GIC

User Requirements Document

ESTEC Contract Number 16953/02/NL/LvH

Issue 0

Prepared by:

____

P. Wintoft, H. Lundstedt, IRF-Lund, and Risto Pirjola, FMI

Approved by:

____

L. Eliasson, IRF-Kiruna

Approved by:

____

A. Hilgers, ESTEC

DOCUMENT STATUS SHEET

Document status sheet			
1. DOCUMENT TITLE: GIC WP 100 User Requirements Document			
2. ISSUE	3. REVISION	4. DATE	5. REASON FOR CHANGE
0	0	2003-06-11	First issue

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Purpose

The purpose of this software is to provide a system that can be used for real time forecasting of geomagnetically induced currents (GIC) in the Swedish power grid. The software shall be used by power grid operators and tested for a one-year period. During this period, the accuracy and reliability of the software shall be determined, and the usefulness of the software shall be formulated through a cost-benefit analysis. Another aspect is the need to educate the public and decision makers of the potential hazards of GIC and how forecasts can help to mitigate the effects. Thus, the software shall also have a public part.

At a working meeting in April 2003 more specific requirements were obtained from Håkan Swahn, representing Elforsk. Among other things, useful ways of presenting GIC were discussed. As described in Section 2.1 the Swedish power grid is divided into stations and zones. Therefore, it would be useful to be able to get some average GIC disturbance for these regions.

1.2 Scope

The power grid operators need accurate forecasts of GIC from hours up to weeks in advance. Due to the nature of the physical system, accurate one-hour forecasts should be possible using solar wind data. To push the forecasts further solar data are needed which leads to a much more complex problem. Therefore, this project shall focus on developing software for accurate one-hour forecasts of GIC.

If a software system can be developed that accurately forecasts the GIC values in Amperes with one-minute resolution, then it would suffice. However, there might be a number of problems that does not make this possible. Therefore, alternative ways of representing the GIC shall be explored that are of practical use.

Originally, the software should be capable of producing forecasts at every transformer for the whole of Sweden. This might not be possible, considering the size of the project, and therefore the system shall be developed for a smaller set of transformers. To model the whole grid a complete specification of the power lines, transformers, and so on are needed. The data are not available in a form suitable to this project, and creating an appropriate database will extra resources not available in this project .

1.3 Definitions, acronyms and abbreviations

ACE	Advanced Composition Explorer
FMI	Finnish Meteorological Institute
GIC	Geomagnetically Induced Current
IMF	Interplanetary Magnetic Field
IRF	Swedish Institute of Space Physics (Institutet för rymdfysik)
NaN	Not a Number
NSSDC	National Space Science Data Center
UL1	User Level 1
UL2	User Level 2
WDC	World Data Center

1.4 References

1. ESA software engineering standards, ESA PSS-05-0 Issue 2, February 1991.
2. Guide to the user requirements definition phase, ESA PSS-05-02 Issue 1, October 1991.
3. NSSDC OMNIWeb, `www.nssdc.gsfc.nasa.gov/omniweb/`.

1.5 Overview

The structure of this document follows the document template as described in the ESA software engineering standards [1] and user requirements guide [2].

2 GENERAL DESCRIPTION

2.1 Product perspective

As stated in the introduction this software shall provide forecasts of GIC in Sweden. To support this, a model shall be developed that can predict GIC, where the model relies on solar wind data. When the software system is connected to the Internet real-time solar wind data can be used to provide forecasts. The system shall also contain a database with solar wind data so that predictions can be made on historic data. Thus, the system can run on-line to provide forecasts, or off-line to provide historic predictions.

There shall also be a graphical user interface to the system. On a map, similar to that of Fig. 1, the GIC shall be displayed in way so that locations with large GIC values are clearly visible. By clicking on specific locations on the map, the actual values will be displayed. It shall also be possible to display plots of time series of GIC over a period selected by the user.

