A HIGH-SPEED, SELECTIVE INDUSTRIAL LOAD SHEDDING SYSTEM

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Most large industrial facilities (refineries, chemical processing plants, etc.) typically use underfrequency relays to restore load-generation imbalance in the event of a loss of in-plant generation or utility tie. There are three basic inefficiencies with this approach:

1. even with multiple underfrequency relay settings, the ability to discriminate among low-priority plant loads (such as administration buildings) and high-priority plant processes is compromised,

2. for plants with utility ties in isolated or developing areas, steady-state frequency control is poor and underfrequency relay trip settings must be desensitized to avoid inadvertent tripping due to system frequency excursions, and

3. sheddable load points don’t vary as a function of lost source of supply.

PTI has developed and installed several industrial load shedding systems that offer high-speed, reliable tripping of non-critical loads; this article describes the techniques used, along with a brief description of the hardware and software.

THE IMPACT OF IN-PLANT DYNAMICS

The most important design parameter for a particular load shed application is the time between a generator trip and the controlled shedding of load. The primary factors defining the speed requirement for a given load shed system application are:

- the rate of decay of system frequency following a trip,
- the number of generators on-line just prior to a trip,
- the dynamic characteristics of generators, excitation systems, governors, and motor loads in the plant, and
- the settings of the underfrequency relays used as backup on plant feeders.

A first order estimate of the rate of frequency decay following loss of a utility tie can be made using the following equation:

\[ {ds \over dt} = 60 \cdot ( P_{load} - P_{gen} ) / 2H \]

where \( ds/\text{dt} \) is the rate of frequency decay in Hz/sec,

\( P_{load} \) is the per unit load on the total generation MVA base,

\( P_{gen} \) is the per unit generation on the total generation MVA base, and

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HIGH-SPEED, SELECTIVE INDUSTRIAL LOAD SHEDDING SYSTEM
(continued from Pg. 1)

H is the machine inertia on total generation MVA base.

As an example, consider a system with a utility tie and two diesel generators having the following combined characteristics:

- DG#1: 3 MVA, 2.7 MW, H = 2.4 on own base
- DG#2: 4 MVA, 3.6 MW, H = 2.4

\[
P_{\text{load}} = 10 \text{ MW} = 1.429 \text{ p.u. on 7 MVA base}
\]
\[
P_{\text{gen}} = 2.7 + 3.6 = 6.3 \text{ MW or 0.9 p.u. on 7 MVA base}
\]

Total inertia of both units is \( H = 2.4 \)

The calculated rate of decay following loss of the utility tie at maximum plant load is:

\[
ds/dt = 60 \left( 1.429 - 0.9 \right) / 4.8 = 6.613 \text{ Hz/sec}
\]

To prevent a 1.5 Hz frequency drop, more than 3.7 MW of load must be shed in 227 msec. \((1.5/6.613 = 0.227 \text{ sec})\). Assuming a 50 msec. breaker clearing time, a trip signal would be needed within 177 msec. A typical underfrequency relay set at 59.0 Hz would not be able to achieve the necessary response time.

LOAD SHEDDING STRATEGIES FOR LOSS OF SOURCE

When a loss of generation or utility tie trip is detected, it is necessary to know the current plant loading at the instant of trip and the spinning reserve capability of the remaining generating units. Analog readings of the total plant generation and sheddable load consumption are taken every five seconds. Loads that are candidates for load shedding are prioritized according to their critical importance to plant operations. Low-priority loads, such as administrative buildings and on-site housing, would be the first loads to be shed; critical process loads would be shed only in the event of a major loss of in-plant generation.

If a generator trips, the load shedding system algorithm immediately determines if the loss of source capacity can be absorbed by spinning reserves or if load shedding must take place. If reserves are insufficient, the actual value of load to be shed is given as the difference between the pre-disturbance plant load and the total generating capacity remaining on-line after the unit trip. Beginning with the lowest priority loads, load is shed by priority level such that the shed requirement is met. All loads within a given priority are shed, insuring some overshed of load. At the conclusion of the shed, the system scans the analog load and generator readings to establish a new system operating condition.

