Computer Aided Contingency Analysis

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Abstract—As the need for improved distribution system reliability increases the need for Contingency Analysis system studies increases. Even with the use of Engineering Analysis Modeling and Analytical software, a Contingency Analysis study is very time and labor intensive. This paper explores the characteristics of distribution system outages and defines a computer aided Contingency Analysis software program developed by Milsoft Integrated Solutions, Inc.

Key Words – Reliability, Distribution, Contingency, Computer Aided, Distribution, Distribution System Outage, Engineering Software, Milsoft.

I. INTRODUCTION

Planning and construction of the system with outage minimization as a major design criterion is becoming more important and more common. The utility industry's natural need and tendency to improve reliability is being accented and accelerated by regulatory agencies adopting reliability standards as keys for utility evaluation and by the increased possibility of competition for customers. Of course, the first and most important requirements for acceptable system reliability are proper line construction and maintenance and proper over-current device placement and coordination. However, even with the best possible construction and operating practices, outages still occur.

Given that outages still occur, temporary restoration of power is an effective and economical way to improve reliability. Temporary restoration of service to customers while the cause of the outage is being repaired, reduces the outage duration to specific customers while reducing the system average outage duration index. These customers are more likely to approve of the utility's service and the utility's Reliability Indexes are improved.

Whenever an outage occurs on the electrical distribution system, service crews are dispatched to repair the problem and restore service as quickly as possible. Often less than an hour is required to locate and repair the problem so that power is restored with only minor inconvenience to those customers in the de-energized or outage service area. In other cases, the cause of the outage requires an extensive amount of time to correct. If a substation transformer has failed, it may require several days to locate, transport and install a replacement transformer. In this case, and for others requiring much less time to repair, it is common practice to temporarily restore power to as many customers as possible using alternative feeds.

A Contingency Analysis is an evaluation of an existing or proposed electrical distribution system to determine the capability of the system to restore power using alternative feeds. Dispatching may use Contingency Analysis during an actual outage situation but Contingency Analysis is more often use by Engineering Planning to evaluate the system before outages occur. In either case, a most significant problem with the accomplishment of a Contingency Analysis is the time required. The planning level study requires that many different options be considered for each possible fault or outage situation. The dispatching evaluation usually requires much less time since only existing switching points are considered for only one outage situation. The problem at the dispatching level is that an effective but safe solution is required immediately. Thus, any time required to define the best solution is too much.

This paper explores the characteristics of distribution system outages and defines a Contingency Analysis computer software program developed by Milsoft Integrated Solutions, Inc. (Milsoft). Milsoft's labor saving software program greatly reduces the time required to accomplish a contingency analysis while finding a significantly "best possible solution" for each specified outage situation.

II. CHARACTERISTICS OF DISTRIBUTION OUTAGES

A distribution system outage will result in the isolation or loss of service to all or part of a distribution substation system. The proper installation, coordination, and maintenance of over-current devices (switches, breakers, reclosers, sectionalizers and fuses) will result in the smallest possible number of consumers being left without power for any possible fault or equipment failure problem. Sound line construction practices will result in line that has fewer outage problems.

It is estimated that 80% of all distribution faults can be cleared with the temporary interruption of power to the fault arc. Over-current devices, with reclosing capability, can clear temporary faults and avoid permanent or extended outages.

While over-current devices are required to provide an acceptable level of distribution reliability, their ability to prevent and minimize outages is limited by the number of over-current devices that will coordinate in series. Their use is also limited by electrical system operating constraints and economical tradeoffs.

Even where it is desired to use alternative feeds to restore service, it is not always possible to restore service to the entire de-energized area. Substations located at the edge of the utility service area will have feeders with no possible alternative feed. Customers will be located on taps with no alternative feeds. Where an alternative feed is possible, it may not be possible under peak loading conditions to back feed without causing loading and voltage problems.