The Swedish network consists of about 1300 transformers. It is interesting to know the GIC in each transformer. Our approach is to develop a model that predicts the geoelectric field for any location in Sweden from solar wind data. Having a model of the power grid the GIC can then be computed in any transformer from the geoelctric field. However, the complete model of the power grid will not be available, as first anticipated in the project, therefore the actual GIC calculations will only be possible for a subset of the transformers.

The transformers are further collected into groups that are called stations, where the transformers belonging to one station are geographically close and within the same fence around the station.

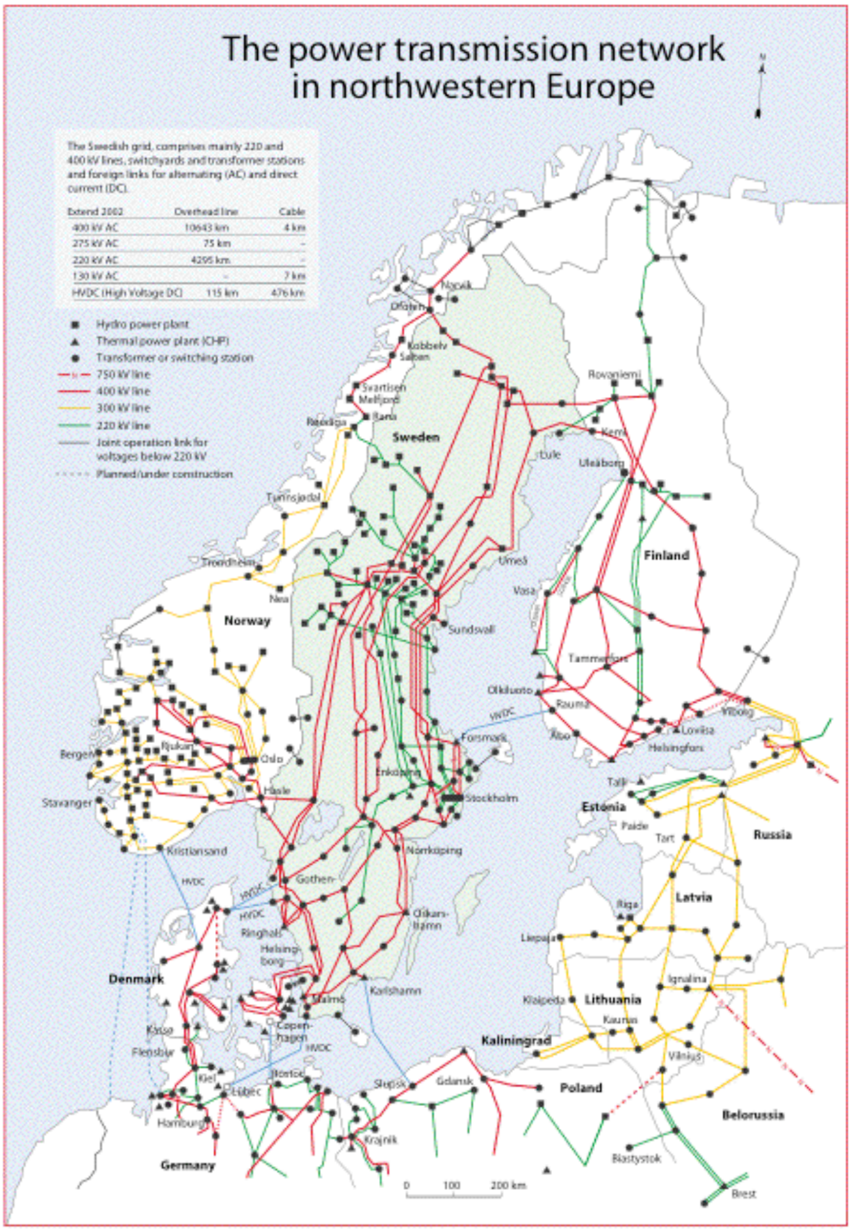

Fig. 1. The power transmission network in north-western Europe.

2.2 Glossary

Forecast

When a model is run on real-time data the output is a forecast.

GIC

Geomagnetically induced current. It is either a positive or negative value in units of Amperes (A).

