Paper 08GM0211

IEEE POWER ENGINEERING SOCIETY
ENERGY DEVELOPMENT AND POWER GENERATION COMMITTEE

How Digital Earth is Visualizing the Power Sector Worldwide

Peter Meisen and Tom Hammons

Working Group on Implementing Technology to Limit Climate Change[1]

2008 IEEE PES General Meeting, July 20-24 2008, Pittsburgh, PA, USA
Wednesday, July 23 2008, 9:00 a.m~12:00 noon (Any Unforeseen Change to be Notified in Preliminary/Final Program and by Letter)

Sponsored by: International Practices for Energy Development and Power Generation

Chairs: Peter Meisen, Global Energy Network Institute (GENI), San Diego, CA, USA
Tom Hammons, University of Glasgow, Scotland, UK

Track: New Technologies

INTRODUCTION

GIS is a powerful tool for modeling geographic networks such as electric grids, rail and telecom networks. Yet network and geographic space are significantly different and often points that are close to each other in geographic space are far from each other in network space, and vice versa.

The needs of power managers and marketers have become more urgent as access to the power grid has opened and competition grown. They must now be able to "*see*" how much existing and proposed transactions will cost and to understand the availability of electricity at any time and place in the system.

The impact of dynamics like power flow, loop flow, and reactive power, which once mattered only to operational engineers, must now be made clear to every player in their system -- marketers, ISOs, RTOs, commissions and even some consumers. Visualization software for the electric grid can display a large amount of information in each computer generated image, enabling viewers to interpret this data more quickly and accurately than previously possible.

Visualization software can now display multiple images to:

- measure key system operating and market parameters (frequency, voltage, congestion, market power)
- monitor and graphically represent system performance
- track, identify and save data on abnormal operating patterns
- predict system response in near real time by means of simulations and "*what if*" analysis.

These tools enable system operators and planners time to interpret this data more quickly and accurately. This capability is becoming indispensable.

The Panelists and Titles of their Presentations are:

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[1] Document prepared and edited by T J Hammons

1. Peter Meisen, President, Global Energy Network Institute (GENI), San Diego, CA, USA. Earth at Night Features Prosperity, Pollution and Opportunity (Invited Panel Presentation Summary 08GM0632).
2. Mallikarjun Shankar, John Stovall and Alex Sorokine, Budhendra Bhaduri and Tom King, Oak Ridge National Laboratory, Oak Ridge, TN, USA. Visualizing Energy Resources Dynamically on Earth (Invited Panel Presentation Summary 08GM0619)
3. Thomas J. Overbye, Fox Family Professor of Electrical and Computer Engineering, University of Illinois, USA. Wide-area Power System Visualizing with Geographic Data Views (Invited Panel Presentation Summary 08GM0451).
4. Carlos Martinez, Senior Researcher, Electric Power Group, USA. Intelligent Real Time Tools and Visualizations for Wide-Area Electrical Grid Reliability Management (Invited Panel Presentation Summary 08GM1537)
5. Peter Meisen, President, GENI and John Graham, SDSU Visualization Center, Using Digital Earth to Assist in Power System Planning (Invited Discusser)
6. Jun Xie, Dongyuan Shi, Yinhong Li, Jinfu Chen and Xianzhong Duan, HuaZong University of Science and Technology, Wuhan, China. Study on Power System Heterogeneous Graphics Exchange Based on IEC 61968 Location Package and SVG (Conference paper 08GM1104)
7. Invited Discussers.

Each Panelist will speak for approximately 30 minutes. Each presentation will be discussed immediately following the respective presentation. There will be a further opportunity for discussion of the presentations following the final presentation.

The Panel Session has been organized by Peter Meisen (President, GENI, San Diego, CA, USA) and Tom Hammons (Chair of International Practices for Energy Development and Power Generation IEEE, University of Glasgow, UK).

Peter Meisen and Tom Hammons will moderate the Panel Session.

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BIOGRAPHIES

Peter Meisen is President, Global Energy Network Institute (GENI) an energy research and education institute based in San Diego, CA, USA. GENI focuses on the interconnection of electric power networks between nations and continents with an emphasis on tapping local and remote renewable energy resources. For the past decade, Mr. Meisen has been working with the PES International Practices Committee on two themes: the benefits of regional interconnections on each continent, and harnessing the untapped potential of the 6 primary renewable energies around the world.

Thomas James Hammons (Fellow IEEE 1996) received the degree of ACGI from City and Guilds College, London, U.K. and the B.Sc. degree in Engineering (1st Class Honors), and the DIC, and Ph.D. degrees from Imperial College, London University. He is a member of the teaching faculty of the Faculty of Engineering, University of Glasgow, Scotland, U.K. Prior to this he was employed as an Engineer in the Systems Engineering Department of Associated Electrical Industries, Manchester, U. K. He was Professor of Electrical and Computer Engineering at McMaster University, Hamilton, Ontario, Canada in 1978-1979. He was a Visiting Professor at the Silesian Polytechnic University, Poland in 1978, a Visiting Professor at the Czechoslovakian Academy of Sciences, Prague in 1982, 1985 and 1988, and a Visiting Professor at the Polytechnic University of Grenoble, France in 1984. He is the author/co-author of over 350 scientific articles and papers on electrical power engineering. He has lectured extensively in North America, Africa, Asia, and both in Eastern and Western Europe. Dr Hammons is Chair of International Practices for Energy Development and Power Generation of IEEE, and Past Chair of United Kingdom and Republic of Ireland (UKRI) Section IEEE. He received the IEEE Power Engineering Society 2003 Outstanding Large Chapter Award as Chair of the United Kingdom and Republic of Ireland Section Power Engineering Chapter (1994~2003) in 2004; and the IEEE Power Engineering Society Energy Development and Power Generation Award in Recognition of Distinguished Service to the Committee in 1996. He also received two higher honorary Doctorates in Engineering. He is a Founder Member of the International Universities Power Engineering Conference (UPEC) (Convener 1967). He is currently Permanent Secretary of UPEC. He is a registered European Engineer in the Federation of National Engineering Associations in Europe.

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Paper 08GM

1. Earth at Night Features Prosperity, Pollution and Opportunity: A Layered Visualization of the Global Energy Use and Consequences

Peter Meisen, President, Global Energy Network Institute (GENI), San Diego, CA, USA.

The Earth at Night Map from NASA provides the starting point. The lights of the world identify populations that have electricity. However, all lights are not the same, and 1.6 billion people remain in the dark – mostly in Africa and the Indian subcontinent.

In successive layers, we feature:

● A global population map showing population density, featuring the distinctions between our urban and rural world. We simulate population growth to 8.5 billion in 2050, which underscores the doubling of future energy demand.

- Shading each region/nation per their level of development: developed, transitional, underdeveloped. Several United Nations quality of life indicators define this: infant mortality rate, life expectancy, safe drinking water and literacy.
- All lights are not equal. A layer that reveals kilowatt-hours per capita, correlating electricity consumption and living standards.
- Beneath the lights are interconnected high-voltage transmission grids, which carry that power to 99.9% of all lit population centers.
- We colorize the generation by source: nuclear, fossil, biomass and hydro.
- Subsequent visual shows pollution levels in each region from burning of fossil fuels: total carbon emission per nation and CO_2 emissions per capita.
- A visual of current wind, solar and geothermal development, which remains less than 2% of current global production.
- Finally, we view the renewable energy potential of each region – solar, wind, geothermal, hydro, biomass and ocean -- and aggregate those into a total renewable resource potential. This is compared to existing electrical demand of the region to visualize the transitional path to non-carbon fuels.

As final analysis poses the following questions:

1. What if we tapped the renewable energy resources and fed them into the transmission grids that already exist?
2. Can you meet the energy needs of your customers using non-fossil resources?
3. How would we get electrical services to the 1.6 billion unserved people in an ecologically sustainable manner?

BIOGRAPHY

Peter Meisen is President, Global Energy Network Institute (GENI) an energy research and education institute based in San Diego, CA, USA. GENI focuses on the interconnection of electric power networks between nations and continents with an emphasis on tapping local and remote renewable energy resources. For the past decade, Mr. Meisen has been working with the PES International Practices Committee on two themes: the benefits of regional interconnections on each continent, and harnessing the untapped potential of the 6 primary renewable energies around the world.

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2. Visualizing Energy Resources Dynamically on Earth

Mallikarjun Shankar, John Stovall and Alex Sorokine, Budhendra Bhaduri and Tom King, Oak Ridge National Laboratory, Oak Ridge, TN, USA.

Abstract-- For the North American hurricane season, in partnership with the Tennessee Valley Authority (TVA) and working with the U.S. Department of Energy, Office of Electricity Delivery and Reliability, we have developed a capability that helps visualize the status of the electric transmission system infrastructure. The capability toolkit, called VERDE – Visualizing Energy Resources Dynamically on Earth, takes advantage of the Google Earth® platform to display spatio-temporally informed power grid and related data. Custom libraries describe the electrical transmission network in the Eastern United States and the dynamic status of each transmission line. Standard Google Earth layers provide rich spatial context. In addition to live status, VERDE provides a framework and mechanism to ingest predictive models, data from different sources, and response

***Index Terms*—**Electric Grid, Spatial Reasoning, Temporal, Visualization

1. INTRODUCTION

Major power outages in the United States over the past decade have a recurring theme - the lack of wide-area situational understanding were key factors that contributed to blackouts and also in managing the preparedness for and response to destructive events. Real-time geo-visualization capability characterizes the dynamic behavior of energy resources (such as the electric grid) across multi-regions, substantially mitigating the risk of and accelerating the recovery from a large area power disruption. For the North American hurricane season, in partnership with the Tennessee Valley Authority (TVA) and working with the U.S. Department of Energy, Office of Electricity Delivery and Reliability, we have developed a capability that helps visualize the status of the electric transmission system infrastructure. The capability toolkit, called VERDE – Visualizing Energy Resources Dynamically on Earth, takes advantage of the Google Earth® platform to display spatio-temporally tagged data. Custom libraries describe the electrical transmission network in the Eastern United States and the status of each transmission line. Standard Google Earth layers, external feeds, and additional layers from analysis and modeling capabilities in VERDE provide further valuable spatial context.

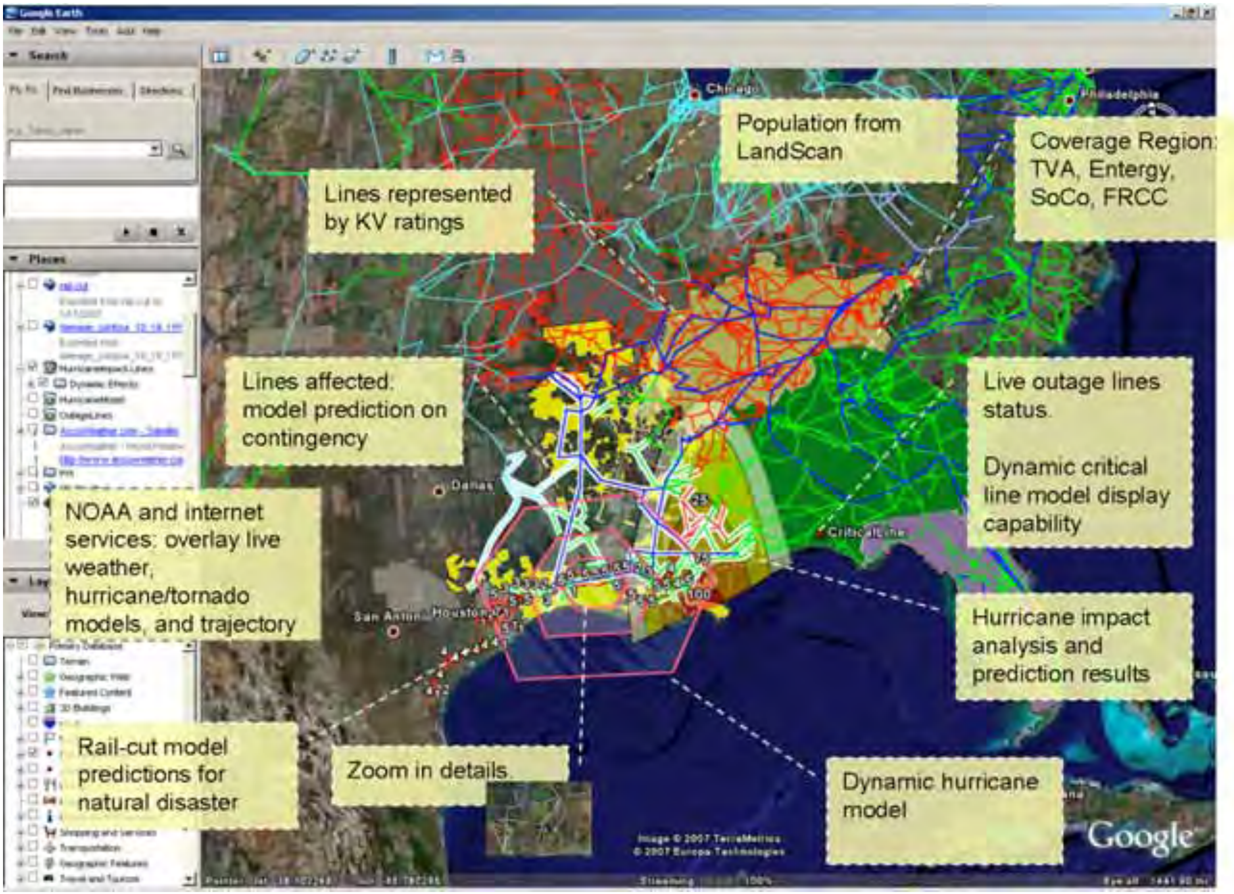

Fig. 1. VERDE Sample Visualization Overview

Figure 1 gives a snapshot of the VERDE capabilities with specific features pointed out. The capabilities include: (i) line descriptions and status of outage lines, (ii) geo-spatio-temporal information and impacts – population, transportation, and infrastructure impacts, (iii) analysis and predictions results, and (iv) weather impacts and overlays. We structure the rest of this paper around a sample set of illustrative visual captures of VERDE's display and discuss each image briefly.

2. ELECTRIC GRID STATUS

The real-time process for monitoring the electric grid in the large uses existing communication, computer hardware and computer software systems. The monitoring is based upon the standard utility SCADA systems and communications systems used for daily electric network operation from the control centers throughout the Southeast. During a hurricane, the individual utilities in the storm path will continue to use these systems to monitor and control their network. To gain the entire view of the storm's impact across the affected utility systems, each utility is automatically queried to compile a status list of their transmission lines. This information is accessed in real-time from a private Internet operated by the utility industry for sharing information about the electric grid performance and status. This private and secure communications network is called the Interregional Security Network or ISN and uses a custom communication protocol called Inter-control Center Communications Protocol or ICCP.