Most customers are tolerant of outages as long as they are infrequent and short in duration. However, all customers eventually reach a tolerance limit, especially to long duration outages. Indeed, extended outages during freezing or extremely hot weather can become a life-endangering situation to a large number of customers who would not normally be threatened by short duration outages.

Some customer situations may not be tolerant of any frequency or duration of outages and require the construction and design of non-interruptible service. Non-interruptible customer situations resulting from commercial or industrial constraints can be addressed with non-interruptible rates and aid in construction contributions. Customers who need life support systems cause the most serious and sometimes difficult non-interruptible service situations.

III. DISTRIBUTION COMPARED TO TRANSMISSION

Almost all transmission system failures involve large blocks of load that if not automatically corrected would result in interruption of service to large numbers of customers. A transmission outage not properly sectionalized would usually outage an entire substation service area and often would outage multiple substation service areas. Because of the large amounts of load involved and long restoration times required, transmission systems are designed for single contingency. Single contingency design requires that for any given single line or equipment failure no load is dropped. Single contingency design requires that all of the system must operate at peak loading, without overloads and voltage problems, with any one line or transmission transformer out of service. Single contingency design requires automatic fault isolation and automatic outage correction.

Smaller substations, located far from main transmission lines, are sometimes served with a radial transmission tap and thus would be excepted from single contingency design requirements.

While the worse case distribution outage can involve the entire substation service area, distribution system outages usually involve blocks of load less than the entire substation and require less than one or two hours to correct. Because of the lesser amount of load involved, and usually short restoration times, distribution system design criteria does not require the serving of all loads while the outage problem is being corrected. Exceptions are downtown systems served by secondary (or primary) networks and non-interruptible loads.

Distribution system sectionalizing design is based on fault isolation. The primary goal of distribution sectionalizing is to remove power from the faulted line or equipment while removing service to as few customers as possible.

Where system design allows or requires load transfer during outages, load transfers are not automatic and seldom is restoration of service possible to all loads. Load transfers are accomplished by manual switching and are determined by predefined emergency plans or based on operating personnel experience. When based on operating personnel experience, switching operations are often accomplished by trial and error. If closing a switch to pick up load does not cause an immediate or obvious problem, it is considered successful.

IV. IMPROVING RELIABILITY:

Increased competition for customers will result in some utilities using reliability as a marketing factor. To do so will require an improved reliability to existing customers. Regulatory agencies are increasing their use of reliability as a significant criterion for utility comparison and ratings. If the utility’s reliability is below average, then the utility’s rating will be below average.

These market and regulatory forces will result in reliability improvement becoming an even more important utility operating goal. Reliability indexes are based on both the frequency and duration of outages. Thus, utilities must decrease both outage frequency and duration in order to gain an overall reliability improvement.

Outage frequency is a function of system construction, system maintenance and system over-current coordination practices. Outage frequency rates cannot be improved by using alternative feeds to provide temporary service restoration, since alternative feeds are used only after the outage occurs. Beyond good and proper construction, maintenance and operating practices, automatic service restoration (as used by transmission systems) would be required to reduce outage frequency. This may be required in some cases, and may, in the future, prove to be feasible or a regulatory requirement, but at this time it does not often prove to be an economically viable distribution practice.

Even though non-automatic service restoration cannot reduce outage frequency, Contingency Analysis is still useful in the reduction of outage frequency. The results of Contingency Analysis can be used to locate areas of the system that are subject to outage problems and thus generate construction projects that will help reduce outage frequency.

Where Contingency Analysis is of the most benefit is in the reduction of outage duration. For de-energized systems and customers where an alternative feed is possible and the switching operation can be performed in less time than correction of the outage causing problems, the outage is over as soon as the system is re-energized with the alternative feed. This then reduces the number of customers experiencing the outage and reduces the utility’s average outage duration index. For any given outage, the benefit is dependent on how many customers have power restored and how long it takes to fix the initial outage-causing problem. Overall, reliability can be greatly improved.

