Application of Distributed Superconducting Magnetic Energy Storage System (D-SMES) in the Entergy System to Improve Voltage Stability

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Abstract—**The Western Region of the Entergy System is limited in both generation and transmission. Past events as well as extensive steady state and dynamic voltage stability analysis have indicated that the region can be subjected to potential voltage stability problems under certain contingency conditions. In order to improve voltage stability in the area, Entergy evaluated several shunt reactive reinforcement alternatives and Distributed Superconducting Magnetic Energy Storage System (D-SMES) was selected as the preferred option. This paper discusses the application of D-SMES on the Entergy System to improve voltage stability.**

Index Terms—**D-SMES, Voltage Stability, UVLS, Induction Motors, SVC, STATCOM, Overexcitation Limiter**

I. INTRODUCTION

The Entergy System is one of the largest investor owned electric utilities and is located in New Orleans, Louisiana. Entergy provides power to the states of Arkansas, Mississippi, Louisiana and portion of Texas. The Western Region of the Entergy System, which is located in Texas, is one of the fastest growing areas in the system.

The Western Region is limited in both generation and transmission. The one line diagram of the Western Region is shown in Figure 1. Past events and Voltage stability studies have indicated that this region can be subjected to potential voltage stability problems. This problem is of particular concern during peak load and under certain double contingency conditions. It has been observed that the voltage collapse can occur over several minutes driven primarily by generator overexcitation limiter and distribution transformer LTC action. In order to increase the load serving capability in the region, Entergy is in the process of adding transmission reinforcements. A fast acting Under Voltage Load Shedding Scheme was put in place in 1998 to avoid widespread voltage collapse. [1]

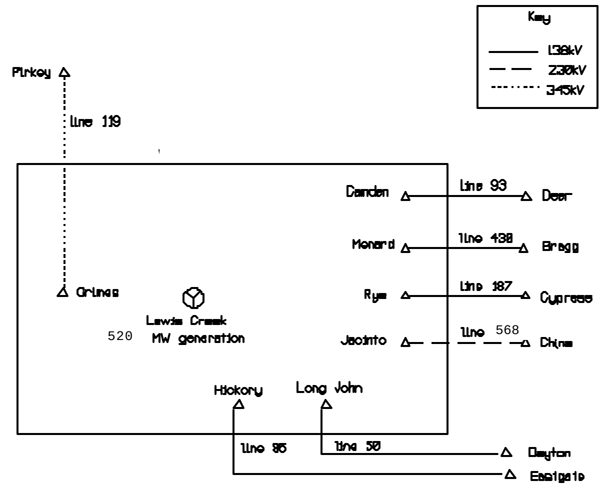

Figure 1. One-Line Diagram of the Western Region

However, as the load in the area continues to grow, there is a concern that the nature of voltage instability is changing from a slow collapse to a fast collapse, with the system response dominated by heavy concentration of induction motors. In order to improve voltage stability in the region, Entergy evaluated several shunt reinforcement alternatives such as Capacitor Banks, SVC, STATCOM and Distributed Superconducting Magnetic Energy Storage System (D-SMES) [2,3]. Based on certain technical and economic considerations, D-SMES was selected as the preferred option. As a part of the 2002 system reinforcement plan, four 8 MVA, D-SMES units were recommended for the Western Region, along with several mechanically switched capacitor banks. However, Entergy decided to take a phased approach and in order to meet the 2001 system conditions, it was decided to install two 8 MVA, D-SMES units at Metro and New Caney 138 kV Stations at the 34.5 kV level. These two units went into service in May 2001.

This paper discusses the application of D-SMES technology to improve the voltage stability problem in the Entergy system.

II. VOLTAGE STABILITY ASSESSMENT

A dynamic voltage stability assessment was carried out for the 2002 peak load condition using GE's PSLF software. The peak load in the Western Region under this condition was expected to be 1575 MW, with a total generation of 560 MW at Lewis Creek. All planned reinforcements in the study area were modeled including the newly commissioned series compensation on the China – Jacinto 230 kV line and several 138 kV mechanically switched shunt capacitor banks.