LOAD SHEDDING STRATEGIES FOR UNDERFREQUENCY CONDITIONS

The underfrequency shedding algorithm included in the load shedding system provides for controlled load removal based upon a user-programmed series of underfrequency steps. Conventional underfrequency relays do not provide the selectivity of load shedding required to discriminate between low-priority and high-priority loads. The operator can set up minimum target frequencies, time spans between individual load shadings, amount of load to shed, recovery frequencies, and total number of load shedding operations to perform. As with the shed logic for loss of generation, load is shed by priority level.

HARDWARE AND SOFTWARE IMPLEMENTATION

The load shedding system is designed as a distributed monitoring and control system, comprised of the following hardware elements:

- A central control console, containing control and alarm computers and interface equipment to control units.
- Distributed control units (DCUs), serving as remote focal points for analog and digital inputs from generating units and load points, as well as providing load breaker trip relays. Fast programmable logic controllers (PLCs) can handle much of the analog I/O and digital inputs with the exception of the breaker trip coil sensing signals. Original systems delivered by PTI used a proprietary hardware design for distributed communications and control.
- Load breaker interface panels, consisting of a watt transducer and interposing trip relay.
- Source interface panels, consisting of a watt transducer and breaker trip coil sensing circuit.

Software consists of:

- A real-time executive program to control the overall data acquisition, display, and load shedding functions.
- A user interface program for tabular display of real-time measurements and database maintenance functions.

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Power Technologies, Inc., P.O. Box 1058, Schenectady, NY 12301-1058.
• Alarm software residing on a separate alarm computer, designed to display log and alarm messages.
• Remote communication and display software via Ethernet for display of real-time data at sites other than the control room.

If necessary, custom controls can be included in the system.

CONCLUSIONS

A combined PC/PLC-based load shedding system offers the highest, most secure level of selective load shedding for an industrial plant. Installing such a system can result in significant fuel and/or purchased electricity savings by trading off unnecessary spinning reserve requirements for high-speed sheddable load points. It is not unusual for a system such as that described above to pay for itself in one to two months of operation.

ENGINEERING APPLICATIONS OF GIS

M.J. Barlow, Senior Consultant
Power Technologies Ltd.
(m.j.barlow@ptl-uk.com)

INTRODUCTION

In recent years, Geographical Information System (GIS) technology has become popular in the utility industry as a user-friendly means to access physical asset data via geographic maps. GIS technology provides a graphical interface to an application database: the database stores information on objects (such as lines, transformers, houses, etc.), while the GIS displays the information on the screen.

From this foundation, GIS technology is expanding to incorporate engineering applications such as load and voltage drop calculations. Interfacing to third party application software is an attractive and technically desirable means to accomplish this objective. PTI provides the analytical software that permits such computations to be embedded within GIS systems.

This article describes how two of PTI's software products have been linked to the GIS developed by Smallworld, Inc. The combined system provides enhanced power system analysis capability in a Geographical Information System environment.

POWER SYSTEM ANALYSIS TOOLS

Two of PTI's analysis products were used with the Smallworld GIS: the PSS Engine and PSS/U (Power System Simulator for Utilization). These two PTI products permit engineering applications to be invoked directly from the GIS, or run in a stand-alone program using data extracted from the GIS.

The PSS Engine is a library of functions that perform load flow, short circuit, and motor starting calculations when called from an application program. The PSS Engine contains functions to build and modify an electric network, perform calculations on the network, and retrieve the results.

The PSS Engine models three-phase electric networks by explicitly representing each phase of the network. The network can also be simplified and represented by positive-sequence and zero-sequence components through a symmetrical component transformation. Internally, the PSS Engine maintains a phase-by-phase representation of the network. Externally, it provides functions to define the electric network in terms of symmetrical components (sequence representation), as well as functions to define the wire by wire (phase representation) configuration. Both representations may be used in a single electric network.

