Southwest Transmission
COOPERATIVE, INC

ENGINEERING RE-RATING STUDY

OF

APACHE TO BUTTERFIELD 230 kV LINE

DOCKET NO. E00000D-09-0020

JANUARY 28, 2011

SOUTHWEST TRANSMISSION COOPERATIVE, INC.

ENGINEERING RE-RATING STUDY

OF

APACHE TO BUTTERFIELD 230 kV LINE

Prepared for the

ARIZONA CORPORATION COMMISSION

IN FULFILLMENT OF ACC 6TH BTA REQUIREMENT

Docket No. E-00000D-09-0020

TRANSMISSION PLANNING

JANUARY 28, 2011

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SOUTHWEST TRANSMISSION COOPERATIVE, INC.

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INTRODUCTION AND PURPOSE OF STUDY

This Engineering Re-Rating Study of the Apache to Butterfield 230 kV Line ("Study") is hereby submitted to the Arizona Corporation Commission ("Commission") by Southwest Transmission Cooperative, inc. ("SWTC") to satisfy the requirements of the 2010 6th Biennial Transmission Assessment ("BTA"), which states:

"SWTC shall determine if an engineering 're-rate' of the Apache-Butterfield 230 kV line as proposed in the Sixth BTA filings would be an acceptable measure until the line is upgraded in 2016, and to file the results of this assessment by January 31, 2011."[1]

This 6th BTA order was spawned by the Southeast Arizona Transmission System ("SATS") 2009 report and the SWTC 2010-2019 ten-year plan that both identified overload issues on the Apache to Butterfield 230 kV line beginning in 2012. In particular, 2012 is the year that the 2009 SATS report had identified an outage of the Apache to Butterfield 230 kV line as a result of an N-2 loss of the TEP Winchester to Vail and Springerville to Vail 345 kV lines. By 2013, the line also overloaded for N-1 loss of the TEP Winchester to Vail 345 kV line.

The mitigation measures mentioned in the SATS report were to either trip the SWTC Bicknell 345/230 kV transformer or the SWTC Vail to Bicknell 345 kV line. Either of these measures is acceptable to SWTC. However, discussions at the 6th BTA Workshops indicated that ACC staff and the BTA consultant were not in favor of these measures.

The SWTC 2010-2019 ten-year plan filing stated that through its studies for 2014, an overload of the Apache to Butterfield 230 kV line occurred as a result of the N-1 loss of the Tucson Electric

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[1] ACC Sixth BTA, Docket No. E-00000D-09-0020, Decision No. 72031

Power Company (TEP) Winchester to Vail 345 kV line. SWTC also noted that a few Category C (N-2) outages, mostly due to the loss of various EHV facilities, continue to show high flows on the Apache to Bicknell 230 kV line. It stated that the Apache to Butterfield portion was being proposed to be upgraded in 2016 and the Butterfield to Bicknell portion was being proposed to be upgraded in 2017. SWTC also wrote "As of this writing, SWTC is working with LiDAR to re-rate the Apache to Butterfield 230 kV line, which will alleviate this problem."

The recommendations of staff in the 6th BTA also expressed concern for interim mitigation measures in the 2012-2015 time frame, should an overload of the Apache to Butterfield 230 kV line occur, in order to maintain system reliability. These, then, are the reasons for the BTA Order.

The purpose, then, of this study, is to address these two items – mitigation measures to put into place prior to 2012 to resolve an overload of the Apache to Butterfield 230 kV line, and a re-rate of the line to determine if this is an acceptable measure prior to upgrade of line, to satisfy the 6th BTA requirement.

MITIGATION MEASURES TO ALLEVIATE OVERLOADS PRIOR TO UP-RATE

The studies used to prepare the SWTC 2011-2020 ten-year plan took into consideration additional mitigation measures that could be used to alleviate an overload of the Apache to Butterfield 230 kV line that would not involve operator tripping of EHV equipment as noted in the SATS report. SWTC found that under loss of the Winchester to Vail 345 kV line, or under a loss of the Winchester to Vail 345 kV line with the Springerville to Greenlee 345 kV line, re-dispatch of Apache station generation alleviated the overloads. There were no issues to report in 2011 with an overload of the Apache to Butterfield 230 kV line, as caused by an EHV N-1 or EHV N-2 outage, as noted in the Technical Study Report filed with this year's SWTC 2011-2020 ten-year plan. In 2015, there was an overload of the Apache to Butterfield 230 kV line associated with an N-1 loss of the Winchester to Vail 345 kV line, an N-2 loss of the Springerville to Greenlee and Winchester to Vail 345 kV lines, and an N-2 loss of GreenleeSW to Greenlee and Winchester to Vail 345 kV lines. Again, re-dispatch of generation at Apache

Station alleviated the overloads. The power flow plots found in the Technical Study Report for 2015 reflect this.

In 2020, there are no problems to report, as the studies assumed that the Apache to Butterfield 230 kV line had been upgraded in 2016. However, this study will show that it is technically feasible to defer an upgrade of the Apache to Butterfield and an upgrade of the Butterfield to Bicknell 230 kV well beyond the current ten-year plan horizon.

The 2010 SATS Report also notes that generation re-dispatch is the means of mitigation for loss of the Apache to Butterfield 230 kV. The SATS Report also discusses another measure that can be utilized that involves a procedure that will be put into place by TEP in 2015, to shut off Bowie generation, under certain EHV outages, to alleviate this overload.

These mitigation efforts are acceptable to SWTC.

TRANSMISSION LINE RE-RATING EFFORTS

While SWTC has considered re-rating its transmission lines for several years, its efforts in this regard began in earnest in 2009. In this year, SWTC hired LiDAR to fly the 115 kV transmission system from Marana Tap to Bicknell and the 230 kV transmission system from Apache to Bicknell. The information provided by LiDAR, along with historical weather data in Southeast Arizona in proximity to SWTC's transmission lines, allowed SWTC to determine that it was feasible to re-rate its transmission lines in order to increase transmission line capacity. SWTC has been involved in a considerable effort in 2010 to study the thermal ratings of its system, by utilizing the LiDAR data, checking its results against internal SAG programs, and gathering the necessary information needed to re-rate its 115 kV and 230 kV lines. A document entitled "Thermal Ratings of Existing Overhead Transmission Line Conductors" has been completed to document this study effort, the main body of which, without the attachments, is attached to this report as Appendix 2. The results of this document provided SWTC with the framework it needed to analyze the re-rating of the Apache to Butterfield 230 kV line for this Report.

The conductor of the Apache to Butterfield 230 kV line is 795 ACSR, which carries a normal rating of 334.63 MVA. SWTC uses the thermal line rating of ACSR conductors that are based on the Western Area Power Administration ("Western") Power Systems Bulletin 510, dated January 14, 1992 for its transmission system. These line ratings are based on a conductor operating temperature of 75° C. Studies conducted by SWTC, as noted in the document found in Appendix 2, show that the Apache to Butterfield 230 kV line can be safely operated at 93.3° C without reducing the life of the conductor. This would give the line a normal rating of 401 MVA. An emergency rating of 431 MVA can be applied to the line if it is operated at 100° C for short periods of time, again, without reducing the life of the conductor.

However, LiDAR found clearances issues with three structures on the Apache to Butterfield 230 kV line that will need to be resolved before the line can be re-rated to operate at 100° C. These issues are described below, along with a description of the short and long term fixes:

Structure No.	Field Comments	Short Term Fix	Long Term Fix
47	Violation to 115 kV Foreign Trans. Crossing	Maintenance issue – line will need to be de-energized when being worked on.	Raise pole or replace with a higher structure to achieve 100° C operation.
98	Violation to ground	Clear ground to achieve necessary clearance	Raise pole or replace with a higher structure to achieve 100° C operation.
118	Violation to ground	Clear ground to achieve necessary clearance	Raise pole or replace with a higher structure to achieve 100° C operation.

These fixes will be done immediately and are scheduled to be completed by December 31, 2011. Until these fixes are completed, SWTC will operate the line at 75° C, using the existing rating of the conductor, 334.63 MVA.

SWTC will be using the document in Appendix 2 in the months ahead as a basis to establish new line ratings for its bulk transmission system. These new ratings will then be incorporated into the WECC power flow base cases. The new rating for the Apache to Butterfield 230 kV line, however, will not be implemented in any WECC base cases until the above noted fixes are completed.

POWER FLOW STUDIES

With a rating of 401/431 MVA for the Apache to Butterfield 230 kV line, the next step was to implement this rating in the power flow models used for the SWTC 2011-2020 ten-year plan filing and determine if the re-rate is an acceptable measure to be used prior to an upgrade of the line.

Using the power flow models used for the SWTC 2011-2020 ten-year plan, simulations of an N-1 outage of the Winchester to Vail 345 kV line and simulations of N-2 outages of the Springerville to Greenlee & Winchester to Vail 345 kV lines, and the GreenleeSW to Greenlee & Winchester to Vail 345 kV lines were performed for the years 2015 and 2020. The Apache to Butterfield and the Butterfield to Bicknell 230 kV line were re-rated for these studies. As noted earlier, there are no issues associated with an overload of the Apache to Butterfield for any EHV outage in 2011.

The results show that the simulated outages that caused previous overloads of the Apache to Butterfield 230 kV line were no longer a problem in 2015 and were also not a problem by 2020. These power flow plots can be found in Appendix 1.

Additional power flow cases were run beyond the ten-year plan horizon to determine an approximate time when it would be necessary to upgrade the Apache to Butterfield 230 kV line and also the Butterfield to Bicknell 230 kV line. Using the 2020 base case, SWTC Loads in Southeast Arizona were increased in increments of 10% and then analyzed. At a 10% increase, which equates to a member-system load on the SWTC system of 687.4 MW, there are no issues with an overload of the Apache to Butterfield 230 kV upon the N-1 loss of the Winchester to

Vail 345 kV line or the N-2 losses of the Springerville to Greenlee & Winchester to Vail 345 kV lines, and the GreenleeSW-Greenlee & Winchester to Vail 345 kV lines, or loss of any other transmission line(s) in the area. However, the following overloads appear:

1) The Bicknell to Three Points 115 kV line overloads for loss of the Marana Tap to Marana 115 kV line, and for loss of the Saguaro to Marana Tap 115 kV line, which also transfer trips the Marana Tap to Rattlesnake and Rattlesnake to Tucson 115 kV lines.
2) The Rancho Vistoso to LaCanada 138 kV line overloads for loss of several TEP EHV N-1 and N-2 outages. TEP would likely have its own criteria for how these outages are to be dealt with under these specific outage contingencies.
3) The Winchester to Vail 345 kV line overloads for an N-2 loss of the Springerville to Vail2 & Pinal West to South 345 kV lines, as does the Winchester to Willow 345 kV line. TEP would likely have its own criteria for how these outages are to be dealt with under these specific outage contingencies.

In addition, there are new voltage and delta-voltage violations that appear, which would need to be resolved by the addition of capacitor banks or other measures. The Bicknell to Three Points 115 kV line would need to be upgraded by this time frame, which according to the medium economic scenario of the 2010 SWTC Load Forecast, is between 2026 and 2027. If the loads were to substantially increase, the High Economic Scenario projects this time frame to be between 2023 and 2024.

