Enhancing Transmission Utility System Reliability Through Advanced Power Blackout/Brownout Mitigation Measures: A Georgia Case Study

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Presented at the
11th Asia Clean Energy Forum (ACEF) 2016
ADB Headquarters, Mandaluyong City, Philippines
June 6 – 10, 2016

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***Abstract*—Georgia experienced partial and total electrical blackouts for many years. The economic cost of total blackouts was around several million dollars per hour. The Transmission Operator (GSE) applied new technologies to address the known causes of electrical blackouts. An inexpensive country-wide emergency control system (ECS) was implemented by GSE, which successfully prevented power system total blackouts five separate times in the two weeks, immediately after its implementation. The technological solution was first implemented on a 500kV transmission line which included the national power system's most critical locations. Blackouts were reduced to almost nothing after adoption of the new technologies. Return on investment includes millions of dollars saved for each blackout prevented. Georgia has subsequently become an electrical power transit hub in the region given its new capabilities to prevent blackouts, raising system reliability, and increasing its national power grid stability, even during times of power generation shortages.**

I. Introduction

A. Georgian State Electrosystem (GSE) (Fig. 1)

Georgia is located at the intersection of Eastern Europe and West Asia and considered to be part of Europe. It is bounded to the west by the Black Sea, to the north and northeast by Russia, to the south by Turkey and Armenia, and to the southeast by Azerbaijan. The electrical transmission system is operated by Georgian State Electrosystem (GSE). GSE is a 100% state-run T&D company.

GSE provides power transmission and dispatch services to eligible customers in Georgia which includes distribution companies. GSE is actively participating in power exchange operations with neighboring countries.

GSE has 500/400/220/110/35kV Overhead lines (OHLs) with the total length of 3,055km and 88 substations (500/220/110/35kV) with the total installed capacity of 10,213 MVA.

GSE has two (2) subsidiaries: Energotrans Ltd. (100% GSE shareholding) and Karchal Energy (99% GSE shareholding).

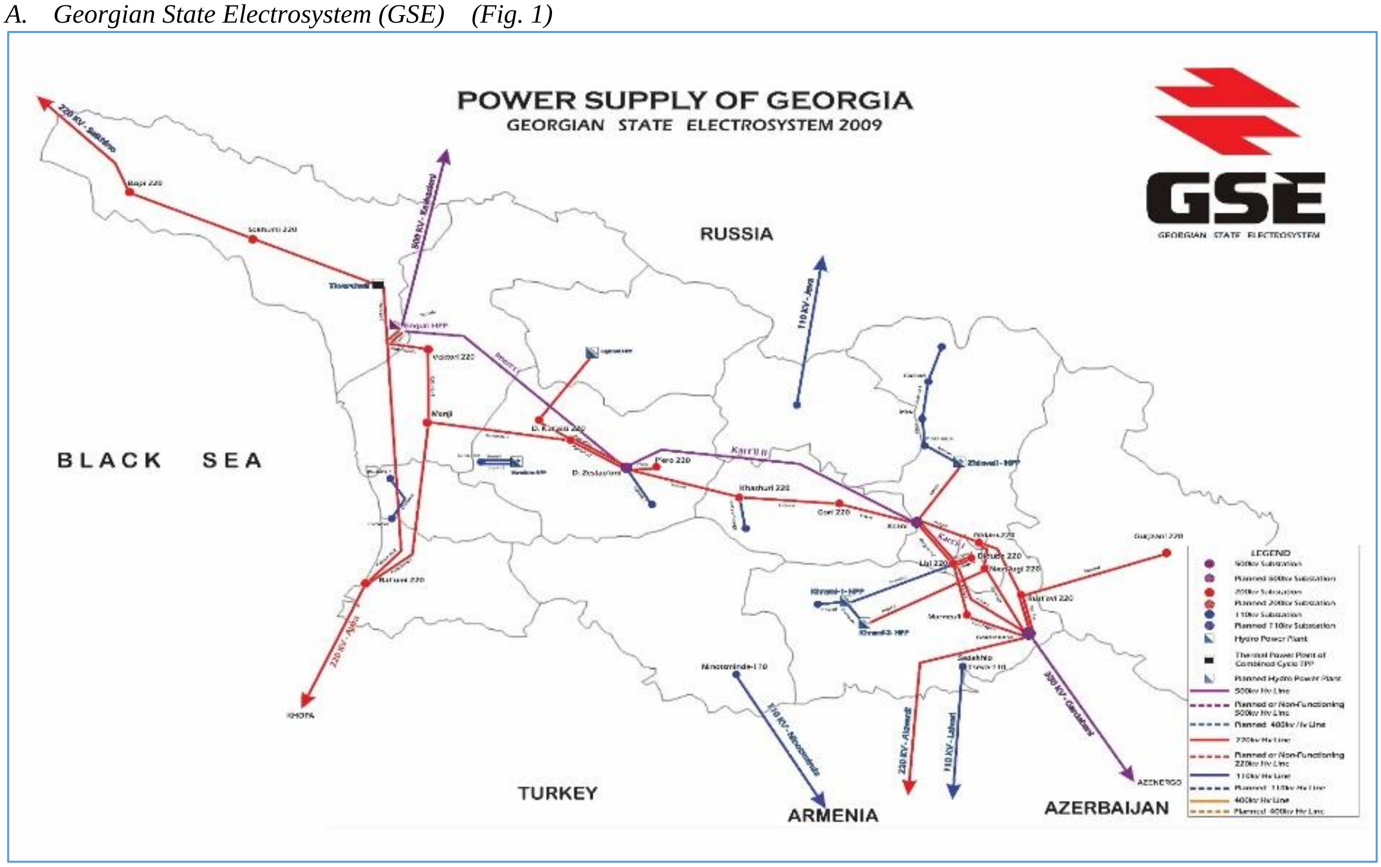

Fig. 1 (GSE)

B. GSE Customers

Since GSE is the transmission company and transmission operator in Georgia, they provide electricity to three main Distribution System Operators (DSOs). There are many other important customers such as railway, water, and power companies. Any blackouts in the Georgian transmission systems will disrupt almost the entire country that supplies electricity to the Georgian population and other major utility companies. Blackouts that occur during the wintertime are a major problem for the general population's heating service.

