FINAL PROJECT REPORT

MULTI-AREA REAL-TIME TRANSMISSION LINE RATING STUDY

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A CIEE Report

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

This is the draft final report for the *Multi-Area Real Time Transmission Line Rating Study*, contract number 500-99-013, Work Authorization number 121, conducted by The Valley Group (a Nexans corporation). The information from this project contributes to the Energy System Integration program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

This project is a continuation of the related work begun under PIER Contract (#500-02-018). For consistency and completeness, the report includes findings of both projects.

Table Of Contents

List of Tables

Abstract

In 2003, the Sacramento area was identified as one of the regions in California where combined voltage and thermal limits could significantly curtail dispatch options, mainly regarding imports to the area. Accordingly, the initial objectives of contract #500-99-013 were a) the investigation of such limits, and b) studying the predictability of transmission line real-time ratings to improve the economies of dispatch.

The project has managed to identify one of the key constraints, namely the limitations of the O'Banion-Elverta transmission circuits, and has shown that during daily critical load conditions, the use of real-time ratings could increase energy imports to the Sacramento area by 750 MW with a probability of 95%.

A number of software-based algorithms were tested regarding their suitability for ratings prediction. None were found which could be applied for daily dispatch purposes, because of the inherent unpredictability of ratings and market rules. On the other hand, significant ratings persistence was identified. Ratings persistence is considered highly applicable for management of system contingencies.

Key words: Sacramento, transmission line, circuit, rating, real time rating, predictability, dispatch, voltage constraint, contingency, reliability.

Executive Summary

Introduction

A prior PIER project titled "Sacramento Area Ratings," CEC Contract #500-02-018, was initiated in 2002 as it was recognized that both thermal limits and voltage limits interact to cause combined dispatch restrictions in California's transmission network [1]. This project builds on that work.

Purpose

Based on the analysis of PIER project #500-02-018, a solution was sought for the combined restrictions that were particularly limiting dispatch in the Sacramento area. Earlier projects had studied the more general aspects of real-time tension monitoring, the specific conditions of Path 15 in California [2] and the application of The Valley Group's ICW software in operations at a California utility [3].

Project Objectives

The three main objectives of the current project were a) to identify conditions where combined constraints restricted dispatch; b) to quantify the magnitude and cost of such restraints; and c) to investigate prediction of line ratings in the timeframe which would be useful for dispatch purposes.

Project Outcomes

1. Constraints in the Sacramento area changed significantly in 2003 compared to assumptions at the start of the project. Because of the critical need for voltage support, several of the voltage constraints were alleviated by the installation of VAR support. Further changes in system configuration and operations may change the applicability of project results.
2. Coordination of schedules with the three utility participants became complex and difficult. Each faced a different set of limitations regarding funding availability, availability of engineering manpower, contractual negotiations, communications systems, communications interface to SCADA, confidentiality requirements, scheduling constraints, and priorities.
3. Different SCADA and communications systems required modification of data collection and analysis systems for all three participants, which in turn required significant modifications in software. This complicated and prolonged the data analysis process.
4. Project objectives were changed during the project, mainly to accommodate slipping installation schedules, but also to manage expenses within budget.
5. One of the important lessons of this project is that management of this type of project with three cofunders with differing objectives and scheduling constraints is logistically very difficult.

Conclusions

The project has resulted in several important conclusions:

1. In the Sacramento area, there are thermal limitations that interact with voltage constraints and limit the energy imports to the area. One of these limitations (O'Banion-Elverta line rating) was studied extensively. It was found that this limitation resulted in at least three unnecessary generation curtailments of the Sutter generation facility and that the actual real-time capability of the circuits during peak loading periods was at least 20 MVA higher than the static rating. Increasing the thermal rating of O'Banion-Elverta circuits by 20 MVA with real-time ratings could increase import capacity to the area by over 250 MVA.

2. Despite extensive studies of various available rating prediction algorithms, none of the algorithms were found to have acceptable accuracy for prediction of ratings in the targeted time range of 4-24 hours. While the day-to-day rating patterns usually exhibit a high degree of similarity, especially during the summer, the actual predictability of rating values varies greatly. For example, the O'Banion-Elverta circuits had a median real-time rating of approximately 150% of static rating, but only a 110-115% capability with a probability of 90% during the most critical loading periods (late afternoon – early evenings), while the lowest ratings could occasionally be slightly below the static rating. At night, ratings were always safely over the static rating, but the circuits were never heavily loaded.

The original objective was to identify prediction methods that could be used in daily dispatch. But as market rules changed and tightened during the project, it became increasingly clear that there were no opportunities for economic dispatch which were applicable to "probable" capacity, as operation of present-day markets is based only on firm capacity.

3**.** While ratings are not sufficiently predictable to be used for daily dispatch purposes, ratings have persistence. Ratings can increase rapidly, for example, during a storm. On the other hand, ratings cannot decrease rapidly, as it would require either a rapid increase in ambient temperature or an abrupt reduction of kinetic energy in the atmosphere [4].

Persistence of ratings can have a major impact on the management of contingency events in the network. It can increase operating economies because operators can either avoid changes in system dispatch or minimize them. It can also substantially increase system reliability, especially during times of high system loads.

Recommendations

1. Real-time rating is a technically mature methodology and shows substantial promise for increasing the efficiency of system dispatch and improved system reliability. California's utilities own a substantial number of real time monitors. A number of such systems are not in active use, because they were installed on lines which are no longer thermally limited. Redeploying such systems could be beneficial for system economies and reliability.

2. Investigation of methods to combine data from both real-time ratings and synchro-phasors into a single integrated display system could help speed the implementation of advanced real-time operating systems in utility control centers.
3. Further investigation of coincidence between daily ratings patterns with renewable generation's daily generation patterns could open up new opportunities for generation siting or minimize the impact of network constraints on renewables plants' output.
4. The concept of ratings persistence could be applied for contingency management by either identifying three-sigma limits for each monitored line by statistical analysis, or by development of and deployment in EMS systems of software that would continuously update persistence limits based on the most recent data.

