Advanced Technology
Dynamic Line Rating
Final Project Report

Developed by

SCE Transmission & Distribution, Advanced Technology
Organization

Address
Southern California Edison – Advanced Technology
14799 Chestnut St.
Westminster, Ca 92683

Disclaimer

Acknowledgments

Prepared for: Southern California Edison, Advanced Technology, Public Utilities Commission of the State of California

Prepared by: Backer Abu-Jaradeh

Principle Investigators (s) Backer Abu-Jaradeh, Farrokh Habibi-Ashrafi

Change Log

Version	Date	Description of Change	Project Report No.
0.01			

Table of Contents

List of Figures

None

List of Tables

Preface

1 Executive Summary

Transmission Line ratings are currently preset based on many environmental and engineering factors such as cable material, weather conditions... etc. Usually, Line ratings are set to be conservative to prevent exceeding minimum clearance above ground and line overheating. Dynamic Line Rating is an approach that uses sensors to measure current operating conditions and develop a real time rating that reflects the current conditions of the line. This may allow better utilization of the line and increase in line transfer capacity during normal operating conditions.

The system will change the line ratings based on near real-time measurements which reflect the current operating condition of the line rather than having a fixed conservative rating for all weather conditions throughout the year.

The system will cut down O&M costs as it will delay the need of building new transmission line by better utilizing existing transmission system. The system will use the near real-time measurements to evaluate how much added ampacity can be pushed through the transmission line during cooler hours.

2 Project Summary

The objective of this project is to install advanced sensors on high-voltage transmission lines to be able to better utilize the lines by pushing more power through them when needed based on current conditions (e.g. temperature, line sag, wind… etc.). Line ratings will be dynamically changed to provide the operators with near-real time ratings based on line conditions as opposed to the fixed pre-calculated ratings.

2.1 Project Objective

Transmission Line Monitor (TLM) devices will monitor line temperature and direct line clearance of the ground in real-time to evaluate the capacity of the transmission line dynamically instead of relying on conservative static ratings. Dynamic ratings will help better utilizing the system and accurately measure transmission line capacity and loading capability in real time under current operating conditions.

2.2 Problem Statement

The existing SCE operating practice is to use fixed line ratings that are pre-calculated based on assumed-fixed conditions throughout the year. The primary DLR instrumentation deployed with CAT-1 technology is based on a tension monitoring system developed by The Valley Group, a component of Nexans. The CAT-1 system incorporates a load cell into the dead-end insulator assembly at the end of each stringing section of conductor. The load-cell measures the tension of the conductor and sends a signal to a local processor at the structure. The main units are configured to communicate by DNP 3.0 protocol via an RS-232 interface. The tension data, ambient temperature and data on the solar radiation affecting the conductor are sent to a nearby substation via radio transmission. At the substation the data is streamed via RTU and SCADA system to the Energy Management System (EMS) using any supported SCADA protocol.

Through the Nexans algorithm, the data is transformed into a conductor temperature representative of the line section the load cell is monitoring. From that information, the effective ambient conditions are measured and calculated. Then the algorithm calculates what the maximum current capacity would be before the conductor would reach the minimum clearance (maximum sag condition). This revised allowable current is the *Dynamic Line Rating* for the line section. By monitoring multiple sections of a transmission line to account for different line orientation, stringing conditions or terrain, the minimum dynamic rating can be identified and used for optimum operation of the transmission line.

2.3 Scope

The CAT-1 Transmission Line Monitoring System monitors the mechanical tension of the transmission conductor. The sag of any transmission span is inversely proportional to the horizontal component of the tension and is directly related to the temperature of the conductor; therefore CAT-1 data can be used to accurately calculate conductor temperature and report the actual current carrying capacity of the transmission line.

The CAT 1 remote unit is mounted on the transmission structure. The load cells are mounted between the "un-energized" side of the dead-end insulators and the structure. The components of the system located on the transmission structures are:

- One CAT 1 Main unit – in an aluminum enclosure, which houses the circuit board and communications device
- One CAT-PAC unit – in an aluminum enclosure, which houses the batteries and solar regulator charger
- Two 20W solar panels – mounted to the CAT-PAC enclosure
- Two stainless steel load cells - with integral hardware and shielded cables
- One ambient temperature sensor - in an aspirated shield
- Two Net Radiation Sensors – to measure the effect of solar radiation on the conductor
- One directional (Yagi) antenna and antenna cable

The radio signals used in this system require the antennae to have "line-of-sight" installation arrangement. To achieve this, a CAT 1 Repeater Unit may also be required. This unit consists of:

