

Evolution of Probabilistic Methods and Power Flow Solution Engines to Assess Impacts of Topology Changes to Transmission Networks

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Abstract-- The combined uses of component reliability and power flow solution engines have been used in the electric utility industry. The evolution of these tools now includes substation bus arrangements, Remedial Action Schemes (RAS), and Common Mode failures. This paper will describe in a general way how The Bonneville Power Administration Transmission Planning used specific knowledge of its transmission network and the tools of General Reliability to obtain the impact of the change in reliability of a project.

Index Terms—

Circuit breakers
Disconnecting switches
Load flow
Stochastic
Reliability

I. NOMENCLATURE

Powerflow will be used in the paper in the manner which load flow is usually used. Remedial Action Schemes are automatic actions to improve power system security. North American Electric Reliability Council (NERC) members include electric utilities and other electricity suppliers; the organization promotes the reliability of the electricity supply for North America. Western Electricity Coordinating Council (WECC formerly WSCC) WECC continues to be responsible for coordinating and promoting electric system reliability as had been done by WSCC since its formation.

II. INTRODUCTION

Bonneville Power Administration (BPA) was unsatisfied with the reliability assessment tools that were available to evaluate the probability of a degraded topology and the resultant impact of that degradation. The impact in this case means low voltage a load buses or thermal overload. The enhancements needed for the powerflow modeling were: (1) Substation detail; and (2) Remedial Action Scheme (RAS).

The substation modeling includes buses, disconnect switches, circuit breakers, and shunt devices. Shunt devices can be loads, switched reactive shunts, and generation.

Substation modeling complements transmission modeling, and demonstrates the substations roll in transmission reliability.

RAS is a cost effective way of increasing the utilization of existing transmission. RAS has three parts: Arming(based on pre-contingency conditions); Pre-solution (based on degraded topology), and Post-solution (based on over-loads or undervoltage). In the study presented, nine RAS models were used.

III. METHODOLOGY

The task of enhancing the reliability assessment tools was broken down into three parts: Contingency enumeration; Contingency Solver and; Post processing. General Reliability had the software responsibility for the first and last parts. These were GRTools – Subrel and GRTools – Transrel, respectively. GRTools is a graphical user interface (GUI), tailored to specific tasks. GRTools – Subrel, makes the task of entering data and looking at reliability indices easy. All data resides in MS Access. The data contains topology, ratings and information related to reliability. It does not include an impedance matrix. A connectivity algorithm is used to determine the probability of getting power to loads. For those familiar with MS Access data mining is available and may be necessary to understand unexpected results.

The enumeration algorithm used in Subrel is the starting point GRTools - Transrel. Transrel queries the Subrel database and produces a contingency list for the Contingency solver. The Contingency Solver uses a powerflow program, PowerWorld in this case, to find overload violations and undervoltage violations after applying the appropriate RAS. Transrel imports the violations into its own database and does some generalized analysis and reporting. Again data mining may be necessary to understand unexpected results.

A. *Substation Reliability program, SUBREL*

SUBREL files represented the network topology, ratings, and reliability data. The following reliability data is included for each component: Failure rate; Isolation time; Repair time; Maintenance rate; Maintenance time and; Stuck probability. Default reliability data can be used, or the user can supply reliability data by component type or for each individual component. Selected sets of components can also have a common mode failure rate. This is useful for situations like lines in the same transmission corridor. The maximum overall contingency level, the maximum number of forced outages, the maximum number of stuck devices, and the maximum

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number of components out for maintenance per contingency can also be set.

SUBREL recognizes both faulted and isolation events in the case of an outage of a component. When a component is faulted or stuck it is first cleared with circuit breakers and then isolated with disconnecting switches until it is repaired. This event produces two topologies, each with its own probability of occurrence. When two or more components are considered for an overlapping event all possible topology-probabilities must be considered. At present the following combinations are examined: Faulted

- Isolated
- Faulted + Isolated
- Faulted + Faulted
- Isolated + Faulted

- Isolated + Isolated
- Faulted + stuck
- Isolated + stuck
- Faulted + stuck+ stuck
- Maintenance + faulted
- Maintenance + isolation
- Maintenance + faulted + stuck
- Maintenance + isolation + stuck
- Maintenance + maintenance + faulted + stuck

Some of these combinations are of particular interest and are given category number that can be used for specialized analysis. These special combinations are listed in the table 1.