VERDE displays transmission lines with a voltage rating of 230-kV and above. The selection of the 230-kV and above transmission lines is based upon the sheer number of lines to be monitored. Selecting a lower voltage threshold dramatically increases the number of lines. (The intent is to focus on the big picture and not to be overwhelmed with details - an analogy to a national roadway system would be to monitor the health of the Interstates but not the state highways.). Spatial and Temporal presentation of the electric grid status is a basic requirement for utility operators to place in context the data they obtain from the SCADA systems. This context includes potential contingencies due to weather or equipment failures.

2.1 Topology

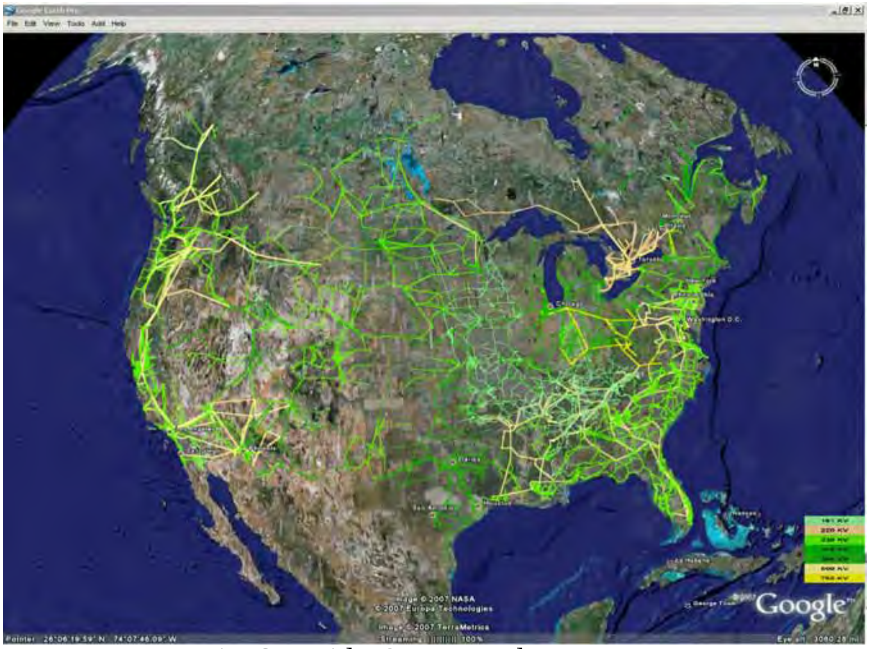

Fig. 2. Wide-Area Topology

Utilities have responded well to the ability to view the power system topology in a color-coded fashion in an easy to use “browser” – here Google Earth. VERDE allows the end-users to selectively see parts of the vocabulary by rating and allows Being able to zoom to a location with albeit old imagery creates a “human” value and context that operators seem to find useful. (We see spatio-temporal browsing with platforms such as Google Earth, Virtual Earth, NASA World Wind, etc. as the norm going forward for spatio-temporal information.)

2.2 Abnormal State: Visualizing Outages and Low Power Flow

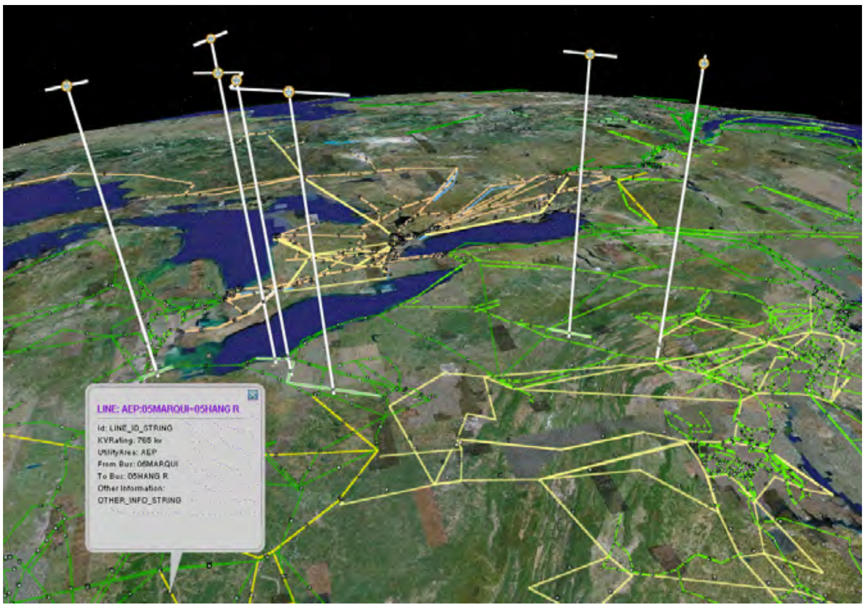

Fig. 3. Three-Dimensional Outage Displays

We describe outages in three dimensions, extruding them and blinking them to attract the attention of operators.

2.3 Associated Streaming Feeds and Graphs

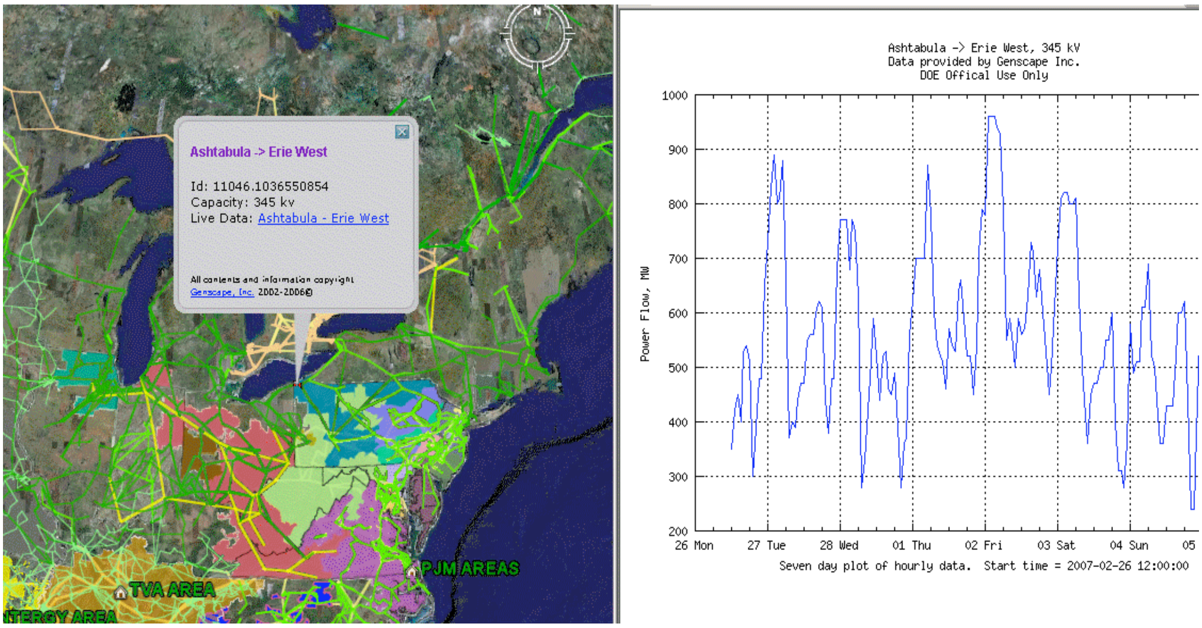

Fig. 4. Plotting the Status for Analysts

Data that is archived can be linked and made to point to plots and streaming analysis outputs in real-time.

2.4 Displaying Run-Time Contingency Analysis Model Outputs

Fig. 5. Plotting the Status for Analysts

Contingency estimates from the path of a hurricane can be evaluated on the fly and rendered for the end-user. Although these models are certainly not exact, they may give utilities a rough estimate of likely impact.

3. WEATHER IMPACTS

3.1 Live Overlays of Weather Imagery

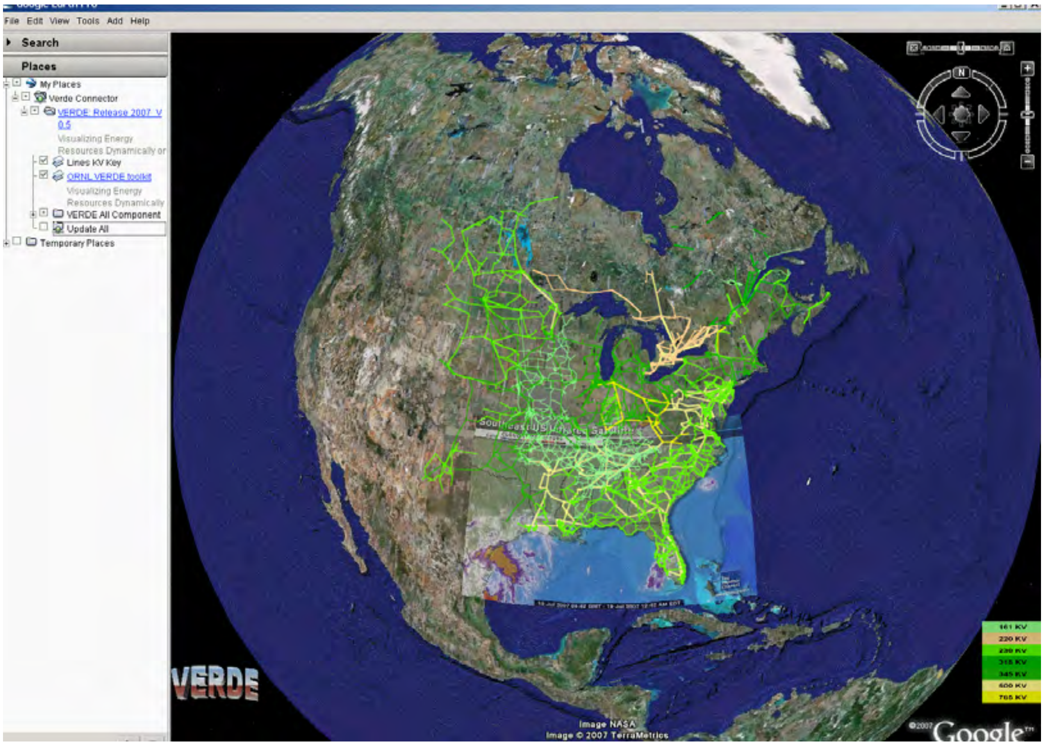

Fig. 6. Live Weather Imagery

Weather in VERDE from providers such as weather.com easily overlay on the platform (at a user’s desired level of transparency) to deliver a compelling layering of external conditions. This imagery is typically updated in the order of 10 to 15 minutes and is automatically refreshed on the screen.

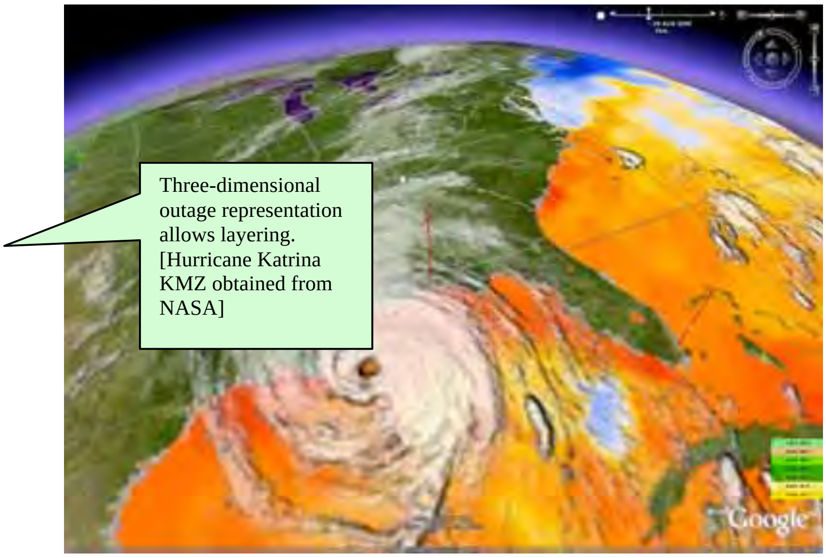

Fig. 7. Storm Overlays: Replay and Layered Information

Figure 7 shows outage lines extruding over the weather patterns – which is a useful resource to track grid and weather dependency and status at the same time.

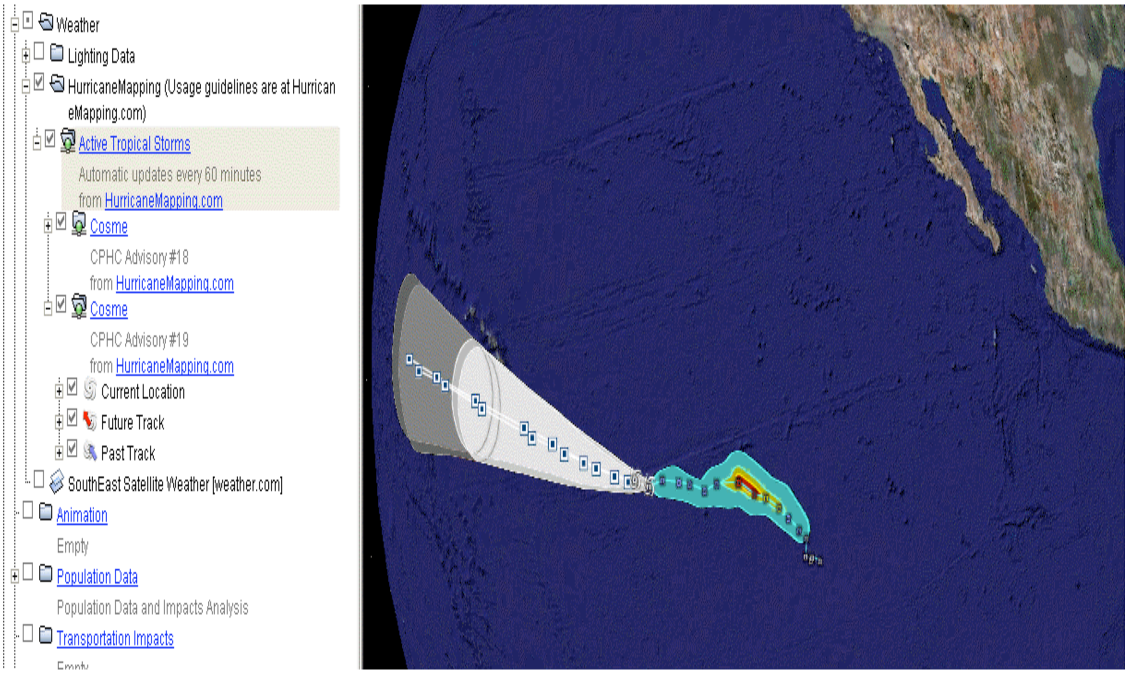

Fig. 8. NOAA, National Hurricane Center, Private Companies (e.g., HurricaneMapping.com provide predictive overlays)

4. RESPONSE TO CONTINGENCIES

Providing estimates of population in areas of impact, power loss anticipated, transportation routes impacted offer tremendous value to utilities in the power and non-power sectors, and to local, state, and federal response agencies.