Below is a listing of major customers:

- Distribution System Operators (DSOs):
  - Telasi, JSC;
  - Energo-Pro Georgia, JSC; and,
  - Kakhetis Energo Distributsia, JSC.
- Georgian Railway (GR)
- Large Manufacturers
- Georgian Manganese, LLC
- Other Utilities:
  - Georgian Water and Power, LLC
  - Rustavi Water Company, LLC

C. Major Problems for GSE to Resolve

The generation of power in Georgia is mainly out of the western part of the country which is primarily a large hydro plant. The largest electrical load is in Tbilisi which is the capital of Georgia and is located in the eastern part of the country. The country's electrical flow is from the west to the east.

The biggest problem with the transmission network is that there are only two (2) line networks that bring power to the east. One (1) is a 500 kV network and the other a 220 kV network. When the 500 kV line is opened (disconnected) either by environmental reasons (e.g. fire), overloads, or other reasons, then the 220 kV line cannot deliver all of the power required from west to east. The country goes into a blackout or brownout.

Fig. 2 shows the number and duration of blackouts/brownouts from 2003-2010 before the new technology was acquired.

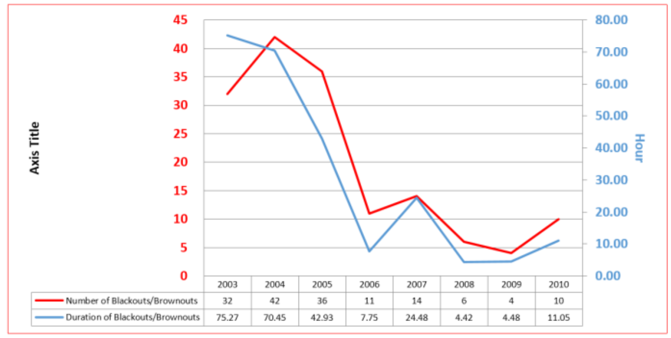

Fig. 2 Number and duration of blackouts/brownouts from 2003-2010 before the new technology.

GSE has experienced high temperatures with maximum loads in the power system, and in some situations the power system was separated and produced blackouts/brownouts. GSE had many power system separations during the years 1990-2000. In 2008-2009 GSE installed an optical ground wire (OPGW) cable (Fig. 3). In 2011, GSE acquired a remedial action scheme (RAS) system utilizing the OPGW infrastructure and a new communication multiplexer to provide an emergency control system for the blackouts and brownouts. The RAS system operated properly for the contingencies, and the system became stable and basically eliminated most of the blackouts and brownouts previously experienced. This was a project funded by USAID.