At a 20% increase, which equates to a member-system load on the SWTC system of 749.89 MW, there are still no issues with an overload of the Apache to Butterfield 230 kV upon the N-1 loss of the Winchester to Vail 345 kV line or the N-2 losses of the Springerville to Greenlee & Winchester to Vail 345 kV lines, and the GreenleeSW to Greenlee & Winchester to Vail 345 kV lines, or loss of any other transmission line(s) in the area. As in the 10% case, the same overloads noted above occur but are more severe, and additional new voltage and delta-voltage violations show up that would need to be resolved. At this 20% level, an outage of the Apache to Butterfield 230 kV line results in a non-solved case. To resolve this, it will be necessary to add an additional capacitor bank at San Rafael by this time frame, which according to the medium economic scenario of the 2010 SWTC Load Forecast, is between 2029 and 2030. If the loads were to substantially increase, the High Economic Scenario projects this time frame to be between 2026 and 2027.

At a 30% increase, which equates to a member-system load on the SWTC system of 812.39 MW, there are again no issues with an overload of the Apache to Butterfield 230 kV upon any of the previous N-1 and N-2 outages studied, or loss of any other transmission line(s) in the area. And, as in the 10% and 20% cases, the previous overload and voltage issues continue to be seen. In addition, in this 30% case, certain 115 kV outages do not solve, mostly those associated with the Western System from Saguaro to Tucson, along with SWTC's Marana Tap to Marana 115 kV. In order to resolve these non-solves, it will be necessary to look at other solutions, which could involve additional upgrades to the SWTC system, with the addition of more reactive support, or it may be necessary to provide an new 115 kV or 345 kV injection into the SWTC 115 kV system, by this time frame, which according to an extrapolation of the medium economic scenario of the 2010 SWTC Load Forecast, is between 2032 and 2033. If the loads were to substantially increase, the High Economic Scenario projects this time frame to be between 2029 and 2030.

No additional load increases were studied as the simulations show no overload of the Apache to Butterfield 230 kV line substantially beyond the current ten-year planning horizon.

CONCLUSIONS

The power flow studies show that with the Apache to Butterfield and the Butterfield to Bicknell 230 kV lines re-rated at 401/431 MVA, by the year 2012 and after all clearance issues have been resolved, an upgrade of the Apache to Butterfield 230 kV line could be deferred well beyond the ten-year plan horizon. There are no HV or EHV N-1 or EHV N-2 outages that cause an overload even with the SWTC loads increased to 30% beyond 2020. However, as noted above, there are actions that will need to be taken to resolve other overload and voltage issues that arise beyond the ten-year plan horizon. This will be done in later ten-year planning cycles.

Until the Apache to Butterfield 230 kV line issues have been resolved and the line can be re-rated, mitigation measures to alleviate an overload of this line, as noted earlier, will be a re-dispatch of Apache generation.

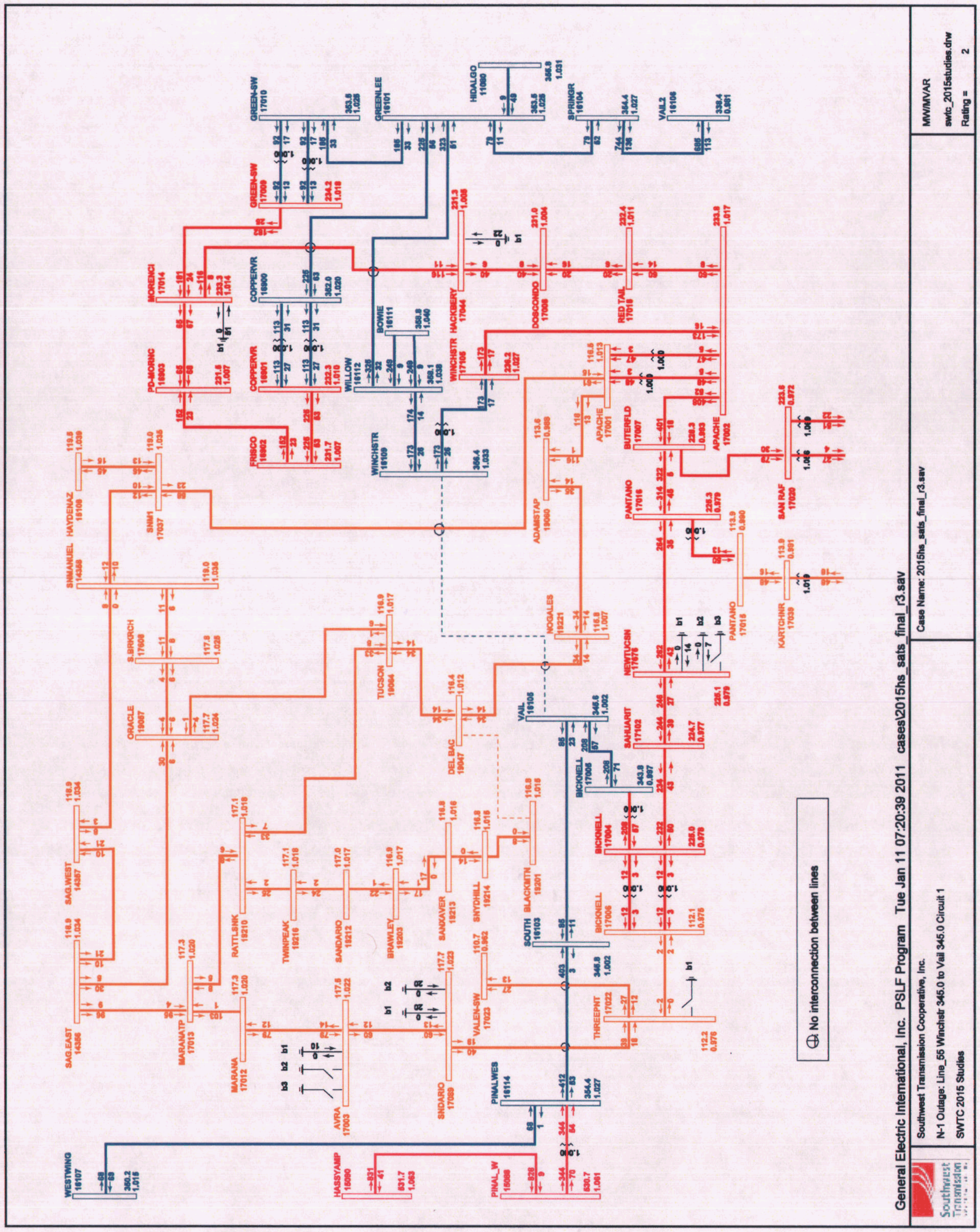
The studies also show that there are no issues associated with an overload of the Butterfield to Bicknell 230 kV line throughout the study period. For this reason, the SWTC 2011-2020 ten-year plan has removed the upgrade of the Apache to Butterfield 230 kV line in 2016 and the upgrade of the Butterfield to Bicknell 230 kV line in 2017, as they lie well outside of the ten-year plan horizon, due to the re-rating of these lines.

Additional studies in future ten-year plan filings will carefully follow this conclusion and any changes will be reported to ACC staff.