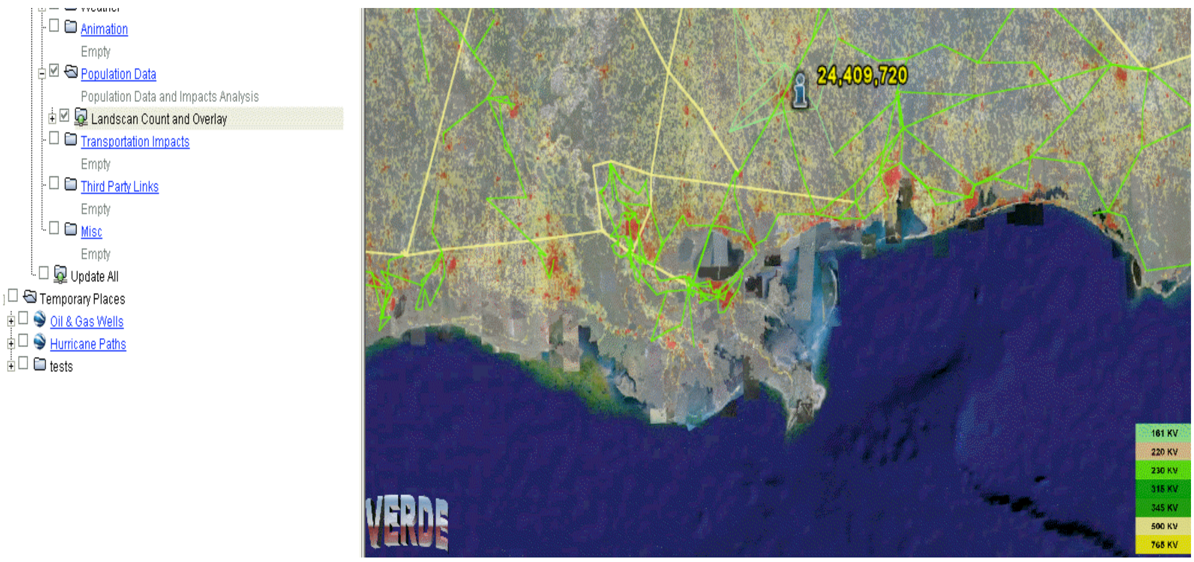

Fig. 9. Population Estimates from the Area of View obtained from ORNL’s Land Scan® Database.

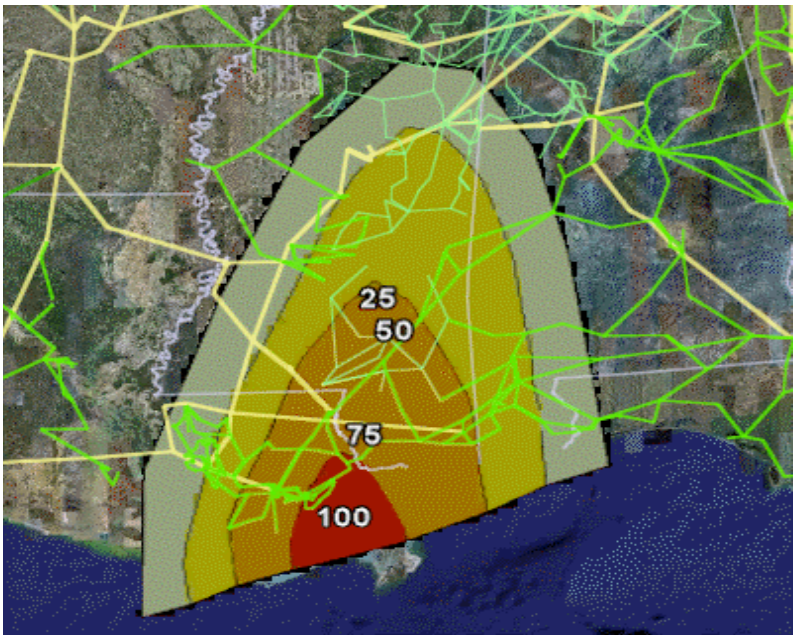

Fig. 10. Predictions of Impact based on Hurricane Path and Intensity

The above figures show how the visual representation of the impacted area along with model outputs gives a simple situational awareness feed to the end-user.

5. OTHER ENERGY INFORMATION AND INTERRELATIONSHIPS

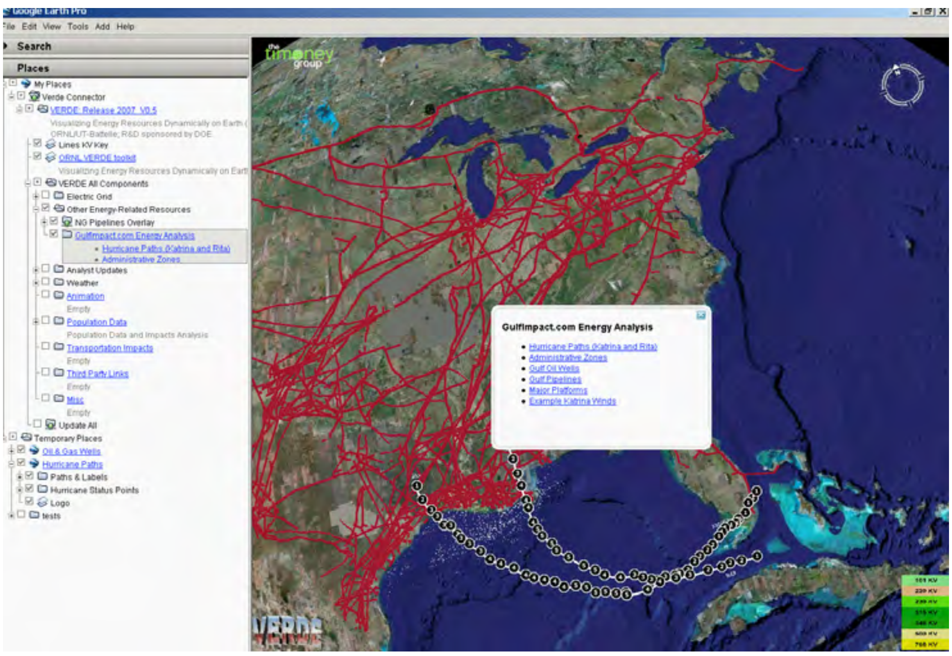

Fig. 11. Red-Lines Describe Network of Natural Gas Pipelines; Inset is a Label of Data from the Gulf Obtained from External Sources (e.g., Hurricane Paths for Katrina and Rita from the Timoney Group©)

Lessons from Katrina directly showed how the electric grid affects other energy infrastructures and is impacted by their health in turn. Bringing up natural gas networks, transportation network (impacts – pre- and post-event) provide immense benefits to a decision maker who has to make an estimate of the situation in real-time.

6. SUMMARY

The digital earth is an important enabler for utility operators, outage response and recovery crews and planners, and system engineers to visualize and comprehend the true implications of current system state. These data mashups provide a value add to human operators who can interpret the importance of (spatially and temporally) contextualized information rapidly.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] R. Klump, D. Schooley, T. Overbye, "An Advanced Visualization Platform for Real-Time Simulations." 14th Power System Computation Conference (PSCC), Seville, Spain, June 2002.

[2] Power World Corporation; http://www.powerworld.com

9. BIOGRAPHIES

Dr. Mallikarjun Shankar (M' 2004) is a Research Scientist at the Oak Ridge National Laboratory (ORNL). He received his PhD in Computer Science from the University of Illinois, Urbana-Champaign.

Mr. John Stovall is a member of the Research Staff at ORNL. Mr. Stovall has an MS in Electrical Engineering from the Ohio State University.

Dr. Alexandre Sorokine is a member of the Research Staff at ORNL. He received his PhD in geography from the State University of New York, Buffalo.

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Paper 08GM0451

3. Wide-area Power System Visualizing with Geographic Data Views

Thomas J. Overbye, Fox Family Professor of Electrical and Computer Engineering, University of Illinois, USA.

Abstract-- The paper gives an overview of a panel presentation on a power system visualization technique known as geographic data views, or GDVs. The impetus behind the development of GDVs is to use dynamically created visualization in order to show a wider range of power system information than is possible using the existing geographically based wide-area visualizations that are becoming common in electric power control centers. With the GDV approach operators or engineers using power system information along with geographic information imbedded in the power system model can dynamically create power system visualizations.

***Index Terms*—**Power System Visualization, Geographic Data Views

1. OVERVIEW

The idea behind GDV displays is to dynamically create power system visualizations by combining information derived from a power system model with geographic information that is embedded within the power system model [1]. The resultant visualizations usually contain graphical symbols to represent power system quantities, with the location of the graphical symbols determined from the embedded geographic information. Typically one or more symbol attributes are dependent upon the values for the underlying power system data. Example attributes include size, color, rotation, and shape.

The key to an effective GDV implementation is to allow these dynamic displays to be easily customized to display the desired power system quantities. For wide-area visualizations the most important geographic information will be the bus locations, or at least the locations of the substations containing the buses. Once the location of the buses (or their substations) is known, the location of some other objects, such as operating areas can be estimated. Transmission lines could be dynamically drawn either by embedding the actual coordinates for the lines with the model, or by approximately their paths just from the location of their terminal buses. Depending upon the application, geographic display information about the location of devices modeled within a substation, such as generators, switched shunts, and loads, could either be stored explicitly, or just default to their bus's location. Simple overlap avoidance algorithms could be used to avoid overlapping display symbols.

2. GDV EXAMPLES

As a motivating example for the GDV approach, consider the North American Eastern Interconnect, whose high voltage one-line is shown in Figure 1. The key point associated with the creation of GDV displays is that the underlying power flow model for the Figure 1 display has been augmented to store the latitude and longitude information for each electrical substation in the interconnect. Hence this information can be used dynamically to create a whole host of new geographic visualizations.

Figure 1: Eastern Interconnect One-Line Diagram

As a first step in developing the GDV, first recognize that each bus in the model is assigned to both a substation, for which geographic information is available, and an operating area. By assuming that all buses in a substation are at approximately the same geographic location (a reasonable assumption when one is interested in a high level display such as that shown in Figure 1 in which the display dimensions are over 1000 KM in each direction), a reasonable geographic estimate of the operating area’s location can be determined by a simple averaging of the locations for the area’s buses. Then a GDV display can be dynamically created by using relatively simple display elements, such as rectangular blocks, with selected attributes of each element dependent upon values in the underlying model. Such a display is shown in Figure 2, in which the size of each rectangle is proportional to the area’s total real power generation, the color of the rectangle indicates the real power interchange, and the name of the area is indicated by black text centered on the rectangle. To provide a geographic context, the rectangles are shown superimposed upon a map of the US state boundaries.

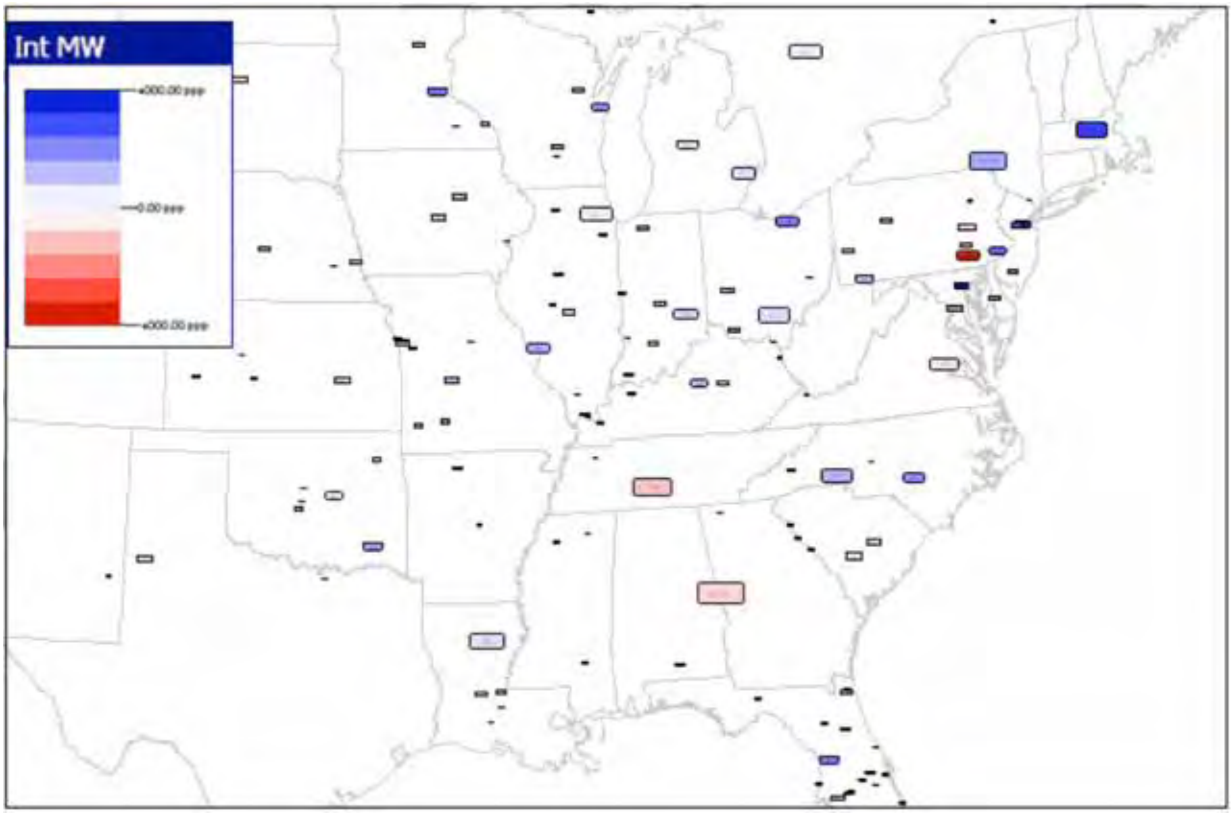

Figure 2: Dynamically Created GDV Showing Area Total Generation (Size) and Area Interchange (Exporting Areas are Blue, Importing Areas are Red)

The power of the GDV approach is that since the geographic information is encoded with the model itself, essentially any power system information that can be mapped to an element with a geographic location could be displayed. For example, Figure 3 demonstrates how the approach could be used to show information associated with a transient stability. In particular, the figure shows the location of generators modeled in the case with IEEE Type 1 exciters in which the object color corresponds to an exciter parameter (gain in this example).

