

DOE Award DE-FC02-05CH11327

**Development of an Enhanced GenVARRTM
(Generator Volt Ampere Reactive Reserve) System**

**Final Report
March 2007**

**Southern Company Services
600 North 18th Street
Birmingham, AL 35203**

Principal Investigator
J. Schatz

I. Abstract / Executive Summary

This final report details the components, functionality, costs, schedule and benefits of developing and enhancing the Southern Company's GenVARR™ system for power system operation. It will also represent the experience of Southern in the implementation of the GenVARR™ upgrade project.

Transmission system operators require near real time knowledge of reactive power capability to reliably operate large electric power transmission systems. Reactive power produced by, or capable of being produced by, a power generator is often estimated based on a series of mega volt amperes (MVA) capability curves for the generator. These curves indicate the ability of the generator to produce real and reactive power under a variety of conditions. In transmission planning and operating studies, it is often assumed, based on estimates for these capability curves, that the generator can provide its rated MVA capability output when needed for system stability

However, generators may not always operate at levels depicted by the maximum MVA capability curve due to present constraints. Transmission system operators utilizing the generators' capability curves for operation decisions regarding transmission system stability or for planning horizons may overestimate the capability of the generators to supply reactive power when required.

Southern Company has enhanced GenVARR™, the system of plant data query, retrieval, and analysis and calculates the actual – not estimated -- remaining reactive power output capability. The remaining reactive output is considered spinning reserve and is displayed graphically to transmission control center and generating plant operators to identify real time VAR limits. GenVARR is capable of aggregating generators from a defined region, or other user selectable combinations, to represent the available reserves that the operators are specifically interested in.

GenVARR™ has been put into live production operation and is expected to significantly improve the overall visibility of the reactive reserve capability of the system. Next steps include review of commercialization possibilities of GenVARR™ includes the use of the Electric Power Research Institute to promote this product and application to other interested utilities.

This new version of GenVARR™ significantly enhances the products structure and performance, and enables links to other key transmission system operation tools.

II. Project Description

Transmission system operators require near real time knowledge of reactive power capability to reliably operate large electric power transmission systems. Reactive power produced by, or capable of being produced by, a power generator is often estimated based on a series of capability curves for the generator. These curves indicate the ability of the generator to produce real and reactive power under a variety of conditions. In transmission planning and operating studies, it is often assumed, based on estimates from these capability curves, that the generator can provide its rated MVA capability output when needed for system stability

However, since operating generating plants at conditions needed to produce more reactive power can result in higher operating costs, generators may not always operate at levels depicted by the maximum MVA capability curve. Transmission system operators utilizing the generators' capability curves for operation decisions regarding transmission system stability or for planning horizons may overestimate the capability of the generators to supply reactive power when required.

Southern Company has developed a system of plant data query, retrieval, and analysis trade-named GenVARR™, which samples real time data from generating plants and calculates the actual – not estimated -- remaining reactive power output capability. The remaining reactive output is considered spinning reserve and is displayed graphically to transmission control center and generating plant operators to identify VAR limits that are based on generator capability or plant station service voltage.

Southern Company Services, through funding assistance from the US Department of Energy, is upgrading its first version of GenVARR™ to significantly enhance its structure and performance, and enable links to other key transmission system operation tools. Development of the upgrade/enhancement of the Generator Volt Ampere Reactive Reserve (GenVARR™) application for power system operation in the .NET software environment is completed, and it will continue to provide near real time knowledge of reactive power capability to reliably operate large electric power transmission systems. GenVARR™ allows system operators to determine the real-time VAR reserves thus providing more accurate operating information than traditionally assumed based on generator capability curves. The upgrade in a more modern and robust software platform was necessary to improve performance and also position GenVARR™ for future links to other transmission systems with additional functionality and to make it into a more generic application for potential use by other utilities.

III. Overview of the Project and Final Report

This is the Final Report of the GenVARR™ Project and includes completed project information, expenditures to date and future plans. The project had the initial go ahead given by DOE while under negotiations with the contracting phase. Work initiated in September of 2005 and this version of GenVARR was put into production use has been

underway since then, initially at a slowed pace until contracts and the Advance Waiver of Patent Rights documents were approved.