- Two Radios – one for communicating with the CAT 1 field equipment, the other for communicating with the Substation equipment
- Two Batteries – to power the radio equipment
- Three solar panels – to provide a charge supply for the batteries
- Two directional antennae – one for each of the radios

2.4 Schedule

A high level schedule overview is presented in the following table:

Task Name	
Authority to proceed	**Jan 2, 2015**
Publish Standard pilot approval process	**Aug 28, 2015**
Substation Construction	**Aug 28, 2015 – Sep 15, 2015**
Telecom Construction	**Sep 18, 2015 – Oct 16, 2015**
System Configuration & Testing	**Oct 19, 2015 – Dec 18, 2015**

Pilot operation	**Dec 19, 2015 – Dec 19, 2016**
Project Close out	**Dec 19, 2016 – Feb 16, 2017**
End project	

Table 1 Project Schedule

2.5 Milestones and Deliverables

Table 2 shows a list of milestones and deliverables. Due to early close-out of project, a status of "cancelled" is shown in status column.

Milestone/Deliverable	Status
PO Issued	Completed
Towers Selected and technical specs drafted	Completed
Computer based Line-of-sight analysis conducted	Completed
Equipment delivered	Completed
Pre-engineering Job walk conducted	Completed
Transmission Standards and training material drafted and approved	Completed
Engineering drawings issued	Completed
On-site Line-of-sight analysis	Cancelled
Transmission outage and construction	Cancelled
Substation construction	Cancelled
Pilot Operation	Cancelled
Final Report Out to Stakeholders	Cancelled

Table 2 Milestones and Deliverables

3 Test Set-Up/Procedure

The following test procedures were developed as part of the project to better assist in construction and implementation phases of the pilot.

1.0 Pre-Installation Checklist

Step 1. Identify dead-end hardware that may need to be changed or removes because of the extra slack that will be caused by the load cells additional length. Make sure that to have proper hardware to interface with the integral eye hardware of the load cells. It is a good practice to assemble all the pieces of hardware before going to the field. Re-check that load cells are properly rated for the maximum tension of your line.

Step 2. Check battery voltages to make sure that the CAT-1 is fully charged (over 12V reading at battery terminals). If necessary, the battery can be charged through the terminals on the control panel by using a standard battery charger. The charging current should not exceed 2A or the main fuse will open. It is a good idea to charge the batteries overnight before installation.

Step 3. Verify the line direction from line maps. The CAT-1 enclosure(s) and NRS mounting bracket should be located on the South (or North in the Southern hemisphere) face of the structure in order to maximize input to the solar panels and to reduce the possibility of shadowing of the NRS(s). For RTR systems, the azimuth for correct positioning of the radio antenna to direct it towards the CATMaster receiving site should be determined.

Step 4. Take a small electronic toolkit and a multi-meter with you, in addition to the equipment required by the linemen. Check that you have a spare fuse for CAT-1 in the main unit (component "F2"). A laptop computer and an RS 232 interface cable will allow Local mode use in the field.

Step 5. Edit the configuration table of the CAT-1 unit if necessary. Mark down, log, or print current log as well as changes made. See "Edit configuration (;E)".

Step 6. Take the right CAT-1 with the right accessories. All equipment shipped with a CAT-1 system is labeled with the intended installation location identified. The system is preconfigured with settings and offsets specific to the various components provided. It is therefore very important that the equipment for a given site is kept together and installed as indicated.

Step 7. Let us know about your planned installation dates well ahead of time. A minimum of two weeks of advance notice is suggested. We can discuss the installation with you, and ensure that technical support will be available to assist in the field as required for validation of your system warranty.

2.0 Field Installation of Hardware

2.1 Install the load cells. Depending on your company's practices, load cell installation may or may not be possible as hot line work. Insulators and extraneous hardware can be removed to lessen any slack created by the load cells. It is important to mount the load cells in a manner that does not cause torque on the load cell. Any torque exerted on the load cell may have a significant effect on the output of the cells. For connection to the eye hardware of the load cells, Y-clevis hardware is suggested. See diagram in Appendix A7 for typical load cell dimensions.

Make sure the load cell connectors do not come in contact with moisture! This will cause the load cell readings to go to full scale.

Electrically bypass and ground the load cell (for flashover current protection) with a copper braid of at least 200 kcmil. Snake the load cell cable down to where the CAT-1 main unit will be located. Temporarily attach the cable, if necessary. If installing on a wood structure, ground the load cell hardware to the structure ground.

The load cell cabling should be routed down the structure using a reliable method of affixing the cables to the structure to prevent them from blowing in the wind and abrading against structure components. Common methods include cable clamps, routing through PVC pipe, etc. Where the cable is routed along the transmission arm, it is crucial to ensure that it is not possible for the means of support to fail enabling the cable to fall into the energized phase. Wrapping the cabling around the transmission arm is one method of ensuring this.