The functions within the PSS Engine are fully re-entrant, i.e., an application program can maintain more than one network at a time, and multiple application programs can simultaneously access the functionality provided by the PSS Engine.

PSS/U is a stand-alone product that performs engineering analysis for subtransmission, distribution, industrial, and auxiliary power systems. PSS/U models three phase, two phase, and single phase systems and performs balanced or unbalanced power flow and short circuit calculations, capacitor placement studies, relay coordination, harmonics, reliability, and optimal switching (loss minimization) analyses. A wide variety of reports are available, including reports on loss and economic analysis.

INTERFACING POWER SYSTEM ANALYSIS ENGINES WITH GIS

The interface of Smallworld's GIS and these PTI products provides dual functionality: the GIS provides all the necessary menus and displays, while the PSS Engine provides the analysis tools to calculate voltage drop, circuit flows, and fault currents from within the GIS environment.

For more detailed analysis, users can create a data file from the traced portion of the network and pass this information to the stand-alone analysis package, PSS/U. This data file contains both network parameters and coordinates to allow a network diagram to be automatically created in PSS/U.

The interface has been split into two layers, one layer provided by the GIS system and one by the documented API. This allows vendors to make changes to the GIS interface which do not affect the documented API or the GIS front end, thereby providing a layer which can be customized on a project-by-project basis as shown in Figure 1.

Figure 1. System Overview

OPERATION OF THE SYSTEM

Users select the part of the network they want to analyze and then opt either to run a load flow or create a PSS/U data file. In either case, the GIS system traces the network from the selected component through all connected distribution components until it comes to an
open switch or a substation connected to a higher voltage. 

Figure 2. Network Trace

After executing a load flow, the user is allowed to select a display of either minimum voltages or maximum currents around the network. Displayed results are automatically stored for later retrieval.

Minimum phase voltages are displayed in bar chart form, sorted in order by descending magnitude. The bars are colored by phase; voltages outside an allowed range (e.g., 6% below nominal) are highlighted. The results are repeated in tabular form beneath the bar chart. See Figure 3.

Figure 3. Voltage Drop Results

Maximum phase currents in each cable or line are also displayed in bar chart form, sorted in descending order. The bars indicate the percentage loading of each cable’s capacity.

DIRECT GLOBAL POWER — FOCUSING ON PHOTOVOLTAIC INITIATIVES

These countries typically lack the financial resources to construct power lines to numerous dispersed villages, along with the associated substations and new generating stations. Conventional utility systems are, by their nature, vastly oversized for the electrical needs of rural communities. A relatively modest level of electrification, however, can make a dramatic improvement in the quality of life and the productivity of these rural populations. In such situations, PV systems are often less costly (over their lifetime), more reliable, and environmentally superior to the conventional power supply method — typically a diesel engine generator.

DGP differs from most other companies in the PV industry. While others pursue existing market opportunities by responding to various requests for proposals, DGP devotes its resources to growing new markets. It has initiated a Productive Uses Program which involves the identification and development of new uses for solar-generated electricity that will produce income in impoverished rural communities. Examples are:

- powering looms, spinning, and sewing machines
- crop harvesting and processing for export
- woodworking tools
- shearing wool-bearing animals and processing the wool
- sterilizing and preserving agriculture produce for export
- grinding and polishing machines for jewelry manufacture
- powering fans for crop drying
- food preparation for small restaurants
- water purification

DGP is working with economic development agencies — both government and private — whose mission is to improve the standard of living in rural villages. It is also assisting private entrepreneurs in these countries to train local workers to install and service PV systems; developing and supporting a local service infrastructure is essential to success. Work is currently under way in several South American countries to assist newly-formed agricultural cooperatives to employ photovoltaic systems for powering fans in solar crop dryers and electric motors in shredding machines. This equipment is needed to convert an agricultural residue which has previously been discarded (leaves and stems of the cassava plant) into animal feed which will be sold to cattle ranchers. The income from this enterprise will enable the farmers to purchase solar power systems for their homes, along with water pumping, fluorescent lights, refrigerators, radios and TV sets.