The “Key Deliverables” that are part of this GenVARR™ project include:

1. Rewrite existing GenVARR™ software in .net application format for implementation within Southern Company that in a later phase could potentially be made available to a commercializer to license the software externally.
2. Develop and establish baseline evaluations of the existing GenVARR™ application to use as comparison with the newly developed GenVARR™ deliverable.
3. Develop methods to sample specific generators or an aggregated number of generators to monitor and address reactive reserve for user defined areas.
4. Develop methods to visually display outputs from GenVARR™ and link to other forms of visual transmission operation (wide area view) displays and incorporation of a historical look-up graphical display.
5. Develop methods to output the results of GenVARR™ analyses to be imported and utilized in other utility applications such as State Estimation load flow.
6. Demonstrate and showcase the capabilities of the GenVARR™ software tool to interested parties and utility operators.

These deliverables are not progressive activities and many activities required to complete these deliverables were worked on simultaneously and in a parallel fashion.

Following are some of the progressive accomplishments which were reported on GenVARR™ throughout the progressive reporting periods in the development cycle of the GenVARR tool:

- Design and construction of the code generation shell template and drivers for GenVARR™.
- Analyzed, designed and prototyped the help and tool tips.
- Reviewed and approved design at the 50% mark.
- Design of the GenVARR™ banner.
- Prototyped 43 screens in .net ASP 2.0 including voltage information, miscellaneous, charts and help screens.
- Completed the analysis, including security requirements, project estimate and project work plan and the sponsor approved the analysis package.
- Reviewed the infrastructure requirements and installed a .net 2.0 development server, moved the GenVARR™ prototype to the development server, set up live feeds from EMS and Plant OIS to GenVARR™ prototype and demonstrated.
- Designed batch process, interfaces, methods, use cases, object model, security, implementation plan, data and data base model, master page, them, style sheet, web services, test strategy and test baseline test.
- Set up BugNet in preparation for user testing.
- Constructed the development data base.
- Continued construction of the generic Code Gen, which was used as the foundation for the GenVARR™ application

- Conducted a review meeting with DOE and received approval to proceed as planned.
- Added an additional developer to the project team to get through some high activity areas.
- Reviewed and approved BugNet as the tool of choice for User Acceptance Testing.
- Completed construction of the SoCo Code Generator, deployed and integrated into GenVARRTM and tested code generation providers on GenVARRTM batch, online and security processes.
- Constructed and tested the plant and Energy Management System import process.
- Completed all design on user screens and charting information screens
- Completed test plan templates and partial system test plans.
- Completed 100% design reviews and 50% code reviews and made appropriate changes resulting from those reviews.
- Completed and tested the following: charts, unit overrides, area voltage schedule & change log, voltage variations, plant voltage exception & change log, default application settings, low and medium voltage systems and help screens/objects.
- Completed the analysis, constructed and then tested the system for security.
- Planned and developed the Information Technology stress test.
- System tested voltage information, charts, areas and voltage schedule.
- Developed the first draft of the complete implementation plan.
- Prepared and documented the user acceptance and production environments, maintenance agreements and release strategy.
- Prepared user test plans and set up a user test team.
- Documented GenVARRTM overview and explanation of concepts and added to help menu
- Started testing code generation providers in a non Southern Company environment
- Completed user test of GenVARRTM
- Conducted final BatLab test for certification and deployment to production.
- Deployed to production, IT and key users checked it out
- Defined release 1.1 functionality
- BatLab certified and deployed release 1.1
- Started IT and key user check out of release 1.1.
- Went live in production environment on October 5, 2006

The above accomplishments kept the project moving at the scheduled paced and the project was put into a “Go Live” deployment on October 6th, 2006.

Much of the anticipated accomplishments around the .net application of GenVARRTM, besides the ability to offer the application in a more generic approach, were for an overall enhancement to the performance. This was accomplished as detailed in the following description of the stress tests and baseline evaluations between the prior application and the .net GenVARRTM application.