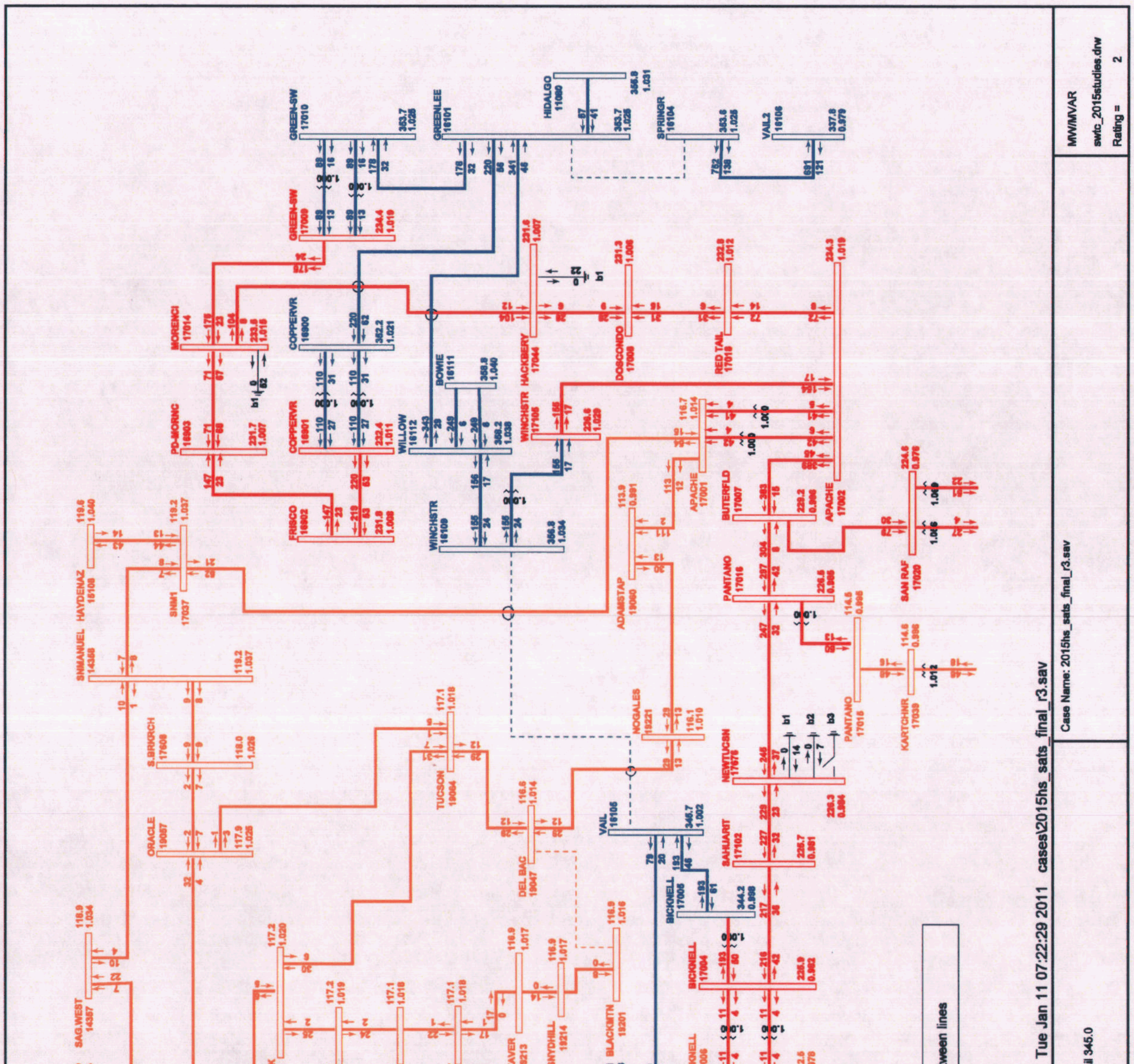
APPENDIX 1

POWER FLOW DIAGRAMS

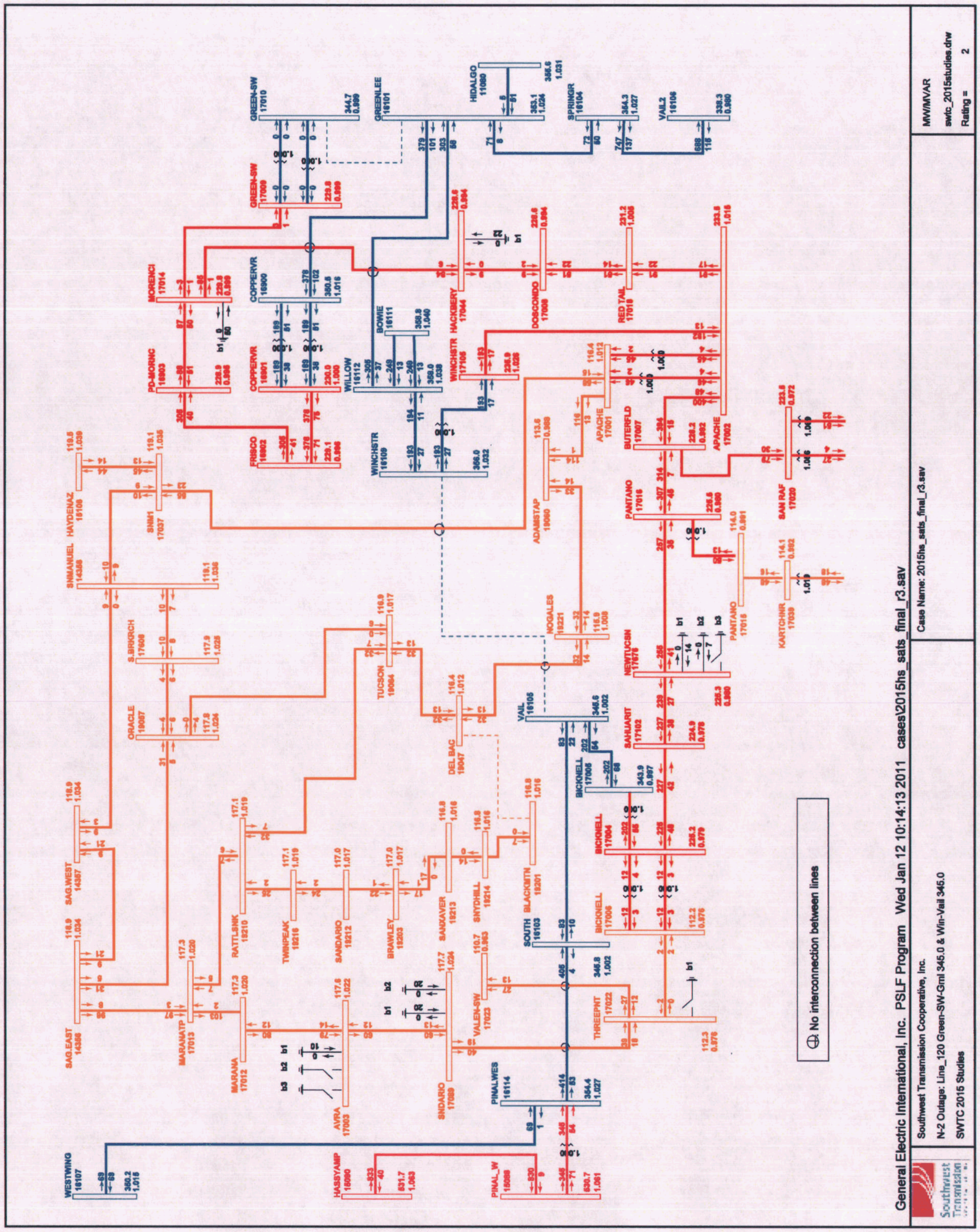
2015HS Southwest Transmission Cooperative Base System with Winchester to Vail 345 kV line out of service



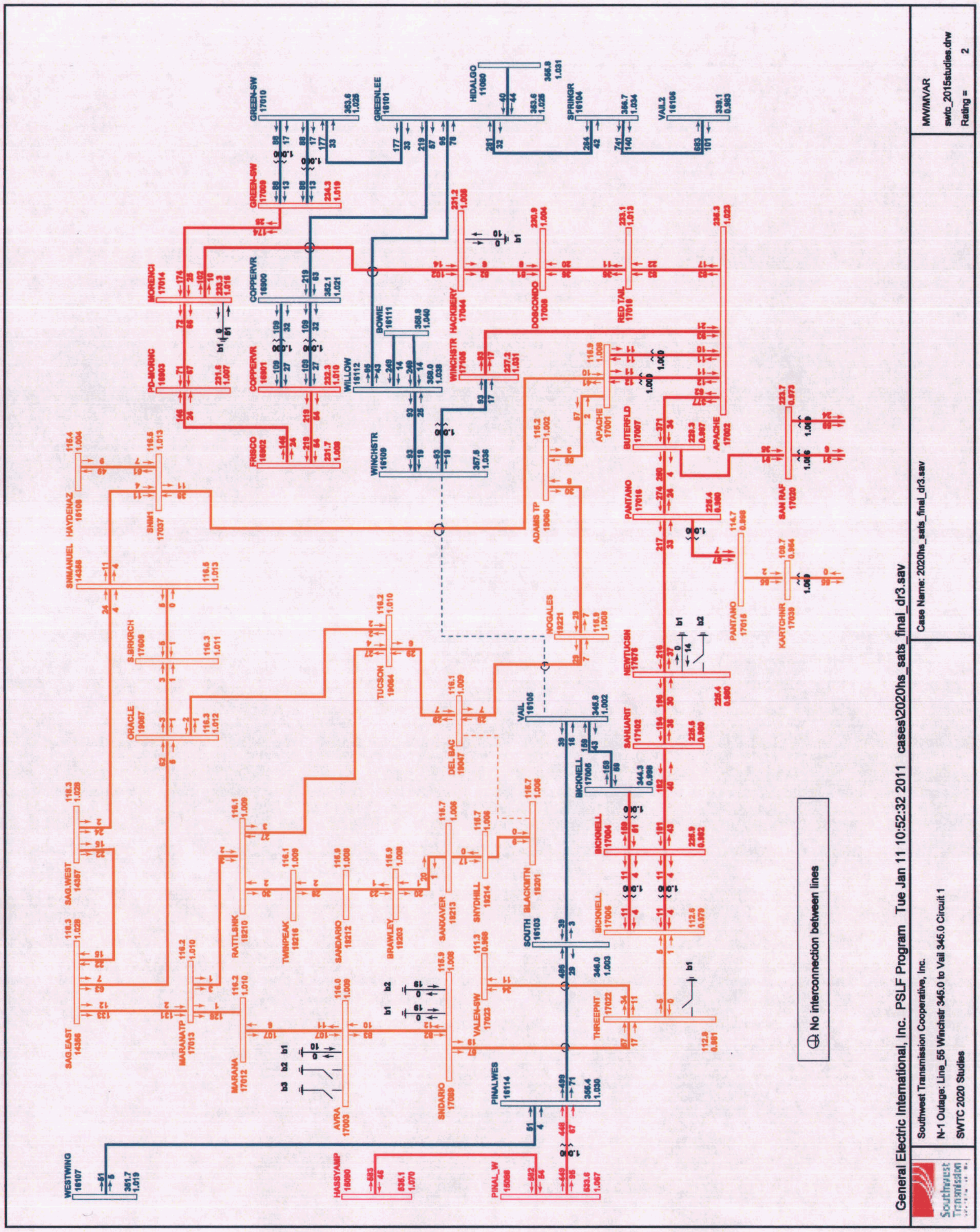
2015HS Southwest Transmission Cooperative Base System with Springerville to Greenlee and Winchester to Vail 345 kV lines out of service



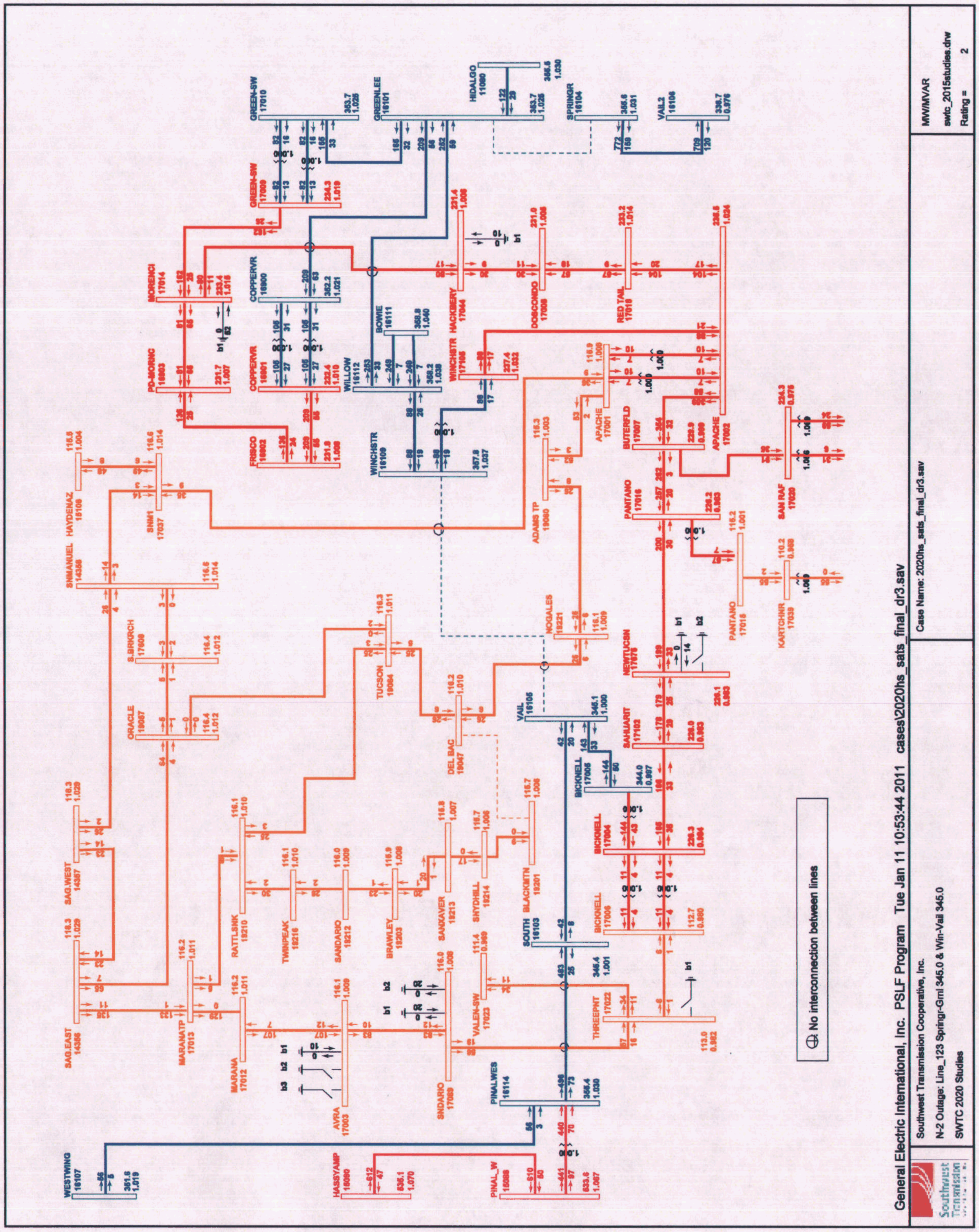
2011HS Southwest Transmission Cooperative Base System with GreenleeSW to Greenlee and Winchester to Vail 345 kV lines out of service