Table 1

Contingency/Case	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Planning Criteria	A	B	C	CR					CT		C			C			
Presently in SUBREL	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Desired to be added																	
No outage (Normal)	x																
Single circuit fault		x	x	x	x	x	x	x									x
Two correlated circuit									x								
Two circuits within 30 min.										x							
Stuck breaker or relay failure			x		x	x											
2 Stuck breaker or relay failure																	x
Bus fault											x	x	x				
Breaker fault														x	x	x	
One circuit scheduled outage				x	x		x					x			x		
Multiple circuits scheduled outage*						x											
Breaker out for maintenance							x	x					x			x	
Three or more lines in ROW																	
Two generators, same switchyard																	

- Circuit Line, transformer, generator
- A NERC Level A
- (1) B NERC Level B
- C NERC Level C
- CG WSCC Level C
- CR NERC Level C (system readjusted)
- CT NERC Level C (same tower only); WSCC (same ROW)

If generators and loads are modeled a topology check for all events can be done to determine the probability of an adequately rated path or paths between generation and load. This tool provides insight by rigorous examination of all the above possibilities. The speed of this type of study means that many project alternatives can be checked. The best projects can be rigorously examined by submitting a contingency list

to a positive sequence powerflow program. The idea here is to embed a detailed model of a relatively small part of the network into a larger less detailed network. To do this data must be entered into the optional Transrel component table. This table maps the Subrel component representation into the powerflow representation.

Some topologies will occur more than once as a result of different events. When preparing a contingency list the topology need only be submitted once. A specific topology can be associated with all the events that produced it. Our experience is that the ratio of events to contingencies is nearly three to one. This saves a lot of powerflow solution time. Using a database makes this type of processing natural.

B. Transmission Reliability Program, TRANSREL

TRANSREL (part one) examines the Subrel database, copies relevant information to its own database, prepares the contingency list mentioned earlier, sets a “done with part one flag” and exits. The next time TRANSREL is called it will process the data from the Contingency Solver.

C. Powerflow Case Preparation

The detail as modeled in SUBREL must be reproduced. SUBREL circuit breakers are modeled as lines in powerflow representation using low impedance ($X = 0.00001$ p.u., 100 MVA base). As long as the detailed topology is the same, the same contingency list can be use with other powerflow cases to represent different transfer levels, load levels, or other conditions.

Arming RAS is part of powerflow case preparation. The powerflow program used for this project (PowerWorld Simulator) has Custom Case Information Sheets to store user data with the case. Information relevant to the RAS was displayed on these sheets by our Arm program. Arm examines the case, applies algorithms, nomograms, and suggests units for generator dropping schemes. This allows quick examination of the status of flowgates, the level at which RAS is armed, and notes on the criteria. At this point the user can disarm RAS to test weather it is still necessary or change the scope of the RAS. The Contingency Solver needs to find “Armed” on these sheets to apply the RAS.

Early runs with the Contingency Solver produced results that were dominated by overloads of generator step-up transformers. Since this is not considered to be a real problem the monitor flag on these transformers were turned off.

D. Contingency Solver

The Contingency Solver loops through the contingency list, apples pre-solution RAS, solves the case if possible, saves unsolved cases, reports initial violations, applies post-solution RAS, and reports final violations. Each of these tasks is more appropriately managed by the utility because of the knowledge base and security implications.

The choice of powerflow program will have an influence on the Contingency Solver. The Ideal powerflow program will be fast, have easy access to its internal tables, robust, and be familiar to the user. The time spent in the solution process

F. BPA Study System

was roughly equivalent to the time spent on RAS and reporting violations. All of the unsolved cases were solved using some manual intervention. A special version of the Contingency Solver was used to check the manually solved contingencies for initial and final violations. These manually found violations can replace the “unsolved” originally reported for the contingency in the violation file before it is submitted to Transrel.

E. Transmission Reliability Program, TRANSREL

TRANSREL (part two) processes the data from the Contingency Solver. The probability and duration of each topology of each event is calculated as well as the total probability and duration of each topology. The impact is loosely defined as the product of the probability and violation. I have introduced set of functions collectively called Th to weight overload violation of transmission lines and transformers to determine the impact. The total Th gives a overall figure of merit for project.

