Understanding Third Party Access Issues: A Simulation and Visualization Tool for Nontechnical Personnel

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Abstract

The third party access issue has brought to the fore the need for a tool to explain the complexities of a power system to people who have no technical background in general, and no knowledge of power system operations, in particular. This paper describes a power system simulation package that presents the basics of power system operations and control to individuals involved in the electricity business who have a nontechnical background.

Keywords: Simulation tools, visualization/display, third party access.

1. Introduction

The electricity industry is undergoing its most turbulent period in history. Throughout the world there are myriad rapid and deeply impacting changes which are resulting in a restructuring of the industry. The primary driving forces behind these changes are market forces, legislative/regulatory initiatives and technological innovations. In addition realignment of political systems as in Central and Eastern Europe and the realization that a solid electricity infrastructure is a prime requisite for a healthy economy, as is the current situation in much of the Pacific Asian region, are important contributors to the changing environment. The open borders created by the European Union Treaty are having serious and profound ramifications in the electricity sector of the 15 member nations. The European Commission is at the center of the debate on unifying the electricity system of the EU nations. EU nations with vastly diverse electric power industries, economies and energy goals are intent to protect their energy policies and security of supply. At the same time the European Commission, charged with administering the EU Treaty is intent on opening up the borders of the nations to free trade including electricity. The Commission is spearheading the drive for third party access, the term used in Europe for transmission access and wheeling. TPA has become a very controversial and highly divisive issue with the need to reconcile open borders, system reliability, security of supply, the rights of states and the interest of customers [1], [2]. In addition, the huge changes in the privatized English electric supply industry are fueling increased demands for customer choice.

Similar changes are occurring in the United States where the passage of the Energy Policy Act (EPACT) of 1992 and the series of new decisions and proposed rulemakings by the Federal Energy Regulatory Commission (FERC) [3] are bringing about a complete overhaul of the structures of the industry. The legislative and regulatory changes combined with strongly persistent market forces have created an unprecedented need within both the regulated and unregulated segments of the industry as well as the economic regulatory agencies and legislative circles to understand how power and transmission systems operate. This need has become particularly more pressing given the entry of many new players -- independent power producers, brokers/marketers and policy makers -- into the industry. These people, many of whom have no extensive technical training or experience must become conversant with the potential reliability and security impacts of generating decisions and wheeling requirements, the effects of regulatory and legislative initiatives and the accommodation of environmental concerns. The numerous policy debates on the TPA issue have brought to the fore the need for a tool to explain the complexities of a power system to people who have no technical background, in general, and no knowledge of power system operations, in particular. This is, then, the motivation of creating a simulation and visualization tool for explaining the impacts of policy initiatives on a nontechnical level.

We have developed a state-of-the-art methodology for illustrating the many physical difficulties and impediments to power flow in actual power networks. Over the years computer visualization programs have played an important role in providing users with a better understanding of power system operation; recent examples include [4], [5], [6], [7]. This paper describes POWERWORLD™, a power system simulation package that presents the basics of power system operations and control using the foundation described in [8]. It makes major contributions in providing powerful visualization techniques on an interactive basis for system operations. The package has been widely demonstrated to policy makers, legislative analysts and regulatory decision makers. It has been found to be a very effective tutorial tool for communicating the many technical and economic impacts of third party access. In addition, the package has also proved to be a useful tool for actual operational use by small utilities.

2. POWERWORLD Simulation Package

The POWERWORLD simulation package was developed to clearly communicate the intricacy and complexity of many of the issues involved in third party access. The design goals were to develop a simulation package which could accurately model power system operation in the longer timeframe associated with the third party access issues (minutes to hours), yet also be easy to use, suitable for presentations or individual

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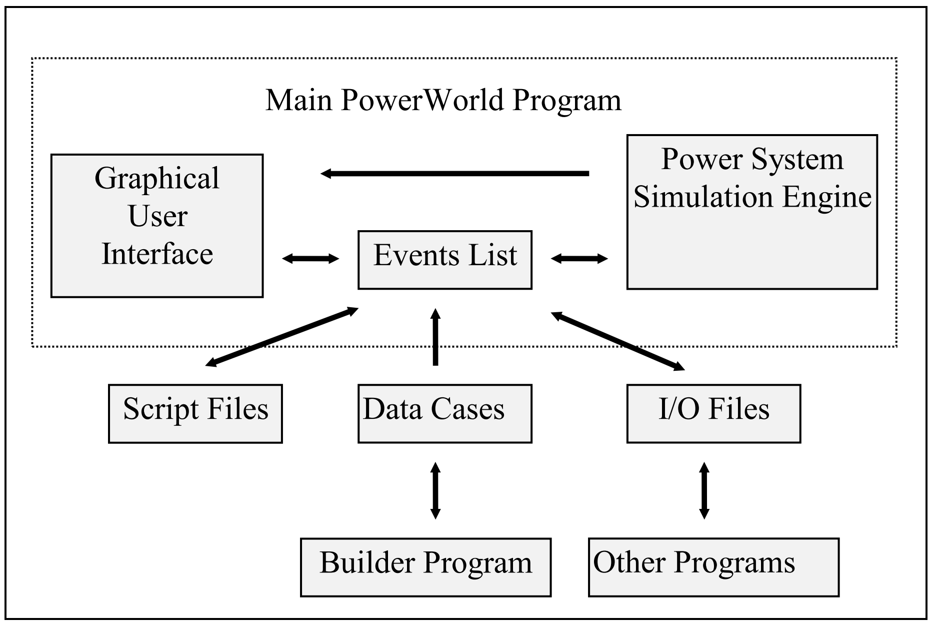

Figure 1: POWERWORLD Simulation Package Block Diagram

usage, flexible and extensible. In order to allow distribution to the maximum number of users, POWERWORLD itself runs as a self-contained program in the Microsoft Windows environment; object-oriented programming techniques resulted in a program executable of just 650k. This paper describes how PowerWorld achieves the forementioned design goals, and how it can be applied to effectively illustrate the issues involved in third party access.