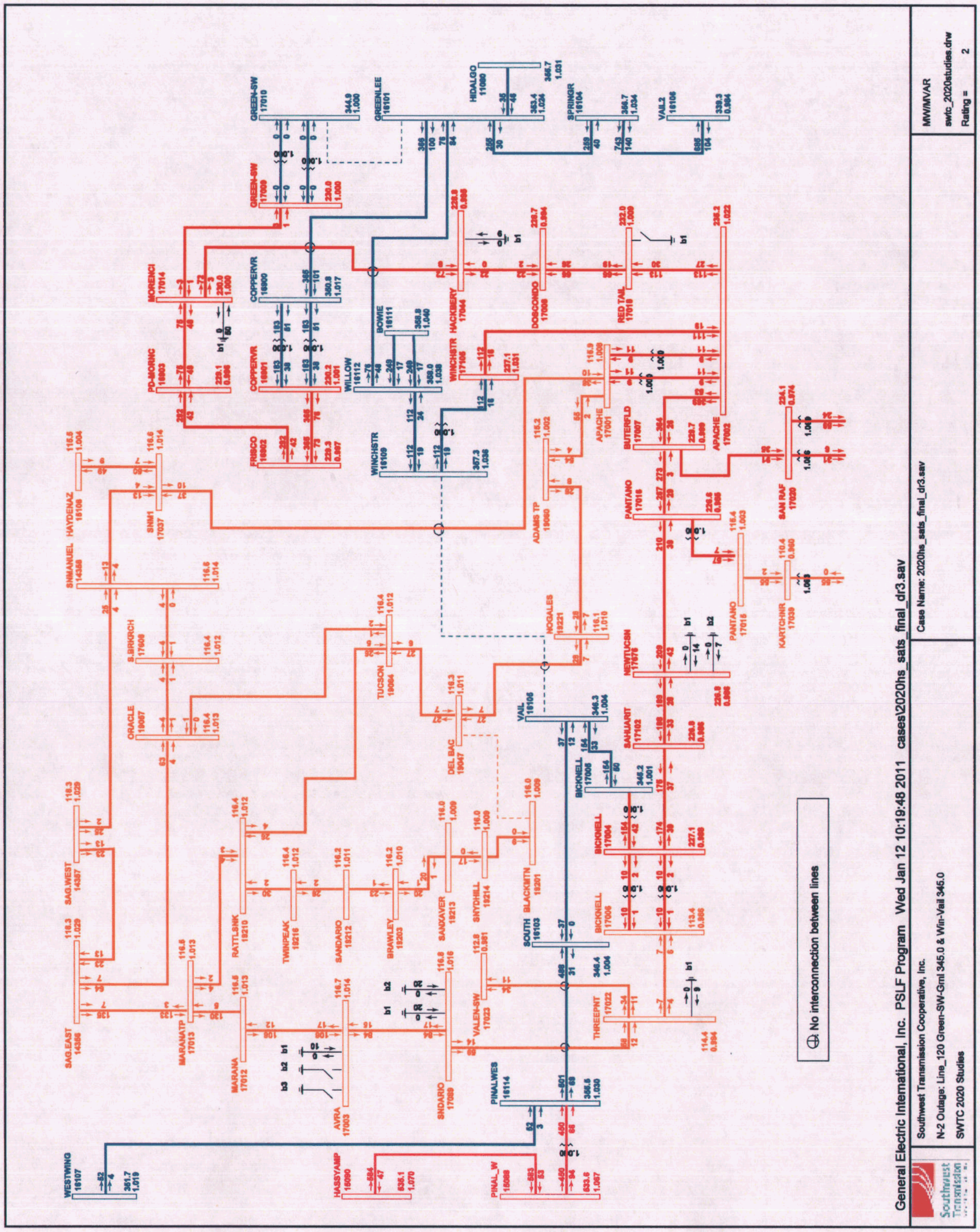
2020HS Southwest Transmission Cooperative Base System with Winchester to Vail 345 kV line out of service



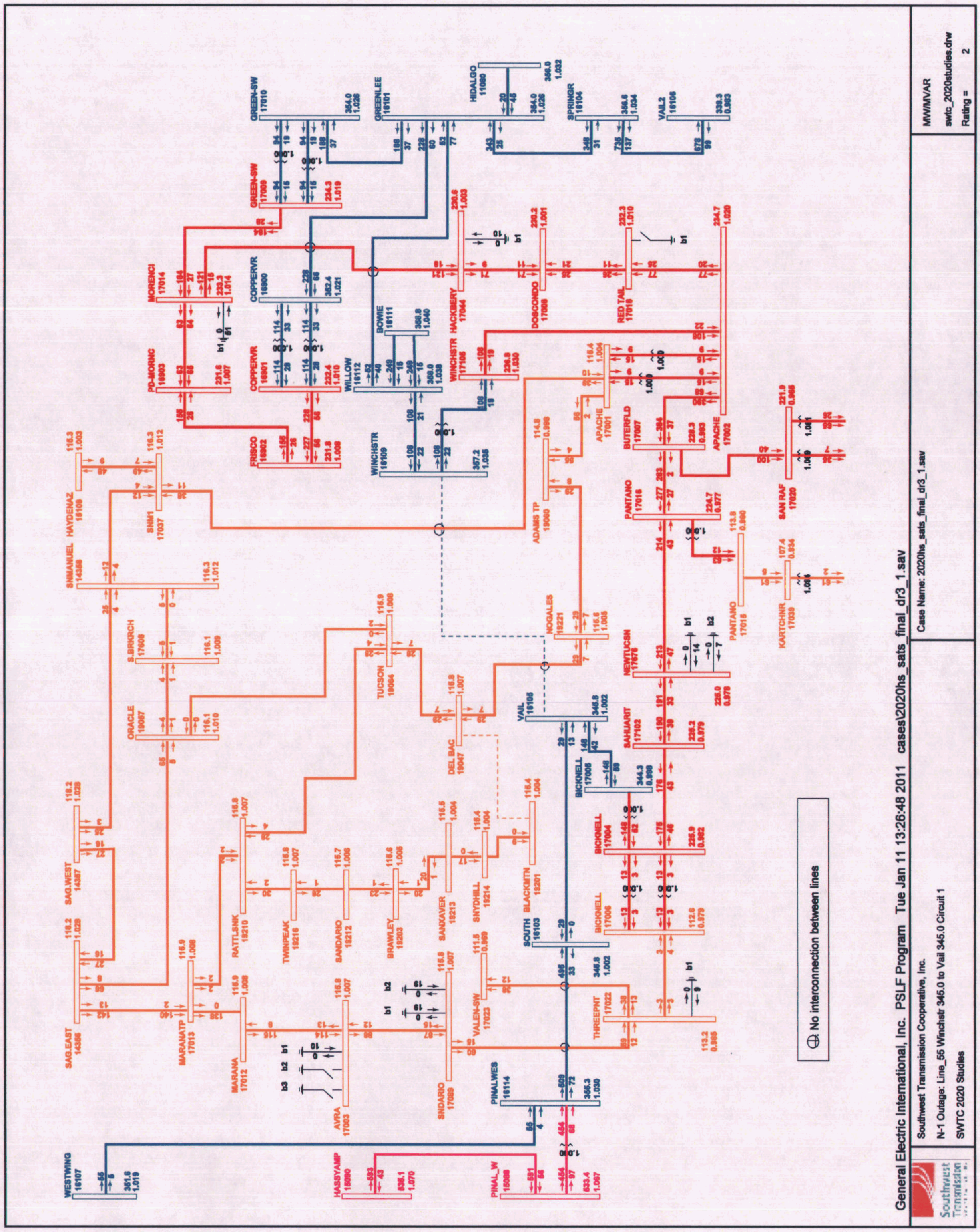
2020HS Southwest Transmission Cooperative Base System with Springerville to Greenlee and Winchester to Vail 345 kV lines out of service



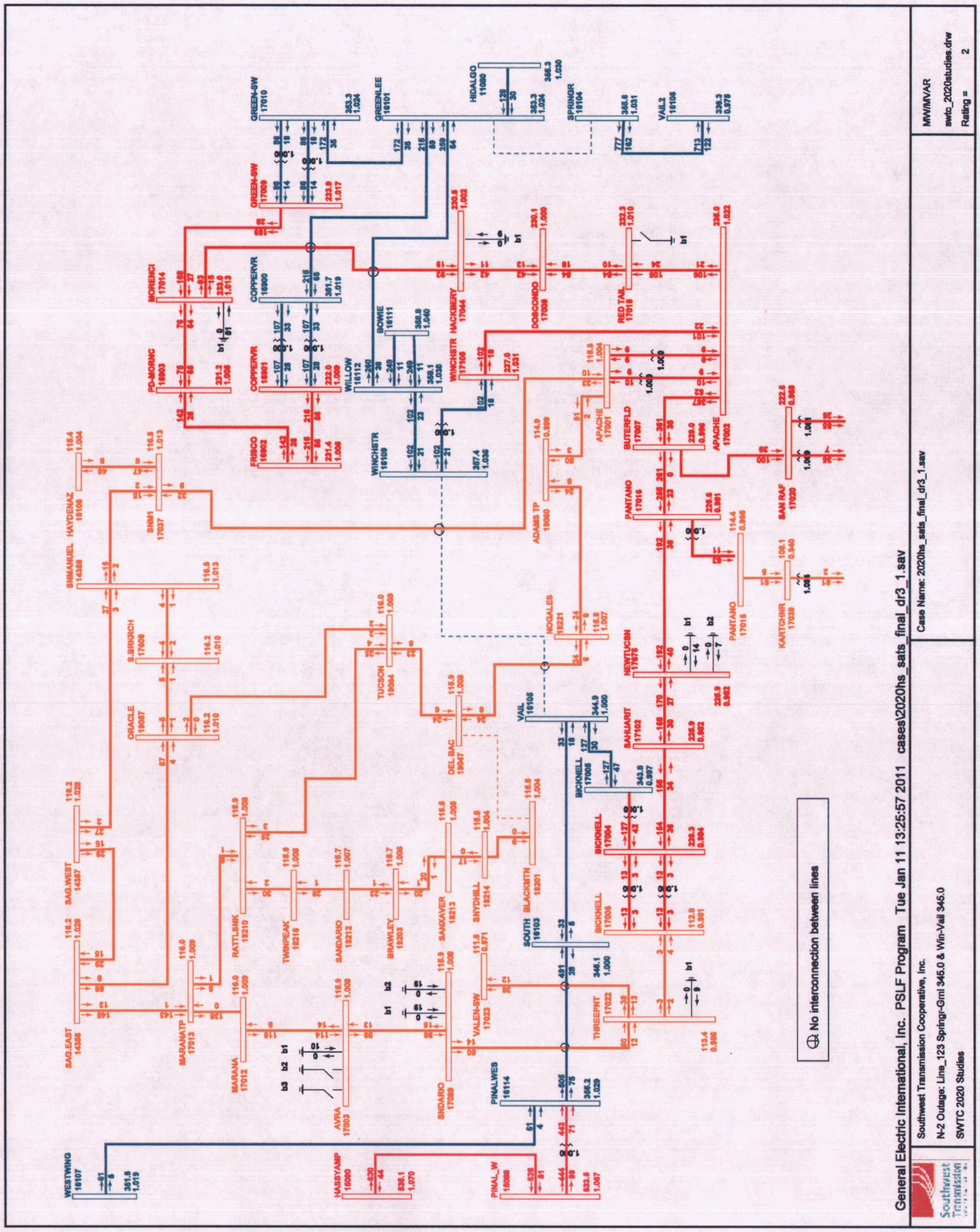
2020HS Southwest Transmission Cooperative Base System with GreenleeSW to Greenlee and Winchester to Vail 345 kV lines out of service