Benchmark Test Overview

The benchmark test involved comparing the performance of the prior Gabrielle interface GenVARR™ application with the new .net GenVARR™ application. The stress test focused on measuring and observing the performance of the new GenVARR™ system under various load conditions.

The goal of the benchmark test was to observe and reliably measure the performance differences between the new .net GenVARR™ application and the existing Gabrielle GenVARR™ application.

The first decision that had to be made was to determine which sections of the application would be compared. While there are over 50 pages within the new .net GenVARR™ application, there is only one section which is heavily used. That section is the voltage information (summary) pages. Upon logging in, a user is defaulted to the voltage information grid. This page refreshes automatically every minute. From that page, a user can click on one of 4 charts. These charts are used frequently by the user to analyze the MVar for a given unit. The other sections of the application, which are the system operator and administrative pages, do not come under heavy use and do not have any charts associated with them. Thus, the voltage information grid and the four voltage information charts were selected to be the focus of the benchmark comparison test.

Next, the environment that would be tested for each application was considered. At the time of the test, the new .net GenVARR™ application was not available on a production environment, thus the development servers (GenVARR -DV) were used in the test. It is expected that the production environment, given better hardware, would give even better performance numbers than the development environment for the new .net GenVARR™ application. The production Gabrielle GenVARR™ application is only available from its production server.

The test scenario was simple. One (virtual) user would log in to the system, navigate to the voltage information grid, launch each chart, and then refresh the voltage information grid. A complete user cycle would generate two hits on the voltage information grid page and one hit on each of the four charts. A test session would last between one and two minutes, with the user starting a new cycle whenever finishing a cycle until the test end was reached. The test was executed multiple times. The results were very consistent for the new .net GenVARR™ application. There was a much wider discrepancy for the Gabrielle GenVARR™ application. In all cases, the new .net GenVARR™ user application (UA) significantly outperformed the existing production application. A table of the average response time is shown below:

GenVARR vs. Gabrielle Production Benchmark Test – 1 GenVARR User vs. 1 Gabrielle User

Test Section	GenVARR-DV	GenVARR-UA	Gabrielle
Gen Curve Chart	1.31	1.29	27.96
GSU Chart	0.92	0.92	15.76
Bus Chart	0.51	0.53	8.52
History Chart	1.26	1.19	11.11
Voltage Info Grid	0.37	0.62	2.14

Average Response Time (seconds).

After analyzing the above results, some thought was given to the Gabrielle production environment. Since this was a production environment, the Gabrielle GenVARR™ application could be experiencing additional production load from current logged-on users. That user load could account for some of the differences between the two systems. A query determined that there were 7 users logged into Gabrielle with permissions to the Voltage Info page and charts. While it is very unlikely that each of these users were accessing the charts and voltage info grid in a comparable manner to the heavy use from the virtual user, it was decided that the number of test users on the new .net GenVARR™ application should be increased to at least match the number currently using the Gabrielle application. As a result, another round of testing was performed with an increased user load on the new .net GenVARR™ application and still only one user on the Gabrielle system. The new tests consisted of 10 .net GenVARR™ users vs. 1 Gabrielle user and then 20 .net GenVARR™ users vs. 1 Gabrielle user. The results of these tests are shown below:

GenVARR vs. Gabrielle Production Benchmark Test – 10 GenVARR vs. 1 Gabrielle Users

Test Section	GenVARR-DV	GenVARR-UA	Gabrielle
Gen Curve Chart	3.80	2.27	34.1
GSU Chart	2.97	1.59	16.6
Bus Chart	1.77	1.05	9.01
History Chart	3.51	1.78	15.2
Voltage Info Grid	0.50	0.87	2.04

Average Response Time (seconds).

GenVARR vs. Gabrielle Production Benchmark Test – 20 GenVARR vs. 1 Gabrielle Users

Test Section	GenVARR-DV	Gabrielle-UA	Gabrielle
Gen Curve Chart	5.74	3.80	29.6
GSU Chart	4.77	3.03	16.9
Bus Chart	3.81	2.45	9.55
History Chart	5.64	2.80	14.2
Voltage Info Grid	0.99	1.55	2.14

Average Response Time (seconds).