In general, the package simulates the operation of a number of areas comprising an interconnected power system over a specified period of time (typically, from several hours to several days). Different data cases are used to simulate different systems. During the simulation period the power system usually experiences a number of continuous and/or discrete events (such as continuous load variation or sudden loss of a transmission line). The user interacts with the simulation using a number of different windows. The overall block-diagram representation of the package is shown in Figure 1, with the arrows indicating the direction of data flow. The block diagram functionality shown within the dashed rectangle is implemented using modules in a single program; data flow is internal. The outside blocks correspond to external files and programs; data flow is via text files.

2.1 Graphical User Interface

The main interaction between the user and the simulation is through a user-friendly graphical user interface (GUI) consisting primarily of a number of different windows. This allows users of the package to spend their time gaining an intuitive feel of power system operation, rather than just learning how to use the package. The GUI was designed using object-oriented programming (OOP) techniques. The advantages of this include flexibility for the user to interact with virtually all objects on the screen, small source and executable files, extensibility and reusability of existing code, and a consistent GUI.

Perhaps the most important part on the GUI is the one-line diagram window, shown in Figure 2 for an eight bus, three area system. When the package is running all windows are continuously updated with bitmap copies used to provide a “smooth” animation. The display update rate depends upon the computer’s speed, size of the simulation case, and the

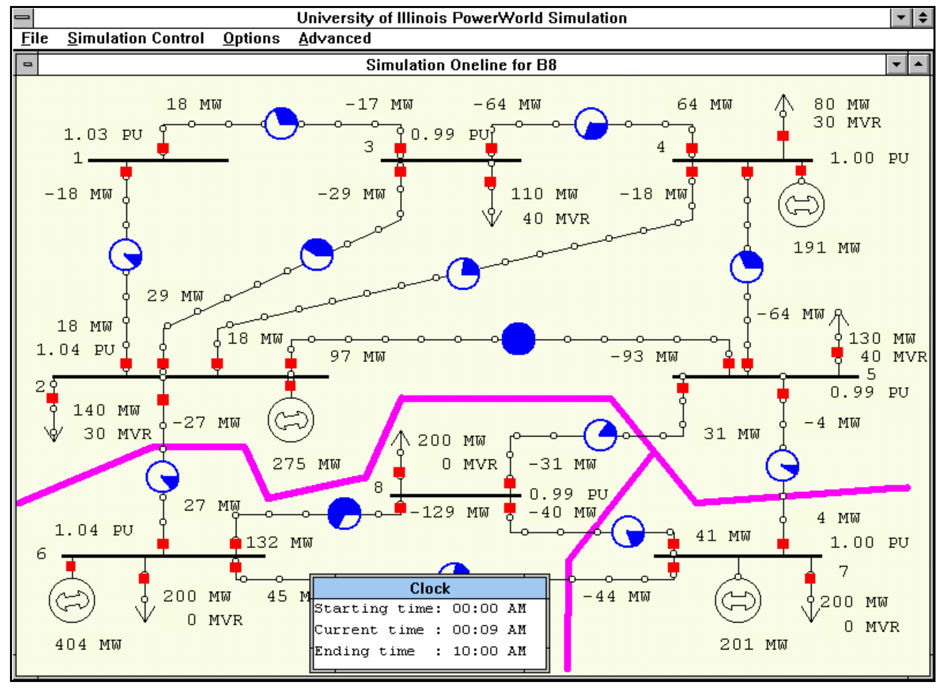

Figure 2 : Eight Bus One-line Diagram Window

number of windows shown, with several times per second typical with a relatively fast PC, a small system (less than 20 buses) and 1024 by 768 display resolution.

The one-line uses graphical symbols to represent system equipment such as buses, generators, loads, transmission lines and transformers. A combination of numeric values and graphical symbols are used to show system values. For example in Figure 2 numeric values are used to show bus voltage magnitudes, and load/generation values, while graphical pie charts are used to show percentage line loading.

