

Connexus Proposal

for

Space Weather Prediction Filters

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I. Introduction

In a world increasingly dependent on electricity and electronics, the space weather can have extreme consequences on our lives, in particular in our human communications.

The irregular solar cycle might well be the reason that violent energy releases occur near sunspots, emitting energy in the form of x-ray and moving plasma clouds. On occasion, this release produces high-energy ions which reach the earth and beyond, and causes variations in the earth's magnetic field, thus producing induced currents in manmade conducting pathways such as electrical utility lines and metal pipe lines carrying oil, gas or chemicals.

These geomagnetically induced currents (GICs) often last for several hours, and in a big space weather storm they can recur for many days.

We are becoming more and more susceptible to this type of disturbance. It can cause much damage to our satellite communications. This damage may be in the form of "distorted observations."

A large magnetic storm can cause higher number of fast electrons that hit our satellites. Not only that but it also causes induced currents in the wires of the electrical power grid, thus producing an overload that can cause "blackouts." This has happened before in 1989 in Canada, where a big transformer heated up due to the GICs (high drop in voltage), and as I understood the exposure resulted to damage in the winding insulation. Molinski, Feero and Damsky explain the situation in detail in "Shielding grids from solar storms" in the November 2000 issue of *Spectrum*.

According to Molinski *et al.* the usual affected systems by the GICs are: power systems, cable systems, pipelines, and satellite communications.

These days, we have “the tendency to move large quantities of electricity over long transmission lines.” GICs flowing through the transformer winding may produce extra magnetization. If the AC magnetization were in the same direction, this would saturate the core of the transformer. Thus, resulting in misoperation of relays, trip-outs and sometimes collapses of the whole system. Even though the change in temperature of the transformer may be negligible, but localized heating may occur and damage the winding.

Let us discuss the cost of such an occurrence. Well, the immediate cost would be that for the replacement of the transformer. A large transformer costs several million dollars. Not to mention that such expensive units are built to order and it might take one year for delivery time. Usually the cost of replacement power from neighboring utilities may cost much more than the transformer.

The fact that the systems are safeguarded from localized failures like lightning strikes and equipment failures makes it more vulnerable to GIC, which may occur simultaneously on many systems.

Thus, the importance of space weather predicting is crucial. It would help us preserve the style of life as we know it. I don't think anybody can imagine life without electricity. Even in the rural areas and in 3rd world countries, electricity, electronics and communications are very important in one's daily life. A sudden failure in that would cause a significant disruption in economy, technological advance, communications and probably more due to interdependencies. The solar wind driven magnetic storms that flare upon the surface of the sun produce disturbances hours later in the electric utility grids in the northern United States and even more strongly in Canada. This is well understood by the physics of the Earth's magnetosphere and is a basic element of the WINDMI of Horton and Doxas published in the J. of Geophysical Research in 1996 and 1998.

In the last solar maximum in 1989 a large disturbance occurred that took down the entire Hydro-Quebec power grid. Six million customers were without power for 9 hours. We understand the basic physics of these processes, but the problem of prediction is one beyond the use of basic physics models due to phenomenon of chaos. We propose to build analog electronic and digital circuits that represent both the basic physical principles of the conservation of charge and energy and yet contain the chaos that arises from the feedback loops intrinsic to complex dynamical systems. The idea is that these electronic filters will take raw data from satellites positioned in front of the Earth and send the results of the processing to Earth with standard communication equipment giving a degree of warning as to the likelihood of at least three categories of GICs. The circuits will be made from programmable chips and microcontrollers in two forms. One is the analog circuit that will represent the actual physical processes in the two large current loops in the WINDMI model. The second will use operational amplifiers to produce analog simulations of the reduced set of differential equations that have been derived by a physicist at the University of Wisconsin. I, current loop in WINDMI induce GICs in the power grids:

GIC = geomagnetically
induced
currents

These GICs are detected on the power grids at the grounding connection of the large step up and step down transformers.

Power stations now monitor these currents in the grounding circuit of the transformers and use prediction filters to assess the probability of an above threshold event. We can provide better methods for longer times.

II. Data Mining

We are searching the web for current material on the problem of space weather predictions and GIC effects. Sources we have found include: <http://www.electric-research.com>; the Canadian Geomagnetic Laboratory web site at <http://www.geolab.nrcan.gc.ca>, and the National Oceanic and Atmospheric Administration's space environment center web site at <http://www.sec.noaa.gov>.

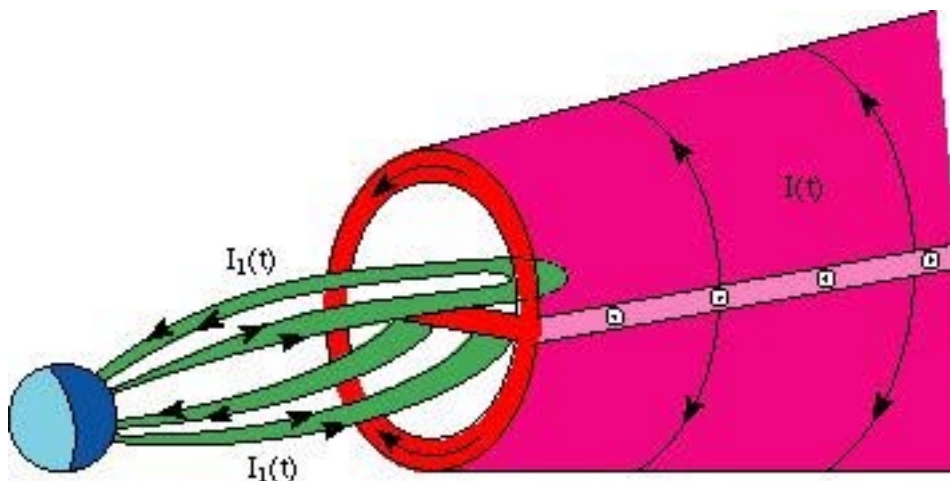
A discussion and general explanation of GIC and its effects on power systems can be found in a paper by Boteler *et al.* (1998). Two other general overviews are a paper by Molinski (2000), forthcoming, and a paper by J.G. Kappenman *et al.* (1997).