These last two sets of tests show that even when the new .net GenVARR™ system is under heavier load (thus accounting for all possible production load that the Gabrielle system might have been experiencing in the first set of tests), it still significantly outperforms the existing Gabrielle GenVARR™ application.

The detailed results of the above tests are a part of saved data files.

Stress Testing

The goal of the stress test was to observe and determine the performance of the system under increasing user loads. The same tool that was used for the benchmark test was utilized in the stress test. The two focus areas were once again the charts and the main voltage information page.

To that end, four sets of stress tests were executed, consisting of 20, 50, 100, and 200 users. For the first 3 tests, the users were added at a rate of one per second for each test until the maximum was reached. For the final test of 200 users, all the users were unleashed on the system at the very beginning. The duration of each test was set to 2 minutes.

The response time of all charts were averaged to obtain a chart measurement. The results are summarized in the table below:

GenVARR Production Stress Test

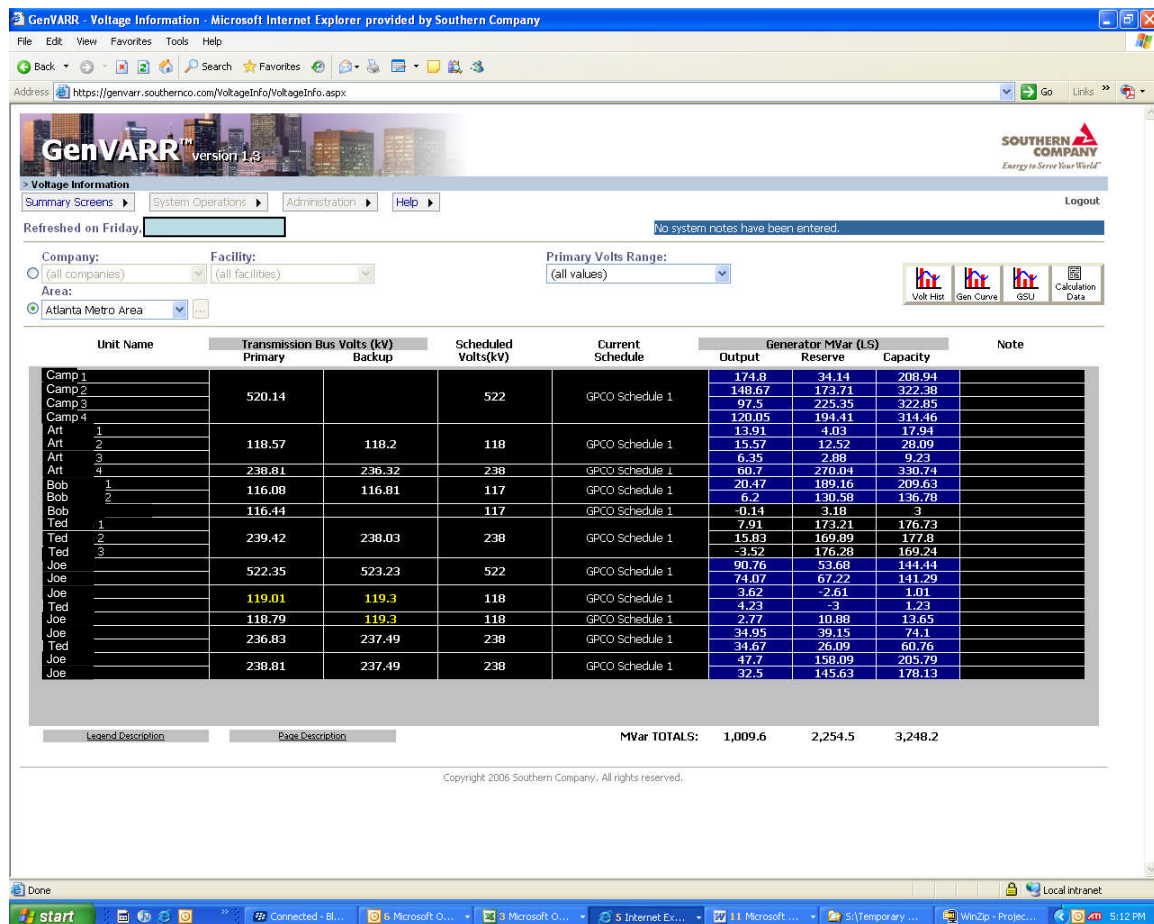
Test Section	GenVARR-DV	GenVARR-UA
Chart – 20 users	4.99	3.02
Chart – 50 users	3.50	4.64
Chart – 100 users	7.79	3.80
Chart – 200 users	13.39	13.10
Grid – 20 users	0.99	0.63