The object-oriented approach allows the users to interact with essentially all objects on the window, providing a convenient means for both new users to easily learn the basics of power system control and advanced users to gain access to detailed system parameters. For example circuit breakers can be opened by positioning the cursor on the circuit breaker symbol and clicking the right mouse button, while they are closed by clicking with the left button. Because of the fast display update rate, the new flows appear almost instantaneously. Similarly, the MW output of the generators is increased by positioning the cursor on the generator MW value and clicking with the left button (or with the right button to decrease the value). However double clicking with the left button on the actual generator device displays a

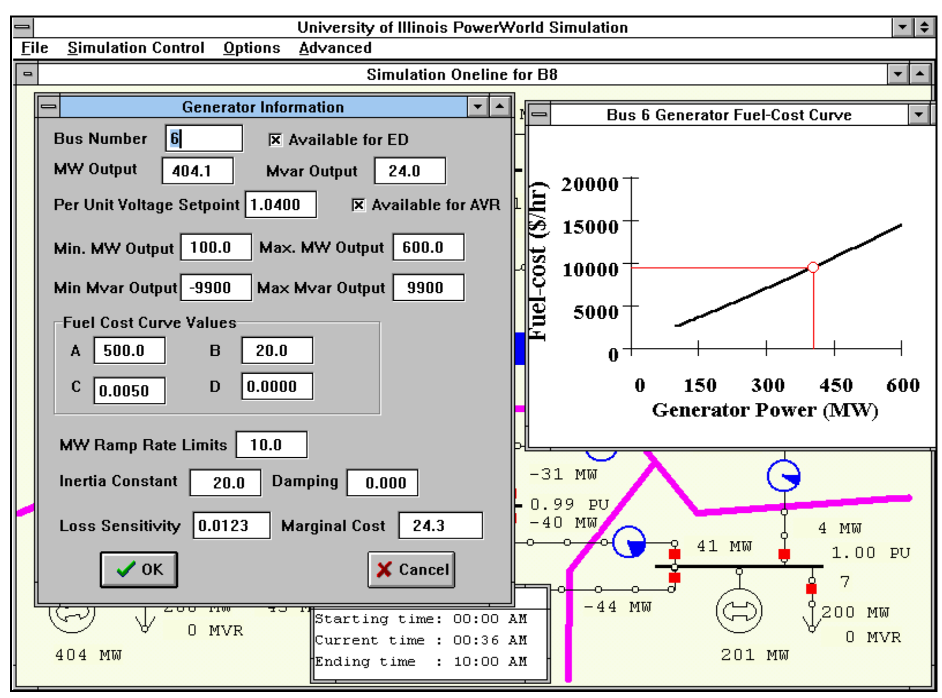

Figure 3: Sample Generator Windows

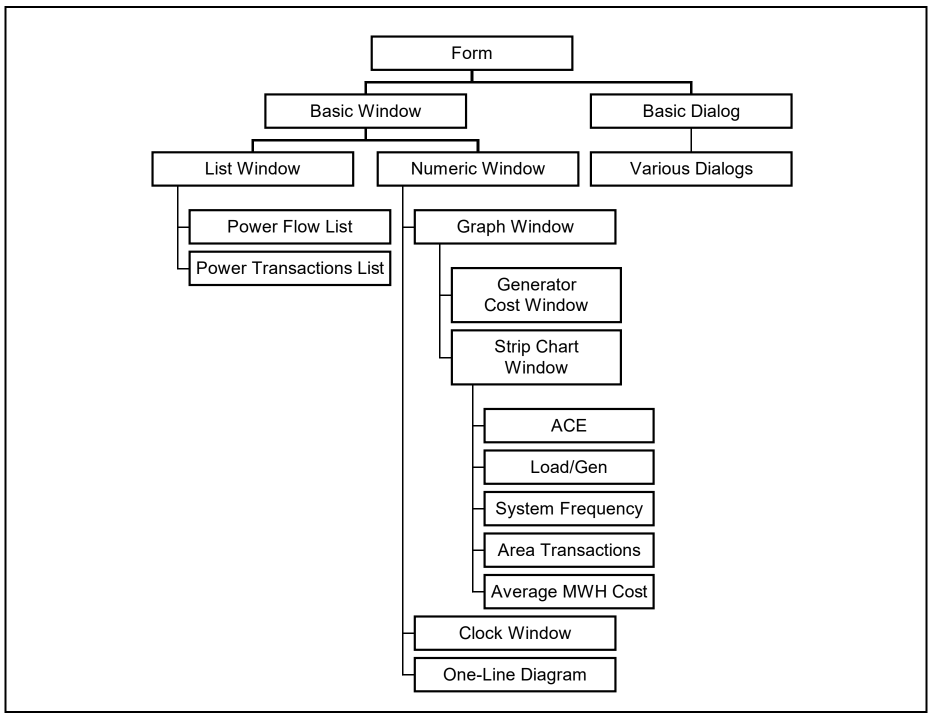

Figure 4: POWERWORLD Window Object Hierarchy

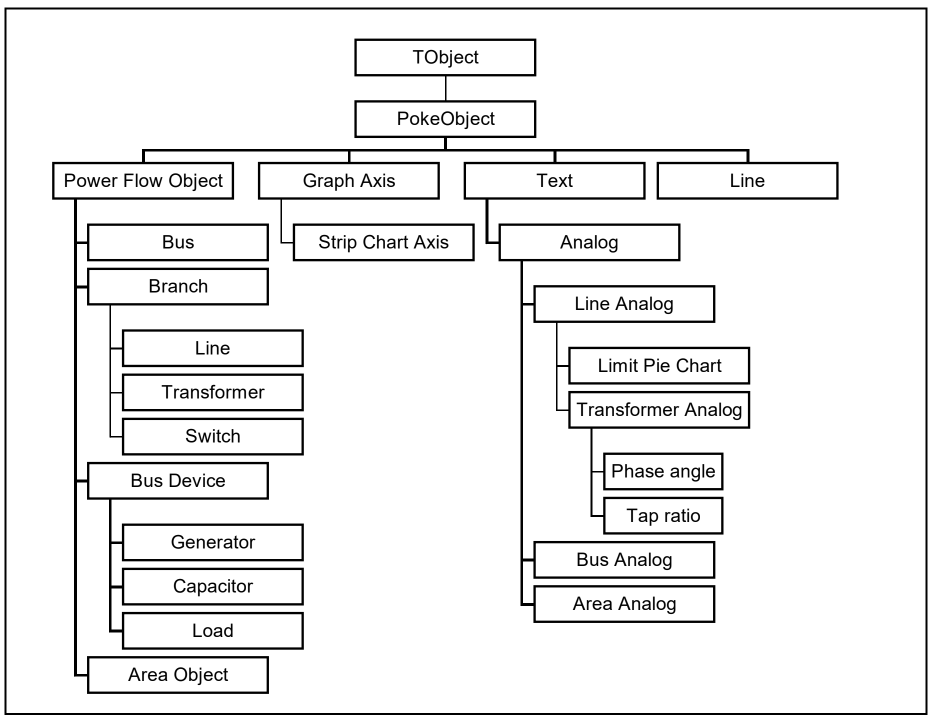

Figure 5: POWERWORLD Device Object Hierarchy

submenu, allowing advanced users to view either graph windows showing generator cost curve information or a dialog window allowing the user to view and modify various parameters associated with the device (shown in Figure 3).

This GUI functionality is succinctly provided using the OOP techniques of encapsulation, inheritance and polymorphism. Encapsulation is the process of combining a data record and the procedures that affect that record into a single entity known as an object. The object hierarchy then defines the relationships between various objects, with descendant objects inheriting access to all its ancestor's procedures and data. Polymorphism is giving an action one name that is shared up and down an object hierarchy, with each object implementing the action in a way appropriate to itself [9]. For example, polymorphism permits clicking the left mouse button on the circuit breaker to open the device, while the same action on the generator MW value increases the generator's MW output.

All portions of the POWERWORLD simulation package, including the simulation engine, have been developed using Borland's Delphi™ [10], an object-based application development environment based upon object-oriented Pascal. Therefore much of the general functionality needed to develop the GUI is already provided by Delphi. To implement the more specific GUI functionality, POWERWORLD actually uses two interdependent hierarchies of objects, one descending from the Delphi TForm object to represent the windows themselves, and one descending from the Delphi Tobject object to represent the devices shown on the windows. These hierarchies are shown in Figures 4 and 5.

The relationship between the two hierarchies is that a PokeObject (or any of its descendants) can be shown on any NumericWindow (or any of its descendants). Specific GUI functionality is then implemented as high up the hierarchy as possible. For example the functionality notifying a PokeObject that the user has clicked (or double clicked) on it with the left or right mouse button (i.e., "poked" the object) is implemented at the NumericWindow level. Likewise the generic functionality defining the "poke region" (the area on the window the object considers its own) is implemented at the PokeObject level, consisting of the rectangular region bounding the object. For most descendent objects this generic functionality is sufficient and thus needs to only be coded once. However some objects, such as multi-segment transmission lines (like the one from bus 2 to bus 4 in the figure) utilize polymorphism to override this default functionality and only respond pokes that are sufficiently close to the line itself.