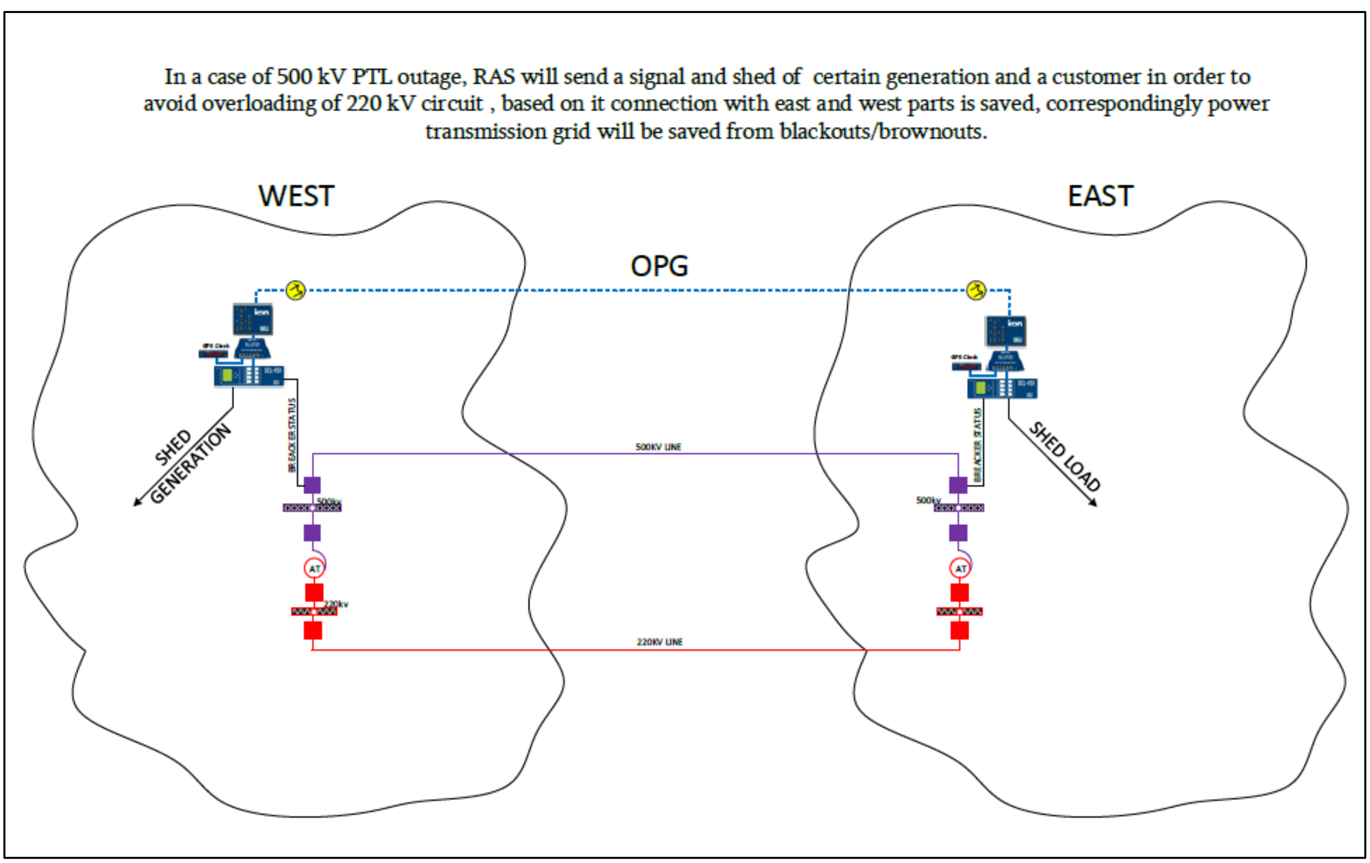

Fig. 3 500 kV PTL Outage Example)

D. GSE's Mitigation Approach to Power Outages

Georgia has become a power hub in this region that brings energy from Azerbaijan to Turkey. In order to have a reliable transmission network, GSE had to resolve the problems related to the blackouts and brownouts. The first step GSE took was to determine the root cause of its problems and then looked for new technologies, which would resolve their power outages. This process took several months of research with the results showing that when the 500 kV line is disconnected either by environmental reasons (such as fire), overloads or other reasons, then the 220 kV line cannot deliver all of the power required from west to east, resulting in the power system losing its stability.

Specifications were written describing the root cause. GSE then searched for a qualified supplier with the latest technologies to solve the problem. During the search, they found a supplier who introduced them to a reliable solution. This solution was implemented with the new technology and was a complete and immediate success.

The GSE transmission network has become very reliable, and resulting in making it available as transmission corridors to allow for the exchange of electric power between neighboring countries. Since Georgia also has gas and oil pipelines running from the Caspian Sea to Europe, a reliable electrical transmission system guarantees that the pipelines can operate without interruption. Finally and most importantly, the Georgian population is benefiting from more reliable electricity. The RAS has been operating for more than 5 years.

E. Results of the RAS Implementation

Fig. 4 illustrates the benefits Georgia has experienced since 2010 by implementing the new technology. The RAS has significantly reduced the blackouts to only one (1) and substantially reduced the number of brownouts.

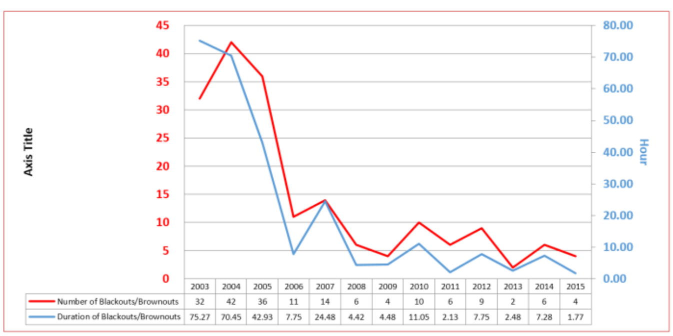

Fig. 4 Blackouts and Brownouts after Implementation of New Technology

Figs. 5, 6, and 7 show the RAS operations for the last three (3) years to prevent blackouts and brownouts. These figures indicate that without the operation of the RAS, GSE would have continued to experience blackouts and brownouts with the durations shown prior to the implementation of the new solution.

When a contingency happens (such as a transmission line opening), the RAS system would operate to maintain stability of the system. From the figures above, the RAS system prevented: 14 Blackouts and 11 Brownouts in 2014; 3 Blackouts and 15 Brownouts in 2015, and so far in 2016 3 Blackouts and 6 Brownouts. Since 2014, therefore, a total of 20 Blackouts and 30 Brownouts were prevented by the RAS.