Benefits to California

1. The indications of real time ratings persistence give a template for application of real time ratings in California. This can increase operating economies and can also substantially increase system reliability, especially during times of high system loads, by managing contingencies.
2. The study of the combined constraints in Sacramento area provides an excellent example how real time ratings can be used to mitigate import constraints to a large area.

1.0 Introduction

Prior project #500-02-018, "Sacramento Area Ratings," was initiated in 2002 as it was recognized that both thermal limits and voltage limits interact to cause combined dispatch restrictions in California's transmission network. Based on the analysis in that project, a solution was sought for the combined restrictions that were particularly limiting dispatch in the Sacramento area.

Thus, the three main objectives of this project were a) to identify conditions where combined constraints restricted dispatch; b) to quantify the magnitude and cost of such constraints; and c) to investigate prediction of line ratings in the timeframe which would be useful for dispatch purposes.

Unfortunately, complications arose regarding pursuit of these objectives. The main complications were:

1. The constraints in the Sacramento Area changed drastically in 2003 compared to project assumptions. Because of the critical need for voltage support, several of the voltage constraints were removed by installation of VAR support.
2. Coordination of schedules with the three utility participants became complex and difficult. Each faced a different set of limitations regarding funding availability, availability of engineering manpower, contractual negotiations, communications systems and their interface to SCADA, confidentiality requirements and priorities.
3. Different SCADA and communications systems required modification of data collection and analysis systems for all three participants and required significant modifications in software, which complicated and prolonged the data analysis.

Project objectives were changed during the project, mainly to accommodate slipping installation schedules but also to manage the expenses within budget. Among budget control measures, the most significant was reduction of the scheduled hours of the two main subcontractors.

A further complication arose because the installations, system calibrations, and operator training at each of the utilities progressed at different time scales. Because most of these expenses were contracted separately with each of the utilities, the planned economies in time and travel could not be achieved. This impacted not only the costs of the Commission-funded portion, but also the separately funded (fixed price) installation contracts of the prime contractor.

2.0 Project Approach

The objectives of this project were to:

1. Evaluate the interrelationship of voltage and thermal constraints and study new approaches;
2. Investigate the feasibility of forecasting line ratings and circuit capabilities, and;
3. To investigate the economic benefits of rating lines over a region and to recommend software approaches for such purposes.

Task 2 of the project consisted of ordering and installing monitoring equipment and software for the targeted lines of the cofunders. The original intent of the project was to collect data simultaneously at the two Sacramento-area participants Sacramento Municipal Utility District (SMUD) and Western Area Power Administration (WAPA), each of which was to install four CAT-1 Transmission Line Monitoring Systems. Four of the units (WAPA) were leased based on a two-year lease paid by the Commission. Because of delays regarding installation engineering and availability of labor, these units were only installed in February-March 2004. To enable data collection for a reasonable period, the equipment was purchased for residual value by WAPA in November 2004. These units were installed on O'Banion-Elverta , Elverta-Hurley and Hurley-Tracy #1 and #2 lines. Unfortunately, during the active data collection period the three latter lines were always very lightly loaded, thus making meaningful data collection possible only from the O'Banion-Elverta circuits. On the other hand, these O'Banion-Elverta lines were very heavily loaded, requiring load relief by runback of the Sutter generating plant on four instances during Summer 2004.

The four other units were purchased by SMUD in 2002. Their installation was significantly delayed because of several successive complications. In 2003, SMUD decided that the communications should be converted from radio to fiber-optic, which was to be installed on the American River transmission lines. SMUD paid for the conversion of this equipment. After multiple delays, the equipment was installed in late fall 2007. Because of communications problems, data collection began finally in April 2008. At this time, the loads of the monitored lines were generally low, and highly useful data could only be collected by one of the monitors.

The communications for SMUD and WAPA were initially planned as a single data collection system. Because of the time delay between the projects, this was not possible and the data was collected during two different periods.

The third cofunder, Pacific Gas & Electric Co. (PG&E), already owned and operated a number of CAT-1 systems. They were interested in the predictability part of the project and selected two heavily loaded lines, Henrietta-Gregg and Metcalf-El Patio, as the data sources for this project. Part of the reason for selection of these lines was to have a wider regional weather variability for the predictability study. The lines were especially heavily loaded during Summer 2005 and were reconductored in 2007.

The CAT-1 equipment used in the monitoring has been described in the Final Report of PIER Project # 700-00-006 and the software used for data collection in CIEE Subcontract C-04-09 (Integration of Real-Time Transmission Line Data with Utility and CAISO Operations) [3].

3.0 Project Outcomes

The separate parts of the combined studies under prior PIER Project #500-02-018 and current CIEE Award No. C-05-32 have been conducted over a six-year timeframe and have been reported during this time in a large number of reports. Therefore, the specific findings will be only shown as an overview, and the detailed results are available in the referenced reports [4-7].

3.1 Task 2: Installation and Performance of Equipment

1. At PG&E, the oldest monitoring equipment used in the study has been operating essentially without problems since 1998, with minimal maintenance. In 2004, PG&E installed a uniform software/server system, which calculates steady state and transient ratings and which allows data sharing with CAISO. This system was funded by CIEE Subcontract C-04-09, based on PIER funding [3]. Except for certain communications issues related to changes in the SCADA system and its maintenance, the system is performing to PG&E's satisfaction.
2. At WAPA, all the installed CAT-1 units performed flawlessly during the whole data collection period. The system has not been integrated into WAPA's operational systems.
3. At SMUD, the changeover to fiber-optic communications caused substantial delays and initial communications problems. The decision to daisy-chain all units into one communications loop was unfortunate. A single connection problem in the power supply of one of the units, at a hard-to-access location, caused a significant delay in commissioning.