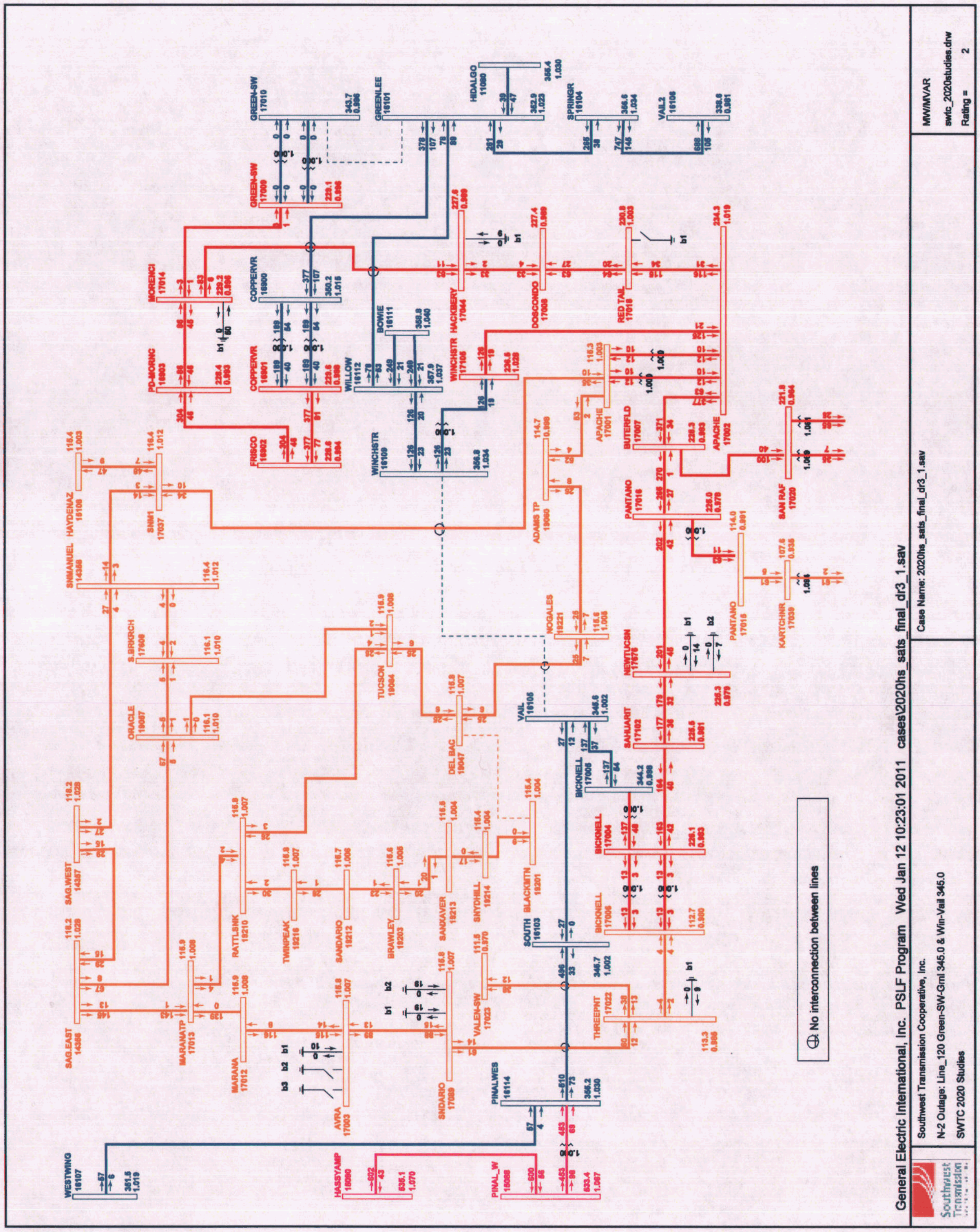
2020HS Southwest Transmission Cooperative Base System, SWTC member-system load increased 10%, with Winchester to Vail 345 kV line out of service



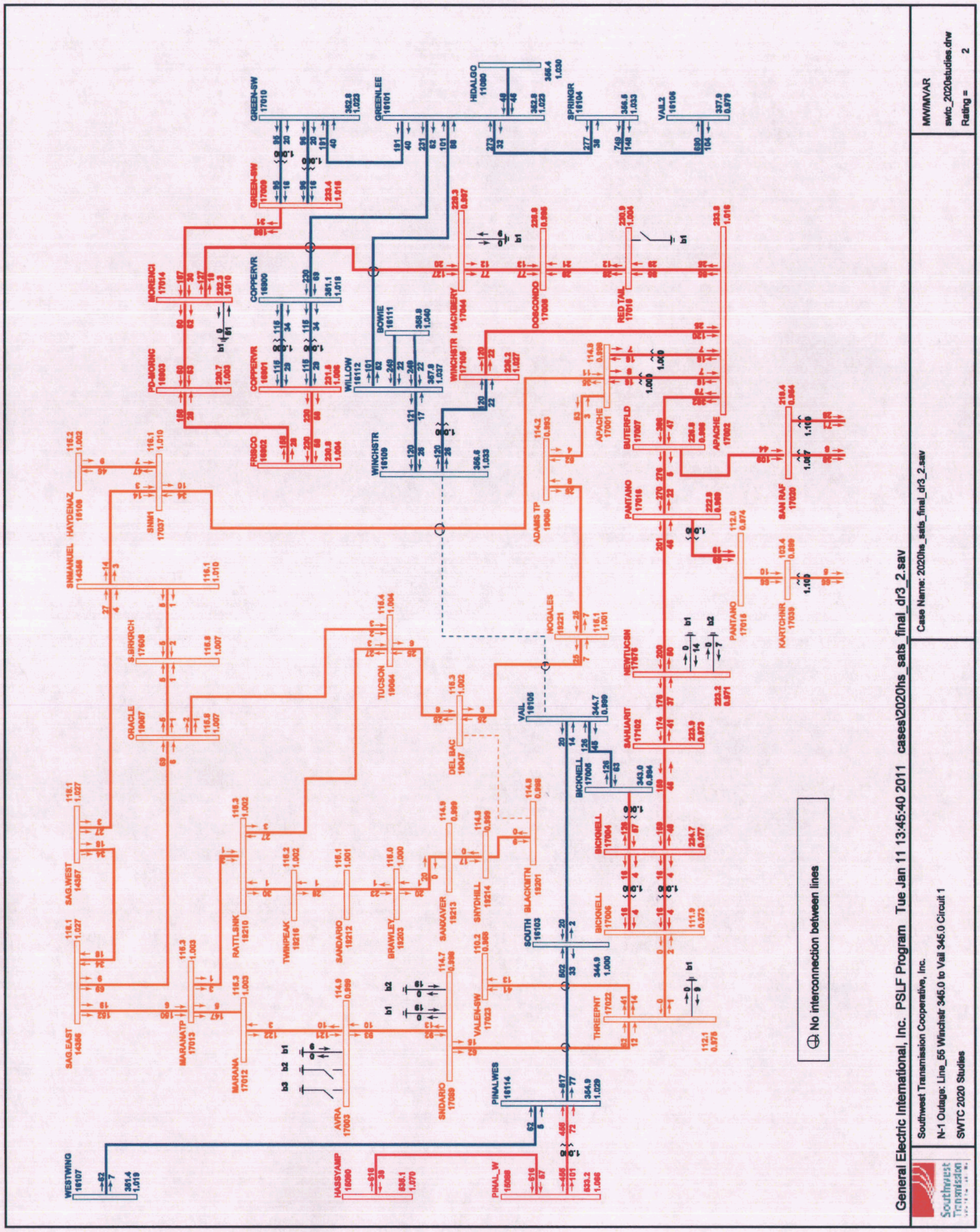
2020HS Southwest Transmission Cooperative Base System, SWTC member-system load increased 10%, with Springerville to Greenlee and Winchester to Vail 345 kV lines out of service



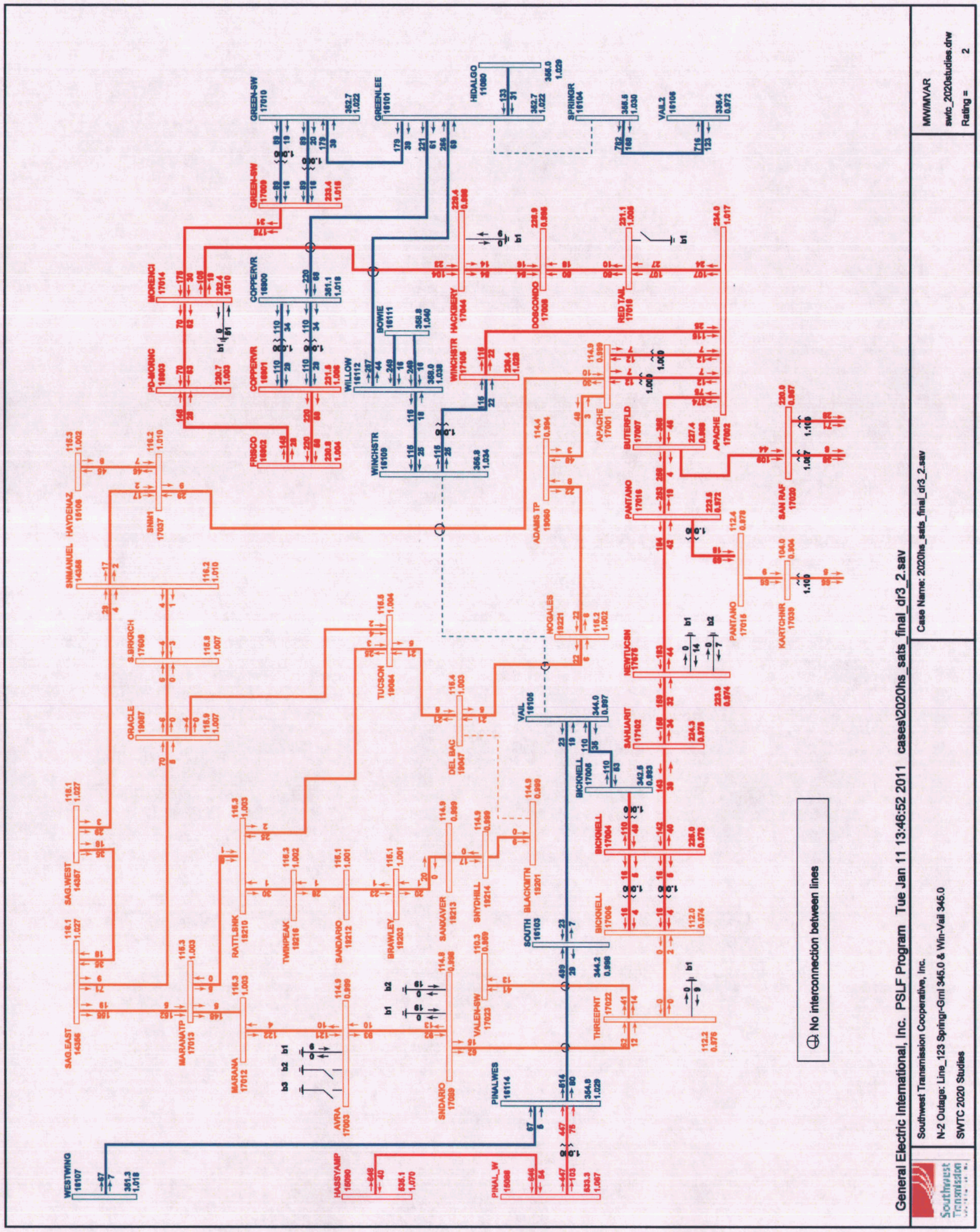
2020HS Southwest Transmission Cooperative Base System, SWTC member-system load increased 10%, with GreenleeSW to Greenlee and Winchester to Vail 345 kV lines out of service