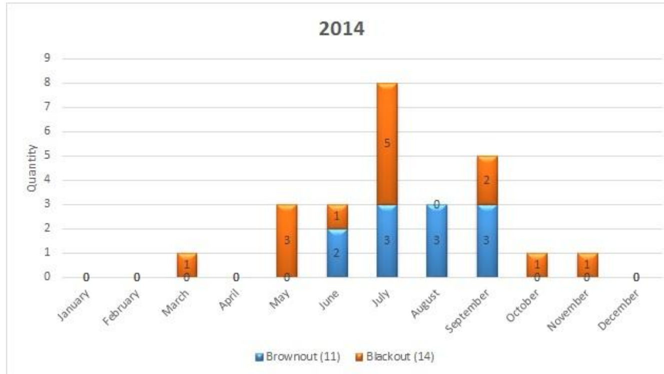

Fig. 5 RAS operations for 2014

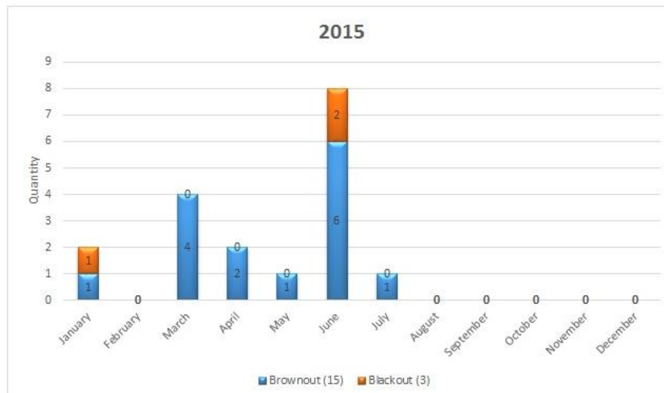

Fig. 6 RAS operations for 2015

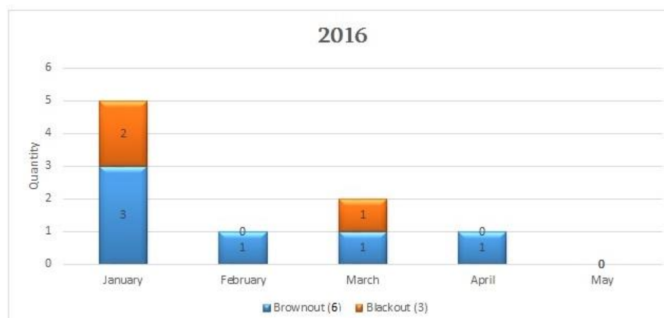

Fig. 7 RAS operations for 2016

F. Financial Analysis of Implementation

GDP for Georgia is about US$13.96B according to the TRADING ECONOMICS Report (Fig. 8) or alternatively approximately US$1.59M per hour. This effectively means that a blackout duration of one (1) hour in Georgia would cost about US$1.59M. Implementation of the RAS was approximately US$2M.

Based on the number and duration of blackouts and brownouts previous to the new technology, it is a clear conclusion that the implementation of the RAS has been financially very beneficial for the country of Georgia by preventing them.

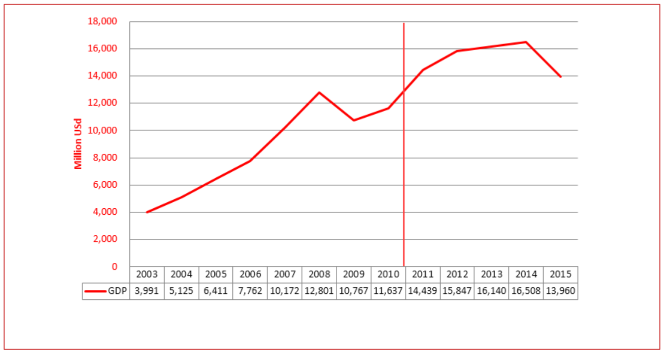

Fig. 8 Georgian GDP Growth

G. Additional Benefits of the RAS

This new technology with the RAS implementation has brought additional technological benefits to GSE. GSE engineers are now learning more about their power system operations, emergency controls, and how the different controllers are reacting with contingencies in the power system.

These new technologies can be easily installed into existing transmission infrastructure.

This technology allows engineers and operators to better understand the interaction of all of the components and devices in their power system – which was unknown before.

H. RAS Mitigation Real Results

Future application of this new technologies means that it will be able to eliminate a lot of unnecessary hardware. This will minimize costs for maintenance, testing and installation.

This new solution would also be used to predict what could happen with the power system when new contingencies would occur. The GSE Power system is growing with new power plants, new substations, new transmission lines and new customers. The new technology would be very flexible to adapt and accommodate new installations as well as changes to the power system.

As described above, the biggest root cause of the transmission network was the transmission of power from the 500 kV line to the 220 kV when the 500 kV line is disconnected. Fig. 9 shows just one (1) example of a phase failure over the 500 kV Imereti OHL. The operation of a phase auto reclose was not successful which led to an outage of all three phases of 500 kV line load transfers over to 220 kV lines. When this happened, the RAS operated immediately and saved the 220 kV lines from overloading to avoid the system from a total blackout.

Fig. 9 Phase Failure Over the 500 kV Imereti OHL Example.

The RAS system followed the topology of the system which means it is a very flexible solution to implement. If the power system changes topology due to a contingency or due to a change in the power system (like adding new lines or adding new power stations,) the RAS system can be adapted to the new topology.

Another benefit of the RAS is that it allows GSE engineers to learn more about the power system and all the cascading effects that can happen when a contingency occurs.

Fig. 10 shows the RAS system not only sheds loads but also allows control of generation to compensate for the power deficits caused by the contingency. Furthermore, it also indicates frequency stability immediately after load shedding. Fig. 10 is a display of a Kavkasioni outage when frequency would have increased drastically, but the RAS operated immediately and stabilized frequency in the system.

The 500 kV Kavkasioni PTL is connecting the Georgian and Russian power grids.

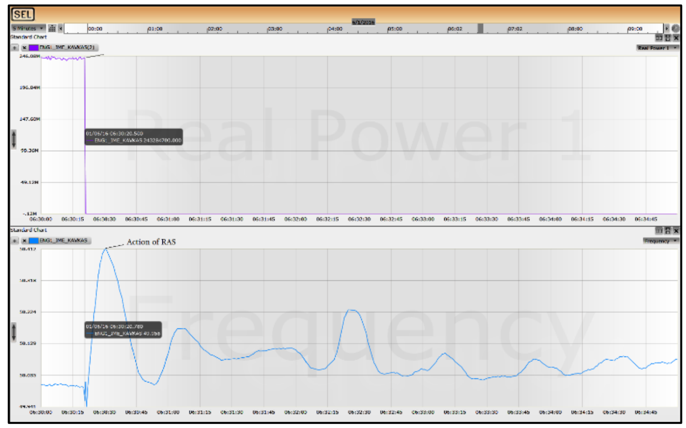

Fig. 10 Power and Frequency after RAS Operation

GSE intends to do a new SCADA renovation and one (1) of the objectives of this new project is the proper coordination with the RAS system and the synchrophasor solution provided in order to do off-line simulations.