2.2 Simulation Engine

A key question which must be addressed in the development of any simulation package is the level of modeling detail required, with the best solution usually hinging on the intended use of the package. Power systems are extremely complex systems with dynamic time scales ranging from less than 1 μs for lightning propagation studies to many years for resource planning studies. No simulation package can adequately cover this range of time scales.

POWERWORLD was developed with a strong desire to provide a simple construct for explaining power system operation in the time frame of minutes to hours. We believe that most of the key concepts involved in third party access on this time scale can be adequately simulated using a constant frequency model (i.e., the power flow approach)[1]. The simulation solution cycle is then as follows:

1. Read user selected simulation case, script file, and main one-line diagram information from disk files; set simulation time to start time, do initial events and perform initial power flow solution.
2. While simulation time <= end time Do
    a. Change load, perform any scheduled or user requested events, and, on an optional basis, introduce stochastic events.
    b. Perform power flow solution, including network

[1] POWERWORLD has recently been modified to also include the option of using a simple uniform frequency model to expose more advanced students to concepts such as the effect frequency has on ACE and generator speed-governing characteristics; this functionality is not described here.

topology processing and enforcement of longer timeframe dynamics.
   c. Update GUI and write any requested text output.
   d. Update time according to a user selected scaling relative to real-time.
3. Stop the simulation

When using the constant frequency model the heart of the simulation engine is a Newton-Raphson power flow. Because of the need to simulate longer time frames, simulation time is usually scaled to be many times real-time (typical values might be 30 or 60). For each time step in the simulation a number of adjustments are first made to the system. These include changing the loads at each bus according to a piecewise linear model, enacting any scheduled or user requested events, checking for transmission line thermal limit violations, and, optionally, introducing stochastic events. Examples of scheduled or user requested events include opening circuit breakers, setting up MW transactions between areas, or changing the tap position for LTC transformers. All transmission lines are assumed to have thermal loading limits, with the line capable of indefinite operation for any loading below this value. However, for loadings above this limit the line temperature starts to increase. Line heating is approximately by integrating over time the square of the line current. Eventually, if the line flow does not decrease to a value below its limit the line is automatically removed from service. The only stochastic events considered are loss of transmission lines and/or transformers.