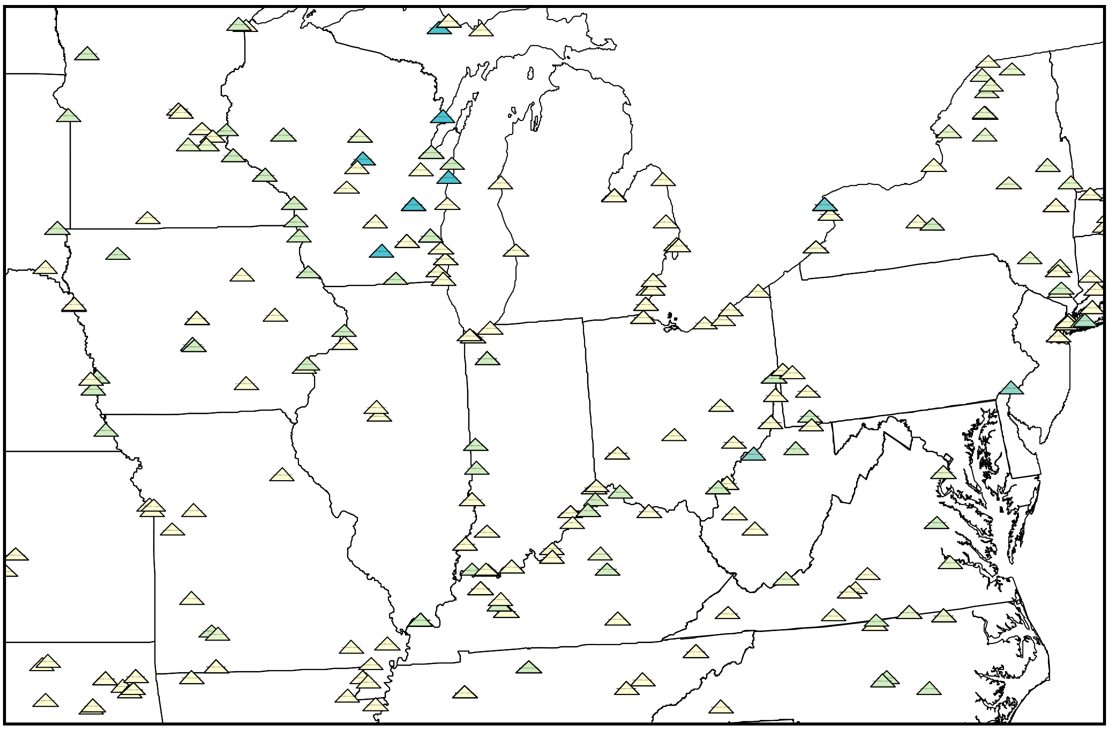

Figure 3: GDV Display Showing IEEE Type 1 Exciters

3. EXACT VERSUS PSEUDO GEOGRAPHIC LOCATIONS

One issue that naturally arises in a discussion of GDVs is the degree of geographic precision required, or whether the geographic coordinates even need to correspond to latitude and longitude. Traditional utility control center map boards and other wide-area displays have usually been constructed using pseudo-geographical coordinates at best. That is, while the displays have some relationship to the actual geographic location of the modeled devices, the need to show the one-line in a readable format tends to be the dominant design factor. A pure geographic representation, as might be done in a geographic information system (GIS), is seldom practical since locations of great interest electrically (e.g., substations) usually have a very small geographic footprint. Also, transmission lines sharing a common tower would be indistinguishable in a true GIS representation. Finally, some one-line elements, such as aggregate loads, are often spread over a large geographic area. Therefore it is expected that most GDV models would use such a pseudo-geographic approach.

However, there may be times when having a visualization that contains the exact geographic location of the power system elements could be useful. For example, one might wish to superimpose power system information with weather radar images, lightning strike data, or show the exact location of a transmission line fault. Or perhaps a substation level GDV could be used to show the exact equipment locations. Therefore it might prove useful to design GDV models so buses, lines and other elements (e.g., breakers), are modeled using two coordinates systems. One coordinate system would contain the pseudo-geographic location for the device, with the design goal being display clarity, while the second coordinate system would contain its exact latitude and longitude. Which coordinate system to use would then just become another option when the display is created? Morphed displays could also be created in which the coordinates change gradually from one system to another as a display parameter, such as the zoom level, is modified. All of the GDVs shown in this report were created using a pseudogeographic approach.

4. CONCLUSION

The purpose of this paper is to provide an overview of the information from a panel presentation at the IEEE PES 2008 General Meeting. The paper has introduced the concept of GDVs, in which new visualizations are created on the fly based upon power system information coupled with embedded geographic information. A key advantage of GDVs is they can be used to visualize a wide variety of different power system field values with the ability to use different display attributes to simultaneously show different fields. However, it should be emphasized that GDVs are not intended to replace existing text-based and predefined object visualizations. Rather they are intended to supplement existing techniques, with the major uses expected in the areas of power system analysis and corrective control particularly for wide-area visualizations.

5. REFERENCE

[1] T.J. Overbye, E.M. Rantanen, S. Judd, "Electric power control center visualization using geographic data views," Proc. Bulk Power System Dynamics and Control - VII, August 19-24, 2007, Charleston, SC.

6. BIOGRAPHY

Thomas J. Overbye (M'83-SM'96-F'06) received the B.S., M.S. and Ph.D. degrees in electrical engineering from the University of Wisconsin-Madison. He is currently the Fox Family Professor of Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign. Prior to joining UIUC in 1991 he was with Madison Gas and Electric Company, Madison, WI, from

1983-1991. Professor Overbye is the original developer of Power World Simulator and a founder of Power World Corporation.

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4. Intelligent Real Time Tools and Visualizations for Wide-Area Electrical Grid Reliability Management

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Abstract-- The establishment of competitive electricity markets worldwide, the deregulation of the electricity industry, and the response of the industry to the U.S. Energy Policy Act of 2005 have resulted in both very large and very small Balancing Authorities, greater operational complexities, and new reliability management needs at the wide-area level. Both the industry and government organizations responsible for different aspects of reliability management are adapting and responding to these new developments. This ongoing evolution of the industry and the increasing numbers of major blackouts around the world spotlight the need for wide-area visibility of the health of power systems and real-time monitoring of electrical grid reliability performance in order to prevent blackouts. Traditional real-time monitoring tools, real-time hardware–software architectures, and user interfaces all developed for vertical integrated environments have proved to be inadequate for the development of these new wide-area intelligent tools and visualizations required to operate and manage the evolving electrical grid. This paper describes the new reliability management needs and organizations emerging at the wide-area level; new hardware–software user-interface configurations; intelligent alerts and alarming and geo-graphic multi-view visualization technologies resulting from the Consortium for Electric Reliability Technology Solutions' (CERTS) research and tailored and applied by the North American Electric Reliability Corporation's (NERC) functional organizations for wide-area real-time Resources Adequacy monitoring, and Intelligent Alert and Alarming tools currently in use by about 75 operational organizations in North America.

Index Terms-- Balancing Authorities, Consortium for Electric Reliability Technology Solutions (CERTS), Geographic Multi-View Visualizations, Intelligent Alarms, Intelligent Tools, North American Electric Reliability Corporation (NERC), Real-Time Applications, Wide Area.

1. INTRODUCTION

Competitive electricity markets worldwide and increasing numbers of major blackouts around the world spotlight the need for wide-area visibility of the health of the power system and real-time monitoring of electrical grid reliability performance in order to prevent blackouts. Traditional monitoring applications, real-time hardware–software architectures, and user interfaces have proven to be inadequate for the development of the new wide-area intelligent tools and visualizations required to operate and manage the evolving electrical grid.

This paper describes the new reliability management needs and organizations emerging at the wide-area level; new hardware–software user-interface configurations; intelligent alert and alarming and geo-graphic multi-view visualizations technologies resulting from the Consortium for Electric Reliability Technology Solutions' (CERTS) research and tailored and applied by the North American Electric Reliability Corporation's (NERC) functional organizations for wide-

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area real-time Resources Adequacy monitoring, and Intelligent Alert and Alarming tools currently in use by about 75 operational organizations in North America. This paper also focuses on how these new wide-area technologies are helping to create wide-area real-time "Intelligent" tools, which can be adapted to the reliability management needs of NERC Reliability Coordinators and regulatory and reliability standards compliance monitoring organizations to help them carry out their Reliability Management responsibilities.

2. BACKGROUND

Deregulation, competitive markets, and mandatory reliability standards are driving the evolution of the electricity industry in North America. The emerging new layers of reliability management at the wide-area level are significant drivers for this evolution.

CERTS,[2] working together with NERC Reliability Subcommittees and with financial support from the Department of Energy (DOE), has been researching and prototyping new real-time wide-area monitoring tools exploring hardware–software configuration alternatives and new geographic multi-view interactive visualizations [1].

The lower half of Figure 1 shows the three traditional layers of operation at the local level, while the upper half shows the three new emerging layers at the wide-area level. These three emerging layers are as follows: NERC, with its role in monitoring wide-area reliability via Reliability Coordinators and compliance with reliability standards; FERC, monitoring the adequacy of approved reliability standards; and the DOE, using situational awareness for Resources Adequacy. The needs and requirements of these three wide-area layers have been the objectives of CERTS research for adequate intelligent tools and visualizations, which NERC then applies to the development of tools for production that help them carry out their Reliability Management responsibilities.

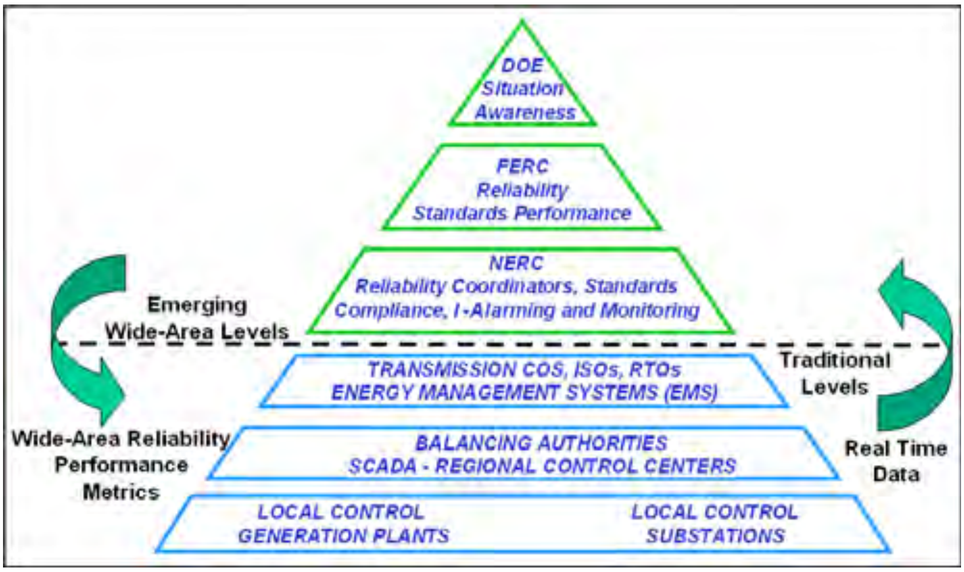

Fig. 1. Traditional and Emerging Reliability Management Layers at Wide-Area Levels in North America

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[2] CERTS was organized in 1999 as a partnership among universities, the private sector, and Department of Energy national laboratories. The Consortium includes four laboratories (Lawrence Berkeley, Oak Ridge, Sandia, Pacific Northwest), the Power Systems Engineering Research Center (consortium of universities led by Cornell), and Electric Power Group.

3. INTELLIGENT TOOLS

CERTS visualization research results for monitoring resources for wide-area levels indicated the need for the creation and broadcast of intelligent alerts and alarms for critical abnormal conditions. The alarm intelligence implemented included: a) the impact on wide-area reliability, b) possible root causes for critical abnormalities, and c) impact and results of possible remedial actions. The following sections describe how intelligence has been integrated for alarms and visualization for monitoring wide-area resources [2].

3.1 Tools Information Presentation Including Intelligence

Traditional SCADA and EMS systems collect raw data and make it available in raw or estimated format to operators and security analysis applications. Operators are supposed to monitor the application displays 24/7 for alarms or indications of abnormal behavior. The lower half of Figure 2 shows the configuration of this traditional monitoring approach. An alternative way to present information, particularly possible root causes of critical events and possible remedial actions, was investigated by creating and introducing a new layer of intelligence where for abnormal events, specific reliability performance metrics are compared with thresholds, and using related calculations and information from the adequacy monitoring tools, a summary of all related information is presented identifying the most probable root causes and possible remedial actions. The right side of Figure 2 shows the flow of information from the raw data collected, to the tools, to the new intelligence layer, and from there to the end-users.

Figure 3 shows the data and information flow architecture using the intelligence layer described above for the resources and transmission adequacy and for the situational awareness tools currently in use by about 75 operational organizations.