After GSE SCADA system renovation, there will be an exchange of data between network application functions of the SCADA system, such as a State Estimator, contingency analyses, and RAS system. From one side, state estimation will come from more precise contingencies within the Georgian power grid which have to be implemented in RAS system. On the other hand, the information about the behavior of the system after RAS has operated will be provided to contingency analyses and to off-line simulation systems.

It is very useful for dispatchers and relay protection people to analyze overall and general processes in the network when a significant tripping event happens in the system. Once the tripping of the line or transformer or busbar happens, the synchrophasor information of the 500kV lines provided by RAS PMUs becomes very useful. When RAS operates in conditions of high power flow, then voltage and frequency stabilization has to be performed. Developing a RAS with voltage and frequency stabilization functionalities will help the power system to maintain stability, not only after RAS operation, but in any case of voltage or frequency instability. From this point of view, RAS solved its primary purpose locally and also operated to maintain the stability of the whole system.

Fig. 11 shows another sample of when there is an overloading on the 220 kV lines. The RAS operates immediately and reduces the power to a minimum in the HVDC link.

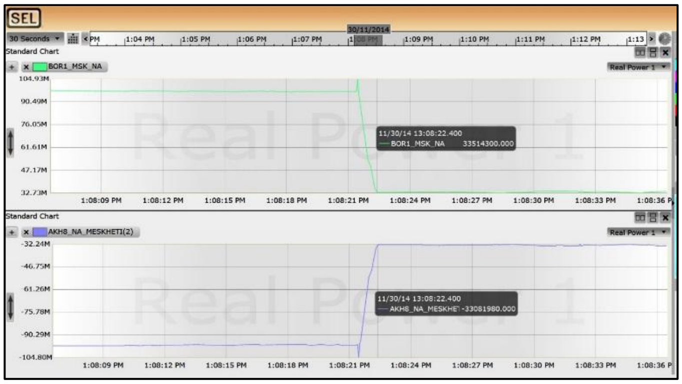

Fig. 11 HVDC-Power Reduction

I. New Supplier Solutions

GSE implemented ECS system to resolve one (1) of the major root problems that they had in the transmission power from the west to the east of Georgia. This solution was very simple but effective in eliminating blackouts.

GSE decided to implement this solution for different areas of the country. This RAS solution is called local RAS today. In addition to the local RAS, GSE decided to have a centralized RAS backup for the local RAS. Fig. 12 shows a partial view of the local RAS, the Centralized RAS and Remedial Action Execution System. All the systems are connected through the new communication multiplexer solution.

Fig. 12 shows that the local RAS hardware is composed mainly of new supplier controllers that provide not only all the control functions but also provide the synchrophasor measurements that have been very useful for GSE. These new controllers also provide monitoring and I/O that is normally provided by RTU equipment. So, the new controllers are devices that can provide and exchange information and solutions for WAMS, RAS, SCADA, off-line simulation systems, and short circuit calculation systems.

This new technology will thus provide monetary savings in future budgets for the EMS, SCADA, installation, testing, and maintenance cost.