For example, a substation serving 2,000 customers has a failure on the substation transformer. It will take 10 hours to change out the transformer and restore normal service. If all 2,000 customers are de-energized for 10 hours, this outage adds 20,000 “customer out of service hours” to the utility’s outage duration index. However, if in 30 minutes all 2000 customers can be switched to alternative feeds, this outage only adds 1,000 “customer out of service hours” to the index. Of course, the most significant benefit is that 2,000 customers will be much less disturbed with a 30-minute outage than a 10-hour outage.

If outage duration is to be reduced by use of temporary switching, a predefined emergency switching plan must be available to operating personnel or the Contingency Analysis software itself must be available for use by operating personnel.

V. Planning with Contingency Analysis

When accomplished ahead of the outage, a Contingency Analysis would be considered a planning study. A Contingency Analysis performed for planning purposes will usually be done on a model of the system at peak loading conditions. Off peak loading is sometimes considered. The goals of a planning contingency study would include:

- Define switching plans for major outages.
  - Switching plans are implemented by operations when and if an outage occurs.
  - Switching plans must be valid for expected peak conditions.
  - Switching plans may have variations for off peak and/or seasonal conditions.
- Identify system improvement projects and switching point projects that will economically improve reliability.
- Identify system improvement projects and switching point projects that are required to provide service to non-interruptible loads.

Some of the more significant benefits of planning with Contingency Analysis are:

- Needed switching equipment can be identified and installed before the outage occurs.
- Operating personnel can be provided a documented switching plan for each potential outage situation.
- Potential outage situations that could be improved by construction projects are identified.
- System expansion plans are expanded to include consideration for and evaluation of system contingency, thus allowing the plan to give preference to those improvement options that also improve reliability.

VI. Dispatching with Contingency Analysis

When used by operations or dispatching at the time of the outage, Contingency Analysis requires that Distribution State Estimation capability is implemented or that “loading cases” valid for the conditions at the time of the outage be predefined. When used by operations, Contingency Analysis settings should specify the use of only existing switching points. This use of Contingency Analysis works best when planning has used Contingency Analysis to locate switching points and correct system switching weak points.

The benefits of dispatching with Contingency Analysis include:

- The need for predefined switching plans is eliminated.
- Switching recommendations are based on existing loading conditions and actual outage situations.
- Switching recommendations can be updated as loading conditions and the outage situation change.
- Unexpected and unforeseen situations can be dealt with.

VII. Need for Computer Aided Contingency Analysis

A Contingency Analysis can be accomplished using the standard load flow and voltage drop applications of a Distribution System Modeling and Analysis software system. However, such a study is very time consuming. The time required considering all possible solutions to each possible outage often results in the use of short cuts. Short cuts result in the possibility of missing the best possible solution and reduce the engineer’s confidence in the validity of study recommendations. Even with short cuts, a Contingency Study requires a significant amount of time.

With the existing and ever increasing need to improve reliability, comprehensive Contingency Analysis is becoming a necessity. As a result labor saving software that significantly reduces the time required to do a Contingency Analysis, while ensuring a best possible solution to each outage situation, is also becoming a necessity.

VIII. Settings and Options

An engineering software tool must be accurate while being flexible. Different study purposes and levels of use will require flexibility in how the software solution interprets the system model and what solution assumptions are used to obtain the desired solution results. In the case of Contingency Analysis the following user settings are required.

A) Switching Options:

1) *Allow installation of new switching points to isolate outage element?*
   - If set to true, a switch will be installed or opened at the beginning of the outage element and at the end of the outage element. This results in only the customers and load on the outage element being isolated from the system. Isolated parts of the system will not be subject to service restoration from alternative feeds.
   - If false, then the first existing switch, or over-current device, up line from the outage element will be opened and the first existing switch, or over-current device, on each branch down line from the outage

element will be opened. Only existing switching points will be opened.