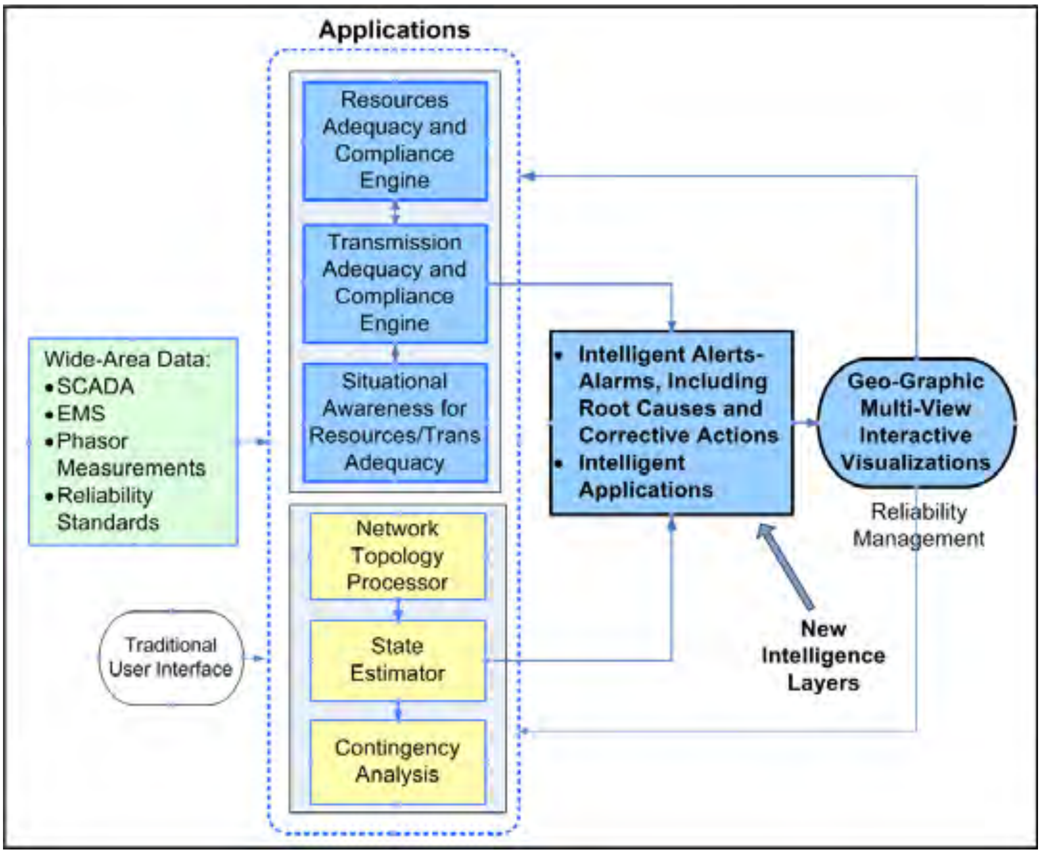

Fig. 2. Wide-Area Resources and Transmission Adequacy Tools Information Flow Including Intelligence

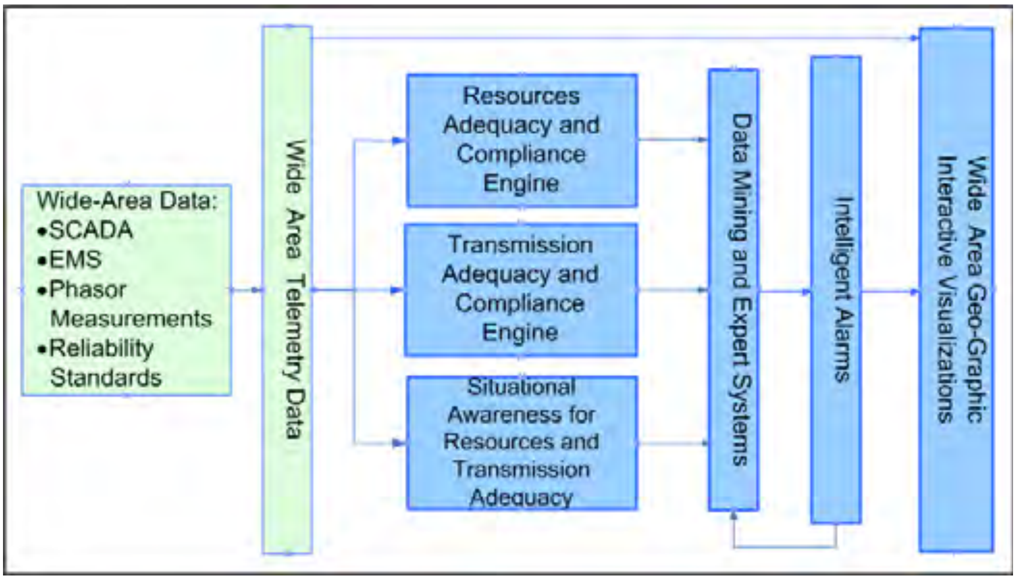

Fig. 3. Adequacy Monitoring Tools Data and Information Flow Architecture Including Intelligence

After the 2003 blackout in the eastern interconnection, NERC established the Real-Time Tools Best Practices Task Force (RTBPTF) to identify the industry's best practices for building and maintaining real-time network models and for utilization of security analysis tools. In their final 2006 report, the Task Force recommended that a minimum portfolio of security analysis tools, visualizations, and architectures, be made mandatory for Reliability Coordinators and Transmission operators. The intelligent information presentation and architecture presented in the paper follow these NERC Task Force recommendations very closely.

3.2 Geo-graphic Multi-View Visualizations Format

This section presents the design process, criteria, and key aspects of the geo-graphic multi-view visualizations technology researched and prototyped by CERTS, giving an example of its utilization by NERC for a wide-area real-time resources adequacy tool as described in Section 5. Figure 4 shows the approach CERTS chose to explore and defines the most appropriate geo-graphic multi-view configurations that most effectively serve as user interfaces and interaction for a wide-area real resource adequacy tool. Three fundamental dimensions are used: space, time, and the key performance parameters for the specific monitoring tool under study [3]. Analysis of the components of each dimension as well as the interaction between dimensions involves active participation and interaction with future tool users to address and resolve human-factor issues and define the visuals and configurations that will best suit their real-time monitoring needs. Figure 4 also shows, as a real example, the final three-core dimension components explored, agreed upon, and developed for the wide-area real-time resources adequacy tool.

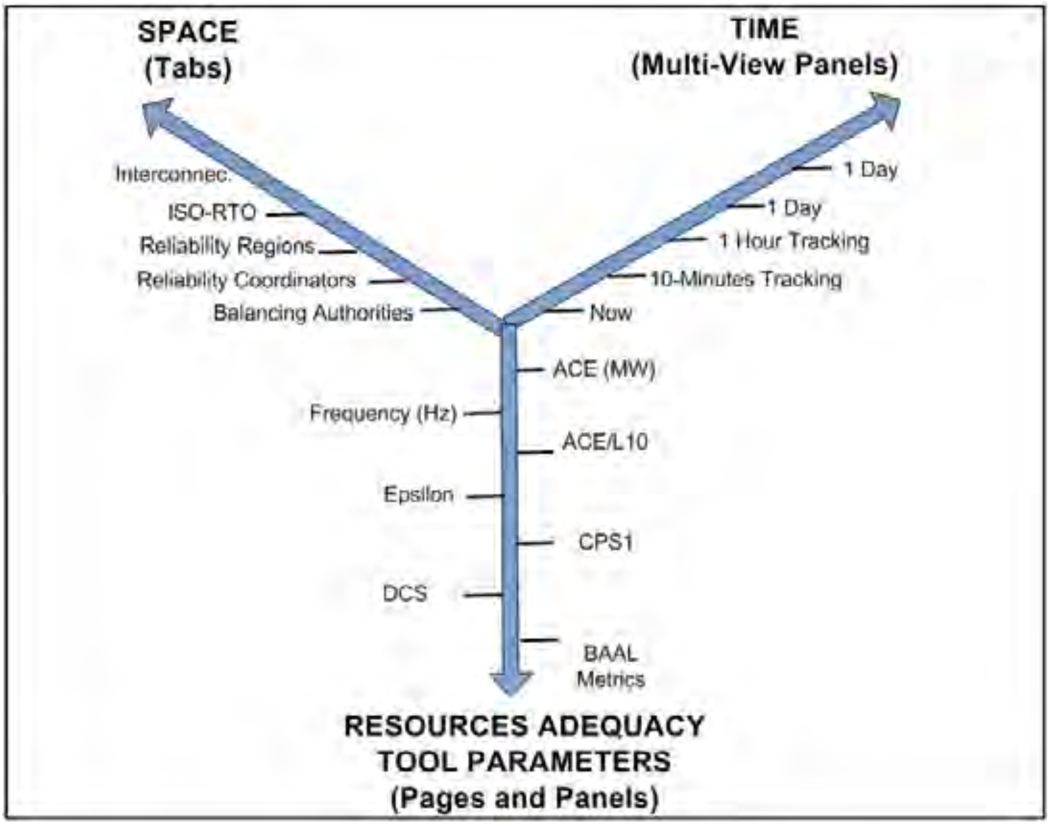

Fig. 4. Design Approach for Geo-graphic Multi-View Visualization with Three Core Dimensions – Space, Time, and Tool Key Parameters

Figure 5 shows the resulting geo-graphic multi-view visualization for the wide-area real-time resources adequacy tool. The visual space dimension components were implemented as tabs at the top-left of the display, the time dimension components and the different possible combinations were implemented using the four panels for each visual, and the key tool performance parameters and its possible combinations were implemented as different pages for each visual. There are no drop-down menus for navigation; users can click once to access tabs and use the right-mouse-button to choose between pages, minimizing confusion. This visualization has been used since 2003, and the basic design has remained the same. Only additional visuals for combining dimension components which users have identified as complements for their resource adequacy real-time monitoring needs have been implemented.

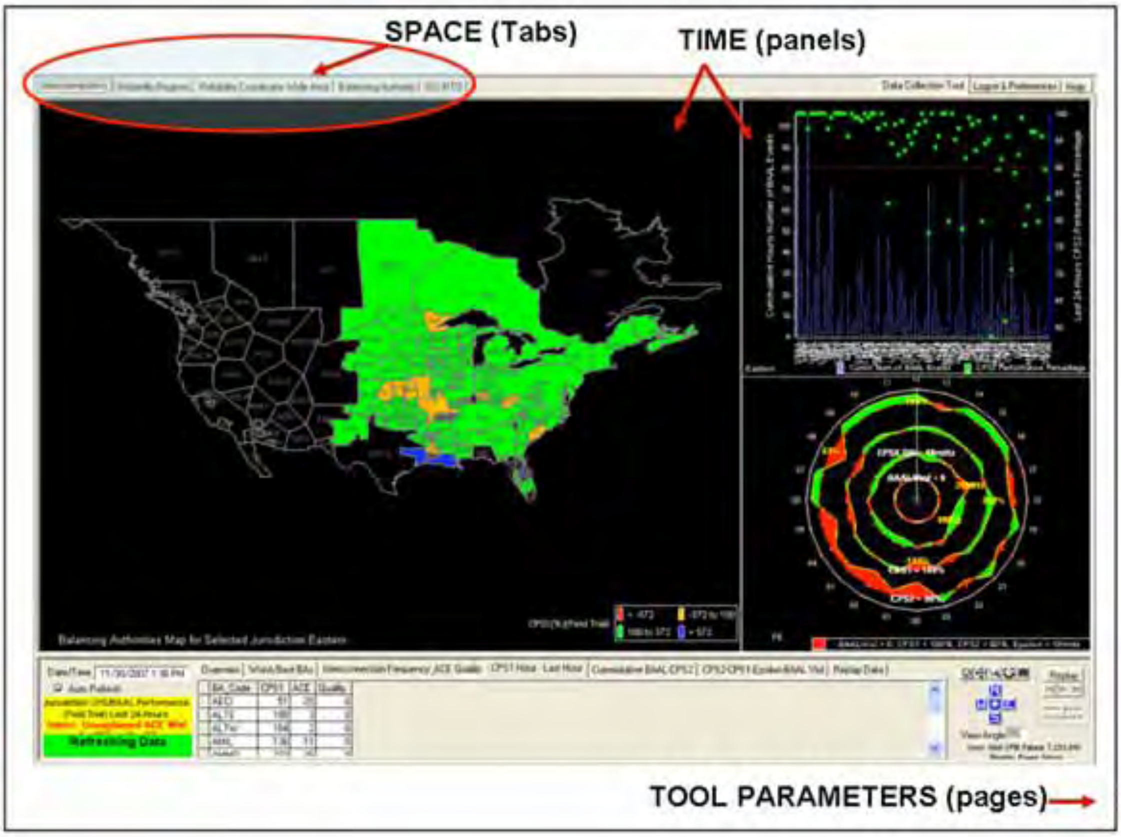

Fig. 5. Implementation of Core Visualization Dimensions for the Wide-Area Resources Adequacy Tool

4. RESOURCE ADEQUACY AND INTELLIGENT ALERT-ALARM TOOLS

4.1 Wide-Area Real-Time Resources Adequacy Tool

The Wide-Area Real-Time Resources Adequacy tool uses raw data from all NERC Balancing Authorities to produce real-time intelligent alerts–alarms and meaningful measures of resource inadequacies using the geo-graphic visualization described in the above section. This new tool ensures that the event review process, which took 5 months to accomplish in 1999, can now be accomplished in minutes.

Figure 6 provides a step-by-step illustration of how the Resources Adequacy tool was designed using some of CERTS' research results and how it is currently used. It utilizes real-time data from all NERC balancing authorities that is updated every 4 seconds and sent automatically from each balancing authority to a central server at NERC's headquarters in Princeton, New Jersey. The tool reads and processes this data and converts it into meaningful monitoring resources adequacy performance metrics displayed on geo-graphic visual displays that can be accessed, via a secure Internet connection, by NERC reliability authorities and members of NERC Reliability Subcommittees.