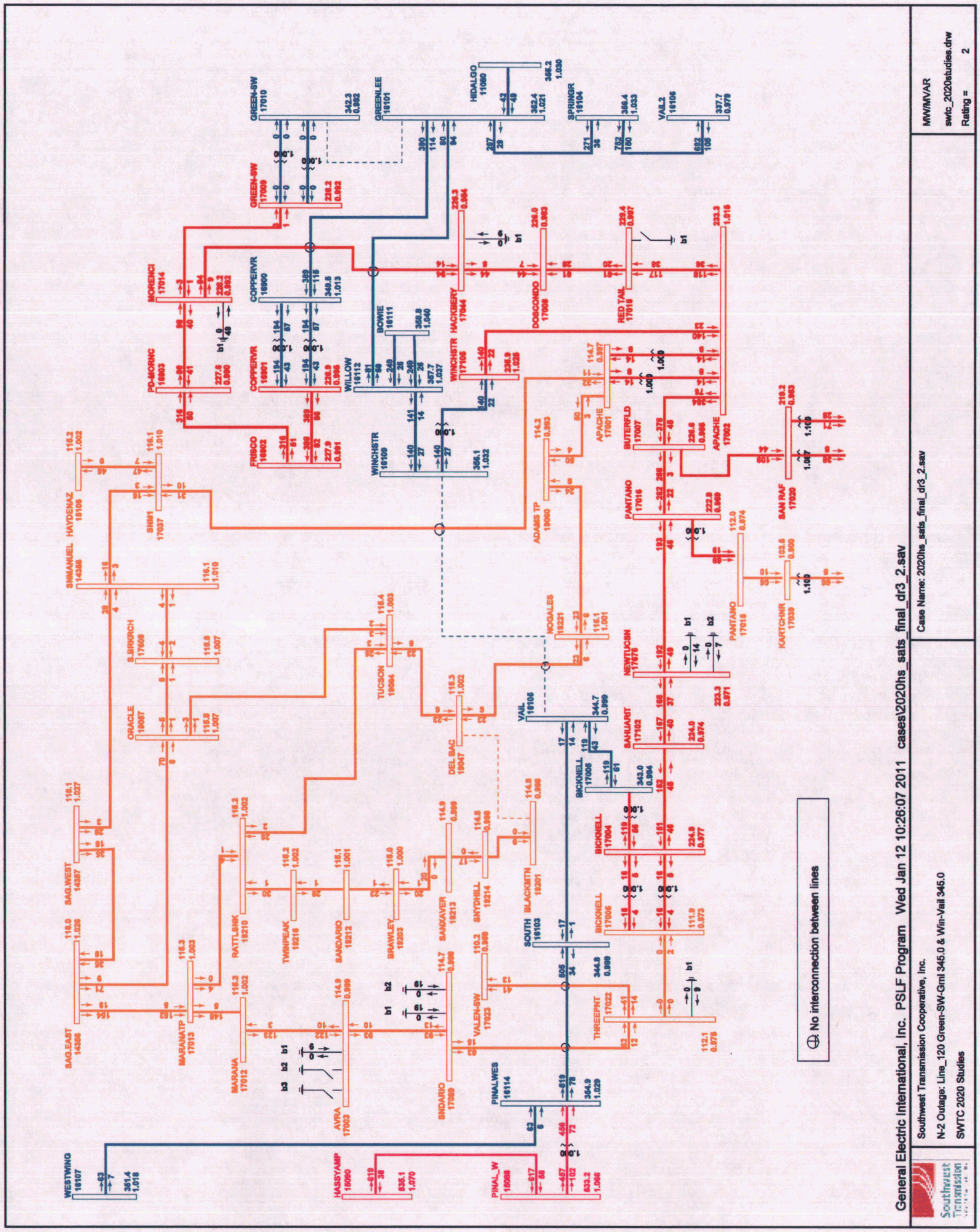
2020HS Southwest Transmission Cooperative Base System, SWTC member-system load increased 20%, with Winchester to Vail 345 kV line out of service



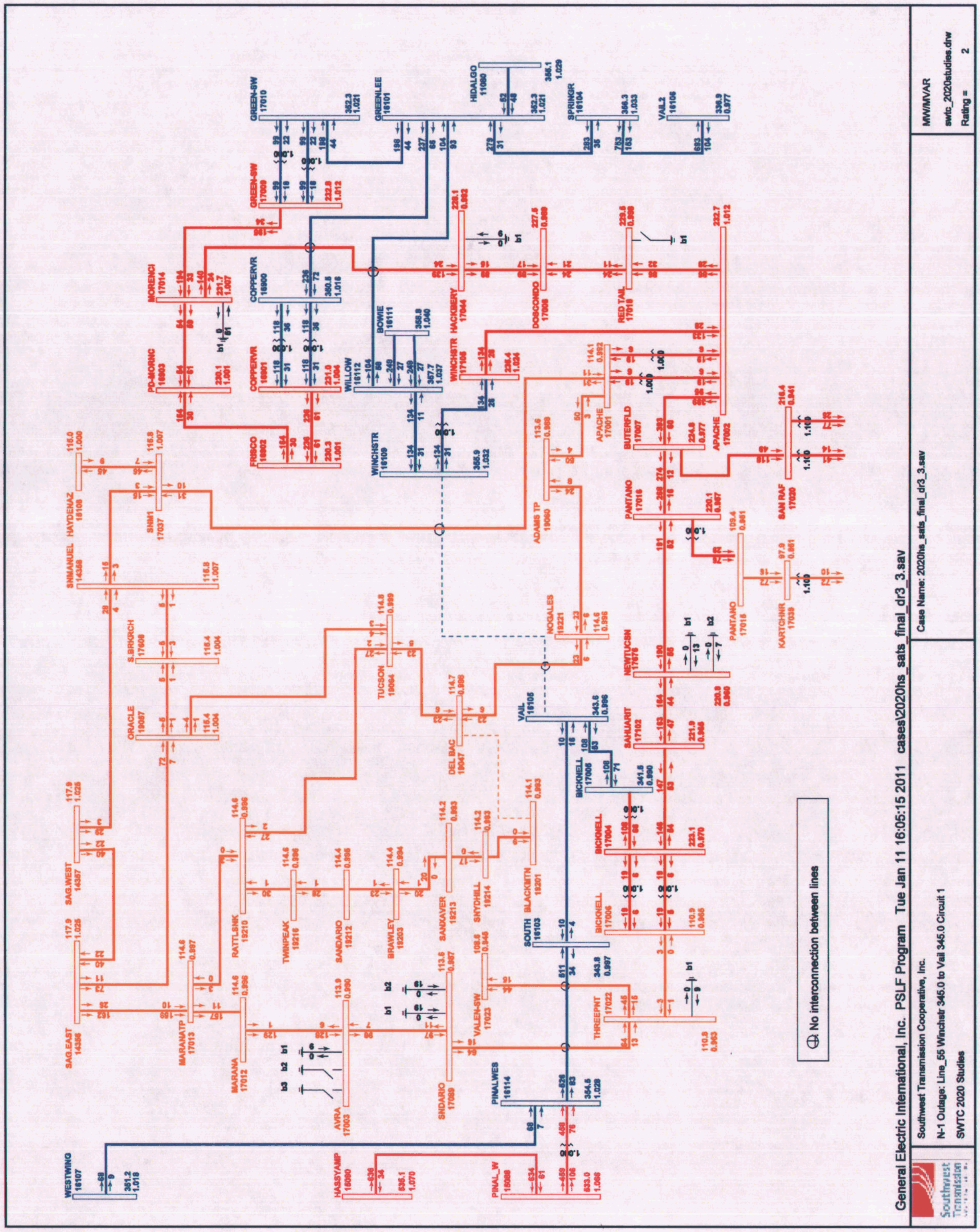
2020HS Southwest Transmission Cooperative Base System, SWTC member-system load increased 20%, with Springerville to Greenlee and Winchester to Vail 345 kV lines out of service