2) *Allow installation of new switching points as required to re-energize load?*
   - If set to true, new open switching points will be installed where necessary to minimize the amount of load dropped.
   - If false, only existing closed switching points will be opened for the purpose of dropping load in order to solve loading and voltage problems.
3) *Allow switching only to and within the initial outage area?*
   - If true, only switching points within the initial outage area will be used to restore load and to solve loading and voltage problems. This includes those open switches that connect the outage area to alternative feeds.
   - If false, switching is allowed (but not load dropping) anywhere in the Work Environment.

B) Regulation Point Options:

1) *Do not change regulation points.* If selected, regulator output voltages and source bus voltages will not be changed.
2) *Set regulation points as required without exceeding maximum voltage level.* If selected, regulator output voltages and source bus voltages will be increased as necessary to solve low voltage problems. In no case will the voltage be increased to greater than the maximum allowable voltage.
3) *Set all regulation points to maximum voltage level.* If selected, all regulator output voltages and all source bus voltages will be set to the maximum allowable voltage level.

C) System Operating Limits:

1) *Maximum allowed loading on Overhead line?*
2) *Maximum allowed loading on Underground line?*
3) *Maximum allowed loading on Transformers (and Sources)?*
4) *Maximum allowed loading on Regulators?*
5) *Maximum allowed voltage?*
6) *Minimum allowed voltage?*

D) Load Dropping Options:

1) *Do not allow loads to be dropped other than as required to isolate fault?* If selected, only loads on system isolated by the fault will be dropped. Operating limits (overloads and low voltage) will be ignored and all loads, which have an alternative feed, will be served.
2) *Allow only interruptible loads to be dropped?* If selected, only loads on system isolated by the fault and load identified as "interruptible" will be dropped. Non-interruptible loads will be served anywhere an alternative feed is possible.
3) *Allow any loads to be dropped?* If selected, all loads are subject to being dropped in order to maintain system-operating limits.

IX. METHODS

Contingency Analysis software must either use an existing engineering circuit model, with load flow or voltage drop capabilities, or must define and perform these functions in addition to contingency analysis. Milsoft's Contingency Analysis has the advantage of using the WindMil® engineering circuit model and load flow capabilities.

The first step in a Contingency Analysis study is to identify the circuit element that is to be the outage element. Actually, we will want to perform contingency analysis on all elements in a list of selected elements or on all elements of a given type in the model. For example, we may want to accomplish a contingency analysis on all defined source elements and all defined over-current device elements in the database.

The second step is to define the initial outage situation. Information required from this step includes:

- What switch is opened (or installed and then opened) to de-energize the faulted or outage element?
- What system is de-energized with the initial switching operation?
- How much load (number of customers and total kW) is de-energized with the initial switching operation?

The third step is to define the switching required to isolate the faulted element on its load side and to restore service to all loads with a possible alternative feed. Information required from this step includes:

- Which switching points are closed and which switching points are opened (or installed and opened) to isolate the fault on its load side while re-energizing as much of the de-energized load as possible?
- What system is re-energized?
- How much load is re-energized?
- How much load is still de-energized?
- What are the resulting voltage and current loading conditions?

The fourth step is to identify and define switching and regulation changes required to solve current overloads and voltage problems. This may require dropping part or the entire load re-energized by alternative feed. While the actual solution sequence varies with system conditions, the following is a typical solution path:

- Drop load as required to solve overloads on radial line and equipment.
- Adjust regulation points where possible to solve voltage problems.
- Move load where possible to solve overloads and voltage problems on lines with alternative feeds.
- Drop load as required to solve overloads and voltage problems on lines with alternative feeds.

The fifth and final step is to summarize and report final outage and restoration data.

- What is the final regulation and switching configuration?
- How much load is left de-energized?
- How much load is re-energized from the initial outage situation?
- What are the current and loading problems still on the system caused by non-interruptible loads?

X. SUMMARY

The need for distribution system Contingency Analysis is increasing with the need to improve distribution system reliability. The need for fast and comprehensive computer aided Contingency Analysis is increasing with the need for Contingency Analysis. Computer aided Contingency Analysis programs are now available and can help the distribution engineer by making it possible to quickly accomplish an accurate and comprehensive Contingency Analysis study.