In this study, a 138/13.2 kV distribution transformer including feeder impedance was added to all 138 kV load buses. Loads were moved to the low bus of the transformer and modeled as 50% induction motor and 50% static. Sensitivity studies were also carried out with 60% motor load. The motor load was divided into three classes: motors driving high inertia load, motors driving low inertia loads and motors driving low inertia loads that could trip under low voltage conditions. In all the cases, one Lewis Creek Unit was considered off line, and three critical contingency scenarios were analyzed, the most critical of them being the Grimes- Crockett 345 kV line. In order to evaluate the dynamic voltage performance, the WSCC criteria shown in Figure 2 was applied [4]. As per the criteria the voltage at any load bus should not dip below 20 percent of the initial value for more than 20 cycles.

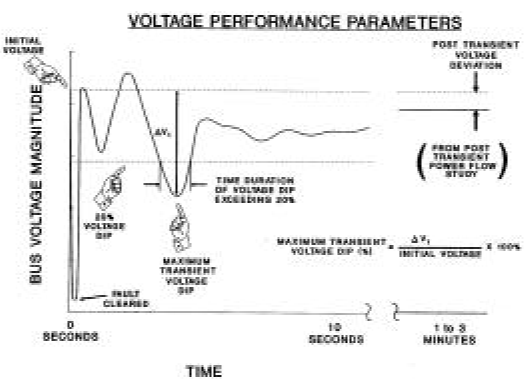

Figure 2. WSCC Voltage Criteria

Figure 3 shows the voltage response at four critical 138 kV buses in the region for a 3-phase fault and trip of the Grimes-Crocket 345 kV line. There are 3 plots associated with each bus - one for static load, one for 50% induction motor load and one for 60% induction motor load. Table 1 gives the summary of the results. From the plot it can be noted that the induction motors cause a deeper transient voltage dip than seen with the static load. Voltage criteria is violated at a large number of buses and Lewis Creek unit was found to be well above the maximum field current rating. With 50% induction motor load, the transient voltage dip was found to be greater than 20% for more than 2 seconds. With 60% motor load the voltage dip was found close to 50% and voltage collapse is more rapid. However, based on information on load composition in the Western Region, it was decided that a 50% induction motor load assumption would be appropriate for determining the number and size of the DSMES units. In addition, it should be noted that all the faults assumed a 4 cycle clearing time. If a 6 cycle clearing time is assumed, the voltage dips will be deeper and for longer duration. Similar, results were observed for other critical contingencies in the region.

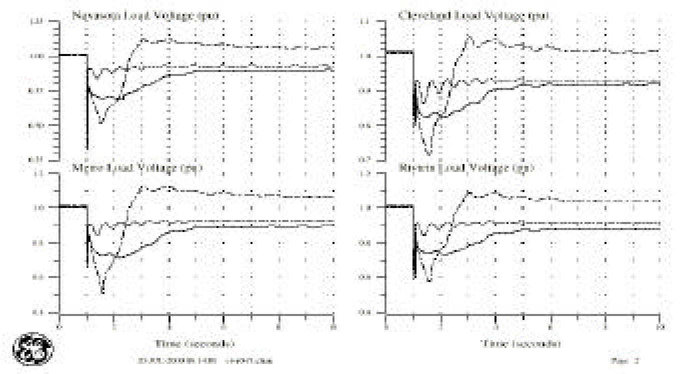
Figure 3. Voltage Response at 138 kV Buses – Outage of Grimes – Crockett 345 kV Line

Table 1
Summary of Results – 50% Induction Motor Case

Load % 2002 Peak	Max Volt Dip %	# Vdip 20% > 20 Cycles	# Vdip 20% > 40 Cycles	Motors Tripped
100%	32% @ Navasota	63	62	8.5 MVA
95%	26% @ Grimes	43	0	0
90%	26% @ Grimes	4	0	0
85%	26 %@Grimes	0	0	0

Several alternative reinforcements such as Shunt Capacitor Banks, SVC, STATCOM and D-SMES were evaluated to improve the dynamic performance of the system. However, based on certain technical and economical considerations, D-SMES was selected as the preferred option. Several locations were tested for D-SMES and switched capacitors and as a part of 2002 reinforcement plan four 8 MVA D-SMES units were recommended for the Western Region, along with shunt capacitor banks.