GIC index

A parameterization of GIC.

Prediction

When a model is run on historic data the output is a prediction.

Station

A group of transformers that are physically close are called a station.

Zone

Sweden is divided into five different zones in latitude. Zone 1 is in the north and zone 5 is the south.

2.3 User characteristics

As stated in the introduction both power grid operators and the public shall have access to the system, thus we have identified two types of users. In addition, there is also the system manager.

2.3.1 System manager

The system manager shall have full access to the data, source codes, and documentation. During the project development the system manager shall be a person at IRF, but after successful completion of the project this role can be shifted to Elforsk or ESTEC. This shall only be a hand-full of people that are involved in the development and the maintenance of the system. The system manager should have a good knowledge of computers, web techniques, and Internet. He should have good knowledge in HTML, Java, and Matlab programming. He is also responsible for the extension of the database. However, all new data that are added must first be agreed by the project team.

2.3.2 User level 1: power grid operator

In the group of power grid operator, there are people who should make decisions out of the information given by the GIC forecast service. They require an easy to understand general overview and data directly useful for quick decisions.

2.3.3 User level 2: public

In the public group, there are people that may have an interest in GIC. In this group, we find scientists, decision makers, educators, and others. The material accessible to this group has its emphasise on outreach and education.

2.4 General capabilities

2.4.1 Definition of prediction and forecast

In this document the term *prediction* when a model is used to produce an output for any historic time. E.g., we can use the model to make a prediction of the March 13, 1989, event. In contrast, a *forecast* is made when the model is run on real time data so that a future value is obtained.

