A NEW METHOD FOR CONTINGENCY RANKING

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The importance of steady-state contingency analysis in both planning and on-line security assessment is well recognized. In both instances, a large number of simulations are performed, each involving circuit and/or unit outage. For each case, system performance and reliability are judged based on the resulting power flows and/or bus voltages.

The computational burden involved in contingency analysis, even with the aid of such efficient techniques as the linearized or dc load flow, is also well recognized. For these reasons, a method of reducing this burden has recently received attention in the literature.1,2

The approach taken involves ranking contingencies in approximate order of severity. Contingencies can then be simulated, starting with the most severe and working down the list to the less severe. In theory, when a point is reached where contingencies no longer produce problems there is no need to proceed further, since all remaining contingencies are less severe. In practice, since the ranking algorithm uses a linear function for predicting a non-linear one, the ranking may not always be as accurate as one would hope.

PTI has been actively investigating methods for improving the accuracy of contingency ranking algorithms. A technique was recently developed which takes into account all higher order derivatives in the prediction of the function mentioned above.

The technique divides the problem into two steps. First, a scalar function, called a performance index (PI), is used to measure the severity of contingencies. Second, an accurate and efficient technique is used for predicting the change in PI when circuits and/or units are dropped.

It will be assumed that circuit loadings are of primary interest. A scalar PI which measures the severity of a system state may be defined as:

$$PI = \sum_{\text{branches}} W_i (P_i/P_{i,\text{max}})^2$$

where $W_i$ is a constant branch weighting factor, and $P_i$ and $P_{i,\text{max}}$ are the real flow and real flow limit of branch $i$.

In most cases, PI provides a good measure of system stress by increasing in value when severe contingencies occur. However, in relatively rare instances, when a single branch becomes overloaded, while many other branch loadings decrease, it can decrease in value and fail to recognize the overload. Minimizing the effects on the ranking of this phenomenon, called masking, will be discussed later.

Under the assumption that the dc load flow is sufficiently accurate in predicting branch flows, exact expressions can be derived for the change in PI when a branch or generator unit is dropped. These expressions are obtained through repeated differentiation of Equation (1) followed by substitution into a Taylor series expansion of PI.

Although the direct evaluation of these exact expressions is prohibitively time consuming, they can be approximated efficiently and quite accurately as the following example demonstrates. (The time required by the ranking algorithm is approximately 10T, where T is the time for a forward-backward solution.)

The real-time system model of a U.S. utility is used for illustration; it consists of 239 buses, of which 56 are generator buses, and 380 branches of which 122 are transformers.

Contingencies causing system islanding or the isolation of load or generation were removed from the ranking algorithm results prior to comparison with the dc load flow results. The reason for this is that in the event of generation redispatch the final value of $

ANALYSIS OF FAULT CHARACTERISTICS FOR UTILITY DISTRIBUTION SYSTEMS

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A number of fault current assumptions must be made both in the design and application of distribution equipment. The penalty for poor assumptions in this regard can be quite severe. Over-design of system components may involve only small individual cost premiums, but in the aggregate, that premium can be substantial. On the other hand, modifying or replacing components which are inadequate can result in serious cost and/or reliability penalties.

While the theoretical maximum fault current magnitude (phase-to-phase, phase-to-neutral, three-phase) can be calculated given impedances at any point on a distribution system, the impedance of the fault itself must usually be assumed. The statistical variations of fault current magnitudes, durations, and dc offsets are generally unknown. Additionally, very little is known about the frequency of faults, the magnitude of high-frequency fault current components, and the current and voltage transients resulting from reclosure after a permanent fault (cold load pickup).

To obtain this information, PTI is making extensive system measurements and analyses, under the sponsorship of the Electric Power Research Institute (EPRI). The project has three broad objectives:

1) To measure fault currents on representative distribution feeders and to compare these currents with calculated values to check the accuracy of fault impedance assumptions.

2) To develop a statistical description of fault current magnitude, dc offset, high-frequency components, and rate of occurrence as a function of distribution feeder circuit parameters.