Grid – 50 users	2.28	0.68
Grid – 100 users	2.83	0.71
Grid – 200 users	3.02	2.80

Average Response Time (seconds).

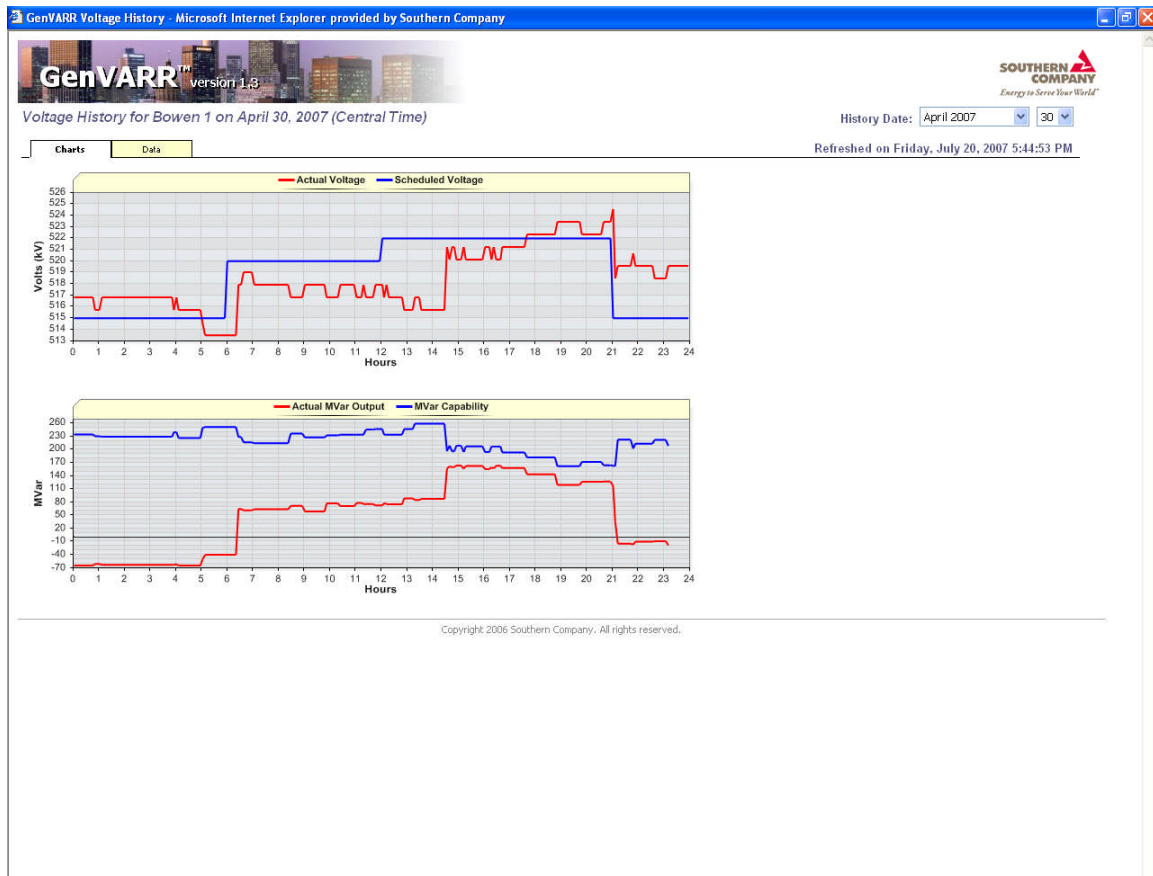
From the results above it appears that the response time on the charts starts to rapidly decay between 100 and 200 virtual users. An important note is that the virtual users which were set up for this test would be exercising the charts far more than a typical GenVARR™ user would. If 200 typical users were logged in to .net GenVARR™, the chart usage would be nowhere near what it was with the 200 virtual users. The voltage grid response time held up well, even with the 200 virtual users test.