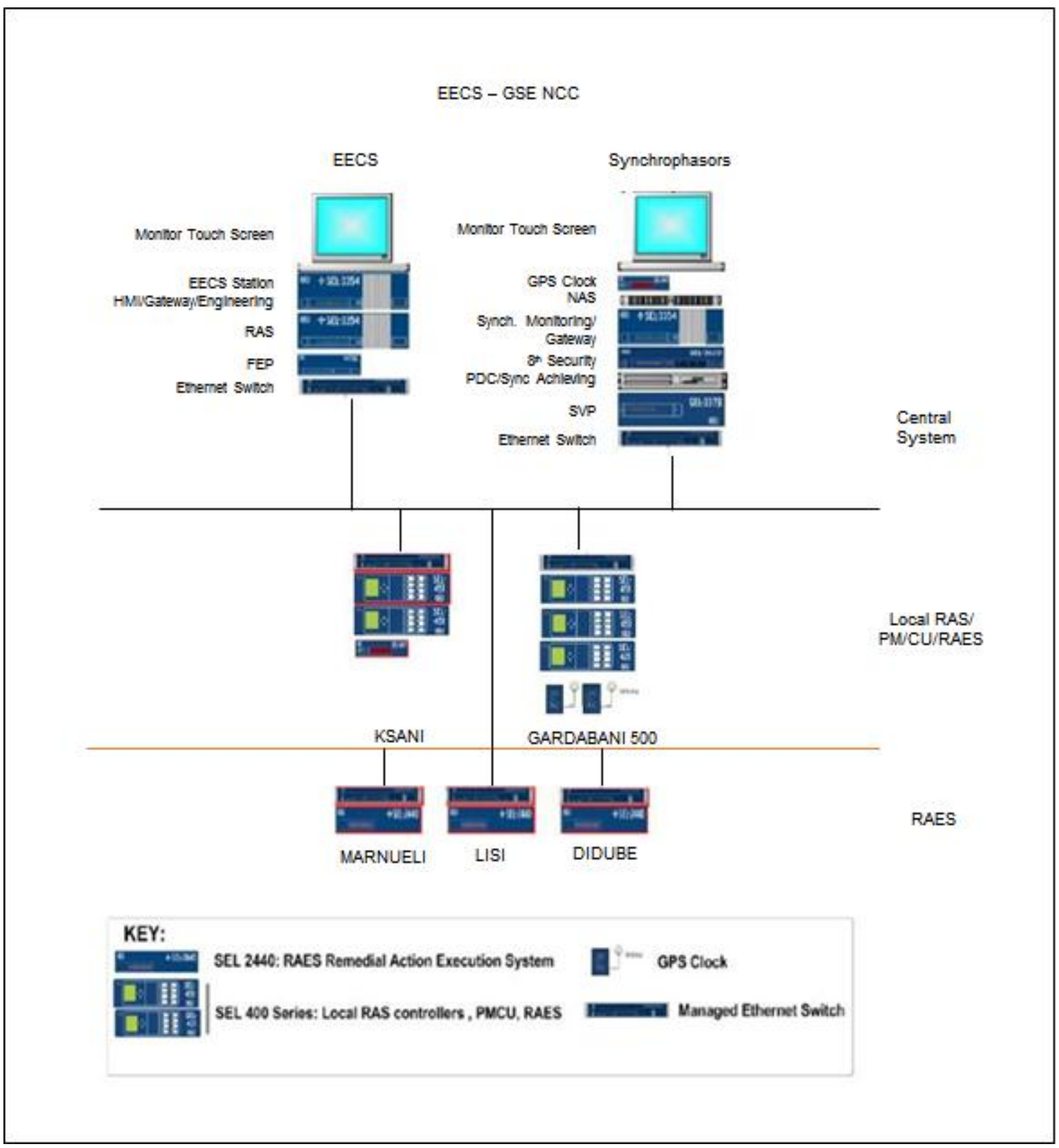

Fig. 12 RAS Structure

GSE decided to upgrade protection, control, and automation for the 220 kV substations. During the design phase, it was decided that the new Supplier's hardware (protection relays) would need to be installed in the substation yard instead of inside the substation control house. One of the major reasons for this was that the new Supplier's relays can support -40°C to +85°C. Another reason was to avoid to replace the old cables (without them having updated drawings) in the existing cable trenches from the substation yard to the existing control house. The new Supplier's devices were housed in a new container in the substation as seen in Picture 1 that facilitated the transition from very old to new technology. This figure only shows one container of the several installed around the yard. Thus, one fiber optic cable and redundant fiber optic cable was connected to each container and brought to the control house to bring all the information and monitoring data. A few fiber optic cables replaced hundreds of old existing cables and saved a significant amount of time in manpower for installation, commissioning, and testing which also leads to savings in maintenance.

The synchrophasors from protection relays go through SDH network to National Control Center, not through the new communication multiplexer. The idea is in future to: 1) connect the synchrophasors of protection relays to the new communication multiplexer system as it has been done for the synchrophasors of RAS; 2) create one database for both synchrophasors; and, 3) use it for WAMS, SCADA, off-line simulations and for RAS partially, since RAS is not very much "interested" in lower than 500kV voltage data. This benefit is showing more expandability and flexibility of the new communication multiplexer system.

Now it is easy to see that any electrical modification in the GSE network can be made through the new communication multiplexer network. GSE will grow as a utility and the new RAS installation will accept information from any new modifications and installations through the new multiplexer network. Of course, the RAS will receive information every time a modification or addition to transmission lines, substations, or power plants is made. The RAS is easily reset for new power system topology and new contingencies.

Picture 1 shows the existing 220 kV substation yard with a new container that holds the new Supplier's solution. Picture 2 shows the inside of this container.

Picture 1 Existing 220 kV Substation Yard

Picture 2 Inside Container

Fig. 13 shows how the new Supplier's controllers in the 500 kV network and protection relays in the 220 kV network have integrated in one (1) network all the RAS, synchrophasor, protection, and RTU data.

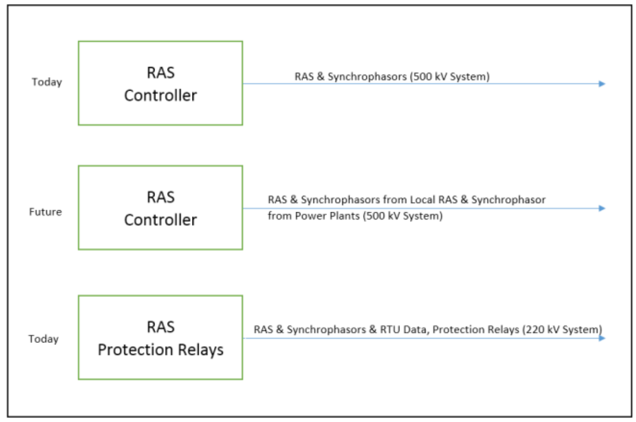

Fig. 13 Evolution of the Implemented new Supplier's Controllers and Protection Relays in GSE electrical network

Over the last 10 years, GSE has been increasing the growth of the power system by 7-8% per year. The RAS has been able to be modified with the growth and changes of the system.

J. Communication Network

The RAS communication system is based on the new multiplexer provided in the RAS. This new multiplexer provides a very reliable and more deterministic communication network for the electric utility system. This new communication network is based on ring topology.

This solution of the new multiplexer has proven that it is very reliable and deterministic to deliver critical electrical utility information that is required when emergency situations occur in the power system.

Finally, the GSE solution (with the new relays installed in the 220 kV network and with the new controllers installed in the 500 kV network) provides information to the SCADA. In the future, GSE will run the SCADA signals to the new communication multiplexer which can support all protocols.