3) To develop a statistical description of cold load pickup currents as a function of feeder parameters and load characteristics.

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Ranking (continued from page 1)

the PTI is a function of how the redispatch was done. The ranking of the remaining 228 contingencies was then compared to the dc load flow results.

In addition, all branches which were 1) part of an external equivalent, or 2) connected to low voltage (distribution level) buses, were unmonitored by the PI (by setting their W’s to zero), since overloads of these branches were not of primary concern.

Figure 1 shows an “effectiveness profile” for the resultant ranking; it consists of a plot of “true” PI (from the DC load flows) as one proceeds down the ranking, and would be monotonically decreasing for a perfect ranking. Also shown in Figure 1 is a table of capture rates; we define the capture rate, \( r_N \), as the fraction of the worst \( N \) contingencies appearing in the first \( N \) entries in the ranking. The excellent agreement between the ranking results and the dc load flow results demonstrates the superiority of the new algorithm over the old one.

In summary, the new ranking algorithm does remarkably well and is far superior to the old algorithm. The ranking agrees almost perfectly with the ranking produced by calculating PI from dc load flows; the correlation between overloads and high rank is also quite good, the only difficulty being masking. The effects of masking can be greatly reduced through partitioning followed by multiple rankings.

REFERENCES

PROJECT INITIATED ON THERMAL-MECHANICAL BENDING PROBLEMS IN PIPE-TYPE CABLES

Variation in cable loading and the resultant temperature changes cause thermo-mechanical expansion and contraction of the conductors in pipe-type cable. The resultant cable flexure can cause localized mechanical instability in the paper-tape insulation, ultimately resulting in electrical failure. In the past six years, a number of such problems have been encountered in 345-kV commercial service as well as at a 550-kV test installation.

PTI, under sponsorship of the Electric Power Research Institute (EPRI) has initiated an extensive program to:

- develop mathematical analyses which will model the mechanical behavior, modes and configurations of movement, and structural integrity of the cable elements under repetitive bending due to thermo-mechanical effects, and apply this model, confirmed by suitable experimentation, to solutions for satisfactory thermo-mechanical behavior of pipe-type cables.
- define the failure mechanisms for pipe-type cables under thermo-mechanical bending and determine remedial measures.
- analyze, with suitable experimentation, the various cable parameters which influence thermo-mechanical behavior of pipe-type cables, and develop improved designs of cables with increased resistance to instability under flexure.
- provide prototype designs fully tested mechanically and electrically for satisfactory service under thermo-mechanical bending.

The five-year project is scheduled for completion in 1983.

REFERENCES
Fault Characteristics (continued from page 1)

To collect the fault current data, multi-channel digital recorders will be installed on 50 feeders of 13 different utility systems. The feeders have been chosen to give widely varied geographical locations (see Figure 1), climatic conditions, load conditions, load density, and construction and design practices. The selected feeders range from 4 to 34.5 kV, with most in the 15-kV class. Fault rate estimates range from 2 to 74 faults per year per feeder, with the average being about 20. Load population sizes range from 2 to 429 MVA, and individual transformers from 2 to 90 MVA. Isokeraunic levels from 2 to 100 thunderstorm days per year are included, with 35 being typical. Most of the three-phase mains are overhead structures, with some partially underground and a few entirely underground.

It was hoped that the project could use commercially available current transformers (CT’s) and potential transformers (PT’s) to ensure reliability and to avoid the cost of special transformers. The accuracy of commercially available instrument transformers is specifically specified at 60 Hz but unknown at higher frequencies. And for CT’s — accuracy during asymmetric faults is not specified. While the available technical literature provides some guidance concerning CT error during asymmetric faults, almost nothing is available concerning CT or PT accuracy at frequencies other than 60 Hz.

The measurement of fault currents — both symmetric and asymmetric — and fault voltages, including frequencies of up to 10 kHz, is to be accomplished with a total magnitude error of less than 3 percent. Our study of CT’s indicates that a high-quality window type CT (such as the Westinghouse EMC or the General Electric JCD-0) with an anti-remanence gap in the core and a large turns ratio (4000:5) can meet the 3 percent error requirement for fully asymmetric fault currents and for frequency components of up to 30 kHz. Our CT’s “burden” resistor must generally be less than 1 ohm and be the only load on the CT secondary.