Following these adjustments, topology processing may need to be performed to take into account changes in bus connectivity. Buses that are not connected to the system slack are marked as dead, with their load and/or generation set to zero. Conversely, loads at buses that had been dead but are not reenergized are immediately reset to their correct (time-dependent) values; generation is optionally either immediately set to its pre-outage value, ramped up to this value, or requested to remain at zero (to simulate when a generator has tripped off-line and cannot be immediately put back on-line).

Following topology processing the power flow is solved using a full Newton-Raphson method. Sparsity techniques have been used to decrease both execution time and storage requirements. This allows the power flow to quickly solve systems with up to several hundred buses. During the power flow solution longer timeframe dynamics are considered as time dependent constraints external to the main Newton-Raphson iteration, with the time period equal to the simulation time elapsed since the last time step. Examples include limiting the allowable change in generation to enforce ramp rate limits on generators, and limiting transformer tap changes according to transformer tap delays. To avoid power flow divergence, the optimal multiplier technique [11] is used. However if the user stresses the system beyond its point of maximum loadability the power flow will not converge. If such a situation were to occur in actual operation, the system would probably experience a voltage collapse induced blackout. In POWERWORLD this is simulated by dimming all the windows to dark gray and sending a message indicating that a blackout has occurred.

2.3 Area Control Modeling

In order to understand third party access issues the user must become familiar with area control concepts and the mechanisms of energy interchange between different operating regions. POWERWORLD can provide this insight by first introducing the concept of the area control error (ACE), then describing how the ACE is used in automatic generation control (AGC) to maintain economic area generation dispatch, and finally showing how transactions are implemented, highlighting key issues such as the difference between contract and actual power flow.

The ACE for an operating area is defined as a weighted sum of the difference between the actual and scheduled real power flow out of a control area, and the frequency error. For constant frequency operation the actual frequency is assumed equal to the scheduled value so the ACE reduced to the difference between the actual interchange and the scheduled interchange. The relationship between generation, load and the ACE can be illustrated by using the ACE and the load/generation strip-chart windows to plot this data as a function of time. These windows are updated at each time step, with new data appearing on the left and scrolling to the right, providing the user with immediate feedback of the effects of changing load or generation on the ACE. These windows can easily be resized, moved or rescaled. Figure 6 shows these charts for a simple three bus/two area system.

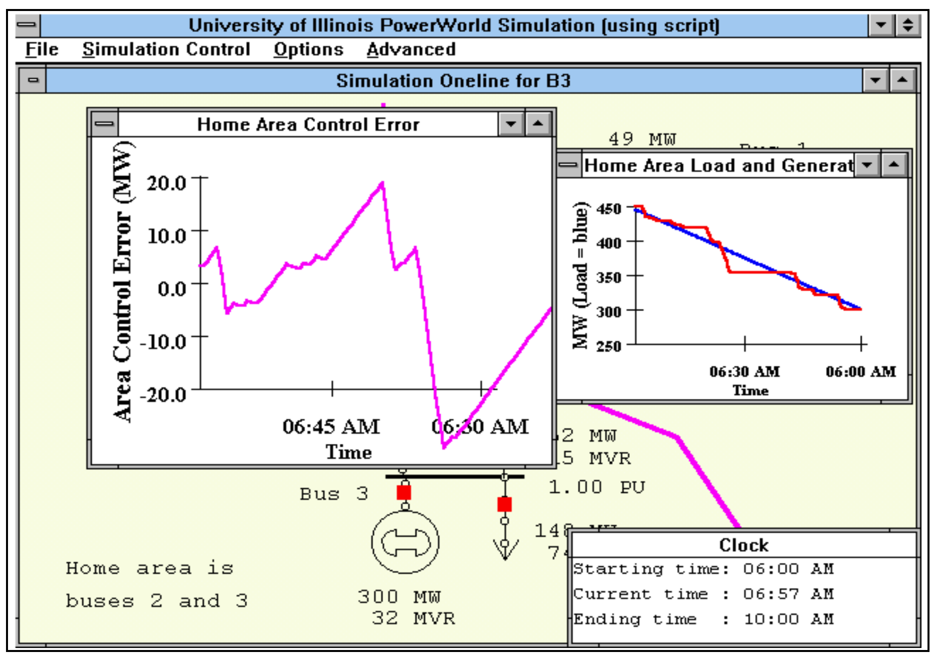

Figure 6: ACE and Load/Generation Strip-Chart Windows

The user quickly determines the tedious nature of trying to regulate the ACE manually and hence the need for AGC. POWERWORLD uses an economic dispatch (ED) algorithm to displatch the generation. This algorithm, which assumes that the generator fuel-cost curves are represented by a cubic cost function, takes into account generator minimum/maximum MW limits as well as area losses. Changes in generation from one timestep to the next can be (optionally) limited to take into account the maximum up and down ramp rates.