In addition to these off-grid applications, there is growing interest in integrating PV into the existing utility infrastructure as distributed generation. The PTI-DGP collaboration is aimed at helping utility companies do this in the most effective manner. An example of this application is the siting of a PV array at the end of a long distribution feeder which is experiencing overload condition during hot weather. The PV system provides the utility with several benefits in addition to the energy produced — alleviating or deferring the need to upgrade the feeder and associated substation equipment, reducing losses, and supporting voltage at the end of the feeder. Another example is a PV-enhanced uninterruptible power supply (UPS). Conventional UPS systems comprise batteries and inverters (which convert the direct current from the battery into alternating current) and sometimes an engine generator. If utility service is not restored before the battery is fully discharged, the engine-generator is operated to recharge the battery and also furnish power to the customer. In locations where utility outages are common and lengthy (e.g., urban areas of many develop-
DIRECT GLOBAL POWER — FOCUSING ON PHOTOVOLTAIC INITIATIVES
(continued from Pg. 4)

ing countries), engine generators are often unreliable or poorly maintained. Installing a PV array to replace or supplement the engine-generator can be an attractive solution and can also supply solar-generated power to the customer during normal utility operation. Some of the facilities which can benefit from PV-enhanced UPS are resort hotels, hospitals, data processing facilities, and factories with critical processes. The PTI-DGP collaboration will build on PTI’s extensive experience in T&D system planning, dispersed generation analysis, and power quality improvement.

For more information on DGP’s Productive Uses Program, please contact the author at 908-549-3400.

SIX-WEEK COURSE OF STUDY CONDUCTED AT PTI

Eleven engineers recently completed PTI’s six-week course of study in transmission system planning and analysis. The curriculum focused on the practical application of transmission planning techniques and hands-on use of analytical engineering software. Participants included Kunsin Methapatara of EGAT, Héctor Ruiz Duque of Empresas Públicas de Medellín, Pan-Young Sung, Wan-Sik Kim, Young-Jin Kim and Bask-Seok Lee of KEPCO, A.A. Al-Otaibi of SCECO-Central, T.K. Bhaskaran of Tata Electric Co., César Puleri of Transener, SA, Lam Hong Chee of TNB, and Salem Ouahes of the World Bank.

ENGINEERING APPLICATIONS OF GIS
(continued from Pg. 4)

The results display is linked to the main GIS display so that actions performed in one are reflected in both. For example, selecting a bar in the bar chart will also select a row in the results table and draw a circle around the related point in the main GIS display — all from a single mouse click.

The GIS editing facilities can be used to examine corrective courses of action, such as opening a switch to disconnect part of the network. Re-running the loadflow enables the two results to be compared side by side to see if the overload has been removed.

This illustration describes a sample system created for a specific user. Since the graphics employed are created with relative ease, a utility or other end-user, working with a system integrator, can create a custom graphical display with a minimum of effort.

CONCLUSIONS

It is important to be able to pass data stored in the GIS database to applications which can use it. With the increasing use of open systems architecture, applications from third party vendors and/or the creation of interfaces to custom applications become easier to develop and deploy. Adding engineering applications greatly increases the benefits of a GIS environment and helps justify its cost.

HANK ZAININGER JOINS PTI’S SACRAMENTO OFFICE

Henry (Hank) Zaininger has rejoined PTI as a senior consultant and director of business development for PTI’s west coast office. Hank has a long career encompassing a wide range of power system disciplines including wind and solar generation, advanced energy technologies, emissions, electromagnetic pulse phenomenon, transmission and distribution line design, and system planning.