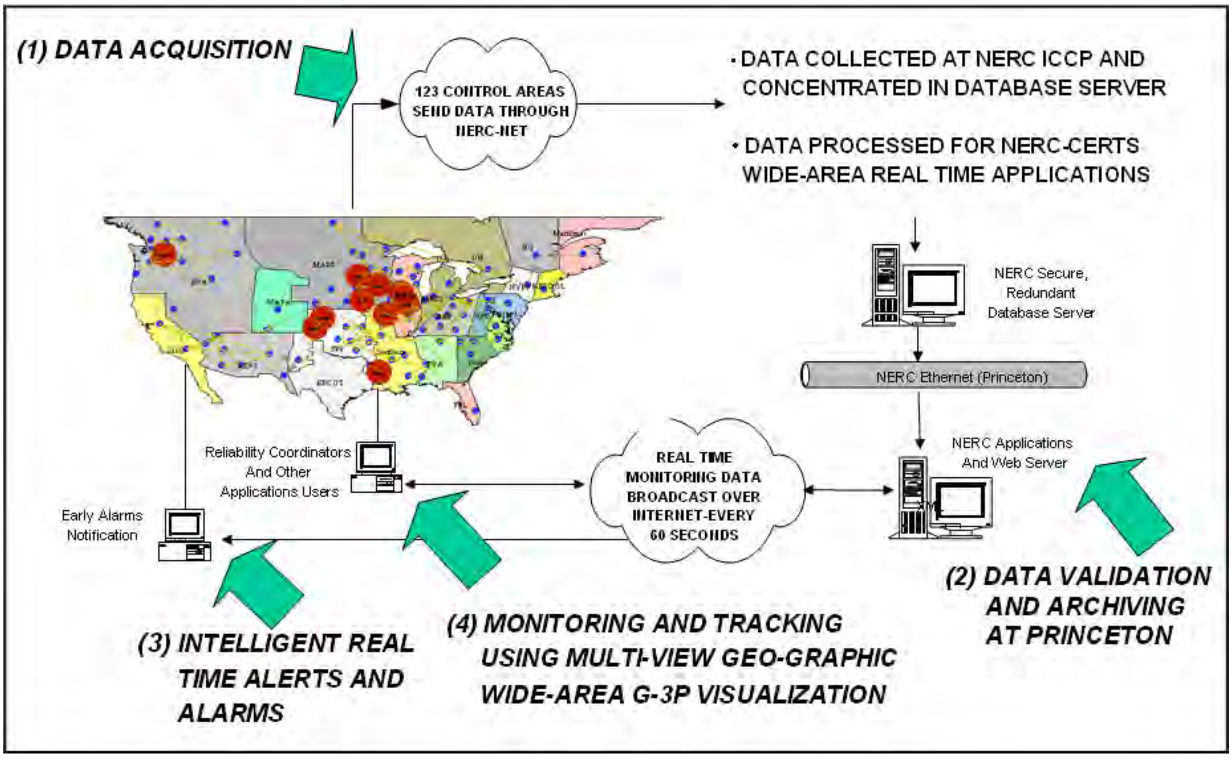

Fig. 6. NERC-CERTS Wide-Area Resources Adequacy Application – Data and Information Flow

4.2 Intelligent Alerts and Alarms

Traditional alarm processors have been developed to detect and report many different events to operators via alert and alarm messages. One serious drawback of the traditional alarm approach is that the diversity and number of alarms could delay a timely response to critical event conditions. Even some critical conditions present an excessively large amount of alarm data that could mislead the operator as to the true nature and root cause of the event. Innovative approaches to alarm processors should target improvements for the form, content, and timing of the alert–alarm presented to operators [4].

CERTS' research for wide-area real-time intelligent alerts and alarms sets the following four goals:

- Reducing the number of alarms presented for events to operators.
- Presenting a simple but clear message of the power system event causing the alert or alarms.
- Identifying and present the most probable root causes.
- Identifying and recommend corrective actions to operators.

CERTS' research results concluded that to identify and process data and information for event alarms, data mining technology, simple rule-based expert systems, and real-time monitoring tools calculations were the most effective technologies to satisfy the above four goals. The alert–alarms are identified, combined, correlated, and broadcasted with the specific event-related information (such as possible root causes and remedial actions) all gathered from field-input data and from real-time monitoring tools. The completed information package is labeled and broadcasted as an Intelligent Alarm. Figures 2 and 3 show how the Intelligent Alarm processor has been integrated and is being used for the wide-area real-time resources and transmission adequacy tools. The upper half of Figure 7 shows the intelligent alarm design process while the lower half of Figure 7 shows the intelligent alarm broadcast and dissemination process.

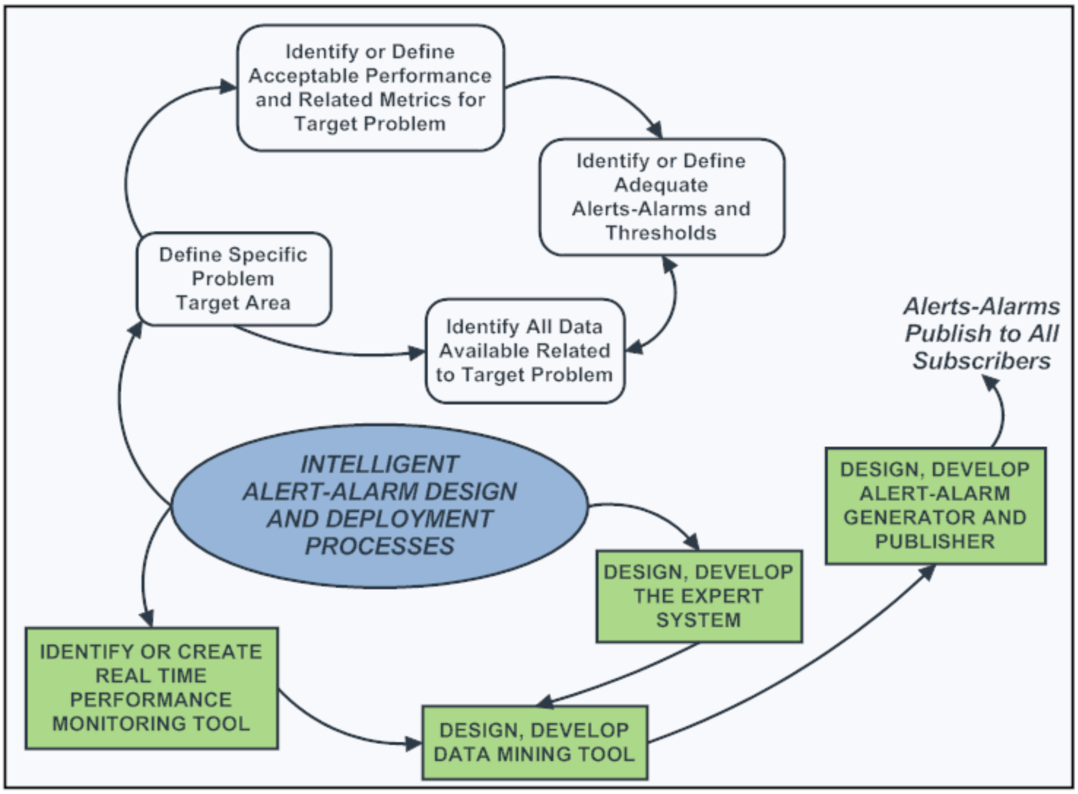

Fig. 7. Intelligent Alarm Design and Dissemination Processes

5. CONCLUSION

CERTS' experience with intelligent resource adequacy, intelligent alerts and alarms, and geographic multi-view visualization tools for wide-area real-time monitoring demonstrates that these tools can be effectively integrated into current wide-area operational environments. In particular, utilization of the tools by NERC operation stakeholders in general and Reliability Coordinators in particular, has shown that they can respond effectively to their wide-area operational responsibilities.

Experience has also demonstrated that acceptance and utilization of new intelligent technologies and tools requires a clear understanding of the problem to address, very close interaction and coordination with operations management, and most importantly, feedback from end-users for the tools' functionality and user-interaction. It also has been demonstrated that real-time monitoring tools for larger and wide-area operations, which include many more participants with very different objectives than before, requires a multi-view, geographic visualization approach beyond the traditional text-only-oriented displays.

6. ACKNOWLEDGMENT

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8. BIOGRAPHY

Carlos Martinez received his M.S. (1975) from the University of Miami, Florida, and his B.S. (1972) in Electrical Engineering from Universidad Nacional, Colombia. He worked for more than 10 years at Florida Power and Light, supervising the implementation and support of advanced real-time applications, and in Southern California Edison for more than 10 years as Manager of EMS and SCADA systems. Since 2001, he has led CERTS’ research and development Wide-Area Real-Time Intelligent Applications sector, working for Electric Power Group in Pasadena, California.

5. Using Digital Earth to Assist in Power System Planning (Invited Discussion)

Peter Meisen, President, GENI, CA, USA and John Graham, SDSU Visualization Center, USA

Discussion Pending

Received 7 March 2008
Paper 08GM1104

6. Study on Power System Heterogeneous Graphics Exchange Based on IEC 61968 Location Package and SVG

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Abstract-- The diversity of graphics models and data models in the electric utility software environment leads to much repetitive work and impede information sharing greatly. CIM in IEC 61970 defines most of the main objects in the electric utility enterprise, which can facilitate data exchange among heterogeneous applications. However, with the development of power system, graphics information exchange among heterogeneous applications becomes more and more desirable. By analyzing two graphics exchange approaches proposed by CCAPI, the way to exchange graphics information in a standardized form combining IEC 61968 Location package and SVG is introduced. An asynchronous graphics exchange mechanism based on publish/subscribe architecture is proposed, which can greatly reduce the redundancy information and enhance the exchange efficiency.

***Index Terms*—**SVG; IEC 61968; IEC 61970; Graphics Interoperation; Publish/Subscribe

1. INTRODUCTION

Nowadays, most EMS and DMS applications are based on standardized software and hardware platform. However, these applications adopt different data models and graphics models supplied by different software developers. Those heterogeneous data models and graphics models restrict access of third parties to these applications and impede information sharing greatly. As a result, much information must be rebuilt when a new application is added.

In order to eliminate significant repetitive work and realize information sharing, much research has been done by EPRI CCAPI project. Firstly, CIM[1] and some guidelines were proposed. CIM defines most of the main objects in the electric utility enterprise by XML. Now CIM serves as a standardized basis of power system data model exchange. CIM is adopted by IEC TC 57 WG 13 group to form IEC 61970 standard. Then a group of CCAPI, Common Graphics Exchange Breakout Group, was commissioned to define a common and preferred mechanism for graphics exchange in the utility in 2001. Since SVG[2, 3] is an XML-based open vector graphics and it is widely used to describe an image in many fields, two graphics exchange approaches based on SVG, graphics centric approach and domain centric approach are presented by the group[4]. Compared with the domain centric approach, the graphics centric approach has many advantages. But it still has some problems:

- In the graphics centric approach, the SVG graphics object and power system domain object are decoupled. Hence, during the graphics exchange the relationship between them should be established.
- In order to support multiple graphics display for a domain object, in the graphics centric approach, a source system can only pass the location, scale and orientation information of those graphics symbols to a target system. Hence, a useful graphics display can be rebuilt in the target system with those information and the target system's own graphics symbols. So a standardized format of the information should be defined to ensure a consistent comprehension among different applications.
- Information exchange is mostly based on a synchronous request/reply mode, in which a source system will export all the information during every exchange. Much information is the same for two different exchanges. It leads to a lot of repetitive work and decreases the exchange efficiency greatly.

In this paper, power system graphics centric exchange based on location package and SVG is studied, and an asynchronous publish/subscribe exchange mode is proposed to reduce the redundant exchange information and improve the exchange efficiency. Firstly the location package in IEC61968 is described, with which the location information exchanged in the graphics centric approach can be standardized. Secondly, the SVG metadata model is introduced. By the metadata model a SVG graphics symbol object can easily associate with a CIM object, and the topology of the graphics display can be simply acquired. An asynchronous publish/subscribe exchange mode is proposed. In addition, an example of the graphics exchange on a power plant is presented to explain the application of the SVG metadata and location information in the asynchronous publish/subscribe graphics centric approach.

<u>Glossary</u>

EPRI	Electrical Power Research Institute
CCAPI	Control Center Application Program Interface
CIM	Common Information Model
EMS	Energy Management System
DMS	Distribution Management System
IEC	International Electrotecnical commission
SVG	Scalable Vector Graphics
XML	extensible Markup Language
W3C	World Wide Web Consortium
GES	Generic Eventing and Subscription
DOM	Document Object Model

2. CCAPI GRAPHICS EXCHANGE APPROACH

The CCAPI project is sponsored by the EPRI, the aim of which is to reduce the cost and time needed to add new applications, especially applications from different suppliers, to EMS. Hence, some guidelines and CIM are proposed by CCAPI. CIM defines most of the main objects in the electric utility enterprise based on object-oriented data modeling technology. CIM, as a standardized data model for EMS and DMS environments, can facilitate data exchange among heterogeneous applications. Hence, CIM has been accepted by the International Electro technical Commission to form the IEC 61970 standard.

The standardization and opening of power system graphics is also an important part of an opening power system. In 2001, the Common Graphics Exchange Request for Proposal was submitted by CCAPI Common Graphics Exchange Breakout Group. In this proposal it is suggested to develop a common methodology to enable graphics exchange between diverse power system software applications within the electric utility enterprise, and it is recommended that the graphics information model should be build in SVG. The aim of this proposal is not to exchange a "snapshot" of a power graphics display, but to exchange some information that enables the receiver to form a graphics display with dynamic refresh of CIM measurement and other dynamic information, without a connection with the sender's system. The target graphics display should have the same layout as that of the source. However, the actual presentation logic of individual items might be different, depending on the current state of the dynamic information and perhaps different visualization rules between the sending and receiving systems.

In order to realize the aim, two approaches from different viewpoints, domain centric approach and graphics centric approach, were proposed.

The domain centric approach is illustrated in fig.1. Graphics information is added to the CIM as its new attributes. When the “new” CIM model is exchanged, the graphics attributes are exchanged together. This enables the receiver to recreate the graphics display with the “new” CIM. But this approach does not support standardized viewers directly. It needs to use an XSL translation tool to extract the graphics information from the new CIM and then create separate domain object and graphics object files. Moreover, in this approach, when graphics model extends, CIM model has to be modified since graphics model is only the attribute of CIM.

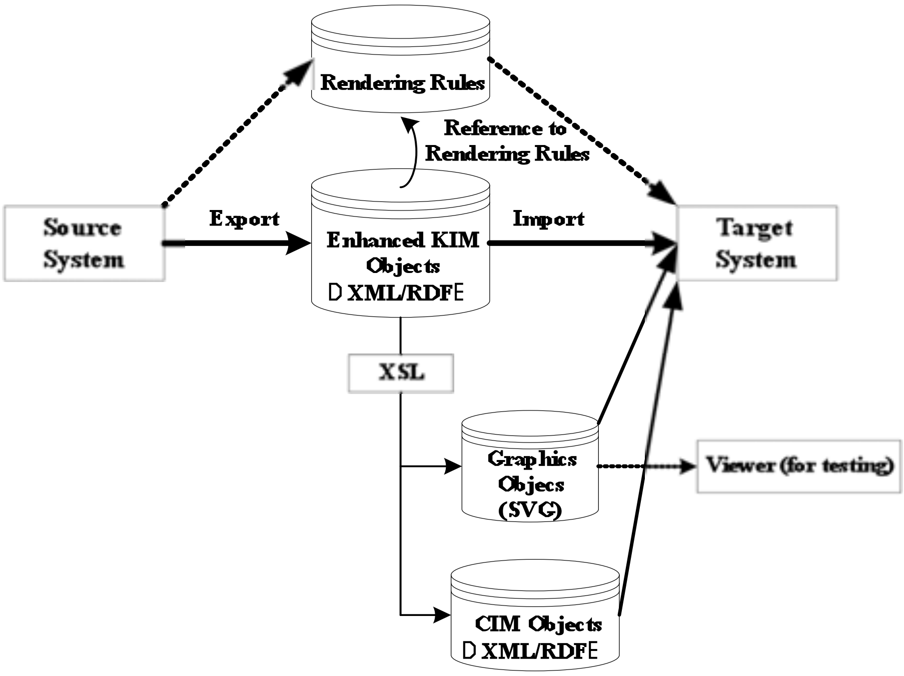

Fig.1 CCAPI Domain Centric Approach

The graphics centric approach is illustrated in fig.2. The common graphics model is built on SVG. During the interoperation process, the SVG graphics model and CIM/XML model can be exported separately from the source system. Then the relationship is established between the graphics objects and the CIM objects. The target system can import them to rebuild a useful graphics display. This approach has the advantages of supporting graphics model extension and standardized SVG viewers [5] during information exchange.