At present, all units are communicating properly. One of the eight load cells has failed and reports data intermittently. Because the failure time coincided with physical work at the structure, it is possible that the load cell cable was damaged during retensioning of one line section.

For installation reports, see Appendix A.

3.2 Task 3: Evaluate the Roles and Interactions of Thermal and Voltage Constraints

Interviews were conducted with WAPA operators and planners, supported by data supplied by CAISO and Commission Staff. Limited interviews with SMUD and PG&E personnel were also conducted.

A summary of the interviews has been made and is presented in Appendix A. We wish to express our thanks to all personnel, especially to Mr. Morteza Sabet of WAPA and Mr. Ben Williams of PG&E, for valuable information on the use of nomograms.

- Nomograms and tables on the impact of dynamic ratings on import limitations were developed and are presented in Sections 4-9 in the Draft Trial Findings Report of Task 3 [5].
- Real Time Management of combined network limitations is analyzed and discussed in the Draft Trial Finding Report.

The most important findings regarding potential near-term benefits of real-time ratings regarding Sacramento area imports are included in the above report, Section 8, and are summarized in the following sections.

3.3 Task 3 Final Report, Section 8: Summary of SMUD Import Limitations Caused by Thermal Limitations on the O'Banion-Elverta Path

The commonly used single contingency criterion (WECC type B) requires that transfers or imports be restricted such that the loss of a single circuit will result in post-contingency loading below applicable ratings without resorting to automatic or manual remedial action. Using this criterion and including only import limits caused by thermal limitations on the O'Banion-Elverta transmission path, the calculated import limits into SMUD are as summarized in Table 1.

System configuration		Sutter operating at 525 MW			Sutter operating at 0 MW		
		Static rating	Dynamic rating		Static rating	Dynamic rating	
No. of circuits O'B-Elverta	Consumnes Output		5% prob.	10% prob.		5% prob.	10% prob.
		420 MVA	470 MVA	504 MVA	420 MVA	470 MVA	504 MVA
2	0	-531	-112	172	2202	2620	2905
3	0	2194	2936	3441	Greater than 4000 MW		
3	500	2098	2840	3345	Greater than 4000 MW		
4	0	Greater than 4000 MW			Greater than 4000 MW		

Table 1. Thermal Import Limits into SMUD Using the Single Contingency Criterion.

(Note: Only limitations caused by thermal constraints on the O'Banion-Elverta transmission path were considered. Limits were calculated assuming incremental imports from the Northwest and increasing load in SMUD with SMUD generation constant. Thus, for the same import level, the SMUD load is 500 MW higher when the Consumnes plant is on line.)

The probability levels for dynamic ratings in Table 1 consider afternoon and evening hours during summer conditions only. Under these conditions and with three circuits on the O'Banion-Elverta path, the thermal import limit based on dynamic ratings is 742 MW higher than for the static rating 95% of the time and 1247 MW higher 90 % of the time. These differences are valid with or without Consumnes. With Consumnes on line and dispatching at 500 MW, the import limits are 96 MW lower. The location of Consumnes in the SMUD system causes a redistribution of the imported power, increasing by a small amount the imported power coming across the O'Banion-Elverta path relative to the import paths from the south.

4.0 Estimating Near Future Benefits of Dynamic Ratings on the O'Banion-Elverta Circuits

4.1 Assumptions

The potential future benefits of dynamic ratings on the O'Banion-Elverta transmission path depend on future utilization (flows) on each circuit, future weather patterns, and the transmission reliability criteria used. The flows on the O'Banion-Elverta transmission path will depend on several future physical developments such as load growth, new generation, and new transmission. Three readily identifiable changes will be considered here. These are listed below along with assumptions to be used in a sample evaluation of the possible impact of future developments on the benefit of dynamic ratings.

1. Load growth. SMUD load is assumed to grow by 100 MW per year. No attempt is made to normalize the load for weather conditions. Loads outside of SMUD are assumed not to change.
2. New generation. Consumnes is assumed to come on line after the 2005 summer season. Other generation additions are not considered.
3. New transmission. A third transmission circuit is assumed to be in service on the O-E transmission path by the beginning of summer 2006. Other possible transmission changes are not considered.

4.1.1 Impact of Load Growth

Without new generation, load growth will tend to increase the import requirements into SMUD and thus increase the flows on the O'Banion-Elverta transmission path. The present analysis assumes that the dispatch of existing internal generation within SMUD is unaffected by the load growth. Under this assumption, the load growth will be covered completely by increased imports, resulting in a 14 MW increase in flow on the O'Banion-Elverta transmission path for a 100 MW increase in SMUD load. Since hourly SMUD load data was not available for the 2004 summer season for which O'Banion-Elverta flow records were available from the CAT-1 system, it was not possible to support this assumption with a direct correlation analysis. However, the results of a correlation analysis of loading of the O'Banion-Elverta circuits and ambient temperature for 2004 were consistent with results of a correlation analysis of SMUD load and ambient temperature for 2003 and 2002, providing some indirect support to the assumption.

4.1.2 Impact of Consumnes

Assuming that Consumnes will operate at full output (500 MW) and that other generation in the area will operate at current dispatches under peak summer load conditions, the impact of Consumnes will be to decrease import by 500 MW, decreasing the flow on the O'Banion-Elverta transmission path by 70 MW.

4.1.3 Impact of the Third Transmission Circuit between O'Banion and Elverta

The reduction in impedance of the 230kV path via O'Banion paralleling the 500kV system because of the third circuit does not have a significant impact on the portion of the import flowing over the O'Banion-Elverta transmission path. Thus, the impact of this circuit is simply to reduce the flow on each circuit between O'Banion and Elverta from ½ of the path flow.