OL Load/Rating (when Load > Rating)

Threat (MVA rating) $\bullet \sin(\text{atan}(\text{OL}^2 \bullet (\text{OL} - 1))) \bullet \text{OL}$

Th(lines) Threat $\bullet X_{p.u.} \bullet (X_{p.u.}/R_{p.u.}) \bullet Z_{base}$

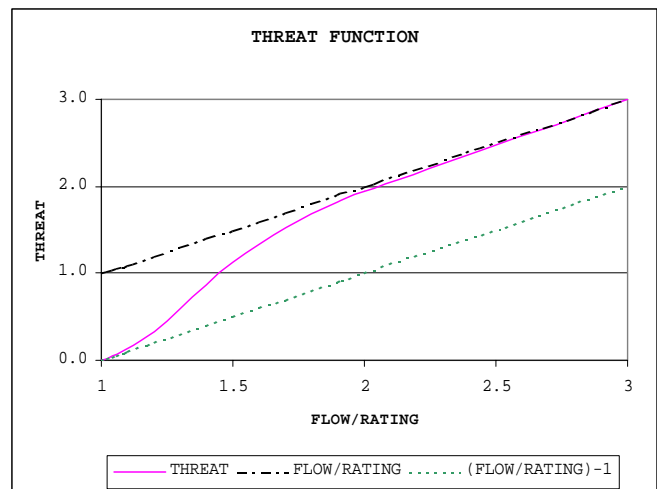
Th (lines) uses $X_{p.u.}$ as a measure of line length. The X/R ratio factor corrects for conductor size and Zbase factor corrects for voltage.

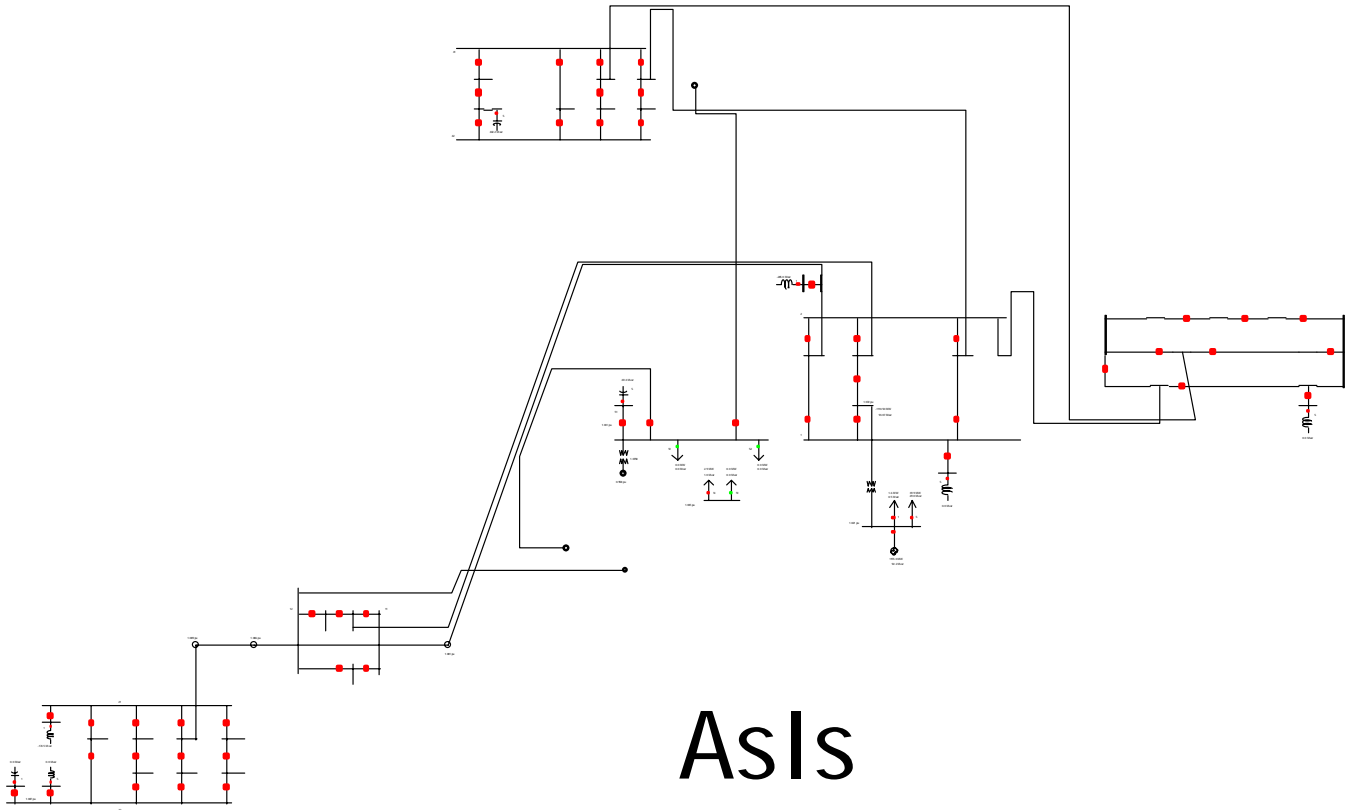
Th(transformers) Threat $\bullet \text{kV}(\text{high voltage side, used as a dimensionless value})$

Th (transformers) recognizes the value of high side voltage.