One of the most important benefits of interconnected operations is the ability for areas to undertake energy transactions. While in actual operations there can be an almost infinite variety of different types of power transactions, POWERWORLD currently only allows two generic types: one can either buy or sell a fixed amount of power from or to another area at a fixed price. Such transactions are normally initiated as a result of economy, but can also be used to alleviate transmission system limit violations.

If the transacting areas are directly interconnected then the transaction can immediately proceed. Otherwise the noncontiguous areas must obtain a "contract path" of contiguous areas. All areas in the contract path are compensated based upon the product of the amount of energy (but not capacity) they "wheel" and an area specific wheeling charge expressed in $ / MWH; the default value is $ 2 /MWH.

The Area Transactions/Information Window is used to summarize existing transactions as well as initiate new transactions. Figure 7 shows this display for an eight bus, three area case. Buy and sell quotes are shown for each area on AGC control. The buy quote is determined by dividing the generation cost decrease for the area due to the proposed purchase by the MW purchase amount, while the sell quote is the generation cost increase divided by the sale amount. The actual versus scheduled power flows can be used to clearly illustrate the actual power flow is usually not along the contractual path. In the Figure 7 area "Top" is currently selling area "Right" 100 MW, yet only 55 MW is actually flowing over the tielines directly joining the two areas; area "Left" is "wheeling" 45 MW.

Areas in POWERWORLD can represent either utilities or independent power producers (IPPs). The costs associated with an IPP can not be properly accounted unless the IPP is represented as a separate area. Within an area individual generators can be removed from economic dispatch, with their output subsequently adjusted manually.

POWERWORLD also includes the important capability of accounting for the costs associated with unserved energy. Anytime a load is outaged, such as due to an unexpected line outage, there is an associated economic cost that must be borne by either the customers or the supplier. POWERWORLD accounts for these costs by penalizing the operating area for any unserved load in that area by the product of the amount of unserved load in MW and a case specific cost value expressed in $/MWH. By default this value is zero.

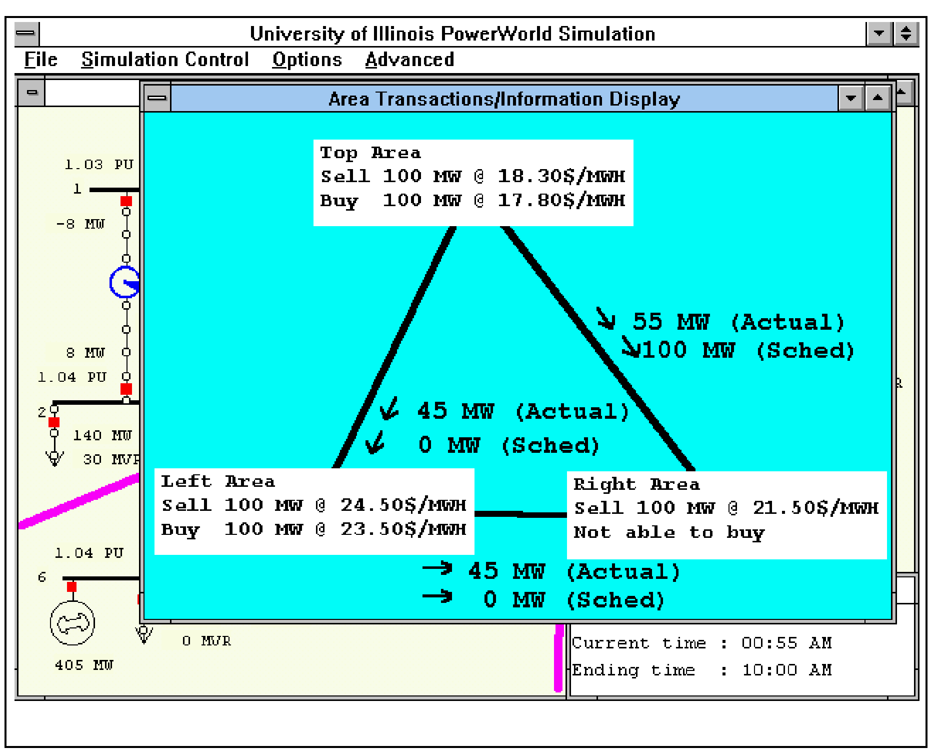

Figure 7: Area Transactions/Information Window

2.4 Events List, Script and I/O Files

Key to the versatility of POWERWORLD are its ability to play script files and its ability to dynamically interact with other modules. As the name implies a script file contains specific action that take place automatically at specific times during the simulation. Through the use of script files, just about any action a user can do manually can be setup to occur automatically. In addition, it is possible to add written annotations that appear on the screen at various times throughout a simulation. Thus an entire demonstration of a simulation case can be setup beforehand and then simply "played" for an audience.

This functionality is implemented internally in POWERWORLD through the use of the Events List. This linked list is used to hold both pending commands to the simulation engine and requests for data from the simulation engine. All entries in the list are time tagged with processing of the entry occurring when the simulation time has reached the tagged value. Referring again to Figure 1, note that all commands from the GUI pass through this list, including commands that only affect the GUI (such as resizing a window). Therefore implementing the scripting capability just required the development of an encoding module that takes a command from the script file (which is simply a text file) and inserts it into the Events List. Once in the list the command is processed just as if it had come from the GUI. The easiest way to create a script file is to use POWERWORLD's "recording" capability. While recording, each entry in the Events list is written into a script file after it has been processed. Thus recording allows the user to keep a permanent copy of a given POWERWORLD scenario.