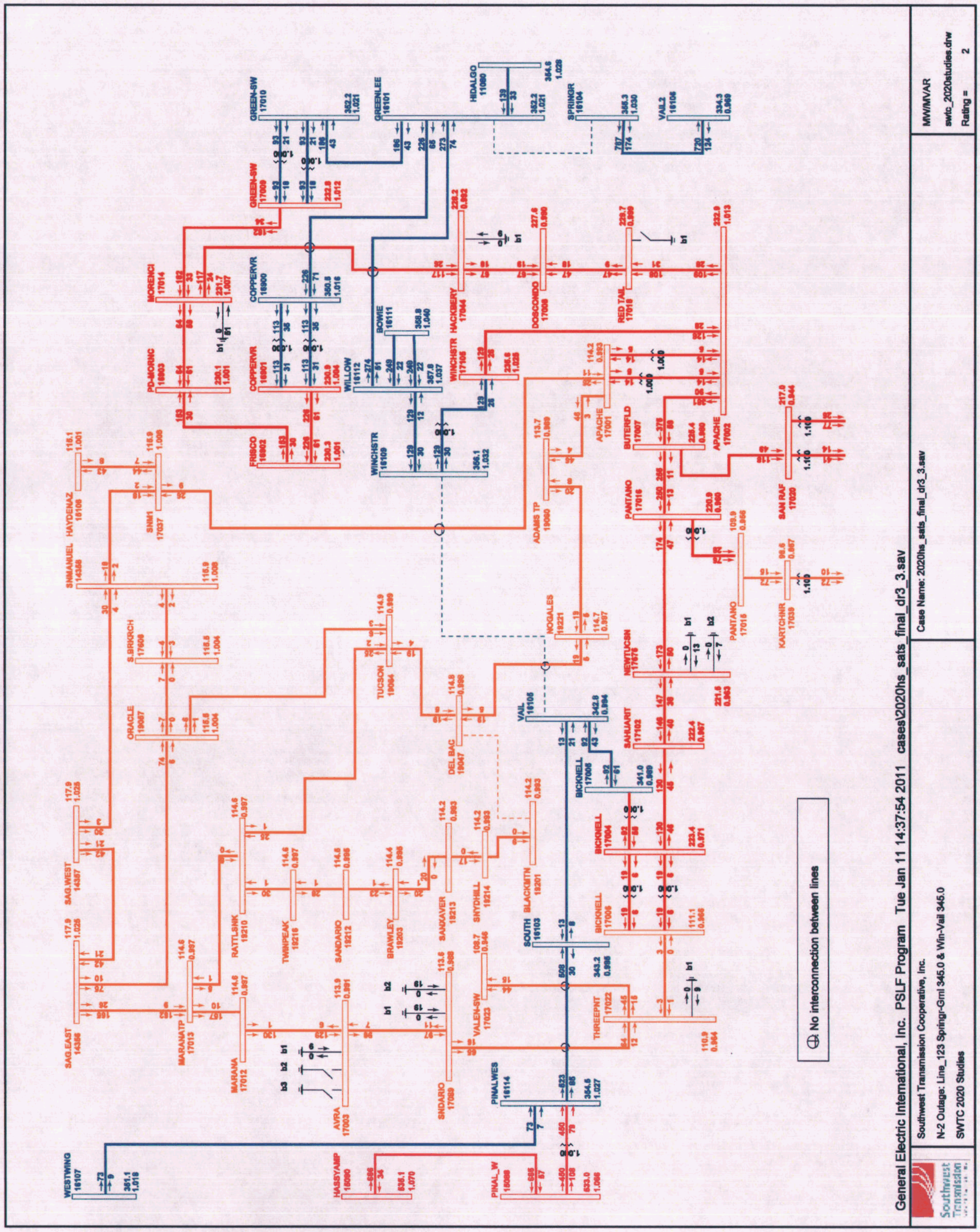
2020HS Southwest Transmission Cooperative Base System, SWTC member-system load increased 20%, with GreenleeSW to Greenlee and Winchester to Vail 345 kV lines out of service



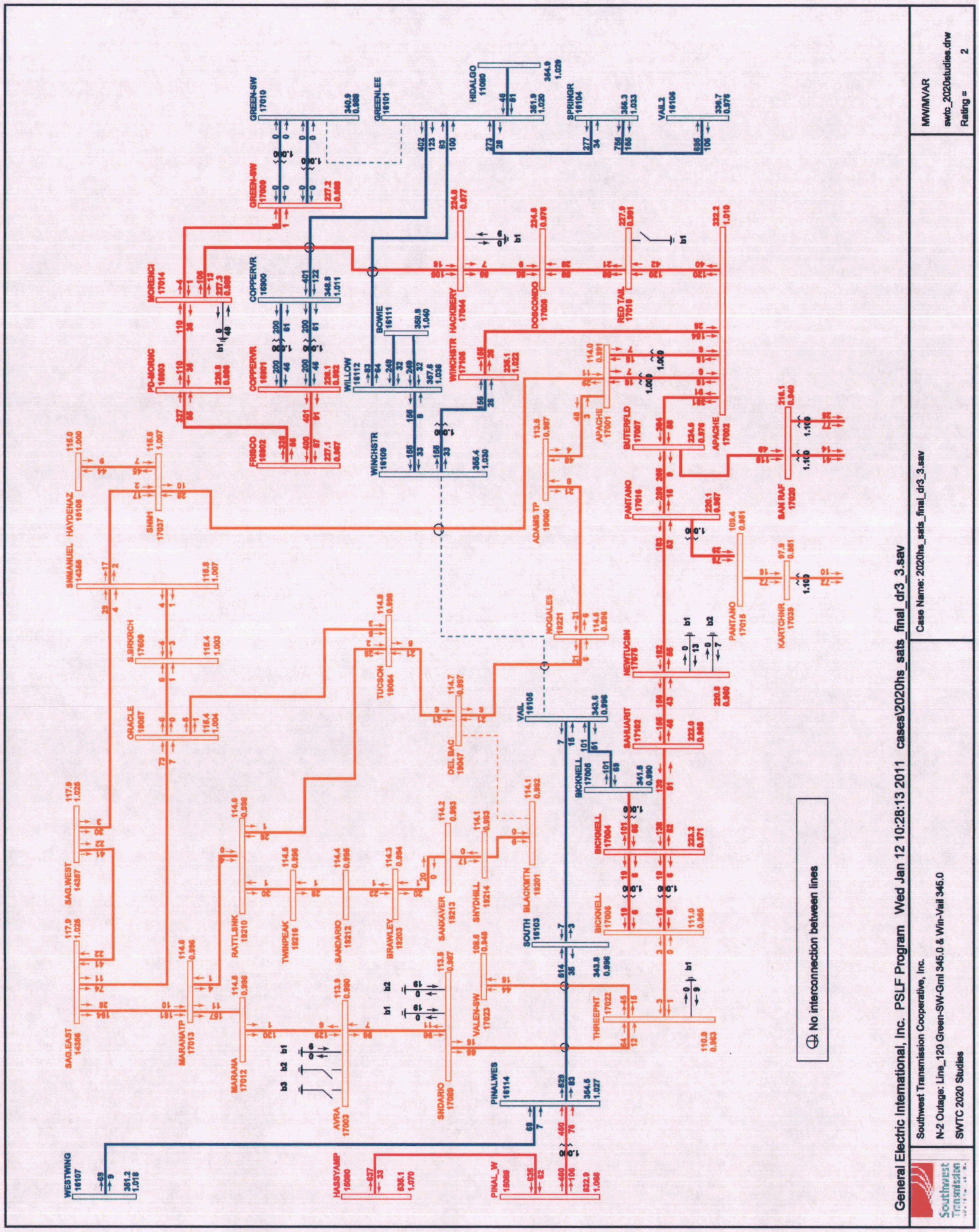
2020HS Southwest Transmission Cooperative Base System, SWTC member-system load increased 30%, with Winchester to Vail 345 kV line out of service



2020HS Southwest Transmission Cooperative Base System, SWTC member-system load increased 30%, with Springerville to Greenlee and Winchester to Vail 345 kV lines out of service



2020HS Southwest Transmission Cooperative Base System, SWTC member-system load increased 30%, with GreenleeSW to Greenlee and Winchester to Vail 345 kV lines out of service



APPENDIX 2

THERMAL RATINGS OF EXISTING OVERHEAD TRANSMISSION LINE CONDUCTORS DOCUMENT

SOUTHWEST TRANSMISSION COOPERATIVE, INC.

Thermal Ratings of Existing Overhead Transmission Line Conductors

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115 kV & 230 kV

Transmission Planning Department

1/1/2011

This document establishes new transmission line ratings based on ambient temperature, wind data and design guidelines. 115 kV and 230 kV transmission line ratings were considered in this document as well as assumptions and verification of parameters utilized.

1.0 Introduction to the purpose of this documentation

Due to the transmission system reaching its maximum capacity, SWTC has determined that the current rating of the system can be rated at a much higher rating based on a collection of weather data. The SWRate program created by Southwire Company was utilized to calculate the conductor ratings based on temperature and line directions. The SWRate program is based on the IEEE Standard 738-2006. Assumptions used on SWRate were confirmed with the data collected from weather stations, LiDAR and simulated by transmission line design engineers to determine maximum clearance based on the conductors maximum temperature. The method presented is applicable to all types of bare overhead conductors. The rating method is intended for use in determining the ampacity of all high voltage (HV) transmission conductors owned and operated by SWTC. This document will detail how the line ratings were established and analyze any design limitations.

2.0 Current Analysis of Conductor Ratings

Current conductor ratings for the SWTC system are based on the Western Area Power Administration (Western) PSD Bulletin 510 published on January 14, 1992 Appendix A. The bulletin assumes a 75°C operating temperature, 2 ft/sec wind velocity and 40°C ambient air temperature. These characteristics are calculated using conservative values which falls in line with the construction of many SWTC transmission lines discussed later in this section. The Western parameters common to all locations and conductors being used under the PSD Bulletin 510 to obtain the ampacity rating of ACSR conductors is as follows:

- Latitude = 32.5° N Latitude
- Wind Speed = 2 ft/sec
- Wind Angle = 90 degree to conductor
- Emissivity = 0.5
- Absorptivity = 0.5
- Line Elevation 2500 ft above sea level
- Line Orientation = East/West
- Time of Day = 12 noon
- Atmospheric Condition = Clear
- Air Temperature = 40°C summer
- Conductor Temperature = 75°C operating temperature

The current transmission line ampacities on the SWTC system based on the criteria above are listed below.

Conductor Type	Ampacity	Voltage Level	Line Rating
4/0 ACSR	360 A	115 kV	71.6 MVA
477 ACSR	620 A	115 kV	123 MVA
556 ACSR	676 A	115 kV	134 MVA
795 ACSR	840 A	115 kV 230 kV	167 MVA 334 MVA
2-954 ACSR	1370 A	345 kV	818 MVA
1272 ACSR	1100 A	230 kV	438 MVA

Table 1: Western Bulletin 510 conductor ampacities

2.1 Limitations Other than Thermal Line Ratings

SWTC considers the ratings provided by equipment manufacturers, IEEE and ANSI standards. Ratings for all of SWTC Bulk Electric System (BES) facilities, including but not limited to lines, transformers, and shunt compensation devices shall be equal to the most limiting applicable equipment rating of the individual equipment that comprises the facility. If other equipment such as switches, transformers, CTs, etc served with the transmission conductor is more limiting, the lowest defines the transmission line rating.

2.2 Accessories and Hardware

Accessory and Hardware limitations are based on the RUS Design Manual for High Voltage Transmission Lines revised in May 2009. The hardware is given due consideration and emphasis is placed on the mechanical and electrical demands on the design of the conductor related hardware. Hardware must be capable of holding at least 90% of the rated tensile strength of the largest conductor during short time load. It must be able to sustain load of 75% of the rated tensile strength of the conductor for 3 days.[4] Per RUS standards all construction of lines and hardware are built to 1½ the tensile strength of any conductor.

2.3 Transmission Line Design Data and Requirements

Transmission Line Design criterion is obtained from RUS Bulletin 1724E-200, which provides the criteria needed to be in compliance with the standards. Items to consider on conductor ratings include conductor size, voltage drop, thermal capability, design tension. Table 2 is a general overview of the line clearance required by RUS. Individual transmission line design tables for SWTC can be found in Appendix B.

Conductor Segment and Voltage Level	Track Rail of Railroads	Public Streets and Highways	Areas Accessible to Pedestrians	Cultivated Field	Along roads in Rural Districts
115 kV	30.6	22.6	18.6	22.6	22.6
230 kV	32.9	24.9	20.9	24.9	24.9

Table 2: RUS Bulletin 1724-200 clearances of conductors

RUS Bulletin 1724E-200 section 4.3.1 indicates that clearances of conductors apply under the following conditions: (1) Conductor temperature of 32°F, no wind, with the radial thickness of ice; (2) Conductor temperature of 167°F; (3) Maximum design conductor temperature, no wind. For high voltage bulk transmission line of major importance to the system, consideration should be given to the use of 212°F as the maximum design conductor temperature. Consideration to ACSR sag increase must be considered in order to maintain safe clearance and distances from objects such as buildings/structures and terrain.