4.2 Task 4. Evaluation of Forecasting Methods for Circuit Capability

4.2.1 Prediction

Forecasting methods were previously studied using archived data from PG&E's Henrietta-Gregg and Metcalf-El Patio lines as well as WAPA's O'Banion-Elverta line, during heavily loaded summer months in 2004-2006 [6]. Numerous different algorithms, including a number of computationally intensive ones, were tried. Typical daily patterns could be identified, usually consisting of generally higher ratings during late morning, afternoon, and nighttime, with distinct rating minima after sunrise and around sunset.

While the daily rating patterns usually have very similar patterns, especially during the summer, the actual predictability of rating values varies greatly. For example, the O'Banion-Elverta circuits had a median real-time rating of approximately 150% of static rating, but only a 110-115% capability with a probability of 90% during the most critical loading periods (late afternoon – early evenings), while the lowest ratings could occasionally be slightly below the static rating. At night, ratings were always safely over the static rating, but the circuits were never heavily loaded.

One of the identified additional difficulties arose from the different maximum operating temperatures. For example, during hot summer days, ambient temperature had a significant effect on the real time rating of the Henrietta-Gregg line, where normal rating is limited to 75°C because of AAC conductor. The effect is much less pronounced for the O'Banion-Elverta line, where ACSR conductor has a normal rating based on 93°C conductor temperature, and daytime ratings are primarily limited by wind conditions. Thus, prediction methods (if any) would have to depend not only on weather patterns, but also on the maximum design temperature of the line.

There are certain specific applications where known predictability of generation could be applied. One of them is solar power and lines with at least 90°C maximum design temperature. It has been recognized that during hot and sunny days, daytime wind speeds almost invariably exceed 4 ft/s and have highly variable directions, thus minimizing the possibility of parallel winds. Another possibility is to rate lines in the general vicinity of California wind generators higher, taking advantage of the known daily generation pattern. These practices might require modifications to market rules.

A detailed report on studies of predictability is found in [6].

4.2.2 Ratings Persistence

While ratings are not sufficiently predictable to be used for daily dispatch purposes, ratings have persistence. Ratings can increase rapidly, for example, during a storm. On the other hand, ratings cannot decrease rapidly, as it would require either a rapid increase in ambient temperature or an abrupt reduction of kinetic energy in the atmosphere.

In 2007, the contractor held discussions with the operations personnel of the project participants and CAISO to identify the most practical potential applications of real time ratings. In these discussions, it became evident that even a high degree of predictability of ratings was unlikely to be applicable for daily dispatch, mainly because of existing market rules. On the other hand, the increasing emphasis of FERC and NERC regarding reliability concerns seemed to indicate the potential for a useful application.

Persistence of the ratings can have a major impact on management of contingency events in the network. It can increase operating economies because operators can either avoid changes in system dispatch or minimize them. It can also substantially increase the system reliability, especially during times of high system loads.

Persistence is defined as the percentage of static rating that is the largest amount that a line's real time rating can decrease in a time interval which is required for system redispatch. Based on operator discussions, the time limit appears to be typically 30 minutes. The recommended concept of use of persistency is that, based on real time rating statistics, system operations selects for each individual line (or a part of the system) the persistency limit (e.g. 8%). The persistence can be based on either two- or three-sigma probability. The maximum dispatch would then be limited to current real time rating minus the persistency. For example, if real time rating is 125% and persistency 8%, the operator could safely dispatch the line up to 117% of static rating.

A more detailed report on ratings persistence is found in [4].

5.0 Conclusions and Recommendations

5.1 Conclusions

1. The monitoring equipment is functionally very reliably and accurately. Collected data has met expectations and has shown substantial operational opportunities for real time applications. It has also identified conditions during which existing static ratings may present a limited amount of risk.
2. The combined constraint study has yielded valuable insights towards potential use of dynamic ratings in mitigating present and future import constraints and generation curtailments in the Sacramento area. Unfortunately, the results will be difficult to quantify in economic terms because the study was limited to WAPA's system. The main findings have been made available to WAPA, who will evaluate the reports for possible operational applications.
3. The data from the monitoring systems appear not to be very applicable for forecasting capabilities for dispatch purposes, except for wind and solar applications. The main difficulty lies in identifying robust algorithms which are not either overly sophisticated or calculation intensive. If continued, the forecasting task should be subdivided into different methods for different operational needs.
4. One of the possible uses of the findings would be to provide dynamic information of real-time ratings (including their persistence) for state estimators to create dynamic nomograms. This would enable operators to identify current dispatch conditions more easily.
5. As a general conclusion, the main contractor has found that for a research project where close cooperation between several utilities (including many departments within each utility) is essential for acquiring contemporaneous data, it can be extremely difficult to manage to the desired objectives within the allocated budgets and fixed time schedules.

5.2 Recommendations for Future Work

1. Real time rating is a technically mature methodology and shows substantial promise for increasing the efficiency of system dispatch during contingencies and improved system reliability. Operationally, its application shares some of the same challenges as the synchro-phasor initiatives: results and opportunities are difficult to visualize by system operators, and improved displays, development of operating protocols and operator training could significantly facilitate adoption by operators. Such displays and methods should be shared by ISOs and individual utilities. Technologically, there already exists a platform for sharing information between CAISO and PG&E, thanks to the aforementioned previous research projects, but several technical issues identified therein remain to be addressed before it will be ready for operational use.
2. There is a clear technological synergy between real-time ratings and synchro-phasors. Both of them are recognized as essential parts of a Smart Transmission Grid, in which real-time information enables advanced applications and promotes operating

efficiencies. Real-time rating deals with thermal limitations of transmission lines, while synchrophasor data fuels applications to deal with voltage and stability limits. Investigation of methods to combine both sets of data into a single integrated display system could be very beneficial and could speed overall Smart Grid development substantially.