2.4.2 Geomagnetically induced current – GIC

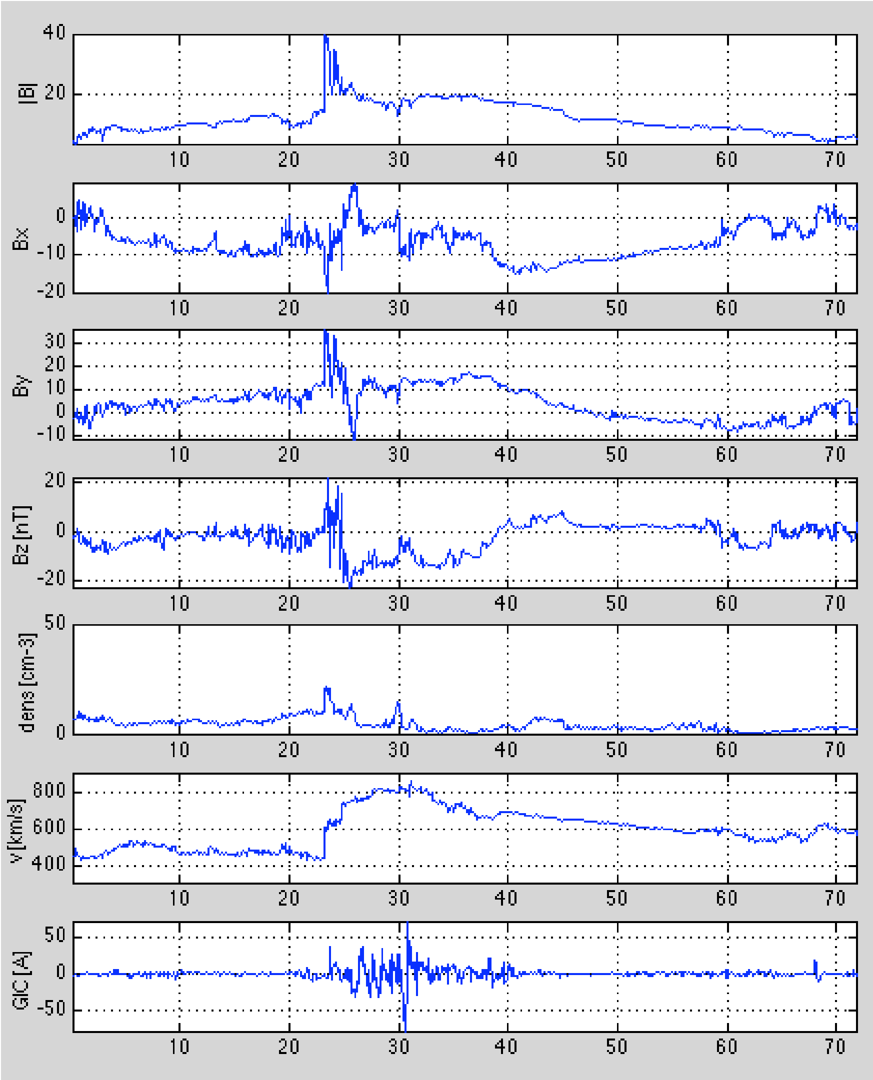

Fig. 2. The figure shows an example of a solar wind disturbance that drives a GIC in south Sweden. The top six panels show the solar wind: total magnetic field, x-component of the magnetic field, y-component of the magnetic field, z-component of the magnetic field, particle density, and velocity. The bottom panel shows the measured GIC. The x-axis is the time in hours from 24 September 1998.

2.4.3 GIC index

From a user perspective it is not necessary to know the exact evolution of the GIC. Instead, it might be more appropriate to have a parameterization of the GIC. A GIC has an onset time, a duration time, and an amplitude as illustrated Fig. 3. We call the parameterized GIC a GIC index. It shall be explored how the GIC index can be derived, and whether forecasting the index gives advantages over forecasting GIC values.

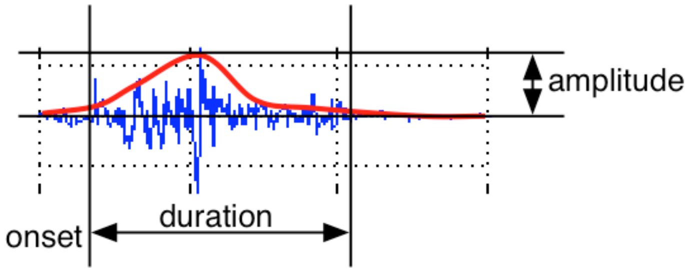

Fig. 3. The figure shows an illustration of how the GIC can be parameterized into a GIC index.

2.4.4 Output from the software

The Swedish power grid consists of about 1300 transformers. Transformers that are geographically close and within the same fence are called stations. The transformers are organised into about 200 stations. Further, the stations are organized into five zones from the north to the south of Sweden.

The GIC occurs in transformers and power lines connecting the transformers and is a result of the geoelectric field. A GIC is characterized by rapid fluctuations with a certain amplitude and duration. With an accurate prediction of the geoelectric field detailed determination of the GIC should be possible.

2.4.5 Graphical interface for power grid operators

It will require repeated display experiments and feedback from the operators before a satisfactory design is achieved. During the first discussions, a sensitive web based map of the power transmission network, was suggested. For various thresholds, stations and zones having problems will be indicated by blinking lights. By clicking on the sections having problems further information will be given.

2.4.6 Graphical interface for the public

First an easy to understand introduction of how GIC can affect power systems and the causes will be given. It will contain animations and cases. Secondly, also predictions and forecasts will be illustrated. The interface will be web based and therefore easily accessible for the public.

2.4.7 Models

2.4.7.1 Local differential magnetic field from solar wind

The solar wind drives the geomagnetic activity. The local magnetic field variations are determined from a number of different sources. However, we do not need to know the magnetic field itself but rather the time derivate dB/dt. A model shall be developed that can predict dB/dt from solar wind magnetic field and plasma data. The model inputs are solar wind magnetic field, density, velocity, and the geographic location of where dB/dt shall be predicted. The output is dB/dt.

The necessary temporal resolution of the predicted dB/dt has to be determined. The resolution is related to the desired accuracy of the electric field and GIC models described in Sections 2.4.7.2 and 2.4.7.3, respectively. The highest possible resolution is one minute using ACE real-time solar wind data. However, it might not be possible to develop a model that predicts dB/dt with one-minute resolution. Therefore, the optimal temporal resolution will be a trade-off between the two.