Due to future uncertainty and budgetary constraints, Entergy decided to phase the project in over several years. Further studies were performed to determine the minimum reinforcements required for 2001 summer peak conditions.

Based on dynamic studies the following plan was proposed:

a. 2001 Plan
   - Install 8 MVA D-SMES at Metro 138 kV Substation on the 34.5 kV bus, with 25.2 MVAR shunt bank
   - Install 8 MVA D-SMES at New Caney 138 kV Substation on the 34.5 kV bus
   - Install 1-37.8 MVAR shunt capacitor bank at Lewis creek 138 kV Station

This project was commissioned in May 2001 and the two D-SMES units are fully operational.

III. D-SMES DESCRIPTION

A. What is D-SMES?

The Distributed Superconducting Magnetic Energy Storage (D-SMES) System is an innovative new application of proven SMES technology that provided two critical capabilities [5]. One is real energy storage through the use of superconductors and the other is instantaneous response through the use of power electronics. Superconductivity makes it possible, by eliminating resistive losses within the magnetic coil, to store and instantaneously discharge large quantities of power. The power electronics module, which consists of an IGBT-based voltage source inverter system, uses advanced power electronics to detect voltage sags and to inject precise quantities of real and reactive power to boost voltage on the transmission system within a fraction of a cycle. D-SMES devices are most effective in addressing voltage stability problems. However, they can be used for other applications, such as flicker correction, capacitor bank switching, and other power quality solutions for both utility and industrial applications [3]. Some of the benefits of using the D-SMES device are: faster voltage recovery when compared to other similar devices, distributed sources, low cost when compared to traditional solutions, quick and easy installation with short lead times, modular design to meet future load growth and portable in case it has to be moved to other locations.

B. D-SMES System

The system consists of a superconducting magnet made of niobium-titanium wire that carries large currents at practically zero electrical resistance. This magnet can provide up to 3 MW of peak power and can average 2.5 MW over the first 0.5 seconds of discharge. The magnet holds up to 3 Mega Joules of energy. A set of inverters can produce reactive power of 2.3 pu for 1 second (overload rating) declining to the continuous rating of 8 MVAR over a period of an additional second. There are four inverters per column and there are eight columns in one D-SMES unit. Each inverter is rated for 250 KVA and each column has a rating of one MVA. A set of step-down transformers is provided for stepping the voltage from 34.5 kV to 480 Volts. The operating characteristic of an 8 MVA D-SMES is shown in Figure 4.

C. D-SMES Installation at Metro Station

A one-line diagram of the D-SMES system installed at Entergy's Metro 138 kV station is shown in Figure 5. The Metro Station has a 75 MVA, 138/34.5 kV transformer. There are 4 distribution feeders at this station. One 8 MVA, D-SMES device was added at this station on the 34.5 kV bus to provide voltage support. In order to accommodate D-SMES on the 34.5 kV bus, an additional 34.5 kV breaker was added to the bay.