In addition to his technical contributions, Hank will focus on client service in our Sacramento, California office. Hank is very excited about his new position with PTI and looks forward to working with our clients particularly those in the western part of the United States. Hank is currently working out of his home in San Jose but he will be moving to Roseville in the near future. You can reach Hank at:

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Power Technologies, Inc.
6035 Assisi Court
San Jose, CA 95138

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Fax: 408-270-0955
e-mail: hzaininger@aol.com
## RECENT PUBLICATIONS

For further information on any of the following publications, please contact:

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1482 Erie Boulevard, P.O. Box 1058
Schenectady, NY 12301-1058
518-395-5047 • Fax 518-346-2777 • jm.aviles@pti-us.com

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<th>Author(s) and (Affiliation)</th>
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<tr>
<td>E.C. Bascom (PTI), G.A. MacPhail (BC Hydro), and F. Rorabaugh (Southern California Edison)</td>
<td>Monitoring and Dynamic Ratings on Underground Cables Maximizes Circuits' Capabilities</td>
<td>February 26-28, 1997 - Presented at the EPRI Real-Time Monitoring &amp; Rating Workshop, San Diego, CA</td>
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<td>J.J. Burke (PTI)</td>
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<td>S.J. Balser (PTI)</td>
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### PTI Course Schedule
#### September 1997 - June 1998

Courses will be presented at PTI Offices in Schenectady, NY unless otherwise noted.

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<td>Voltage Control &amp; Reactive Power Planning</td>
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<td>Apr. 20-22 - Portland, OR</td>
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<td>PSS/E - Introduction to Power Flow &amp; Steady-State Analysis</td>
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<td>Dynamics of Frequency &amp; AGC</td>
<td>Sept. 22-24 - Portland, OR</td>
<td>$1420</td>
<td>Jan. 13-15 - Orlando, FL</td>
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<tr>
<td>PSS/E - Introduction to Dynamic Simulation</td>
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<tr>
<td>Real-Time Thermal Monitoring &amp; Rating of Transmission Circuits</td>
<td>Sept. 29-Oct. 1</td>
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<td>PSS/E - Advanced</td>
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<td>Transmission Access &amp; Power Wheeling</td>
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<td>PSS/E - IPLAN - NEW</td>
<td>Oct. 7-9</td>
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<td>Transformer Concepts &amp; Applications</td>
<td>Oct. 7-9</td>
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<td>Power System Stability &amp; Stabilizer Tuning</td>
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<td>PSS/U - 4 day session</td>
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<td>Capacitor Bank Applications</td>
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<td>Underground Cable Systems: Principles &amp; Analytical Techniques-Joint Course with Power Delivery Consultants, Inc.</td>
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<tr>
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<td>Distribution Lightning Protection</td>
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INTERNATIONAL COURSES

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<tr>
<td>Power Distribution Systems</td>
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SPECIAL COURSES OF STUDY
conducted at Power Technologies, Inc. Corporate Headquarters, Schenectady, NY

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<tr>
<td>Power System Transmission Planning &amp; Analysis Sept. 8-Oct. 17, 1997</td>
<td>A comprehensive approach to gaining the practical knowledge necessary to effectively use and apply power engineering analytical tools and methodologies in transmission system planning. The 6-week course of study includes sessions on planning concepts and principles are combined with intensive &quot;hands-on&quot; use of PTI's PSS/E program, application workshops, and study tours of utility sites for a broad-based learning experience.</td>
</tr>
<tr>
<td>Distribution System Engineering and Analysis Apr. 20-May 22, 1998</td>
<td>This 5-week course covers a broad range of topics in distribution engineering and analysis. It will give participants an understanding of the principles of distribution design, operation and protection, hands-on use of analytical software, and the opportunity to examine new technologies and trends in the industry.</td>
</tr>
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</table>

Cancellation Policy
Occasionally, unforeseen events or insufficient enrollment may necessitate the cancellation of a course. If a course is canceled, PTI will attempt to notify each registrant no later than 14 days prior to the start of the course. PTI is not responsible for any cancellation charges imposed by airlines, hotels or travel agents.

Registration Note
It is recommended that you register one month before any course. Registrations will be accepted within the month time frame but space may be limited.

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