2.2 Attach the CAT-1 main unit and CAT-PAC on the structure or to the pole using standard hardware, such as uni-strut or pole bands. The CAT-1 unit must be grounded. This is especially important to remember when installing on wood structures. Make sure that you mount the main unit on the south side of the structure, so that the solar panel(s) will point towards true south.

2.3 Mount the NRS mounting bracket to the structure on the south face of the structure at an elevation which approximates the position of mid-span sag of the conductor under normal everyday operating conditions. The NRS(s) are aligned in the same direction as the line section(s) being monitored. The NRS with the blue port connector is associated with the black port 1 load cell. The NRS with the green port connector is associated with the red port 2 load cell.

Make sure that the NRS(S) will not be shielded from the sun by the structure for any part of the day.

2.4 Attach the antenna to an antenna mounting bracket and route the antenna cable to the CAT-1 unit. Communications should be tested by taking a field strength reading using software provided with the system.

2.5 Mount the solar panels to the mounting tabs provided on the bottom of the CAT-PAC unit (as indicated in the Mounting the Solar panels and the NRS(s) section). The ambient sensor in its aspirated shield is to be installed on the top right mounting ear on the CAT-1 main unit enclosure at a 45 degree angle away from the box.

2.6 Connect the load cell cables to the bottom of the CAT-1 unit, making sure that the correct load cell is connected to the correct port (Port 1 connectors have black tape, while Port 2 has red). Do not expose the connectors to any moisture, as this may give you full scale readings. They should be hand tightened (i.e. never use a wrench).

2.7 Open the sensor's junction box. Route the cables through the strain relief openings at the bottom of the junction box. Attach black, white, green, brown, red wires to 1-5 (extension cable to CAT-1), and black, white, green, red to 6-9 (to wind sensor). Close the junction box. In most cases, these connections should already have been made at the factory. Attach the junction box to a convenient location on the structure between the anemometer and the CAT-1 unit. Be sure to ground the junction box to the structure ground. Tie or tape the wind sensor cable down. Plug the cable into the appropriate port marked "AUX" at the bottom of the main unit.

2.8 RTR systems can be tested by placing the main unit in “LOCAL” mode. The [;C] command can be used to determine if reasonable tension and temperature measurements are being taken. Next, place the system in “AUTO” mode and cycle the power. After the system has powered on it will sample its ports and wait the programmed report delay interval. The system will then attempt to communicate with the CATMaster via DNP 3.0 protocol. This will be evidenced by seeing garbled ASCII characters appear in the terminal program. This is the binary data traffic being sent over the radio. If the ASCII characters appearing on the screen repeat multiple times, this is an indication that the CAT-1 is not establishing communications with the CATMaster. Please contact TVG for further troubleshooting steps.

2.9 Set the CAT-1 to "AUTO". Cycle the power OFF, power ON. Close the cover and lock the latches. Additionally, it is recommended that a padlock be installed on the provided hasp.

3.0 Mounting the Solar Panels and the NRS(s)

3.1 With the solar panel detached from the CAT, verify proper operation of the solar panel with a multi-meter. The open circuit voltage read between pins A and B of the solar panel connector should be 16.0-17.5V in direct sunlight.

3.2 With the solar panel plugged into the CAT-1, turn the solar panel face down on the ground. Plug your multi-meter leads into the battery terminals. When the solar panel is turned face up into direct sunlight, you should see a change of about +0.2 to +1.0V.

3.3 The NRS(s) are installed on the provided NRS mounting bracket. Make sure that the five (5) thermally insulating washers are placed between the NRS and the mounting bracket (and another five (5) between the NRS's if two are used). Tighten the plastic bolt with care, as it is somewhat fragile.

3.4 Attach the 5-pin connector from the NRS with the blue tape to the corresponding connector on the bottom of the main unit, marked "NRS1". If a second NRS is to be used, it will have green tape and is attached to the corresponding port on the CAT-1 marked "NRS2". Note that the connector can only go in one orientation. Tighten the connectors hand tight only.

3.5 The solar panel you have received should be set to the correct latitude for your installation location. Adjust the bracket to match the marked indication and tighten the bolts.

3.6 Attach the solar panels to the mounting lugs at the bottom of the front face of the CAT-PAC enclosure. Do not fully tighten the bolt yet, allowing side to side movement still.

3.7 Attach the solar panel connectors from the solar panels to the corresponding connectors on the bottom of the CAT-PAC unit. Note that the connector can only go in one orientation. Tighten the connector hand tight only.