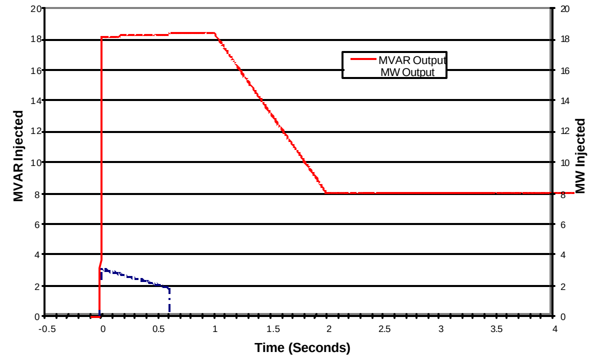

Figure 4. Operating Characteristics of the D-SMES Unit

The D-SMES trailer is connected to the 34.5 kV bus by an underground 535 MCM cable through four 2 MVA, 34.5 kV to 480 volts summing transformers. The reference voltage for D-SMES triggering is measured at the low side of the potential transformer and fed into the trailer. A 25.2 MVAR shunt capacitor bank was installed on the 138 kV bus to provide additional reactive power to the system. The D-SMES unit controls the switching of this bank. The New Caney station has a similar arrangement, except that there is no external shunt bank.

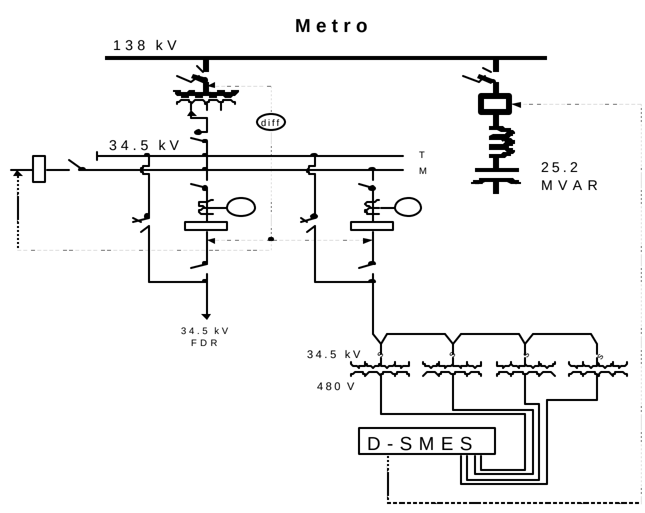

Figure 5. One-Line Diagram of Metro Station with D-SMES Unit

D. Voltage Stability Performance Using D-SMES

As mentioned in Section II, in order to meet the minimum dynamic performance of the Western Region in year 2001, two, 8 MVA, D-SMES units were installed at Metro and New Caney 138 kV stations. Also, to provide additional reactive support one 25.2 MVAR shunt capacitor bank was installed at Metro 138 kV bus and is controlled by the D-SMES unit. Additionally, one 36.2 MVAR shunt capacitor bank was installed at Lewis Creek 138 kV bus. The main purpose of installing this bank was to limit the reactive power output from the Lewis Creek units.

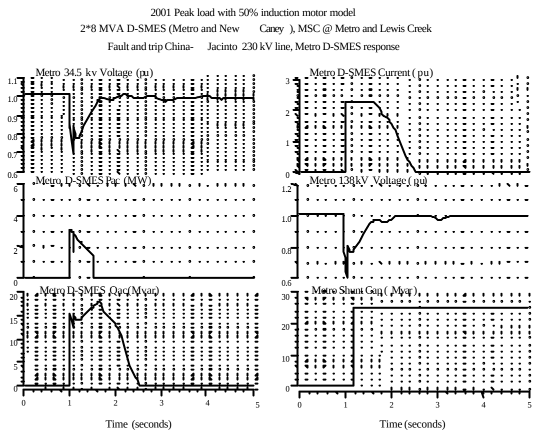

Figure 6. Performance of Metro D-SMES Unit - 50% induction motor case

In order to study the 2001 peak load conditions, each D-SMES units was modeled with a short term overload capability of 2.3 times its continuous current rating and a 3 MW peak power discharge. Cases were developed for both 50% and 60% induction motor loads and one Lewis Creek unit was taken off-line. Figure 6 shows the performance of the Metro D-SMES output for fault and trip of the China-Jacinto 230 kV line.

