explanation of the daily modulation of the experimental impedance function and confirmed his hypothesis by means of polarization analysis of the geomagnetic field.

PROCESSING OF THE OBSERVATORY RECORDINGS

The candidate defined coherency/energy criteria to reject noisy periods and components in order to obtain more accurate statistical results. He performed short and long term spectral analysis on the interpolated experimental impedance function series. He computed certain rotational invariant's function series, namely the central impedances (Weaver, 2000), in order to confirm that the demonstrated daily and annual modulation of the surface impedance independent of the orientation of the recording system.

The candidate performed statistical analysis of the experimental impedance functions to to make sure if any deviation can be demonstrated between the experimental impedance functions computed on the waveguide frequencies and on the complementer frequency classes.

The candidate computed the representative experimental impedance functions related to different geomagnetic activity intervals to demonstrate that geomagnetic activity affects the surface impedance values. The separation of quite and disturbed days has been performed based on three geomagnetic activity index (ULF-Tgr, ASY-H, SYM-H).

ORIGINAL SCIENTIFIC RESULTS

The main results of the PhD works can be summarized as follows:

1. He provided general theoretical formulas of surface electromagnetic field of the ionospheric pulsation current system related to realistic magnetospheric source mechanisms. Namely he extracted the formulas of H_y, H_z and E_x surface field components of an azimuthally limited extent meridional source current system.

2. He prepared the numerical determination of the surface electromagnetic field components as a function of the pulsation source geometry -namely the extension and the wavelength of the source field-, the frequency and the observers relative position. Each parameter domain has been set according to physcally realistic conditions.

3. He determined the general formula of the surface impedance tensor besides pulsation source field by means of his theoretical surface field formulas. He specified the general expression to obtain the surface impedance of the site of the Széchenyi István Gephysical Observatory as a function of the source parameters. He carried out the numerical estimation of the surface impedance function in the grid nodes of the 4D parameterspace -source geometry, frequency and the relative position of the observer.

4. The candidate provided numerical estimation of the deviation of the apparent resistivity function -characterises the site of the geomagnetic observatory-, related to the source effect. He demonstrated that in case of long source wavelength the theoretical impedance function agrees with the result of the direct solution of Cagniard-Tikhonov (CT) impedance, while in case of 100km source wavelength the theoretical estimation results serious deviation besides pulsation source field condition.

5. The candidate theoretically determined the complex relation of the inducing and the induced surface magnetic field as a function of the source parameters -besides pulsation source field assumption- and specified the general formulas by means of resistivity model based on the results of former geophysical explorations (Ádám, 1970). In virtue of the results he demonstrated that the primery and secundery horizontal magnetic fields are parallel in case of 1D medium, and the modulus of the induced and inducing surface field components are similar in case of conductive upper layer.

6. The candidate elaborated short and long term spectral analysis of the four year long (2000-2004) experimental impedance function series computed by means of the observatory telluric and geomagnetic recordings. He demonstrated significant daily modulation of the diagonal tensor elements in the ULF frequency range. He computed function series of rotational invariants -namely central impedances- to verify that the demonstrated modulation effect is independent of the orientation of the recording system.

7. The candidate provided a possible physical explanation of the daily modulation of the diagonal elements of the experimental impedance function. He confirmed his hypothesis by polarization analysis of the geomagnetic field. Furthermore he draw attention on the deviation of the impedance function as a consequense of certain non-uniform distribution of geomagnetic polarization direction.

8. The candidate confirmed that at mid-latitudes no deviation can be demonstrated between the experimental impedance functions computed on the waveguide frequencies and on the complementer frequency classes.

9. The candidate computed the experimental impeance functions related to different geomagnetic activity intervals. The separation of quite and disturbed days has been performed based on three geomagnetic activity index (ULF-Tgr, ASY-H, SYM-H). As a result of the analysis he demonstrated significant discrepancy between the MT response functions related to terms of different geomagnetic activity.

The candidate performed all numerical computations and statistical analysis by his own originally developed scripts and functions of IDL and MATLAB environment.

APPLICATION OF THE RESULTS

Generally in practical EM exploration the representative and genuine geophysical information is obtained by performing long term recordings. The characteristics of the site can be extracted as result of robust statistical processing of the individual measurements. In this manner the distortions extinguished by a sort of weighted averaging. Nevertheless, in case of certain geophysical application the objective is barely the real-time monitoring of accidental changes of subsurface resistivity distribution. Namely in case of MT monitoring of volcano magma tunnel, the main goal is to forecast the exact time of eruption (Kanda et al., (2008)). In case of such applications the impedance variation of external origin can have serious consequences.

The main achievement of the present PhD work is to aid the development of a more accurate MT processing method, which considers the characteristics of the source current system geometry. The candidate pointed out the limitations of the routinish data processing and the conditions of their applicability on mid-latitude MT exploration.

Additionaly the more accurate consideration of the source geometry extend the adoptability of the MT method, namely the correct identification of certain subsurface processes which contribute to the surface EM variations. For instance certain tectonic movements can arise EM surface variations by means of piezomagnetic effect.

Considering the polarization source effect it is possible to obtain more accurate geophysical information through the data processing and interpretation.

LIST OF PHD RELATED PUBLICATIONS

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