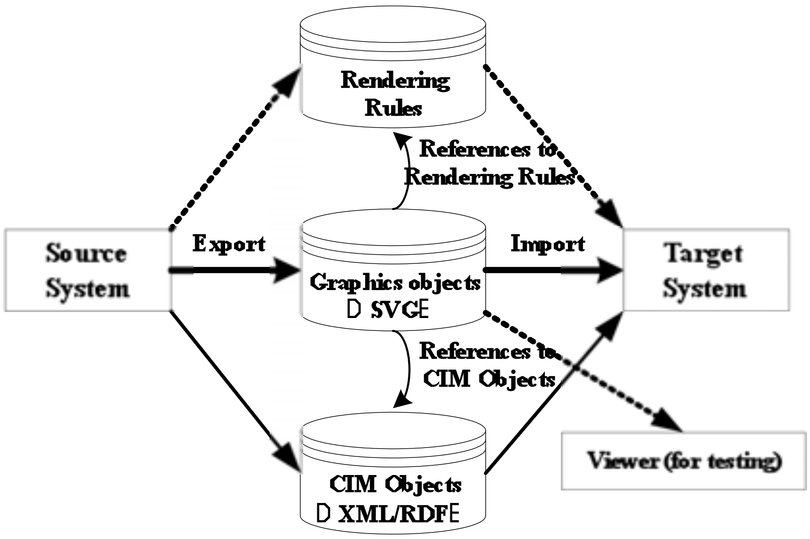

Fig.2 CCAPI Graphics Centric Approach

Different applications in power system have different requirements. Then, each object in different power system applications may have different graphics display. It is difficult to build a uniform SVG graphics model. Hence, in the graphics centric approach, CCAPI suggests that the graphics information exchange can only transmit the location, scaling and orientation information of those graphics symbols. With these information and target applications' own graphics symbol library, the target system can recreate a useful graphics display. Then, the target system can add its own presentation logic to the graphics display to convert the work state of a domain object into its visible representation. With this approach, the multiple graphics display related to one domain object in heterogeneous applications can be realized easily.

Hence, in the two approaches, graphics centric approach is recommended, since it provides easier way to realize multiple graphics display of each domain object and “background” data in graphics display, and supports standardized SVG viewers.

However, in the CCAPI graphics centric approach, besides the location information, the measurement and topology information associated with the graphics display in the source system may be passed to the target system. Those exchange information must be standardized to realize consistent comprehension between two systems. Hence, IEC 61968-location package is introduced to standardize the location information in the section III, and the SVG metadata model is described in section IV to standardize the measurement and topology information.

3. IEC 61968 LOCATION PACKAGE

The Location package, designed in IEC 61968[6], defines many kinds of information about location (e.g. Address, coordinate). The section about graphics location information is shown in fig.3, which can help to reach the consistent understanding of the location, scaling and orientation information among applications.

In the figure, the Location class describes where some graphics of power system resource is at a given moment. Some attributes of Location class is define to specify the characters of a graphics display’s location information. Coordinate Pair attribute describes the horizontal and vertical coordinate of the centric point of a graphics. Coordinate List attribute describes a sequence of x/y coordinate pairs used for drawing non-point assets, such as ACLineSegments and Ducts, or for drawing polygons for objects which can not be easily represented as a point. And Polygon Flag attribute describes whether the last one of a sequence of conductor points should be connected with the first one, thus forming a polygon or a sequence of line segments.

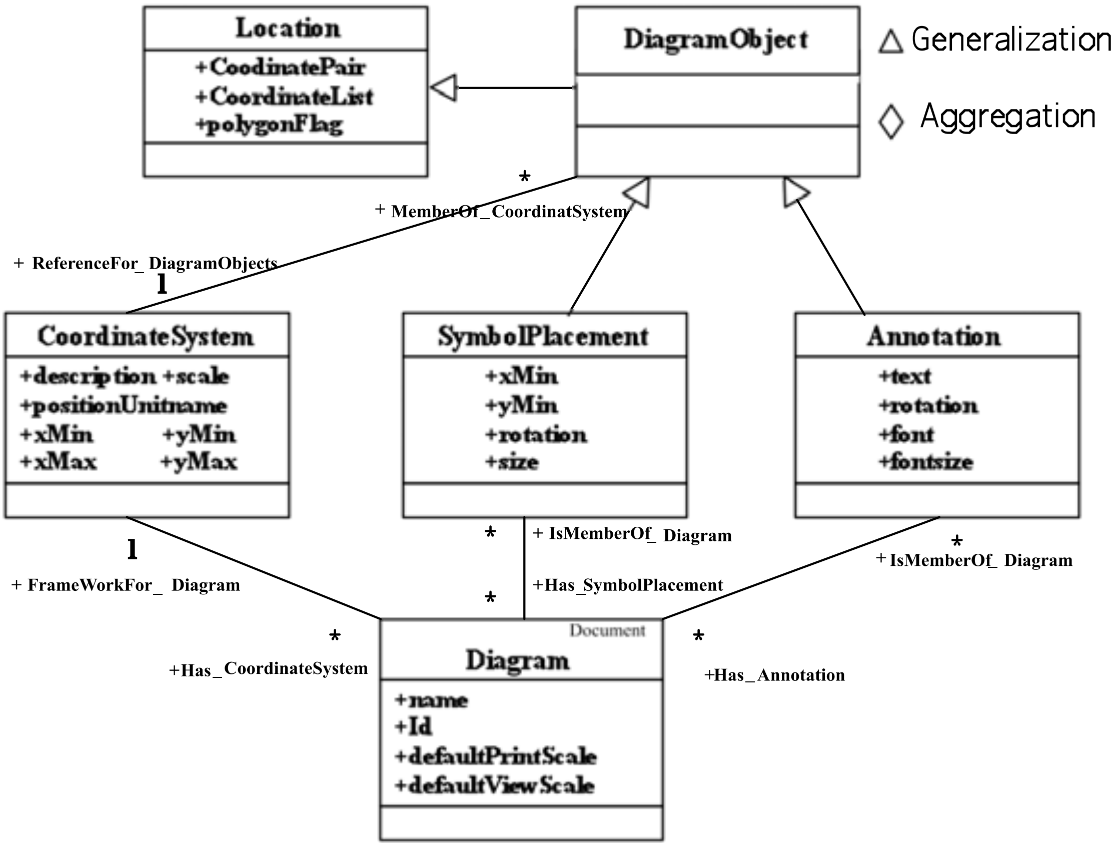

Fig.3 IEC 61968 Location Package

Location class can be reified into the Diagram Object class, which associates with the Coordinate System class to describe the coordinate system used in the graphics display. The scale, xMax, yMax, xMin and yMin attributions of the Coordinate System class define the basic scale information of the coordinate system.

Diagram Object class can be reified into Symbol Placement and Annotation classes. The Symbol Placement class describes the location of a graphics symbol in a graphics display, and the Annotation is used to display text strings or text fields of objects. Coordinate attribute of them shows the coordinate of the centric point of the graphics or annotation, and the rotation attribute shows the specified rotation degrees of them.

Diagram is a document that describes a set of Symbol Placements objects and Annotations objects in a graphics display. IEC 61968 defines the format of the diagram document as follows:

```
Diagram. name
Diagram.id
 CoordinateSystem.name
     CoordinateSystem.scale
     CoordinateSystem.description
     CoordinateSystem.xMin
     CoordinateSystem.yMin
  PowerSystemResource.IsAt.Location
  [0.*]
     SymbolPlacement.coordinate
     SymbolPlacement.coordinateList
     SymbolPlacement.polygonFlag
     SymbolPlacement.rotation
     SymbolPlacement.size
       Annotation.text
     Annotation.font
     Annotation.fontSize
     Annotation.coordinate
     Annotation.rotation
```

The document format is composed of three sections. The first one describes the basic information of the document (e.g. document name, document id). The second one introduces the information of the coordinate system used in the graphics display. The last section specifies the location information of the power system resources and the annotations in the graphics display. During graphics exchange process, the target system can get the same layout as the source system by the diagram document passed from the source system, and then uses its own graphics symbols to form a useful graphics display.

4 THE APPLICATION OF SVG IN GRAPHICS EXCHANGE

Developed by W3C, SVG is designed to take advantages of XML's open standard while offer the same multimedia capabilities of Flash. SVG is an XML-based open vector graphics to describe an image. SVG files are also XML files essentially. Hence, SVG has the potential to play an important role in the heterogeneous information exchange of power system together with CIM/XML. CCAPI recommend SVG as the standardized graphics format in power system graphics exchange.

In CCAPI graphics centric exchange approach, SVG graphics files, CIM/XML files and presentation logic are decoupled. In order to accord with such main idea, the definition and reference mechanism of graphics symbols supplied by SVG can be used. At first SVG graphics symbols can be defined, and then location information and presentation logic should be referenced to them when SVG graphics symbols are used in a graphics display. This mechanism facilitates the extraction of the location information in source system. Moreover, target system also can easily rebuild its useful graphics display with the location information from source system, its own graphics symbols and presentation logic.

4.1 SVG Graphics Symbols

Six basic graphics elements (e.g. line, polyline, rectangle, polygon, circle, and arc) are supplied in SVG. Graphics symbols of electrical devices can be described by the combination of the six basic graphics elements. However, different requirements of different applications lead to each domain object may have multiple graphics display. Hence, each application should build its own SVG graphics symbol and reference them to the CIM model.

Three elements of SVG, <defs>, <g> and <symbol>, can be used to define SVG graphics symbol. For example, a generator graphics symbol, which is described by a circle and an arc in it, can be built in SVG files as follow:

```
<defs>
  <symbol id=“Generator” Viewbox=“0 0 40 40”
    <desc> graphics of a generator </desc>
    <g Style=“fill:none; stroke-width:1”>
      <circle cx=“20” cy=“20” r=“20” />
      <path d=“M5,20 C5,10 20,10 20,20 S35,30 35,20”/>
    </g>
  </symbol>
</defs>
```

4.2 The Reference of the SVG graphics symbol, Location information and the Presentation logic

When the graphics symbols are defined, they will not directly appear in a graphics display until they are referenced by <use> element together with location information and presentation logic. Taking the generator defined in section A as an example, the reference of it is represented as follow:

```
<use id=”g1” transform=”translate (300,235)” xlink:herf=
        “#Generator” stroke=”red” />
```

In the graphics reference file the generator graphics symbol is firstly transformed to the coordinate (300,235), and then it is rendered by the red color to show that the generator is inactive. In graphics interoperation, coordinate information and work state information indicating the operating state of the generator can be extracted and passed to the target system. However, the presentation logic, that red color shows the work state of outage, should be replaced by the target systems, perhaps with yellow color or others.

4.3 The Coordinate Transform of SVG Graphics

The display scale of a same graphics display in different applications may be different. Hence, location information of the source system cannot be directly used in the target system. There are two cases that usually occur. One is that coordinate scales used in two systems are different. The other is that an application's graphics display may be only part of the other's in the process of graphics division or combination between superior and inferior power network control centers. Hence, the target system must transform the location coordinate information passed from source system according to their requirements.

Transform attribute of SVG can be used in <use> element to change coordinate, rotation angle and display scale of a graphics symbol. The type of the coordinate transform can be described by the expression and value of Transform attribute.

When coordinate scales of two systems are different, the scale transformation, transform="scale (sx, sy)", can be adopted to solve the problem. In the expression, sx and sy represents the proportional scale factor in coordinate X and Y between two systems, respectively. Attributes of xMin and yMin are from the diagram document provided from two systems. So the scale factors can be acquired from the ratio of xMin (yMin) between the target system and that of the source system.

In the case of the graphics division or combination between the superior and inferior power network control centers, the move transforms and the rotation transform should be used. The expression "transform="translate (x, y)"" can move the centric point of a graphics symbol to coordinate (x, y). The expression "transform="rotate (angle, cx, cy)"" can rotate a graphics symbol to an appropriate angle.

4.4 The Electrical Metadata of SVG Graphics Symbol

During graphics interoperation, the exchange of measurement information and work state information of each electrical device are also important besides location information. Standardized format of them is also a key to reach consistent comprehension. The <metadata> element of SVG can add that information to SVG graphics symbol. The common format of that information is defined in IEC 61970-453[7], which is shown in fig.4.