To allow dynamic interaction with other modules, at each time step in the simulation POWERWORLD first checks to see if an "input" file exists. The input file, which uses the same format as the script file, can be created by any just about any other type of program. If the file exists and can be successfully opened, POWERWORLD reads the input commands and places them in the Events List. The input file is then deleted. Likewise, at the conclusion of the timestep POWERWORLD writes any requested information into an "output" file. This output file can then be used by other modules.

The simulation of an interchange matching system, such as AIMS [12], can be used to illustrate the flexibility of this approach. The goal of AIMS is to promote economic savings amongst a large number of utilities by automating the matching of hourly non-firm energy between the participants. Quotes for the next hour can be submitted 30 to 60 minutes head of the next hour, with buyer/seller matches determined 20 minutes prior to the hour. Such a system could be simulated using a multi-area model in POWERWORLD together with another module to model the AIMS. At the top of each hour (in simulation time) the AIMS system would place a message in the input file requesting that all areas in POWERWORLD provide quotes for possible transactions for the next hour. POWERWORLD determines these quotes and places them in the output file. The AIMS module then

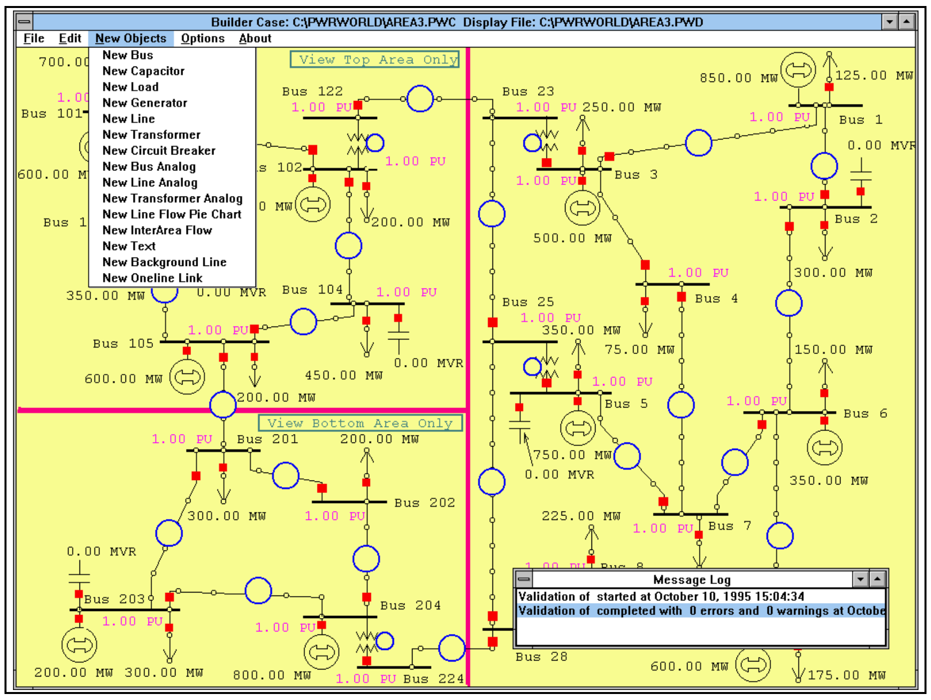

Figure 8: Graphical Creation of a POWERWORLD Case

determines the transactions for the next hour and places them into the input file. Finally, POWERWORLD places these transactions in the Events List with time tags equal to the beginning of the next hour when they would be implemented.

2.5 Data Cases and the Builder Program

Each simulation case has at least two associated data files. The POWERWORLD case file contains the information necessary to model the power system, while the POWERWORLD display file(s) contain the one-line information. The actual power system information is defined in the beginning of the case file using the IEEE command data format [13]. The remainder of the file contains various simulation options and more detailed device modeling information. The display file(s) is a non-ASCII format file used store the information necessary to display a one-line diagram. Each case must have at least one such diagram, but may have multiple one-line diagrams.

Both of these types of data files are created/modified using the separate Builder program. With Builder a user can graphically create a new case by simply selecting various power system devices from a menu and then placing them on a one-line diagram; the program automatically creates all the necessary files. This process is illustrated in Figure 8. This allows users to rapidly generate a wide variety of different systems. Users can also initialize a new case from an existing IEEE common format power flow file and then use Builder to create one or more one-line diagrams for the system.

3. Simple System Illustration

Concerns associated with transmission access include both economic and technical issues. On the economic side, the price of energy is normally strongly linked to the incremental cost of generation. On the technical side, the flexibility of an operator is constrained to avoid situations which degrade reliability and quality of service. The interaction between these two issues is complex and not completely understood by most parties involved. POWERWORLD can be used to illustrate this complex interaction. The following simplified three-area example shows how economic objectives can interact with technical constraints.

Figure 9 shows the "base case" of a 7 bus, 3 area system. The system is divided into a "top" area, a "left" area, and a "right" area as shown. Detailed information about each area is available on the Area Information Display, shown by double clicking on the box representing the area on the Area Transactions/Information display. This process was used to determine all the the cost information presented in this illustration. For the base case the incremental costs of the three areas are substantially different. The top area has an incremental cost of $16.80/MWhr, and is serving its load at a cost of $8,027/hr. The left area has an incremental cost of $17.22/MWhr and is serving its load at a cost of $4,190/hr. The right area has an incremental cost of $22.01/MWhr and is serving its load at $4,717/hr. The right area is offering to buy at $21.80/MWhr, while the top area is offering to sell at $16.50/Mwhr.