Some examples of overall use and applicability in the transmission operation environment are show in the following screenshots and application pages.



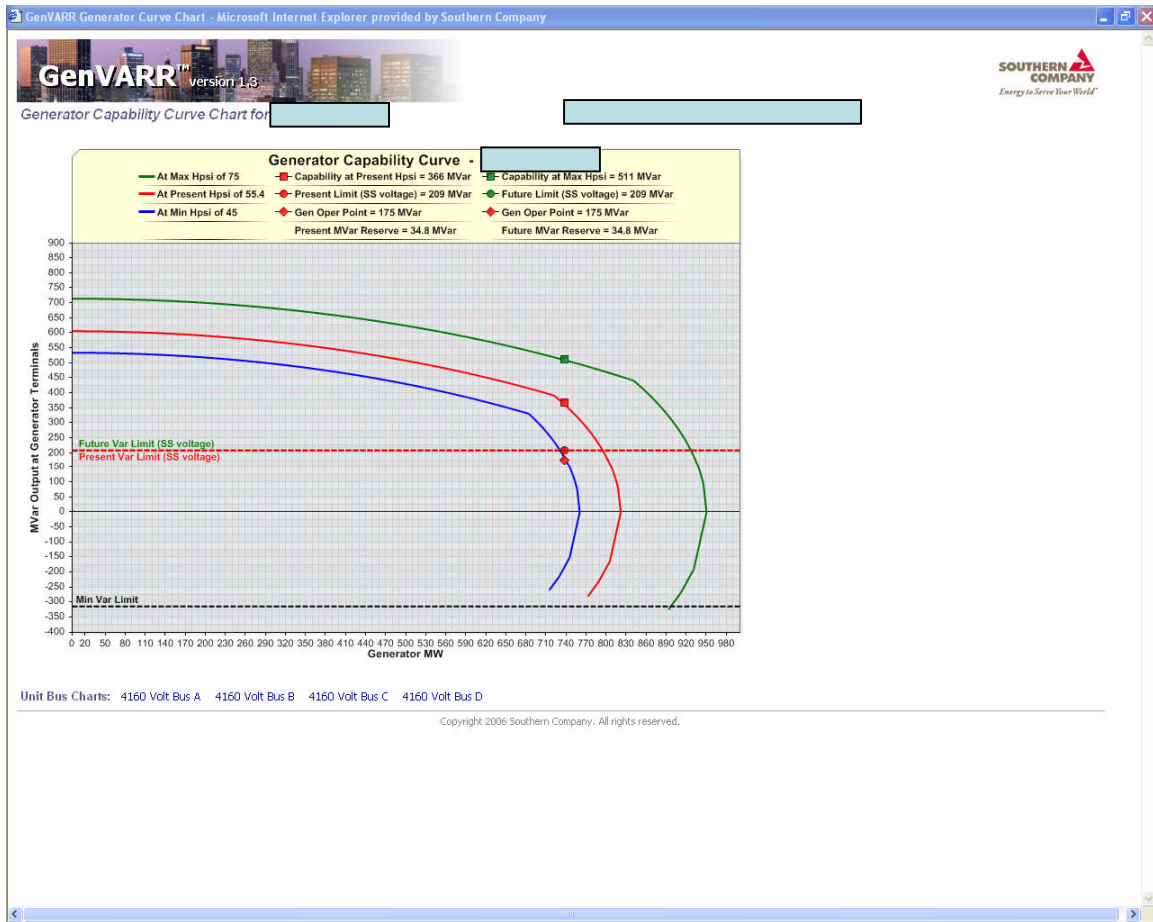
Screen Shot 1 – Regional Voltages and Voltage Schedule

Screen Shot 1 is a regional set-up view which displays the measured voltage, the scheduled voltages and current VAR output and capabilities of each unit in the region selected.