3. While the study has shown that prediction of real-time ratings is generally not generally feasible, one promising application may be investigation of coincidence between daily real-time rating patterns and renewable generation's daily generation patterns. Further investigation could open up new opportunities for generation siting or minimize the impact of network constraints. This would be especially productive if combined with studies and proposal for conditionally firm transmission tariffs.

6.0 References

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7.0 Appendices

Appendix A. Notification Regarding Monitoring Systems

The status of equipment installation and calibration is as follows:

PG&E

Henrietta – Gregg 230kV transmission line

The Henrietta – Gregg monitoring system consists of one CATMaster location and two remote CAT-1 units. All units are calibrated and fully operational.

Device	Location	Serial Number	Installation Date
CATMaster	Henrietta Substation	CM118A36-0300	September, 2000
CAT-1	Structure 30/125	SN 373	September, 2000
CAT-1	Structure 21/90	SN 373	September, 2000

Metcalf – El Patio 115kV transmission line

The Metcalf – El Patio monitoring system consists of two CATMaster locations and three remote CAT-1 units. All units are calibrated and fully operational.

Device	Location	Serial Number	Installation Date
CATMaster	Edenvale	CM152A36-0502	August, 2002
CATMaster	Campbell GC yard	CM153A36-0502	August, 2002
CAT-1	Structure 3/15	SN 3151	August, 2002
CAT-1	Structure 6/30	SN 3152	August, 2002
CAT-1	Structure 12/74	SN 3153	August, 2002

WAPA

The WAPA Sacramento monitoring equipment consists of two CATMaster locations receiving data from four remote CAT-1 units, each of which monitors a separate transmission line. Three of the remote units report to Elverta Substation, while the final unit reports to Tracy Substation. The Elverta CATMaster is listed multiple times below for each transmission line from which it receives data.

O'Banion - Elverta 230kV transmission line

The O'Banion – Elverta monitoring system consists of one CATMaster location and one remote CAT-1 unit. This unit is calibrated and fully operational.

Device	Location	Serial Number	Installation Date
CATMaster	Elverta Substation	CM179C33-0504	December, 2003
CAT-1	Structure 157/4	SN 3179	December, 2003

Elverta – Hurley #1 230kV transmission line

The Elverta – Hurley #1 monitoring system consists of one CATMaster location and one remote CAT-1 unit. This unit is calibrated and fully operational.

Device	Location	Serial Number	Installation Date
CATMaster	Elverta Substation	CM179C33-0504	December, 2003
CAT-1	Structure 7/1	SN 3180	March, 2004

Hurley – Tracy #1 230kV transmission line

The Hurley – Tracy #1 monitoring system consists of one CATMaster location and one remote CAT-1 unit. This unit is calibrated and fully operational.

Device	Location	Serial Number	Installation Date
CATMaster	Elverta Substation	CM179C33-0504	December, 2003
CAT-1	Structure 13/4	SN 3180	March, 2003

Hurley – Tracy #2 230kV transmission line

The Hurley – Tracy #2 monitoring system consists of one CATMaster location and one remote CAT-1 unit. This unit is calibrated and fully operational.

Device	Location	Serial Number	Installation Date
CATMaster	Tracy Substation	CM180C33-0504	May, 2004
CAT-1	Structure 49/1	SN 3182	May, 2004

SMUD

The SMUD monitoring equipment consists of two CATMaster locations which will receive data from four remote CAT-1 units. These four CAT-1 units will collect data from four transmission lines. Since shipment of the equipment, SMUD has decided to use fiber-optic transmission of data between CAT-1 remotes and CATMasters. The final CATMaster locations may change from those listed below. None of this equipment has been installed or calibrated. Concerns regarding obtaining line outages for installation continue to delay installation.

Systems tentatively reporting to Carpenter Hill Communications

Device	Serial Number	CAT Location	Port	Location	Port	Monitored Line
CATMaster	CM154B15-062	N/A	N/A	Carpenter Hill	N/A	N/A
CAT-1	SN 3154	Tower 719	1	Tower 719	1	Camino-Lake (west)
			2	Tower 719	2	Whiterock-Hedge (west)
CAT-1	SN 3155	Str. 232	1	Str. 699	1	Camino-Lake (east)
			2	Str. 232	2	Whiterock-Orangevale (east)

Systems tentatively reporting to Whiterock/Slate Mt.

Device	Serial Number	CAT Location	Port	Location	Port	Monitored Line
CATMaster	CM155B15-062	N/A	N/A	Whiterock/Slate Mt.	N/A	N/A
CAT-1	SN 3156	Whiterock-Hedge Str. 654	1	Str. 654	1	Whiterock-Hedge (west)
			2	Str. 187	2	Whiterock-Orangevale (west)
CAT-1	SN 3157	Camino-Lake Twr. 641	1	Str. 641	1	Camino-Lake (east)
			2	Str. 641	2	Camino-Whiterock (east)

Appendix B. WAPA Sag Correction Study

Final Report: Correlation Study of Field-Collected Sag Data and CAT-1® Monitoring System

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Background

Early in 2001 Western Area Power Administration (Western), SMUD, PG&E and the California Energy Commission (CEC) met to discuss a joint Research and Development project. The Energy Commission also funded the Path 15 real-time rating system using the CAT-1 transmission line monitoring system, to assess if the local area transmission loading limits could be increased to provide short-term relief. The group agreed that studies performed by the Sacramento Valley Study Group (SVSG) and Sacramento Area Transmission Planning Group (SATPG) established the need for such an effort and a joint R&D was proposed to benefit the area customers and establish a basis for future applications elsewhere. The Valley Group, Inc., the commercial suppliers of the CAT-1 transmission line monitoring system, provided four systems and technical support to determine if the CAT-1 system could enhance Sierra Nevada Region's (SNR) ability to utilize the full capacity of their transmission line system and increase operations ability to monitor real-time system conditions. The Sierra Nevada Region requested that Western's Corporate Office (CSO) assist in the evaluation and testing of the effectiveness of the CAT-1 System.

