

## Program Support for Earth Surface Potentials Measuring System

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**Abstract.** *Substation grounding systems need to be inspected periodically to test and verify their original protective functionality and characteristics. The most important parameters are the values of touch and step voltages under fault conditions as they directly affect the on-site personnel safety. Grounding system verification is a multi-stage process, which has to be planned in details prior to actual measurements. That implies a need for an elaborated measuring methodology as well as for custom designed measuring system. Prototype of such a system has been developed and tested in the field. This paper focuses on the description of program support as a framework and foundation of a complex measuring system. Application structure, which is tightly bound to measuring methodology concepts, is presented through the typical example of system usage. Additional issues and references to accompanying measuring instrumentation are also presented.*

**Keywords:** *Earth Surface Potentials, Touch and Step Voltage Measurement, Substation Grounding Systems*

### 1. Introduction

The basic requirement of safe substation grounding system design is to prevent personnel exposing to life threatening voltage levels and absorbing dangerous electrical shock energy. A mechanism affecting people safety is the potential rise of grounded structures during fault conditions: getting in touch with grounded metal parts or standing on positions with high surface voltage gradients can both result in electrical shock. The first case is described by touch, and the second one by step voltage values. The inspections and tests of grounding systems have to be carried out periodically in order to verify the compliance with permissible touch and step voltages [1-3]. Moreover, these tests are useful for predicting or pointing out to the dysfunctions of grounding systems in electrical or mechanical sense.

### 2. Simplified Description of the Measuring Procedure

The inspection procedure, in the case of Heavy Current Injection Method used, includes measuring of the *Grounding Potential Rise* (GPR), determination of *Earth Surface Potentials* (ESP) map and measuring of touch and step voltages. Measuring procedure has been discussed previously [4-5]. All measurements are performed using custom designed Intelligent Measuring Equipment (IME) [5] at a test current that represents the reduced short-circuit fault current. Measured values have to be recalculated according to the rated fault current, flowing at a single-phase short circuit condition through the grounding system.

The ESP-map measurements give information about surface potential distribution above substation grounding system. Visual representation in form of equipotential and gradient analysis is derived from sample points by means of spline interpolation algorithms. This is useful for establishing trends and changes in grounding system structures as well as for detecting suspicious areas with expected high touch and step voltages.

The measurement of touch and step voltages is the next step of the inspection. Measuring points are arranged according to the results of equipotential and gradient analysis of ESP map: touch voltages are measured beside grounded metal objects in areas with high potential deviations from GPR level, while step voltages are inspected on positions suspected for high gradient values on earth surface.

There are numerous practical problems in carrying out measurements in the described manner. Great deal of measuring information need to be gathered, organized and structured. Depending on measuring area size, the total count of sampling points can be up to few thousands. Data about each

measurement, represented by a single measuring point, has to be tracked and maintained, what includes location, measuring results, measuring phase and type for each point, ground properties, etc. The user must be able to easily create, modify and maintain measuring project plans and also to generate reports automatically from the results after performed measurements. Additionally, some more requirements apply, such as: inter-phase measuring data interpretation (equipotential and gradient analysis), auxiliary measurement documentation generation for easier orientation on-site (e.g. maps with denoted objects and measuring points positions), data exchange between personal computer (PC) and IME, etc.

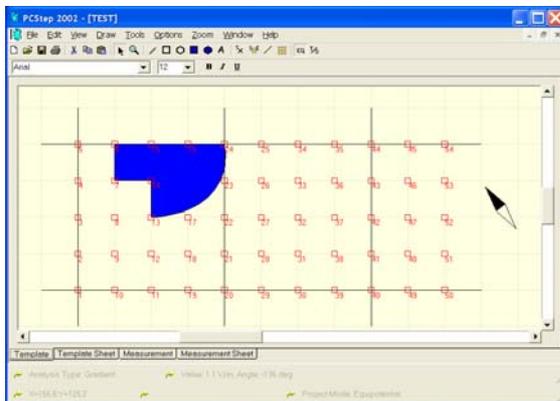
All mentioned requirements and problems lead to development of *Measuring Project* concept [4] as a framework that integrates measurement and validation procedure. The implementation of that concept resulted in a realization of an Integrated Program Environment (IPE) for PC bound with the prototype of Intelligent Measuring Equipment (IME).