The right area decides to buy 50 MW from the top at a cost of $19.15/MWhr (split savings). The result of this transaction are shown in Figure 10. The hourly cost for the top area has been reduced to $7,920 (saving them $107/hr), and the hourly cost for the right area has been reduced to $4,603/hr (saving them $114/hr) while the cost to the left is changed slightly to $4,198/hr (they lose $8/hr). However this transaction is barely allowable since it loads the line from bus 2 to bus 5 in the top area to just below its limit.

Figure 9: Seven Bus Basecase

Figure 10: 50 MW Transaction from Top to Right

Figure 11: Transaction to Right from Top and Left

Since any additional transactions from top to right would cause an overload, the right area looks to the left for additional savings. Seeing an opportunity to reduce costs further, the right area contracts for a 50MW transfer from the left at $19.4/MWhr. The outcome of this second transaction is shown in Figure 11. The hourly cost of the right area has been reduced to $4,547, the left to $4,095, while the top goes up to $7,945/hr. Notice that this transaction between areas left and right causes area top's line from bus 2 to bus 5 to over load.

This illustrates the impact transactions can have on a third party. Top could argue that this transaction is overloading their system and should be aborted. However areas left and right could likewise argue that because of the excess capacity in their direct interconnection they are justified in doing the transaction; furthermore (referring again to Figure 9) in the basecase top is actually "wheeling" 40 MW through their systems. The top area could perhaps eliminate the overload by redispatching its units away from economic dispatch, but this would increase their cost. Rather than do this, the top area terminates their transaction with the right area, eliminating the overload. The hourly cost of the top has gone to $8,043 while the left has gone to $4,089 and the right to $4,625.

Finally right area notices that it can buy more from the left area for savings to replace the lost transaction with the top area. They contract for an additional 50 MW at $19.5/MWhr. The results of this transaction are shown in Figure 12. The hourly cost of the top area is $8,064, the right is $4,592, and the left is $3,987. Both the left and right areas are very pleased because they have achieved very low hourly costs and their systems do not contain any overloads. The top area however has a very high hourly cost and an overload.

Figure 12: Transactions between Left and Right

4. Conclusion

Recent changes in the electric power industry have resulted in the need for a simulation and visualization tool for explaining the impacts of policy decisions on power system operations. This paper has described such a simulation package. The object-oriented design approach allows users great flexibility to dynamics interact with the power system simulation, while retaining a small size for the source and executable files. The use of data files and options windows allow users to simulate a wide variety of different operating conditions.

5. Acknowledgments

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6. References

[1] Niek Ketting, "Currents and Sparks in Europe," *Electric Perspectives*, July-August 1995.

[2] I. J. Perez, H. Rudnick and W. O. Stadin, "International power system transmission open access experience," IEEE PES 1994 Summer Meeting, San Francisco, CA, July 1994.
[3] Federal Energy Regulatory Commission of the United States of America, "Promoting wholesale competition through open access non-discriminatory transmission services by public utilities, Docket No. RM95-8-00, March 1995.
[4] J. Gronquist, W. Sethares, F. Alvarado and R. Lasseter, "Animated vectors for visualization of power system phenomena," *Proc. 1995 IEEE PICA Conference*, pp. 121-127, Salt Lake City, Utah, May 1995.
[5] R. Bachner, "Graphical interaction and visualization for the analysis and interpretation of contingency analysis results," *Proc. 1995 IEEE PICA Conference*, pp. 128-134, Salt Lake City, Utah, May 1995.
[6] F. L. Alvarado, Y. Hu, C. Rinzin and R. Adapa, "Visualization of spatially differentiated security margins," *Proc. 1993 PSCC*, Avignon, France.
[7] P. M. Mahadev and R. D. Christie, "Envisioning power system data: vulnerability and severity representations for static security assessment," *IEEE Trans. on Power Systems*, vol. 9, pp. 1915-1920, Nov. 1994.
[8] T.J. Overbye, P.W. Sauer, C.M. Marzinzik and G. Gross, "A user-friendly simulation program for teaching power system operations," IEEE PES 1995 Winter Meeting, WM 048-9, New York, NY, Feb. 1995.
[9] *Borland Pascal with Objects User's Guide*, Borland International, Scotts Valley, CA, 1992.
[10] *Borland Delphi for Windows User's Guide*, Borland International, Scotts Valley, CA, 1995.
[11] S. Iwamoto and Y. Tamura, "A load flow calculation method for ill-conditioned power systems," *IEEE Trans. Power App. & Sys.,* vol. PAS-100, pp. 1736-1743, April 1981.
[12] R.L. Taylor, "Automated Interchange Matching System (AIMS)," *Proc. of 1995 American Power Conference*, pp. 1019-1023, Chicago, IL, April 1995.
[13] H.E. Pierce Jr. et. al., "Common format for exchange of solved load flow data," *IEEE Trans. Power App. & Sys*., vol. PAS-92, pp. 1916-1925, Nov/Dec. 1973.