Fig. 14 is a diagram of how GSE engineers have implemented the new multiplexer through the network over the last 5 or more years. Today, the new communication multiplexer is receiving and transmitting RAS signals, relay teleprotection, and synchrophasor data. In the future, GSE has plans to expand the SCADA system, and bring the SCADA information through the existing new communication

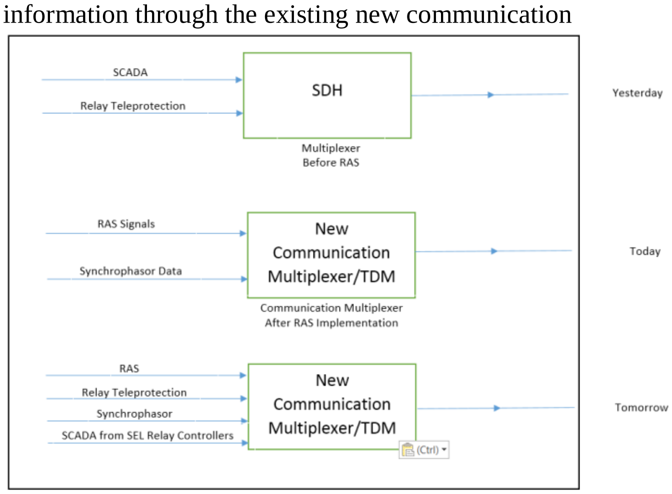

Fig. 14 Multiplexer Network Implementation

multiplexer network. GSE already has eliminated the need for more RTUs by installing the new Supplier's protection relays in 220kV substations and by creating Substation Monitoring and Control System (SMCS) in the substations.

The new communication multiplexer synchronizes all of the information coming from the different substations so that GSE can analyze the data instantaneously, without any delays. GSE created a separate communication network around Georgia that is very reliable for delivering emergency information, as needed, to operate the power system, and to maintain the stability of the electricity network. Fig. 15 shows this new communication multiplexer network implemented by GSE around Georgia.

The new communication multiplexer has proven to be the most reliable multiplexer for the electrical utility application which includes relay information, teleprotection, synchrophasor, and RTU data.

The RAS system brought additional benefits, functionalities, and services that GSE did not expect to be able to use. The new communication multiplexer met all the requirements of the RAS and sent the information from one (1) side of the country to the other in milliseconds. This is a necessary condition for the successful operation of the RAS system.