### 3. Integrated Program Environment Description

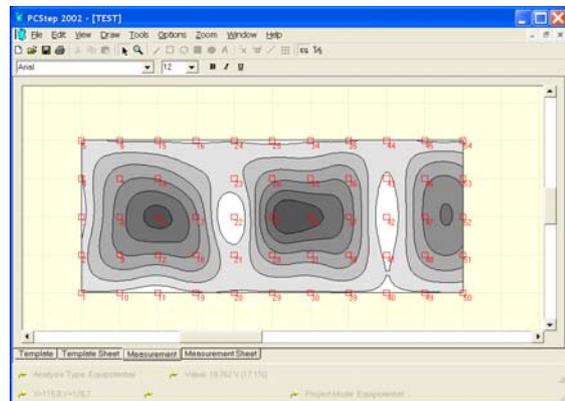
#### *Defining Measuring Project*

Measuring project maintains pieces of information about single grounding system in a compact, highly structured manner. Various types of information are subject of its content, such as map of physical objects in and around power installation, positions of all measuring points, templates and plans for carrying out measurements, measuring results, project history, annotation of on-site changes, numerical analysis visualization, user notes, etc. The most convenient way to present Measuring Project structure to user was to develop highly customized graphic environment that provides means for data representation in a layered visual form. Detailed layer descriptions (*Common, Equipotential and Touch/Step Layers*), along with object classes belonging to each one, were presented in [4].

Creating a new project starts by setting its global parameters such as: general project information, project name (unique identifier in communication with IME, which is capable of managing few projects), virtual drawing page size, map aspect ratio, grid and viewing settings, etc.



**Figure 1: A part of measuring project with reference objects and ESP measuring points (Equipot. mode - Template)**



**Figure 2: Equipotential analysis of ESP measurements (Equipot. mode - Measurement Results GUI)**

The first task is to draw a map of measuring area in selected aspect ratio. It is helpful to scan existing plan and put it into *Background Layer* for easier retouching with reference IPE vector entities. Those reference objects are used to visualize the arrangement of grounding conductors, buildings, fences, gates, transformers, portals, etc. Some of them serve just as a help for easier orientation (*Transparent Object* type) while the other represent true obstacles for performing measurement on certain areas (*Constraint Object* type). Program will automatically prevent user from placing of measuring points on spots or areas occupied by Constraint Objects. All reference objects are drawn using simple 2D geometry primitives (lines, rectangles, polygons, etc.) whose properties can be easily manipulated through user-friendly *Graphic User Interface* (GUI). A choice to restrict measuring point placement outside the polygon that defines Measuring Area Bounds is given to user. Special entity (*Compass* object) is used to define proper map orientation. Map of installation is drawn as a part of the

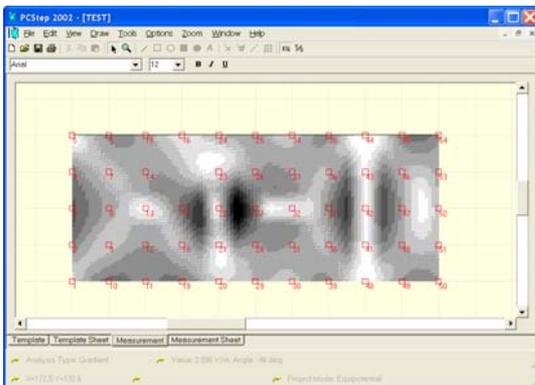
Measuring Project *Template* because it serves as a reference for all future measurement plans for the particular site. Any future changes on the measuring area (e.g. new objects or changes of existing ones) can be easily updated by manipulations on Transparent and Constraint objects in Common Layer of Template drawing.

### *ESP Measurements and Numerical Analysis of Results*

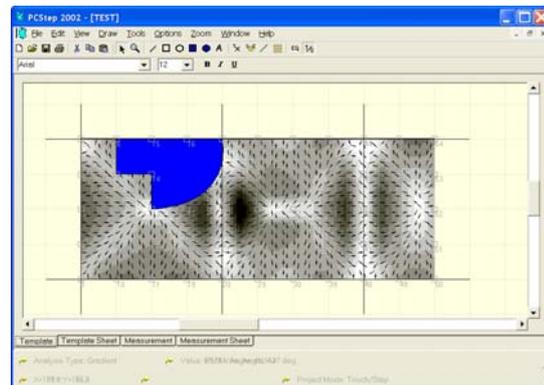
The next step is to define *Equipotential* part of the measuring project. The application needs to be switched to "*Equipotential*" mode, allowing user to place measuring points into separate *Equipotential Layer*, visualized over *Common Layer*. Sampling points for ESP map can be placed as single points or grouped into special entities called *Measuring Lines* and *Autoplacements* [4]. Latter provides means for speeding up measuring project design process by using the predefined automatic placement algorithms. In this phase of project plan definition, it is recommended to place measuring points using *Autoplacement* tool on regular grid related to arrangement of grounding conductors. Overall points count and density depend on measuring area size and the geometry of grounding conductors. Fig. 1 shows an example of Equipotential part of the measuring project with denoted reference objects and ESP measuring points. Filled objects represent constraint areas, while lines visualize grounding conductor layout. For the sake of simplicity, only the small number of measuring points has been placed to illustrate described principles.