Screen Shot 2 – Voltage and VAR History

Screen Shot 2 is a historical display of an individual unit showing the actual voltage and the scheduled voltage on the top graphical display and the bottom graph displays the trend of the VAR capability and actual VAR output of the same unit.



Screen Shot 3 – Generator Capability Curves

Screen Shot 3 is a graphical display of the Generator Capability Curves which shows many pieces of information in a single graphical view. This includes the present operating point on the MW and MVAR output curves, the maximum VAR output based on Station Service voltage and the levels of possible VAR output based on three possible hydrogen operating pressures. This display indicates that the VAR output is limited by the station service voltage.

IV. Project Milestone Summary

The GenVARR™ Project Gantt Chart is shown in Figure 1. The project baseline is shown as the solid black line beside each project task with the expected milestone displayed as a solid triangle at the end of the line. The actual and percent complete is shown on the top bar of each listed task and the completed and revised milestones are displayed as appropriate. Deployment of GenVARR™ at Southern Company was completed on October 5th, 2006 - a 3 week improvement over the original schedule. A Ribbon Cutting Ceremony to showcase the deployment of GenVARR™ with the DOE was held on March 16, 2007 in Birmingham, AL. Project demonstrations and showcasing of the application are anticipated with other interested utilities and will continue to be scheduled.

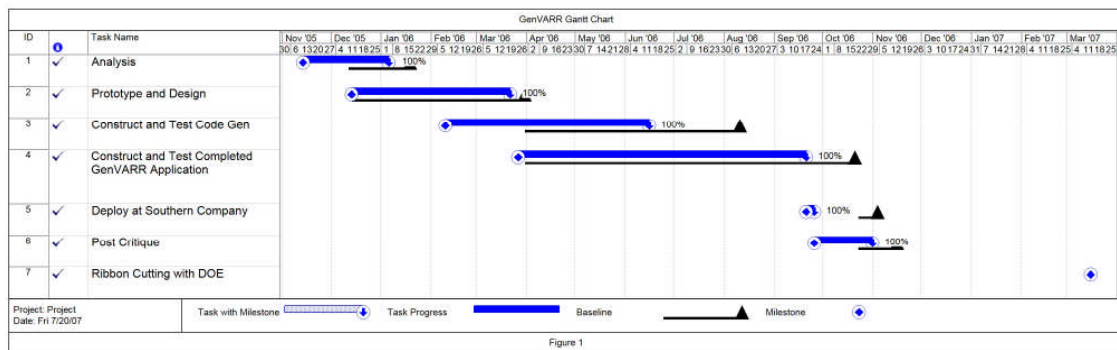


Figure 1. GenVARR™ Project Gantt Chart

V. Project Expenditures

Total recorded project costs through the end of the project are approximately \$521,849 which includes all labor, expenses and allowable OH and fringe benefits. This is under budget from the original estimate and contracted amount for the complete project which was \$663,979. The approved split for this complete project estimate and contracted budget was as follows:

DOE Portion (60.2%):	\$400,000
Cost Share (39.8%):	<u>\$263,979</u>
Total :	\$663,979

Based on these agreed to percentages and the Cumulative Project Costs, the final budget breakdown is as follows:

DOE Portion (60.2%):	\$314,153
Cost Share (39.8%):	<u>\$207,696</u>
Total :	\$521,849

VI. Next Steps

Further involvement with commercialization activities around GenVARR™ will include the use of the Electric Power Research Institute to promote this product and application to other interested utilities. This should lead to industry collaboration with a software entity that would like to commercialize the GenVARR™ tool and support it to the electric utility industry. Southern will attempt to set up a Tailored Collaboration with EPRI and another interested utility to move this product to another industry demonstration.