Four CAT-1 stations were installed on full tension structures in four different 230-kV transmission lines. Each station included two load cells to record wire tension in the ahead and back ruling span sections. The installations are as follows:

Transmission Line	Tension Structure	Ruling Span Section
Hurley – Tracy No. 1	13/4	13/2–13/4 & 13/4–14/3
Hurley – Tracy No. 2	53/1	52/3–53/1 & 53/1–55/1
Elverta – Hurley No. 1	7/1	0/6–7/1 & 7/1–7/4
Obanion – Elverta No. 2	157/4	153/1–157/4 & 157/4–160/3

During one of the installations (Hurley-Tracy No. 2), time did not allow for adjustment of insulator string length to compensate for the load cell length. The two ruling spans were therefore not included in the field surveys.

On August 3, 2004, the author and Western's survey crew performed conductor sag surveys and recorded ambient weather data in a total of nine spans, as detailed in the attached spreadsheet, in six ruling spans monitored by the CAT-1 system. SNR's Operations group provided CSO a record of the lines' loading on August 3, 2004 at fifteen-minute intervals. The Valley Group provided a data record from their monitors for the same time period.

Survey and Data Collection

At each survey site the transit was set up in a location to provide an unobstructed view of the conductor attachment points at each tower supporting the span and two locations within the span and directly below the monitored phase conductor. Measurements at the attachment points were adjusted for the existence of compression deadends and armor rods as appropriate.

Average wind speed and ambient temperature were measured with a hand held device at mid span at an elevation of two meters above ground. For all calculations, the measured wind speed was increased by a factor of 1.1 to compensate for the elevation difference between the anemometer and the conductor. The recorded ambient temperatures differed significantly in some cases from those recorded by the CAT-1 stations. The orientations of the line relative to the sun and wind direction were also recorded.

Analysis and Results

A summary of the data collected and subsequent results of calculations is presented in the attached spreadsheets.

Two calculations were run. The first (see spreadsheet A) used only the data collected by CSO personnel. In the second (spreadsheet B), ambient temperatures collected by the CAT-1 weather station were used instead of CSO's field measured temperatures.

The conductor loaded temperature was determined using the Southwire SWRATE16 software which is based on the "IEEE Standard 738-1997 for Calculating the Current-Temperature Relationship of Bare Overhead Conductors" utilizing the ambient conditions for each span and Operations' loading report. The assumed coefficient of absorptivity was 0.75 and the coefficient of emissivity was 0.40.

Each surveyed span was modeled in Alcoa's SAG10® software using the Inclined Span routine to determine if a reasonable correlation could be obtained between Initial design sags and current (Final) sags. For each measured conductor elevation point, a curve fit was identified by iteratively varying the horizontal tension. SAG10 was then used to correlate the SWRATE16 conductor temperature to the conductor temperature indicated by the horizontal tension derived from the inclined span routine. A reasonable correlation (plus or minus 30 pounds horizontal tension or less than half a foot of sag) was found in all but one span (13/4 – 13/5 on the Hurley-Tracy No. 1 line). This was the only span that had a tension attachment at one end of the span. The author suspects that the compensation made in this span during the conductor elevation survey was inappropriate.

Utilizing all CSO data (spreadsheet A), the CAT-1 calculated conductor temperatures ranged from 3° to 15°C (6° to 26°F) less than the conductor temperatures derived from the field survey. This translates into a sag differential in a 1000-foot Ruling Span of 0.5 to 1.6 feet.

Substituting the CAT-1 ambient temperatures for CSO's field collected temperatures (spreadsheet B), the CAT-1 calculated conductor temperatures ranged from 3° to 8°C (6° to 14°F) less than the conductor temperatures derived from the field survey. This translates into a sag differential in a 1000-foot Ruling Span of 0.5 to 1 foot.

As reflected in spreadsheet A, the difference in calculated conductor temperature tends to increase the further away the measured span was from the weather station.

Discussion

There are numerous opportunities to lose sight of the fact that we are dealing with an inexact science relative to modeling transmission lines. The ruling span method of calculating sags assumes every span in the ruling span is of the same length and that the suspension insulator assemblies are free to displace longitudinally, sufficient to equalize tensions from span to span. Neither of these assumptions can necessarily be accomplished in the final installation. The devices used to measure wind speed and temperature have their own limitations particularly at low wind speeds. The anticipated maximum loads assumed during design may never have occurred or may have been greater than anticipated resulting in undeterminable historic maximum load on the wire in any particular span or wire section.

The key element in establishing the capacity of a line section is determining the conductor temperature (or sag) to a reasonable degree of certainty. Weather conditions at one location within a ruling span may not be exactly the same in another location within that same ruling span. The greater the number of weather station sites, the less uncertainty. Conductor temperature will not instantaneously reflect the heating or cooling effects of a change in wind velocity or direction or a change in electrical current. This said, it must be understood that an instantaneous "snap-shot" of a conductor's temperature is not possible if the derivation of that temperature is dependent on measurement of constantly varying external parameters.

Two of the more compelling concerns for any monitoring device are the reliability and cost of communicating measured data from remote sites back to Operations. Though there were occasional interruptions to the data stream from the CAT-1 monitors, this study did not include an evaluation of the communication system.

Conclusions

The correlations of field measured sag conditions to that of design sag/tension calculations were surprisingly close.

In all cases, the field-measured conductor temperature derivation method reflected greater sags that the CAT-1 system. The difference is not considered to be significant except in spans well separated from the monitoring stations.