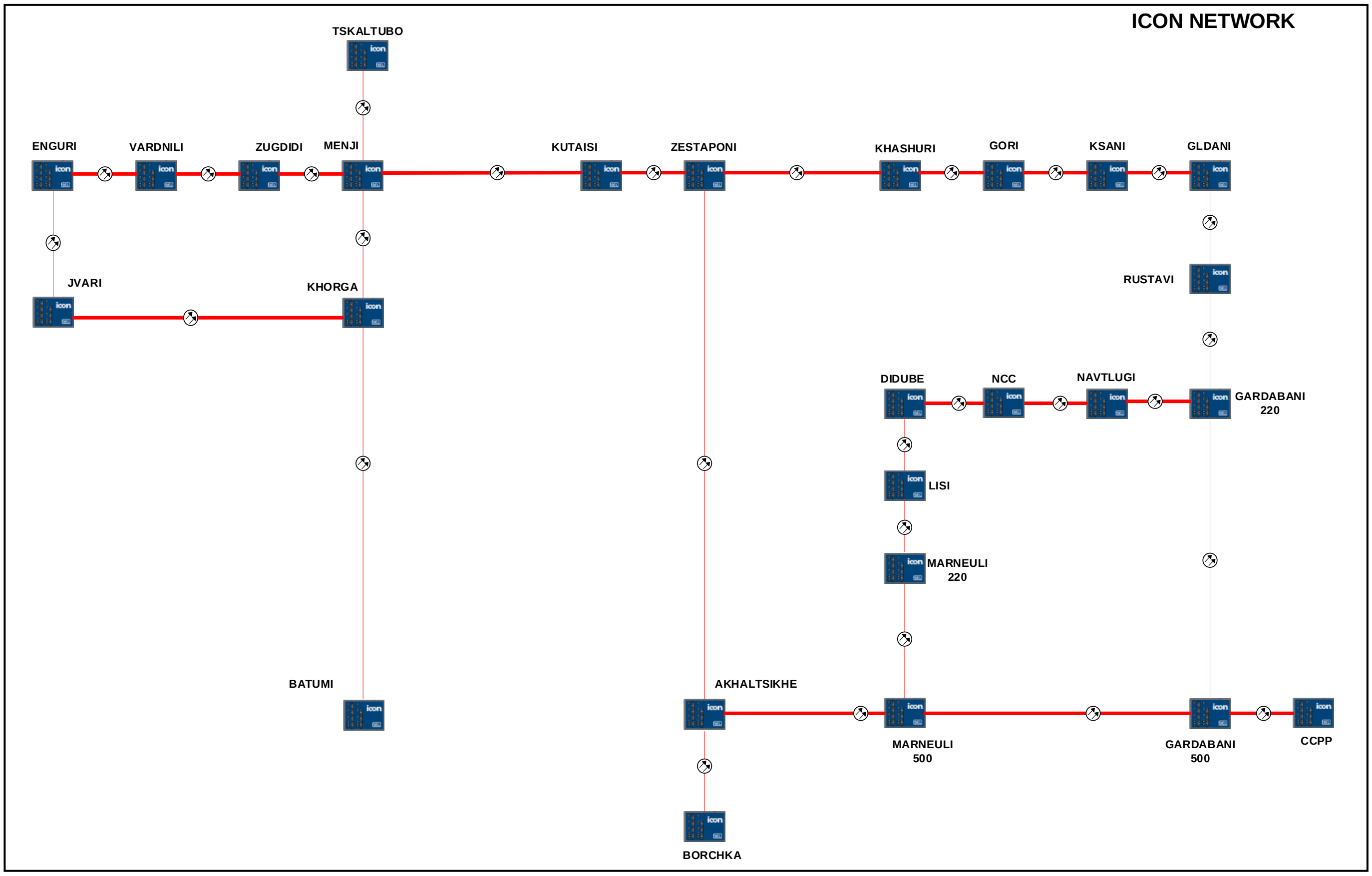

Fig. 15 GSE TDM Network

K. WAMS (Wide Area Monitoring System) Performance

Another example of the effectiveness of RAS system is the interaction of RAS and WAMS (Wide Area Monitoring System). WAMS is the system studying oscillation, islanding and other dynamic processes in the power system, which is completely based on synchrophasors provided by RAS controllers. Based on the information from the WAMS, recommendations can be made on how to avoid islanding or how to mitigate the oscillations. The recommendations will be implemented again by RAS controllers or by means of SCADA. This is an example of the simultaneous interaction of three (3) systems: RAS-WAMS-SCADA.

The RAS system also brought a very important additional and unexpected benefit to GSE: the voltage stabilization system of the Georgia power system network. With this function, GSE can see how the voltage stabilization components are reacting to any contingency in the power system. GSE is also able to see all the possible cascading effects that any contingency may create in the power system.

Depending on a type of contingency occurring in the system, the line protection relays may operate, and the relay functions (such as auto reclose, pole discrepancy, etc.) are then coordinated with the RAS to work properly.

L. Installation Benefits

From the point of view of installation, it was very easy to integrate the new Supplier's devices to the existing system. Additionally, the new communication multiplexer was easily configured and tested compared to the existing SDH multiplexer.

M. Other Benefits

This technology allows engineers to see the cascading effects after a contingency occurs. GSE engineers are learning very quickly to understand data and information about their power system that was unknown before the new technology. The GSE engineers have learned that with the new technology devices, they can monitor and collect information to be delivered to the SCADA, EMS, ECS, and RAS.

N. RTDS

GSE found out that with all the information coming from the RAS, they can do simulations off-line. This benefit is related to the RTDS study made within RAS project. RTDS modeling gives the GSE engineers a new tool to learn more about cascading effects that is created in the power system. From this point of view, RTDS (as the part of RAS project) has been an important tool providing recommendations on how to validate Georgian power system model and what measures have to be performed in order to increase the system stability. The valid power model provided by RTDS is an essential source of data for GSE's EMS or off-line simulation.

II. Conclusions

The cost of the RAS obviously has paid off because it resolved the root problem of blackouts in Georgia, and now the RAS has operated many times to prevent both blackouts and brownouts.

GSE management has realized that the RAS not only integrates the new technology of the electrical network, but the RAS also integrates the management, communication among the different organizations in GSE. So today, protection engineers, SCADA engineers, communication engineers and operation engineers are working with the common RAS solution for emergencies through the common communication network to monitor the wide area protection and control of the GSE electrical network.

GSE top management realized that this technology is eliminating the need to buy unnecessary hardware like RTUs and PMUs, because the new technology devices of the protection and RAS system provide all these functions and services in one system. This is an important benefit for power industry organization management because in many other transmission systems the operators, protection engineers, SCADA engineers, communication engineers and operations engineers all purchase their own solutions with their individual budgets, and later on, they have to use extra time and resources to integrate their solutions. This becomes very expensive with complications and difficulties for testing and maintenance of the complete solution that is needed to provide the required reliability.

Utility companies need to determine the major root cause of their own problems and write the specifications to fix those particular problems. They need to require that the vendors provide and test the performance of the system they are buying. It is very important that the RTDS simulation is run prior to installation. Additionally, a real test of the system should be required of the vendor prior to acceptance of the solution.

Engineering operators and system engineers have a lot of information to determine the root cause of the disturbance that could happen within the system. They would then be able to make the correct decision on how to modify the RAS or operate the system more effectively.

The Supplier's new communication multiplexer has been proven to be a very reliable and deterministic multiplexer for communications networks.

The new technology is very flexible and expandable and can be installed in any location in the power system bringing significant savings in time and money for installation, commissioning, testing, and maintenance.

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IV. Biographies

Sulkhan Zumburidze received diploma in marketing and finance from Berlin School of Economics in 2004. In 2006 he work for Georgian State Electrosystem (GSE) as a Chairman of the Supervisory Board. He became the Director General for GSE in 2007 and then in 2008 moved into the role of Rehabilitation Manager/Chairman of the Management Board.

Alexander Didbaridze received his diploma in electronic and control engineering from Moscow State Technological University in 1994. Upon graduating, he worked for nearly 11 years as an instrumentation and control (I&C) chief engineer for Gardabani Thermal Power Plant, a design and commissioning engineer for Enguri Dam Drain System, and an I&C engineer for companies "Wood Group" and "Capital Turbines." From 2006 through 2011, he was the manager of the projects SCADA and Emergency Control System (ECS) implemented by Georgian State Electrosystem. He has been involved in other projects linked to telecommunications systems and fiberoptic stringing on overhead lines. Since 2011, he has been the International Projects Technical Manager at Georgian State Electrosystem. [2]

Ucha Uchaneishvili received his diploma in electrical engineering from Georgian Technical University in 1994. Upon graduating, he work for Sakenergo as a Dispatcher for 5 years in the Central Dispatch Service of Central Dispatching Division. In 2004, he was employed as a Chief Dispatcher for Georgian State Electrosystem and has been with for over 14 years. Additionally, he is a Board Member of the Georgian State Electrosystem Management Board.