For 50% induction motor load case with 2 D-SMES units, the system is able to meet the minimum performance criteria for all three critical contingencies tested and no motor loads were tripped. The load bus voltages are found to settle at 0.95 PU or higher and the Lewis Creek unit was found to be close to its maximum field current rating. The dynamic simulations were repeated for the 60% induction motor load model and fault on the Grimes – Crockett line. The system was found to be in violation of the transient voltage dip criteria at several locations, with several buses experiencing 20% voltage dip for more than 60 cycles. This indicated that motor tripping can occur at some of the buses for 60% motor load case and additional reinforcements will be needed on the system.

E. Voltage Control Settings for the D-SMES Units

The voltage control settings for the D-SMES unit at Metro station are shown in Figure 7. The voltage sensing is done per phase. The D-SMES unit activates when the voltage at 34.5 kV buses falls below 0.97 pu. Between 0.90 and 0.97 voltage range the unit supplies only reactive power (VARS) up to the rated MVA. However, if the voltage drops below 0.9 p.u., the unit goes into overload mode and up to 2.3 pu of reactive output is injected into the system. The voltage range for magnet operation is from 0.5 p.u. to 0.9 pu. Below 0.5 pu, the unit assumes a close in fault and blocks real power injection, while the reactive power injection is unaffected. If the voltage goes above 1.10 pu the D-SMES operates in the leading mode and absorbs reactive power up to the rated MVA.

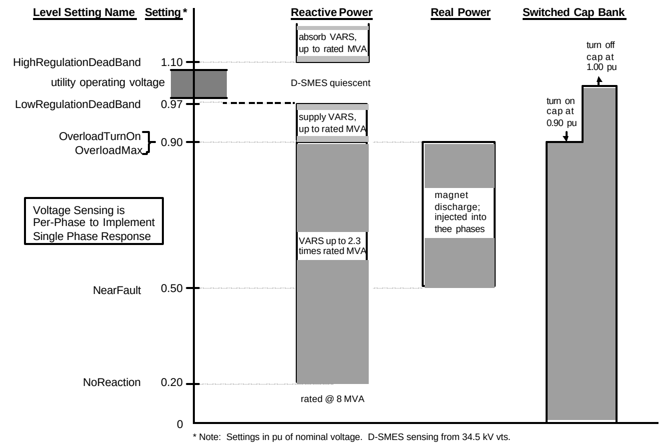

Figure 7. Voltage Control Settings for Metro D-SMES

IV. CONCLUSIONS

The voltage stability analysis indicated that the Western Region of the Entergy System can be subjected to rapid voltage collapse following the loss of major line or generation in the area. The voltage collapse was primarily driven by induction motor dynamics. Additional reactive support was needed in order to support the system during the first two seconds following a contingency. Some portion of the additional reactive support had to be provided by dynamic devices such as SVC, STATCOM or D-SMES. Several options were considered and based on certain technical and economic considerations, D-SMES was chosen as the preferred option. In order to meet the 2001 peak conditions, it was decided to install two, 8 MVA D-SMES units at New Caney and Metro 138 kV stations along with switched capacitor banks. These units went into service in June 2001.

The D-SMES device is found to be an innovative technology to solve voltage stability problems. The combination of real and reactive power, made instantly available at multiple locations on the grid, help in mitigating voltage collapse problem on the Entergy System. In addition to superior performance, cost, flexibility and short lead time, were some of the major factors considered by Entergy when selecting D-SMES over other options.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

[1] S. Kolluri, K. Tinnium, M. Stephens "Design and Operating Experience with Fast Acting Load Shedding Scheme in the Entergy System to Prevent Voltage Collapse," IEEE Winter Power Meeting, Singapore, 2000.

[2] N. G. Hingorani and L. Gyugyi, *Understanding Facts*, IEEE Press, 2000.

[3] Larry Borgard, "Grid Voltage Support at your Fingertips," T&D Publications, October 1999.

[4] WSCC Reliability Criteria Document.
[5] Gregory Yurek, "Superconductivity Starts to Deliver," Fortune, December 1998.