Protective relaying requirements for capacitor banks, transformers, and generators exposed to GIC and harmonics from half-cycle saturation are comprehensively analyzed in a report by Bozoki *et al.* (1996).

A complete discussion of the various types of transformers, construction (core types) and resulting GIC effects can be found in a paper by McNutt (1990).

III. Construction of the WINDMI Prediction Filter

The WINDMI nonlinear prediction filter can be constructed in one of two ways. Either an analog circuit can be built to model the behavior of the solar wind driven M-I system, or the applicable differential equations can be solved digitally using numerical methods. All existing publications have used large, powerful PC servers and super computers to evaluate the system of equations. Here we propose to build small, simpler electronic circuits to do the same work. If the analog route is taken, we have again two possibilities. We can use a circuit which corresponds directly to the operation of the physical system being modeled, or we can use a circuit involving op-amps, which is essentially designed to correspond, term by term, to the differential equations of the mathematical-physics model. If the digital method is used, the most appropriate system would be a microcontroller chip, programmed to solve the differential equations numerically.



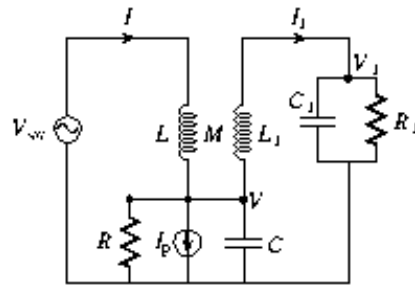
The advantages of the direct analog model are that it is known to correspond directly to the actual physical system, that its inputs can be taken directly from equipment aboard a satellite. We will ask if the system can be easily scaled to different component values, both to make the circuit smaller and to bring the signal to audible frequencies to facilitate analysis. The disadvantages of the

direct physics modeling are that it may be bulky compared to other options, and may be fairly susceptible to electromagnetic noise.

The only advantage of the op-amp circuit is that it is small and lightweight. However, the input solar wind signals require a great deal of processing before they get to the circuit, and it may not be very precise. This does not appear to be a good option, but we need to consider further before ruling it out.

The digital system could be very small, as small as one chip, and could output digital data directly to the other equipment on the satellite. It would have a known precision and could be customized to perform any necessary pre-or post-processing of the data. Such programmable microcontrollers are readily available, are sometimes very inexpensive, can be fairly powerful, and often include analog data inputs. We have yet to see if they are sufficiently powerful for the accuracy desired, however. And the software would need to be rather complex. As with any complex software, we need time and resources for the development and comparison with real systems.

WINDMI Prediction System
Equivalent Circuit



$$Rf^2 \rightarrow \nabla \rho \rightarrow I_p$$

$$R_1(V_1, V, I_1) \text{ nonlinear ionosphere}$$

IV. Significance of Planned Activities

Besides attacking a challenging and scientifically significant

problem using inter-disciplinary approaches, this project will expose the students to several fundamental design issues:

the tradeoffs between analog and digital implementation, and between these and simulation studies.

The analytical approach is also progressively staged, from simple, linear ARMA models to more complex, non-linear models, and will again expose the students to the modeling trade-offs involved with in simple direct methods versus complex, more powerful abstract methods.

Project Resources and Equipment Needs

We have used the National Science Foundation Grant to buy a Pentium III PC for the project along with the Lynux operating system and visualization software from Advanced Visualization Systems commonly know as AVS. We have obtained prime office space (RLM 11.326) with graduated students in the Institute for Fusion Studies who are advanced users of Unix, Lynux and AVS systems.

In Engineering we have obtained laboratory space (ENS 439A) and use of some standard lab instruments in the Laboratory of Prof. Gary Hallock. His graduate students will be able to provide assistance in using advance test equipment for measuring the performance of the devices we build.

Equipment Budget

The following Budget describes items that are essential in starting the project.

1. Microcontroller programmer and two EEPROM microcontrollers	\$400.
2. Analog components including large air core transformer, a large and medium sized capacitor, several heavy duty variable resistors	\$200.
3. Operational Amplifiers with various specifications	\$40.
4. Software circuit simulation package SPICE, software microcontroller simulator and software interface form from oscilloscope to PC	\$300.
	total \$940.

Salary Budget

In starting the project now salary has been provided for the students. After the project is operational and beginning to produce science results we expect to pay the students from the National Science Foundation Grant ATM 9907637 for their time worked up to 20 hours per week. If the project gets to the 20 hours per week level then the students will have to carry a reduced course load or perform the work in the summer. In the start up phase we expect the workload to be reduced to a level consistent

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