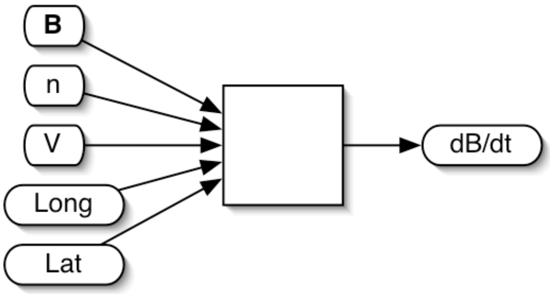

Fig. 4. The dB/dt prediction model has the inputs shown in the figure.

2.4.7.2 Geoelectric field from the magnetic field

The horizontal geoelectric field at the Earth's surface is the driver of GIC in power networks and other technological systems. So, the first step in a GIC calculation is the determination of the geoelectric field in a sufficiently dense grid covering the network investigated. If the source currents in the ionosphere and magnetosphere and the Earth's conductivity distribution are known the geoelectric field can in principle be calculated in a straightforward manner. However, in practice the calculation is easiest to be performed by using available ground magnetic data and a relation between electric and magnetic fields at the Earth's surface. This relation is expressed by a frequency-dependent surface impedance, which characterises the ground conductivity at the particular site. Fourier and inverse-Fourier transforms permit the use of time-domain magnetic data and give the geoelectric field as a function of time.

2.4.7.3 GIC from geoelectric field

After the geoelectric field is known, GIC in the network can be determined by using dc circuit theory. It requires that the geometrical and geographical configuration of the system and its resistances are known. For power systems, which are discretely-earthed at transformer neutrals, a convenient matrix formulation utilizing the "earthing-impedance matrix" and the "network-admittance matrix" is available. The calculation of GIC from the geoelectric field is exact, so possible inaccuracies only result from the determination of the geoelectric field.

2.4.7.4 Single transformer GIC forecast from solar wind

Accurate GIC data exist for one transformer in southern Sweden. This data makes it possible to develop an empirical model to directly forecast GIC from the solar wind. Over the years the transformers characteristics has changed leading to changes in GIC levels not related to the space weather. This makes it difficult to use the model for real-time forecasts. However, it is still interesting to see how well such a model can perform for future developments.

2.4.8 Database

The models that shall be used for the GIC predictions are driven by solar wind data. The approach to predict GIC is to first predict the rate of change of the geomagnetic field (dB/dt) at the Earth's surface at any given geographic location in Sweden, and then compute the geoelectric field, and then finally GIC. The model predicting dB/dt is derived from observed solar wind data and dB/dt. To support the prediction models a database with observed space weather data is needed. The database shall contain the data described below.

2.4.8.1 Solar wind data

There are two main sources for the solar wind data: the OMNI database and the ACE data.

The OMNI database contains hourly averages of the solar wind magnetic field, density, and velocity. It also contains various other solar-terrestrial data. The database covers the period from 1963 to 2002, where the last years have many missing values. The data are stored in annual files and can be obtained from ftp://nssdcftp.gsfc.nasa.gov/spacecraft_data/omni/.

The ACE spacecraft provides real time solar wind data. The time resolution is one minute. The latest data can be found at ftp://ftp.sec.noaa.gov/pub/lists/ace/.

2.4.8.2 Geomagnetic data

The geomagnetic data comes from sites that are relevant to Sweden. The data have a resolution of one minute. The time derivatives of the horizontal components of the geomagnetic field are computed in a dense grid covering Sweden. Both the observed and the computed geomagnetic field shall be stored in the database.

2.4.8.3 GIC data

Observed GIC data exist for a single transformer on the east coast of southern Sweden. The time resolution is one minute. GIC measurements are continuously made and data are recorded whenever the GIC goes above a threshold level. Currently the data are not available in real time.

2.4.8.4 Power grid data

2.5 General constraints

2.6 Assumptions and dependencies

The continuous update of the database assumes that the data discussed above are available in real time over the Internet. It is also assumed that the data format from those sources is not changed.