3.8 Attach the ambient temperature sensor in its aspirated shield to the upper right mounting tab on the CAT-1 enclosure. Position the sensor shield at a 45 degree angle away from the enclosure. The ambient sensor connector is attached to the corresponding connector marked "AMB" on the bottom right of the main unit. Note that the connector can only go in one orientation. Tighten the connector hand tight only.

3.9 Align the solar panels toward due south. Tighten the bolts attaching the solar panels to the CAT-1 enclosure.

4.0 Calibrating the System

In order to determine the tension-temperature behavior of the line a calibration of each load cell must be performed. This is done by taking the line out of service or by reducing the current to a level low enough to ensure that heat rise on the conductor is negligible. A line loading of 5-10% of the static rating is typically low enough to consider being equivalent to an outage.

For the most accurate calibration, it is best to collect outage data at night. Calibration data cannot be collected with rain, snow or ice present on the line because this increases conductor weight by 1-4%. The line should be de-energized a minimum of four hours to allow the conductor to reach ambient temperature and to allow for a sufficient temperature spread to be used for calibration. The ICW application will log the tension, temperature, and line loading data required for calibration. This data is then sent to TVG for generation of calibration coefficients.

For maximum accuracy, the line should be taken out of service a second time, at an ambient temperature at least 20 degrees C different from the first time. Typically this is done in the opposite season from that present during installation.

4 Project Results

The following subsections specifically address the technical results, lessons learned, and technology/knowledge transfer plan for the project.

4.1 Technical Results, Findings, and Recommendations

Although the project was cancelled before construction to install the equipment started, some initial studies were conducted. The main study that was conducted was a Path line-of-site survey that is essential to the success of communication. Poles M3-P4, M3-P7 and M4-P2 we surveyed for line-of-site with the antenna mounted on the transmission tower at Barre substation. It was determined that all three paths are obstructed by vegetation, which could potentially introduce interference in communication.

4.2 Technical Lessons Learned

As a result of all the efforts that were put into this project, it has been uncovered that the Transmission Line monitors require direct line-of-site in between communication boxes to bring the signals back from the transmitter device back to the substation. Unless the critical spans of the monitored line are close to a substation where an RTU installed, it may not be feasible to get a communication path back to EMS. In addition, longer lines will require a lot of routing devices to carry the signal back to the RTU, which makes the solution not practical with the significant increase in equipment, cost, and maintenance of devices.

4.3 Value Proposition

It has been determined from this project that although Dynamic Line Ratings might be feasible in some specific occasions, the adoption of technology with the current operating procedure is not practical. The solution proposed by this technology is not practical for deployment at the high voltage transmission system, given that longer lines will require significant increase in cost, equipment and maintenance. As for the sub-transmission adoption of technology, most of the heavily loaded sub-transmission lines are in residential areas where the establishing communication path would be extremely hard, giving the obstacles blocking the line-of-sight between communication devices.

4.4 Technology/Knowledge Transfer Plan

Findings have been shared with project stakeholders, including Transmission Engineering and Grid Operations. Testing results and preliminary finding have been communicated to the rest of the team, and documented in the project folders. Final closing report was developed and shared with the project team.

5 Metrics

None

6 Appendix

List of Acronyms

ARRA	American Reinvestment and Recovery Act
AT	Advanced Technology (the organization)
ATP	Advanced Technology Procedure, or Authority to Proceed
BOM	Bill of Materials
CCB	Change Control Board
CMO	Compliance Management Office
COTS	Commercial Off-The-Shelf
CPUC	California Public Utilities Commission
DBE	Disadvantaged Business Enterprise
DLR	Dynamic Line Rating
DOE	Department of Energy
eDMRM	electronic Data Management/Records Management
EPIC	Electric Program Investment Charge
FY	Fiscal Year
GRC	General Case
IAW	In Accordance With
ICC	Integrated Change Management
IO#	Internal Order Number
IP	Intellectual Property
O&M	Operations and Maintenance
PDF	Portable Document Format (Acrobat file)
PfMP	Portfolio Management Plan
PM	Project Manager
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PMO	Portfolio Management Office
PMP	Project Management Plan
PMR	Portfolio Management Review
PO	Purchase Order
PPM	PMO Process Matrix
PPP	PMO Procurement Plan
PRR	PMO Risk Register
PSR	Project Status Review

SCE	Southern California Edison
SME	Subject Matter Expert
TFC	Termination for Convenience
TL	Technical Lead
TLM	Transmission Line Monitors
Ts&Cs	Terms and Conditions

Glossary

Term to define	Definition here

Also see glossary's available for the electric utility industry available on the internet like this one: http://www.nwppa.org/advertise_sponsor/Facts_Figures_Glossary_of_Terms.aspx)