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Our study of PT’s indicates that standard units will meet the 3 percent accuracy requirement over the full range of expected 60 Hz voltages during faults. They can also meet the accuracy requirement for frequencies of up to 5 kHz with an error of the order of 10 percent at 10 kHz. PTI recommended the use of these standard PT’s, in spite of the high frequency error in excess of 3 percent, for reasons of simplicity and cost, and because measurements of frequency components between 5 and 10 kHz during faults with an error of 10 percent was considered adequate.

The digital recorders have a frequency response of up to 10 kHz and will record the three phase currents, the three phase-to-ground voltages, and the zero-sequence current on seven independent input channels during each fault or cold load pickup event with an overall error of less than 1 percent full scale. A separate channel is capable of recording up to eight digital inputs such as times of occurrence, breaker operation, etc.

Two types of events are to be recorded — fault events and cold load pickup events. A fault event may consist of up to four subevents as the breaker opens and recloses. A cold load pickup event is singular, but the current is of interest over an extended period. Thus the recorder must be capable of recording two quite different types of transient.

The recorded transients are stored in the recorder’s electronic memory which can store approximately 32,000 eight-bit words. Since there are eight channels, the maximum number of samples (words) that can be recorded in electronic memory per channel during either a multiple subevent fault or a cold load pickup event is 4000. This limitation on stored samples requires a careful tradeoff between sample rate and duration. For example, a multiple subevent fault could be sampled for 1 second at 4 kHz or for 0.5 second at 8 kHz. The first approach would result in an inadequate frequency response of 1 kHz. The second approach would not record the full fault event which would normally be greater than 0.1 second. Therefore, to obtain the required fault data, the digital recorder uses three different sampling rates for three different times. Figure 2 illustrates the sampling sequence for fault subevents. The sampling rate concept for cold load pickup is similar.

The chosen sampling sequence results in 10 kHz bandwidth during the initial portion of the transient (including pretrigger data, for faults). Power frequency harmonics (up to 1 kHz) will be reproducible during the first four cycles.

The recorded transients are subsequently transferred from electronic memory to a cassette tape. With the sampling sequences used, the cassette tape is capable of storing up to four fault/cold load pickup events, or eight faults of four subevents each, or thirty-two temporary faults consisting of one subevent each, for a total of 250,000 eight-bit words. Each month the tape is to be returned to PTI for analysis and a blank tape inserted into the recorder.

Data will be collected and analyzed over a two-year period. Because of the extent of the data and the number of correlations, statistical analyses, and summaries required, nearly all data processing will be done by digital computers. Magnitudes and frequencies of currents and voltages, correlation with fault locations, system configuration and parameters, correlation with calculated values, asymmetrical characteristics, weather conditions, etc., must be analyzed. The data base will be updated monthly to detect trends and ensure any necessary modifications in analysis of measurements are made as early in the study as possible.

The results of this study have potential impact on several areas of distribution system design, application and operation, including: 1) short circuit current rating of circuit breakers, transformers, reclosers; 2) breaker reclosing sequences; and 3) protective device coordination.

PSS/E USERS MEET

Nearly two years ago, PTI’s PSS/E Power System Simulation program began a move from a narrowly distributed and quite specialized tool for which informal communications proved adequate to a very flexible tool serving many electric utility users whose diversity of interests and location made more organized communications a necessity.

Therefore, PTI instituted annual PSS/E Users Group meetings whose purpose is to keep users abreast of our development plans, to clarify technical points of common interest, and to provide a user feedback mechanism which has become a significant input in guiding the evolution of PSS/E.

On June 28, the second annual PSS/E Users Group meeting was held in Denver, Colorado. Some twenty engineers, representing the majority of the North American utilities which have adopted PSS/E, attended along with four PTI engineers.
THERMAL-HYDRAULIC LOAD FLOW

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