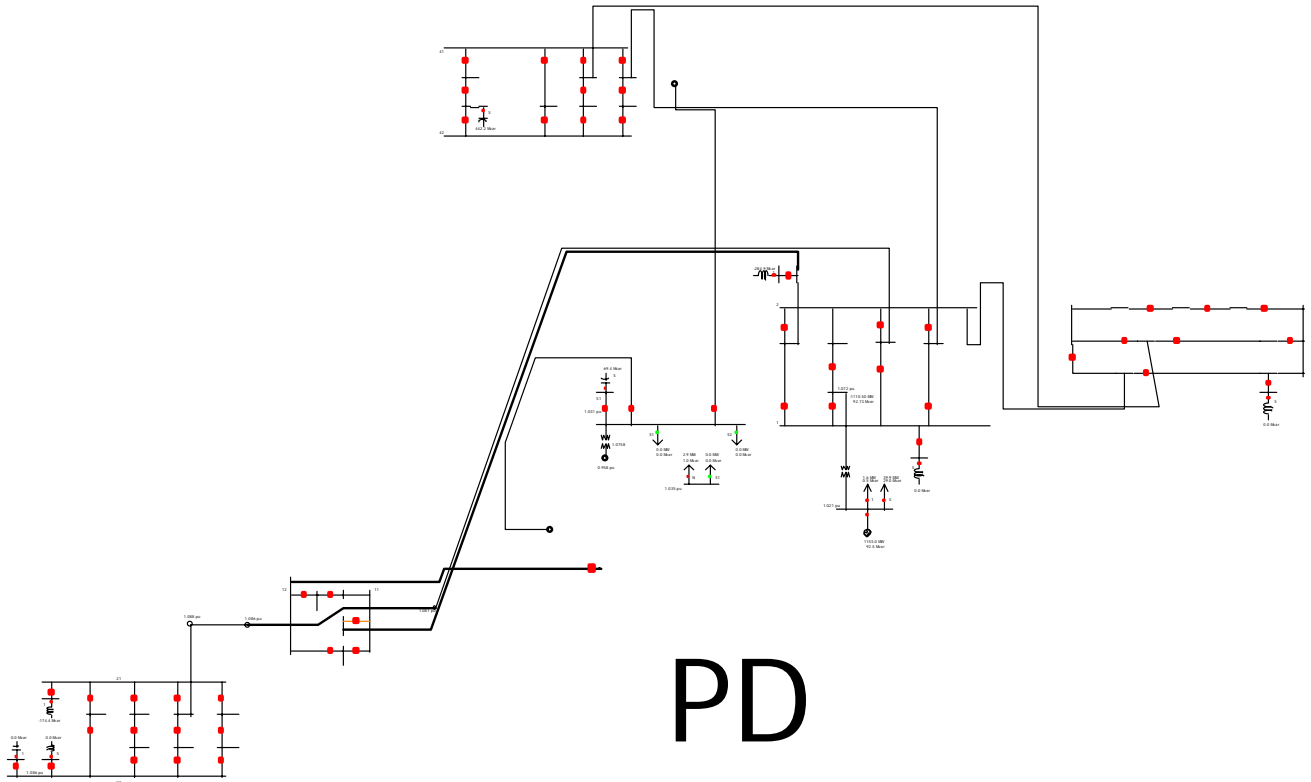
The threat function is designed to smoothly transition from power transmitted divided by rating minus one for small violations to power transmitted divided by rating for large violations. See Figure I. The thinking is that small violations can often be managed, whereas the larger the violation the less manageable it is.