The project description is translated from the vector graphics representation into a binary form and transferred to the IME. That provides the operator of portable measuring instrumentation with all necessary information about the predefined way of moving among the points in the field. IME will automatically select correct inputs according to the measuring point type on particular position and capture measuring results in memory. It is also convenient to generate auxiliary measuring documentation that consists of maps with all denoted objects and measuring point positions, and tables with detailed descriptions of each measuring point.

The useful feature in this stage of inspection is the capability of *Splitting* single project with great deal of measuring points into two or more subprojects, resolvable with two or more different IME devices, respectively. That procedure provides means of performing parallel ESP measurements resulting in faster overall measurements, higher robustness to external environmental changes (e.g. soil resistivity variations due to humidity or weather changes) and reduced total inspection costs.



**Figure 3: Gradient analysis of ESP measurements (Equipot. mode - Measurement Results GUI)**



**Figure 4: Measuring project with ref. objects, numerical analysis and touch and step measuring points (T/S mode - Template)**

After performing ESP map measurements, the results are transferred back from IME to program environment in a "shadow copy" of the project Template, referred to as a *Measurement Results GUI*. In the case of project splitting, an inverse procedure of project *Merging* from two or more subprojects must be applied to join the results together into the Measurement Results GUI of the original project. It is necessary to have a separate graphic environment because distribution of measuring points can be altered in IME during the course of measurements (e.g. some points might have been moved to different locations or invalidated due to inability of performing measurements on predefined positions, some new points might have been added, etc.). The Measurement Results GUI reflects the actual post-

measurement state and results after performed numerical analysis. Fig 2. illustrates an example of the equipotential, and Fig. 3 of the gradient analysis visualization of ESP measurements. It is convenient to synchronize the original Template with captured changes as a reference for all subsequent project plans.

#### *Touch and Step Voltages Measurements and Inspection Results*

Locations of touch and step voltage measuring points are planned in accordance with the results of equipotential and gradient analysis of ESP measurements. For that reason, the visualization from Measurement Results GUI can be copied to background layer of the Template, so potentially harmful spots can be accurately marked for inspection in this measurement phase. Measuring points are placed into the separate layer after switching application to "*Touch/Step*" mode. Points from the Equipotential part of a project are still visible in the background, but they are disabled in this mode. Gradient analysis is particularly useful with points of step type because user has to know the places with high gradients on earth surface and also the electric field direction on the given coordinate. That affects the correct orientation of operator during step voltage measurements, which should be perpendicular to equipotential lines (as marked with gradient arrows on Fig. 4). Auxiliary measuring documentation and communication with IME is similar to previous step.

Results of touch and step voltage measurements are transferred back from IME to "Touch/Step" part of the Measurement Results GUI. The original Template can be synchronized with any changes that might have occurred in IME. Measuring results are recalculated to the rated fault current and compared with Standard requirements. Program automatically marks spots with out-of-range values of touch and step voltages on the map, generate tables with lists and descriptions of fault points and all other necessary documentation in form of predefined reports as the output of inspection. Final results are interchangeable with the most common file formats and external applications (spreadsheets, text processors, databases, etc.) in the case of need for information post-processing.

#### **4. Conclusions**

The prototype of a measuring system for substation grounding inspections has been developed and tested. The practical field tests, in conjunction with accompanying measurement instrumentation, showed great improvements over traditional manual approach with Heavy Current Injection Method. The greatest benefits of described new approach manifest in easier data management, faster and more robust inspection procedure and reduced overall costs.

Integrated program environment, as a part of a system, encompasses important tasks such as inspection plans management, data exchange with measuring instrumentation, data analysis and automatic report generation. Other numerous embedded features provide end-users with powerful tools and working environment for highly efficient substation grounding system inspections.

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