The CAT-1 system is quite effective in determining actual conductor temperature in spans relatively near to the monitoring device. It is not, however, a dynamic system in its current design. The software associated with the monitors assigns “risk” evaluation to the measured and historical data. The soundness of the risk assessment was not part of this study but the concept is a reasonable approach for determining the excess capacity of a line section for long- and short-term loading but not necessarily for emergency conditions which might result in line loading at or near the line’s maximum capacity. The greatest limitation to the CAT-1 system is its inability to predict sag conditions within spans significantly separated from the monitoring stations (long ruling spans on long lines), a limitation Western was aware of prior to testing. In order to provide low risk capacity assessments, additional stations may have to be installed along the line, which would increase the cost of the system. The desirability of its application would have to be assessed on a case-by-case basis.

There may be other devices available which may also suit SNR’s needs. For all the devices/systems, the reliability and cost of the communication mode will remain significant concerns.

SPREADSHEET A

FEATURE		SPAN		SPAN	SURVEY DATA								CAT-1 DATA				NRT	
		STR.	STR.	LENGTH	SURVEY SPAN	AMBIENT TEMP *			AVG. WIND SPEED		CALCULATED COND TEMP		AMBIENT		CALCULATED COND TEMP			
ID	NAME	NO.	NO.	(FT)	(FT)	□C	□F	TIME	(FT/SEC)	AMPS	□C	□F	□C	AMPS	□C	□F	□C	□F
HUR-TRY1	Hurley-Tracy No. 1	13/2	13/3	1130.9	1123.46	23.9	75	9:53	4.19562	90	39.5	103.1	19.8	95	26.8	80.2	25.3	77.5
HUR-TRY1	Hurley-Tracy No. 1	13/4	13/5	1020.7	1010.65	17.2	63	8:35	4.8411	124	30.5	86.9	17.1	121	26.5	79.7	23.1	73.6
HUR-TRY1	Hurley-Tracy No. 1	14/1	14/2	1030	1031.74	18.3	65	9:15	5.64795	92	30.6	87.1	19.1	102	27.4	81.3	25.3	77.5
OBN-ELV2	Obanion-Elverta No. 2	156/4	157/1	1200	1200.36	28.9	84	1:15	4.03425	792	49.4	120.9	26.8	789	43	109.4	34.7	94.5
OBN-ELV2	Obanion-Elverta No. 2	157/1	157/2	1200	1200.47	28.9	84	1:30	4.03425	796.2	49.5	121.1	26.8	795	41.8	107.2	34.5	94.1
OBN-ELV2	Obanion-Elverta No. 2	158/2	158/3	1175	1176.17	34.4	94	2:00	5.32521	789	48.5	119.3	29.2	798	41.1	106	36.7	98.1
ELV-HUR1	Elverta-Hurley No. 1	7/2	7/3	950	949.21	25.6	78	10:45	3.87288	227	45.7	114.3	22.6	220	31	87.8	28.8	83.8
ELV-HUR1	Elverta-Hurley No. 1	6/2	6/3	1010	1009.91	28.9	84	11:00	4.03425	232	39.3	102.7	23.1	223	33.3	91.9	30	86.0
ELV-HUR1	Elverta-Hurley No. 1	6/1	6/2	840	840.47	29.4	85	11:15	3.55014	234	47.4	117.3	23.7	230	34.3	93.7	29.7	85.5

SPREADSHEET B

FEATURE		SPAN		SPAN	SURVEY DATA								CAT-1 DATA				NRT	
		STR.	STR.	LENGTH	SURVEY SPAN	AMBIENT TEMP *			AVG. WIND SPEED		CALCULATED COND TEMP		AMBIENT		CALCULATED COND TEMP			
ID	NAME	NO.	NO.	(FT)	(FT)	□C	□F	TIME	(FT/SEC)	AMPS	□C	□F	□C	AMPS	□C	□F	□C	□F
HUR-TRY1	Hurley-Tracy No. 1	13/2	13/3	1130.9	1123.46	19.8	68	9:53	4.19562	90	33.3	91.9	19.8	95	26.8	80.2	25.3	77.5
HUR-TRY1	Hurley-Tracy No. 1	13/4	13/5	1020.7	1010.65	17.1	63	8:35	4.8411	124	29.8	85.6	17.1	121	26.5	79.7	23.1	73.6
HUR-TRY1	Hurley-Tracy No. 1	14/1	14/2	1030	1031.74	19.1	66	9:15	5.64795	92	30.8	87.4	19.1	102	27.4	81.3	25.3	77.5
OBN-ELV2	Obanion-Elverta No. 2	156/4	157/1	1200	1200.36	26.8	80	1:15	4.03425	792	49.4	120.9	26.8	789	43	109.4	34.7	94.5
OBN-ELV2	Obanion-Elverta No. 2	157/1	157/2	1200	1200.47	26.8	80	1:30	4.03425	796.2	49.5	121.1	26.8	795	41.8	107.2	34.5	94.1
OBN-ELV2	Obanion-Elverta No. 2	158/2	158/3	1175	1176.17	29.2	85	2:00	5.32521	789	48.5	119.3	29.2	798	41.1	106	36.7	98.1
ELV-HUR1	Elverta-Hurley No. 1	7/2	7/3	950	949.21	22.6	73	10:45	3.87288	227	38.9	102	22.6	220	31	87.8	28.8	83.8
ELV-HUR1	Elverta-Hurley No. 1	6/2	6/3	1010	1009.91	23.1	74	11:00	4.03425	232	39.3	102.7	23.1	223	33.3	91.9	30	86.0
ELV-HUR1	Elverta-Hurley No. 1	6/1	6/2	840	840.47	23.7	75	11:15	3.55014	234	40.8	105.4	23.7	230	34.3	93.7	29.7	85.5

Appendix C. Final Thermal Ratings

Final Thermal Constraints and Rating Methods Report (Task 2)

There are four lines that are being monitored by CAT-1 monitoring systems. O'Banion-Elverta, Elverta-Hurley No.1, Hurley-Tracy No.1 and Hurley-Tracy No.2. All these lines are 230kV lines and designed for California light loading conditions. Conductor type at O'Banion- Elverta and Hurley- Tracy No.2 is ACSR Bittern and at Elverta- Hurley No.1 and Hurley- Tracy No.1 is ACSR Drake.