The sag and tension of the line is calculated in order to determine the behavior of the line when fully energized. The sag tension limits will provide the rated breaking strength (RBS) of the conductor. Based on the tension calculations, the conductor may not exceed the RBS otherwise reliability and safety will be violated. The diagram below demonstrates the catenary variations of conductors based on weather and time. The catenary shape of the conductor plays a major role on sag and tension. The conductor is initially pulled to a percentage of the RBS tension. As the conductor is released and hangs from the poles it settles into a final unloaded sag. The next sag tension demonstrates the sag under weather and loading conditions. The final design of the transmission line with weather and loading conditions should yield enough clearance to maintain reliability and safety.[9]

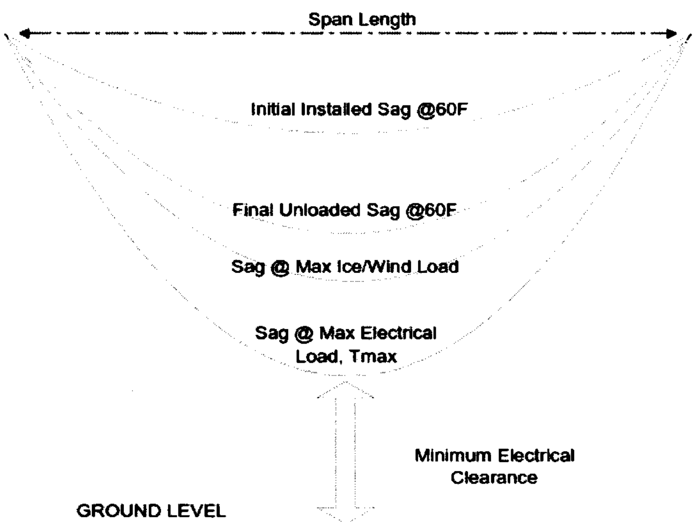

Diagram 1: Catenary Variation of Conductor

3.0 Weather

Weather conditions play a major role in establishing the thermal rating of conductors. Wind speed is the most important parameter as well as ambient temperature. Due to the variability of each of these parameters, careful analysis and selection must be applied as it can greatly change the outcome of the thermal rating of the line. Without proper engineering judgment for each of these parameters, violations may occur such as undesirable sag on the line, increased tension on hardware that may potentially damage equipment or loss of strength of the conductor and associated material and hardware due to increased temperature of the conductor.

SWTC obtained weather data from points along the transmission line system. In most cases weather data was obtained from public sites such as the National Oceanic and Atmospheric Administration (NOAA) National Weather Service, Remote Automatic Weather Stations (RAWS) a climate archive, and Weather Underground stations that list temperature information such as ambient temperature, wind speed and wind direction. The locations of each of these weather stations can be observed on the map located in Appendix C. SWTC substations that have been recently upgraded with fiber communications have included a weather station on the substation itself and data has been collected for the site. A mixture of data was used to find the most limiting ambient temperature and most limiting wind speed. SWTC ensured that the values obtained were still conservative values for each weather parameter; however, it was found that the most conservative values allowed SWTC to obtain additional line capacity on existing lines above those of the Western Bulletin 510 previously used.

SWTC's system was analyzed in three separate sections due to the location of the lines in urban areas, rural areas and mountainous areas. It is observed that the weather data will vary significantly based on the locations of each section.

3.1 SWRate Weather Model Program

The program used to analyze the conductor using weather parameters was the Southwire Company SWRate v3.02 program. The program utilizes the approved engineering methods of IEEE STD738-2006, IEEE Standard for Calculation of Bare Overhead Conductor Temperature and Amapcity Under Steady-State Conditions. The program is also based on information regarding the life of the conductor and location in regards to environmental conditions.

3.2 Weather Assumptions for SWTC

For the purposes of this study, SWTC has defined the Summer period as May through September which is a 5 month period. This time period was selected based on a historical assessment of the non-coincidental load peaks for each cooperative and the load variation between months. The average Arizona Generation and Transmission (AZ G&T) peaking load occurs during July. Winter months are defined as October through April which is a 7 month period. The ambient temperature established for the SWTC system is 40°C as it is a summer peaking utility. The SWTC system was split into 3 sections as the weather characteristics will vary in each section. Sections include the 115 kV line in the Tucson area, Cochise County/Pima County 230 kV line and along the Gila River Valley 230 kV system.

Based on the weather data collected, the values established were conservative in nature. The average wind used was observed at approximately 2.8 miles per hour (mph) which is 4.1 feet per second (ft/sec) wind. To continue with a conservative assessment SWTC used a 2 mph wind which was converted to a 3 ft/sec wind. Appendix D lists the temperature and wind averages assumed for each section of the SWTC transmission system.

4.0 LiDAR

LiDAR (Light Detection and Ranging systems) consists of a sensor located in a helicopter. The laser will direct a pulse and detect any objects located in its range of view. The amount of time it takes for the laser to return to the sensor will result in a calculation of distances for any object detected in its range of view. Once the data is collected it is combined with the Global Positioning System (GPS) of the helicopter and the ground based GPS stations. The Internal measurement unit of the helicopter is also utilized to measure pitch, roll and yaw. A combination of all these components allows the transmission line and surrounding area data to be collected and represented in 3-D modeling.[10]

SWTC hired LiDAR to assess the 115 kV transmission lines from Marana Tap to Bicknell and the 230 kV transmission lines from Apache to Bicknell and provide data regarding the line and any obstruction that may not have been seen while manually checking the line from the ground. The LiDAR information allowed SWTC to utilize the information collected to re-rate the transmission lines in order to increase transmission line capacity. The LiDAR information was coupled with historical weather data from weather stations located along the 230 kV line. Once the data was collected it was verified in the Sag 10 software program to justify the re-rate and show that no new violations occur along the transmission line. Several scenarios were analyzed and spreadsheets can be found in Appendix G.

Initial assessments provided by the LiDAR study have shown a few violations along the 230 kV and 115 kV. The conductor is currently able to operate safely at 75°C but due to the issues found will not allow the line to achieve a safe operating temperature of 100°C. LiDAR provided spreadsheets indicating the violations and the maximum operating temperature of the conductor located in Appendix F. Currently SWTC manually monitors each section of line and monitors line to ground clearances. Any line crossings under SWTC transmission lines are monitored and are subject to regulations of the existing standards per NESC and RUS. SWTC is in the process of addressing the violations noted and will work on clearance violation issues in order to bring the transmission line up to a 212°F operating temperature. The work is expected to be completed prior to December 31, 2011.

5.0 Calculated Line Ratings Based On Weather Data

SWTC compiled the data collected from historical weather points and created a set of parameters that were conservative in nature but would allow for the existing conductor to be reliably re-rated to a higher operating rating. Once the historical weather data was compiled it was placed in the SWRate 3.02 program found in Appendix H. A 0.9 value was used for the emissivity based on the age of the conductor. Similarly, 0.9 was also used for the absorptivity on the existing line. A 90° wind angle was applied to the line and an East-West direction of the line was picked. The east-west is a more conservative approach as it will follow the direction of the sun as it sets from east to west, thus heating the conductor throughout the day.

- Latitude = 32.5° N Latitude
- Wind Speed = 3.0 ft/sec
- Wind Angle = 90 degree to conductor

- Emissivity = 0.9
- Absorptivity = 0.9
- Line Elevation 3752 ft for 230 kV from Apache to Bicknell; ----ft for 230 kV from Apache to Greenlee; ----ft for 115 kV from Marana Tap to Bicknell
- Line Orientation = East/West
- Time of Day = 12 noon
- Atmospheric Condition = Clear
- Air Temperature = 40°C summer
- Conductor Temperature = 93.3°C (200°F) normal operating temperature
- June 21 (Summer) and December 21 (Winter)

5.1 Normal Ratings

The ACSR conductor was assessed and it is believed that the conductor can run at a 200°F or 93.3°C normal rating without reducing the life of the conductor. As an example, the following is a table listing the rating of the Apache to Butterfield 230 kV line using this rating methodology.

Line Section	**Temperature**	**Ampacity / MVA**
Apache to Butterfield	**200°F or 93.3°C**	**1005 Amps / 401 MVA**

5.3 Emergency Ratings

Emergency ratings for the conductor is calculated at 212°F or 100°C operating temperature. The following table lists the rating of the SWTC conductors.

Line Section	**Temperature**	**Ampacity / MVA**
Apache to Butterfield	**212°F or 100°C**	**1081 Amps / 431 MVA**

6.0 Loss of Strength Calculation for Overhead Conductors

A calculation of the loss of strength will evaluate the loss of life of the conductor based on the temperature of the conductor and the amount of time it is run at a given temperature. A maximum of 10% loss of strength is allowable and utilized for design guidelines. The calculation of conductor strength utilized the ASTM B230, B232 and B498 standards for the calculation of conductor weight and initial strengths. ASTM B230 contains the conductor diameters and stranding. ASTM B232 contains the average tensile strength for the aluminum conductor. ASTM B498 contains the strength at 1% elongation for steel. SWTC utilized the method employed by J.R. Harvey[2] similar to the method used in the Southwire Overhead Conductor Manual 2.0. Loss of strength calculation indicated that if the 795 ACSR conductor of the Apache to Bicknell 230 kV line was operated at 100°C continuously for 30 years it would yield an insignificant loss of strength. The 795 ACSR conductor was evaluated to lose 10% of its strength if it was operated for 30 years continuously at 167°C (332 °F). The calculations of these assumptions are listed in Appendix E.

References

[1] IEEE *Standard for Calculation of Bare Overhead Conductor Temperature and Ampacity Under Steady-State Conditions,* ANSI/IEEE Standard 738, 2006.

[2] J.R. Harvey, *"Effect of elevated Temperature Operation On The Strength of Aluminum Conductors",* presented at IEEE Winter Power Meeting, New York, NY 1972.

[3] Shelley L. Chen, W.Z. Black & W. Loard, *"High Temperature Ampacity Model for Overhead Conductors"*, Vol. 17, No. 4, pp. 1136-1141, October 2002.

[4] *Design Manual for High Voltage Transmission Lines*, RUS Bulletin 1724E-200, May 2009.

[5] ASTM Standard, *Standard Specification for Aluminum 1350-H19 Wire for Electrical Purposes*, ASTM B 230/ B 230M, 1999.

[6] ASTM Standard, *Standard Specification for Concentric-Lay-Stranded Aluminum Conductors, Coated-Steel Reinforced (ACSR)*, ASTM B232/ B232M-09, 2009.

[7] ASTM Standard, *Standard Specification for Zinc-Coated (Galvanized) Steel Core Wire for Use in Overhead Electrical Conductors,* ASTM B498, 2008.

[8] American National Standards Institute, *National Electric Safety Code (NESC)*, 2007.

[9] R. Thrash, & A. Murrah, & M. Lancaster, & K. Nuckles (Eds.), *"Southwire Company Overhead Conductor Manual Second Edition"*, Southwire Company, 2007.

[10] Mosaic Mapping System Inc., *"A White Paper on LiDAR Mapping"*, 2001.