Figure I

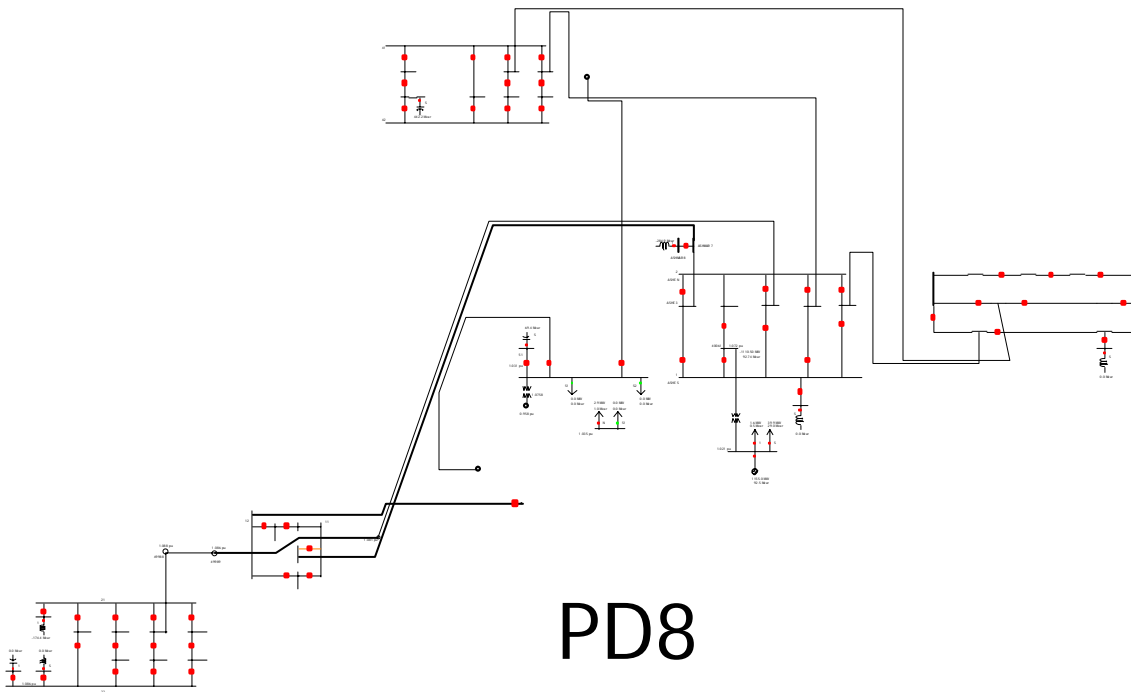




AsIs



PD



The three options above were studied at a station with a perceived reliability problem. The detailed model was extended one substation away from the substation of interest. The parallel lines are shown in the physical relationship because of the deterministic criteria that applies to adjacent parallel lines. The common mode reliability indices for these parallel lines were calculated with a General Reliability tool called GRTTools - TOM (for Transmission Outage Management). This tool uses a twenty year BPA outage history with 8244 line-years and 110907-line mile-years.

The overall contingency depth was set to 4 (maximum). The number of “faulted” components was set to 2. The number of stuck components was set to 2. The number of components out for maintenance was 0. And finally the common mode feature was turned on. The shorthand reference to this setup is 4,2,2,0 & common mode. A 4,2,2,1 & common mode would be used for a non peak load case with reduced transfer levels.

With the settings above the number of contingencies for AsIs, PD, and PD8 were 10,532, 10,448, and 10,368 respectively. These contingencies took between 40 hours and 52 and hours of wall clock time for each configuration to be processed by the Contingency Solver. AsIs with a 4,3,2,0 & common mode would have 20,480 contingencies.

G. Results

SUBREL Fictitious generation was placed at each of the surrounding substations and a 10 kW load placed at the generator modeled in the above one-line diagrams. The

ability to serve this load is proportional to the transmission availability for the generator. See Table II. Expected unserved energy (EUE) is lowest for the do nothing plan. Potential maintenance benefits were not explored.

Table II

10 kW Project non-availability				
Project	Frequency per year	Interruption Min/Occ	Interruption Min/Yr	EUE kWh/year
AsIs	0.1698	4012.4	681.5	113.6
PD	0.3010	2275.2	684.9	114.2
PD8	0.3053	2904.4	886.6	147.8

TRANSREL There was no violations (overloads or voltage problems) for any of the projects. This indicates that the present RAS is adequate for the new projects.

H. Conclusions

The analysis and the approach presented in this paper provide a comprehensive way to compare various station designs. A thorough analysis of a station(s) is recommended as one can arrive at wrong conclusions examining only n-1 or n-2 outages. Outages should then be examined from a system point of view by using a power flow program that can model RAS. In our study, if no RAS were used, the ranking might have been different.

IV. ACKNOWLEDGMENT

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VI. BIOGRAPHIES



Dyson Paul Ferron (S'82, M'83) was Chairman of Student chapter of IEEE At Portland State University, where he received BS in Electrical and Electronic Engineering and Psychology. Paul began work at Bonneville Power Administration (BPA) in '81 as a co-op student. He now works as a transmission System Planner for BPA.