There are four different ratings considered for these lines. Summer normal and emergency ratings and also winter normal and emergency ratings. Summer rating is effective from April till October and winter rating is used from November till March.

WAPA initially provided maximum conductor temperature of 176°F and maximum emergency conductor temperature is 212°F. All these lines are rated with wind speed assumption of 4 ft/sec as well as summer and winter ambient assumptions of 110°F and 55°F respectively. The summer normal ratings for O'Banion- Elverta and Hurley- Tracy No.2 are 1172 and 1178 Amps while the emergency ratings are 1488 and 1494 Amps respectively. Winter normal ratings are also 1910 and 1915 Amps respectively. Elverta- Hurley No.1 and Hurley- Tracy No.1 have summer normal rating of 895 Amps and summer emergency rating of 1126 Amps. Winter normal rating of Hurley –Tracy No.1 is 1289 Amps while Elverta- Hurly has winter normal rating of 1209 Amps. Winter emergency ratings are similar and are 1441 Amps.

WAPA has recently requested that new ratings are being considered for O'Banion- Elverta line for any future studies. New ratings are divided to summer and winter ratings, which are 1050, Amps and 1200 Amps respectively also the maximum conductor temperature has been changed to 93°C. The rating assumptions have also been changed, in order to sustain above ratings and maximum conductor temperature. Summer ambient temperature changed to 40°C and winter ambient temperature replaced with 27°C. Wind speed assumption is dropped to 2 ft/sec with an angle of 30°.

Appendix D. SMUD CAT-1 Systems Status

During the month of April 2008, the final field work was completed to correct remaining issues with the installation of CAT-1 equipment on the SMUD transmission lines. In particular the following work was done:

Tower 723: Contra Costa lowered the CAT cabinet at this tower on April 12, after coordination with Lee Washington on the line outage. The cabinet was lowered about 10-12 feet below the original installation location. The length of the cable from the load cells prevented us from lowering it further. Future maintenance on this unit at this tower, however, will not require any line outage. On April 14 Rob Mohr of the Valley Group, Contra Costa and SMUD Telecomm replaced the CATPAC cabinet with a new cabinet. Rob found some wiring problems on one of the terminal blocks in the replaced unit that was causing the unit to cease operation at night time.

A trip to tower 688 was made on April 15 to replace the ambient temperature sensor.

Previous to the above stated work, during December 2008, the firmware in all four CAT-1 units was updated to correct a compatibility issue with the DAQ RTU.

When data was received during July and August 2008 it was determined that a single load cell on CAT-1 unit SN 3154-P2 located on structure 723 on the Whiterock – Hedge transmission line was failed. A review of the data archives indicates that problems with this load cell began on April 21 when the tension reading was seen to go full-scale positive. On the following day the tension reading on this cell went to approximately -3500 lbs and has stayed at that value since. We believe that this timeframe corresponds with work being done on this line. If this is the case, the load cell may have sustained cable damage at that time. There is another load cell monitoring this line segment, so this failure has not prevented analysis of the segment.

With the exception of the single load cell mentioned above, all CAT-1 field equipment and software has been working properly and providing valid ratings at the control center since April 2008.

Appendix E. Operator Interviews (Task 3)

Two brief meetings were held with WAPA and SMUD in July 2004 to get an overview of system characteristics and the nature of voltage limitations and thermal limitations that may occur on account of thermal ratings on the monitored lines. It appears from the discussions with SMUD that while increased ratings obtained by the CAT-1 monitoring system may increase opportunities for opportunistic imports into SMUD from other regions there is at present no predictable way to establish the monetary benefits of such opportunities.

Two follow-up phone conference calls were conducted with WAPA (9/23/04 and 10/28/04) to better understand the WAPA transmission system, relevant characteristics of system operations and limitations encountered since May 15th on the monitored lines. WAPA also supplied a new load flow case for 2004 (case maintained by the California Independent System Operator), summer maximum load conditions in the Sacramento Valley area and the pertinent portions of the T-121 operating procedure. Plans were also made to have a conference call with SMUD to obtain information on SMUD load and generation characteristics including typical dispatch pattern of SMUD generation.

In the time period from May through October 2004, the only transmission restrictions appearing on the monitored lines occurred on the O'Banion to Elverta 230 kV lines. In all there were a total of four days in June, July and August when runback of the Sutter plant was triggered when the line flow approached the static rating of the O'Banion-Elverta line. Based on the analysis of CAT-1 records for these occurrences the calculated real time rating was substantially greater than the static line rating for each of these occurrences

We are proceeding with the analysis with the following objectives:

- Determine the impact that the use of CAT-1 ratings will have on reducing transmission operating constraints on the O'Banion-Elverta lines considering current operating practices that relies on runback of the Sutter plant whenever the line flow approaches the static line rating.
- Determine the extent to which CAT-1 ratings may increase the allowable loading of the O'Banion-Elverta line for single line contingencies
- Determine under what circumstances the voltage related limitations as described in Procedure T-121 will be limiting and thus limit the benefit of the increased rating obtained from CAT-1.

We intend to investigate how the conclusions drawn from these studies will change after the installation of the proposed reinforcement of the O'Banion-Elverta circuits and the addition of generation located at Rancho Seco (due on-line in August 2005) and at Roseville (no on-line date established).