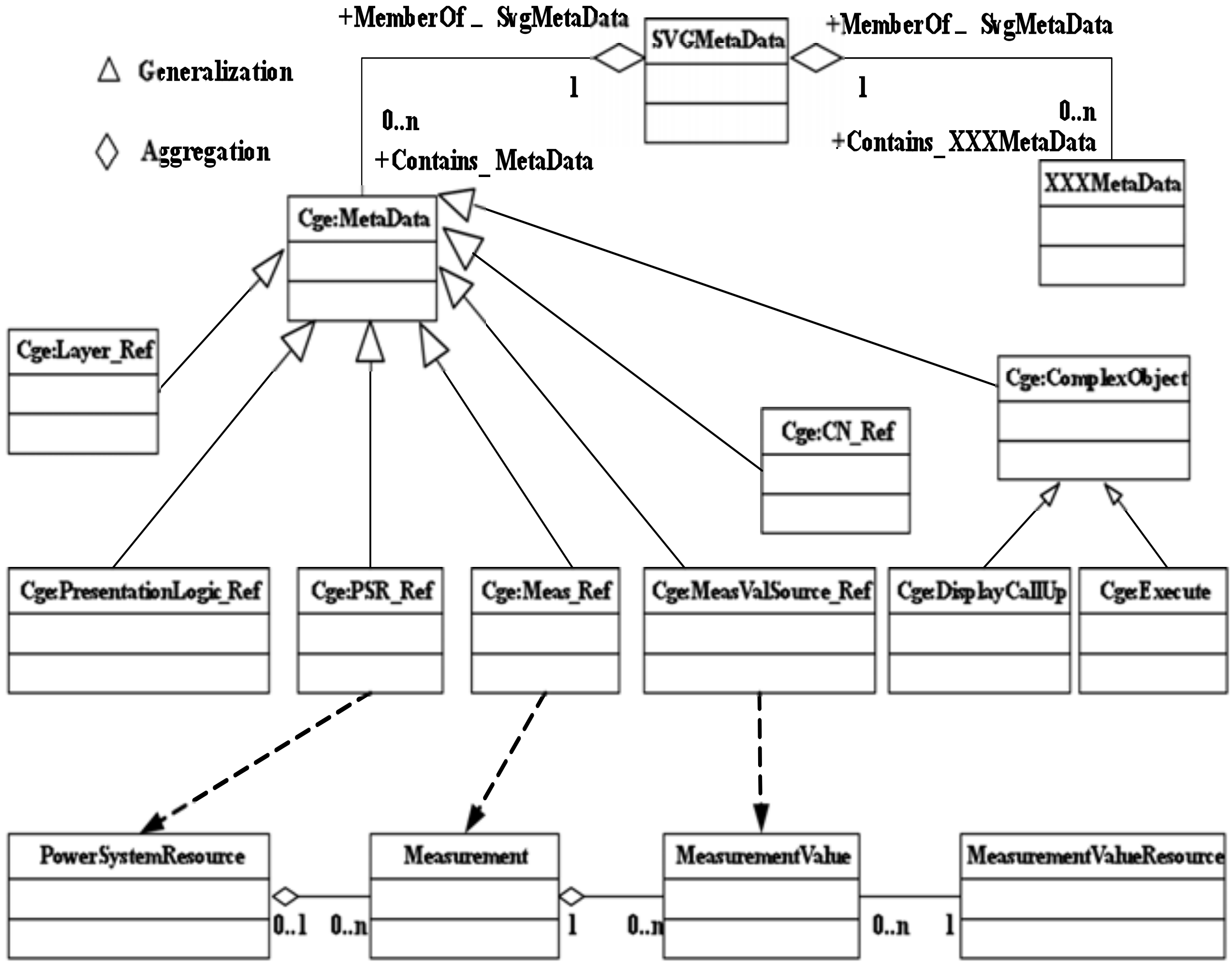

Fig.4 Metadata Model and References to CIM Classes

In the figure, Cge: layer_ref class figures out the graphics layer that the SVG symbol object belongs to. Cge:PSR_Ref class shows the CIM PowerSystemResource class that the SVG symbol object associates with, and the ClassID and ClassName attributes of the Cge:PSR_Ref class can be used to build the relationship between SVG graphics object and CIM object. Cge:Meas_Ref class and Cge:MeasValSource_Ref class associate with the CIM Measurement and MeasurementValueSource class respectively to describe the measurement value and its source related to each SVG graphics symbol. The private attributes defined by each application can be described by xxx: metadata class in an appended namespace.

Cge:CN_Ref class in the metadata model is a very important class, which associates with the CIM ConnectivityNode class to describe the graphics display topology. Each graphics symbol of electrical device or device container may have one or more Cge:CN_Ref instances. If two Cge:CN_Ref instances in different graphics symbol relate to the same ConnectivityNode, it can be inferred that they are conjoint. By this way, the topology of the graphics display can be easily analyzed.

5. THE GRAPHICS CENTRIC PUBLISH/SUBSCRIBE ASYNCHRONOUS EXCHANGE APPROACH

With IEC 61968-location package and metadata model of SVG graphics symbol, the exchange information in graphics interoperation can be standardized. However, the efficiency of exchange also depends on the exchange mode adopted.

Nowadays, information exchange is mostly based on a synchronous request/reply mode [8, 9]. In the mode, when target system asks for graphics information, source system will pass all information. The amount of exchanged information may be very huge and redundant. Herein, an asynchronous graphics exchange mechanism based on publish/subscribe architecture is presented, which can greatly reduce the information redundancy and enhance the exchange efficiency.

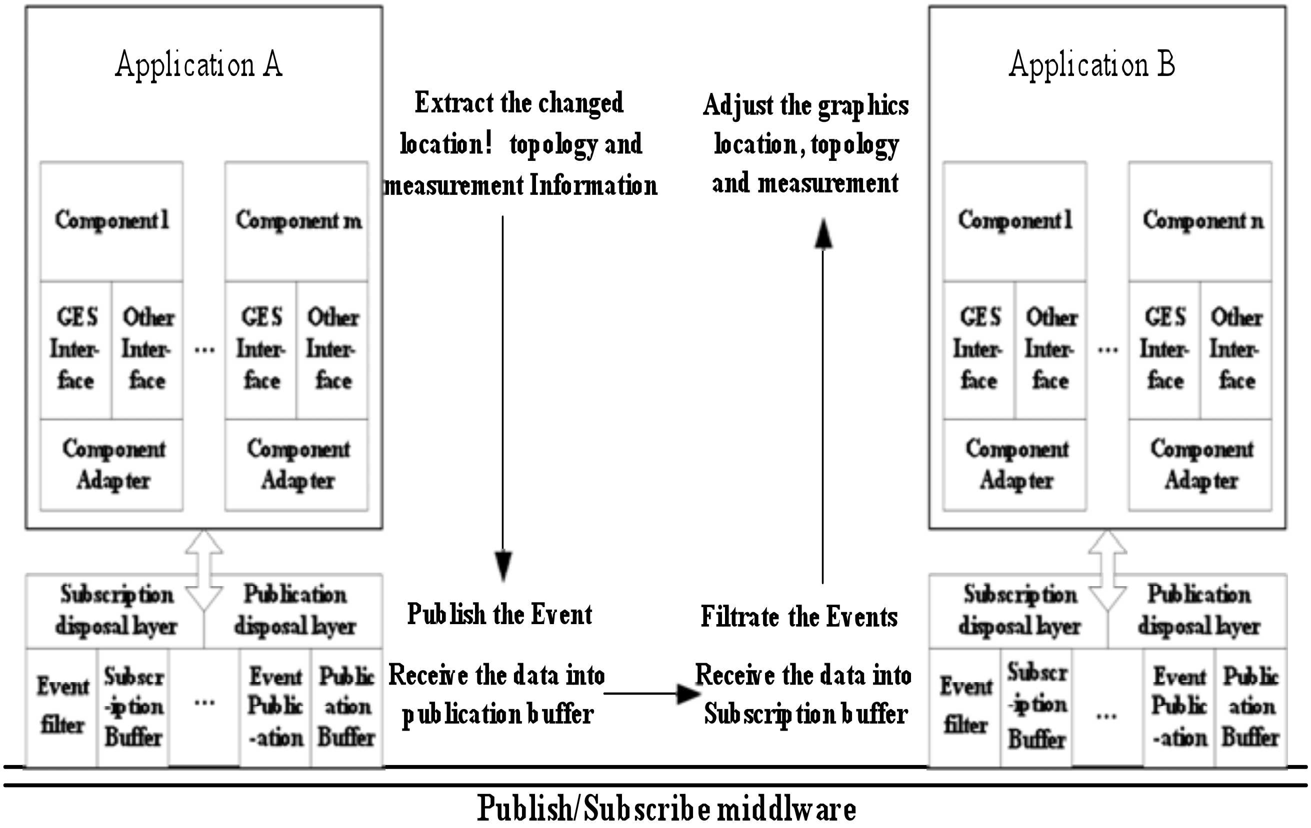

Fig.5 Publish/Subscribe Asynchronous Graphics Exchange

In the asynchronous mode, each application component only needs to publish or subscribe message to the publish/subscribe middleware, and then asynchronous graphics information exchange can be realized by the middleware. The information exchanged in the mode is called event. Each event has a theme that can be consistently understood by each application component. At first, source application can publish some event themes, and target applications may subscribe a part of them. When some changes that accord with an event theme happen, source application will publish the event to middleware. Then the middleware will pass it to all applications that have subscribed it [10]. Hence, this mode can be introduced into the graphics information exchange to improve the exchange efficiency. The graphics centric exchange approach based on publish/subscribe mode is illustrated in fig.5.

In order to explain the application of SVG metadata and location information in the asynchronous publish/subscribe graphics centric approach, an example of a power plant's graphics information exchange between application A and B is illustrated in fig.6. Suppose that the application A is software of the power plant, and the application B is another software in the superior control center of the plant. The graphics display of the plant in the application A may be part of the application B's graphics.

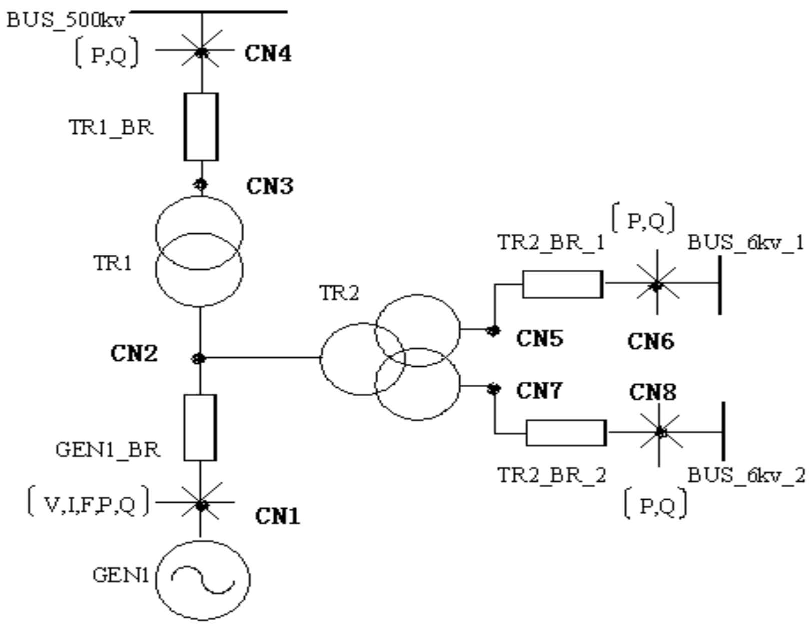

Fig.6 connectivity network of a power plant

Before graphics exchange, application A should define some event themes, such as the event of all location, measurement and topology information, the changed location information, the changed measurement information, the changed topology information and so on. Then the graphics exchange proceeds as follow:

1) Before the first exchange of the graphics information, application B may have nothing about the graphics and measurement information of the power plant. Application B should subscribe the event theme of all location, measurement and topology information. When application A receives the request, it will pass all the data according to the standardized format of the SVG metadata model and the diagram document to middleware as soon as possible. Then application B acquires them from the middleware and parses them with DOM tool to form a useful graphics display. Taking the two Breaker in figure 6,GEN1_BR and TR2_BR_2, as an example, the diagram document may be described as follows:

```
<Diagram name="all_location" id = "2007111656">
    <coordinatesystem>
      <name>X/Ycoordinatesystem</name >
         …….
    </coordinatesystem >
    <PowersystemResource.IsAt.Location>
          <GEN1_BR coordinate="(116,568)" Rotation="90" polygonFlag=true……/>
          <TR2_BR_2 coordinate="(356,568)" Rotation="0" polygonFlag=true……/>
       …….
    </PowersystemResource.IsAt.Location>
</Diagram>
```

2) After the first exchange, application B can subscribe the event themes of the changed location, measurement and topology information. When the above events happen, application A will ask publication module to publish those changed information, and classify the data into different documents according to

different events. The changed location information should be written into a XML document complying with the format of IEC 61968 Diagram document. The changed topology and measurement information should form a document according to the SVG metadata model. For example, assume that P and Q of the generator in the fig.6 changes, application A may form a metadata document as follows:

```
<Symbol1 id="GEN1_BR">
  <metadata>
    <cge:PSR_Ref ID="GEN1_BR" Name="Breaker"/>
    <cge:CN_Ref ID="CN1"/>
    <cge:CN_Ref ID="CN2"/>
  </metadata>
</Symbol1>
<Symbol2 id="GEN1">
  <metadata>
  <cge:PSR_Ref ClassID="GEN1" ClassName="Generator"/>
    <cge:CN_Ref ID="CN1"/>
    <cge: MeasValSource_Ref Name="SCADA"/>
    <cge: Meas_Ref ID="P" MeasType="ActiveEnergy"/>
    <cge: Meas_Ref ID="Q" MeasType="ReactiveEnergy"/>
   …….
  </metadata>
</Symbol2>
```

Application A may also build a document to describe the value of the changed measurement:

```
<cim: Generator id= GEN1 P=300000/>
<cim: Generator id= GEN1 Q=225000/>
```

When the publication module agrees the requst of application A , it will publish the event and send all the data documents to the transmission buffer.

3) When application B received the events theme published by A, by the event filter module it will judge whether the events have been subscribed. If subscribed, application B will receive the data document in the transmission buffer of application A. Then application B will dispose them respectively according to different event themes:

- Disposal of the changed location information

Taking the above Diagram document in section 1) as an example, application B can firstly extract two breaker's coordinate (116,568) and (356,568). Then application B can choose some appropriate coordinate transform to modify the two coordinates according to the different display requirement of the two applications. Application B can place his own breaker graphics symbol in the new coordinates. At last, application B should rotate the GEN1_BR breaker to the vertical orientation and the TR2_BR_2 breaker to the horizon orientation according to the angle described by the rotation attribute in the Diagram document.

- Disposal of the changed topology information

Topology change information can be acquired by parsing SVG metadata document. For example, by analyzing the above metadata document in section 2) with DOM, it can be inferred that the GEN1_BR breaker and the GEN1 generator are connected because they both have a CN-Ref instance associated with connectivity node CN1.

- Disposal of the changed measurement information

Measurement change information can be got from metadata document and measurement change document. Also taking the above documents in section 2) as an example, by analyzing the metadata document it can be acquired that the symbols P and Q represent the active energy and the reactive energy respectively and the value of them gets from the SCADA. Then from the measurement change document new value of the P and Q can be acquired. At last, the value of the P and Q in the generator's annotation label should be refreshed.

6. CONCLUSIONS

This paper studies the power system graphics centric exchange based on location package and SVG, and proposes an asynchronous publish/subscribe exchange mode to reduce the redundant exchange information and improve the exchange efficiency. Firstly the location package in IEC61968 is described, with which the location information exchanged in the graphics centric approach can be standardized. Secondly, the SVG metadata model is introduced. By the metadata model a SVG graphics symbol object can easily associate with a CIM object, and the topology of the graphics display can be simply acquired. An asynchronous publish/subscribe exchange mode is proposed. In addition, an example of the graphics exchange on a power plant is presented to explain the application of the SVG metadata and location information in the asynchronous publish/subscribe graphics centric approach.

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BIOGRAPHIES

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