2.7 Operational environment

The system shall be implemented on a computer at IRF. The system is accessed using a web browser. Thus, to be able to access the data and models an Internet connection is necessary. There shall be two different access possibilities, a web page for registered users and another for public users.

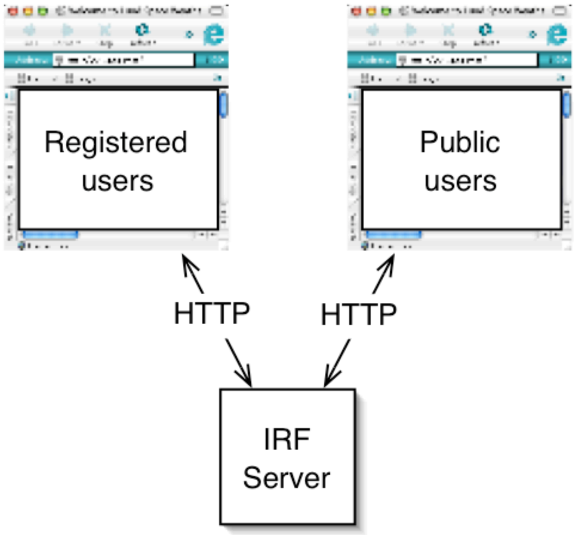

Fig. 5. Illustration of the operational environment.

3 SPECIFIC REQUIREMENTS

The specific requirements are divided into two categories: capability requirements and constraint requirements. The capability requirements describe what the user wants to do and one requirement defines an operation that the software shall be able to perform. The constraint requirements place restrictions on how the user requirements are to be met. Each requirement has a unique identifier with the following fields:

1. **CAP.** or **CON.,** capability or constraint requirement,
2. a sequential number.

3.1 Capability requirements

CAP.1.	Single station GIC forecast for public access.
Source	
Criticality	Mandatory
Verification	
CAP.2.	Single station GIC prediction for public access.
Source	
Criticality	Mandatory
Verification	
CAP.3.	Single station GIC cases for public access.
Source	
Criticality	Mandatory
Verification	
CAP.4.	All transformer GIC prediction for Sweden.
Source	
Criticality	Mandatory
Verification	
CAP.5.	All transformer GIC forecast for Sweden.
Source	
Criticality	Mandatory
Verification	
CAP.6.	GIC index.
Source	
Criticality	Mandatory
Verification	
CAP.7.	All transformer GIC index prediction for Sweden.

Source	
Criticality	Mandatory
Verification	
CAP.8.	All transformer GIC index forecast for Sweden.
Source	
Criticality	Mandatory
Verification	
CAP.9.	Station average GIC index.
Source	
Criticality	Mandatory
Verification	
CAP.10.	Station maximum GIC index.
Source	
Criticality	Mandatory
Verification	
CAP.11.	Zonal average GIC index.
Source	
Criticality	Mandatory
Verification	
CAP.12.	Zonal maximum GIC index.
Source	
Criticality	Mandatory
Verification	
CAP.13.	Graphical display of station values on a map of the Swedish part of NordEl.
Source	
Criticality	Mandatory
Verification	
CAP.14.	Graphical display of zonal values on a map of the Swedish part of NordEl.
Source	
Criticality	Mandatory
Verification	
CAP.15.	Confidence factors on predictions dependent on prediction horizon.

Source	
Criticality	Mandatory
Verification	
CAP.16.	Probability of single station GIC exceeding a threshold value for different durations.
Source	
Criticality	Mandatory
Verification	
CAP.17.	Result files for benchmarking.
Source	
Criticality	Mandatory
Verification	

3.2 Constraint requirements

CON.1.	Minimum one hour prediction horizon.
Source	
Criticality	
Verification	
CON.2.	95% accuracy of zonal average absolute GIC.
Source	
Criticality	
Verification	
CON.3.	95% accuracy of zonal maximum absolute GIC.
Source	
Criticality	
Verification	