

Benefits of Feeder Automation Solutions to Improve Quality of Supply and Reduce Operations and Maintenance Costs

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Abstract—With new requirements being placed on the distribution grid, the cost to consumers of poor supply quality and low reliability is increasing. Consumers are starting to demand higher levels of supply quality from distribution network operators. This paper will discuss various Fault Location, Isolation and Service Restoration (FLISR) strategies with increasing CAPEX investment potential that can be used to improve the quality of supply.

I. INTRODUCTION

Increasing Demands Require Increased Performance

In North America today, one of the key issues facing our distribution networks is the urgent need to make capital investments to replace and upgrade the sometimes neglected, aging distribution infrastructure. Additionally, new technologies are placing greater demands on this already stressed infrastructure. Some of these new and emerging technologies include distributed generation, renewables and plug-in electric vehicles.

A. Distributed Generation and Renewables

Many governments are now mandating a certain percentage of their energy portfolio in their jurisdiction must come from clean sources. Following this requirement, the regulatory environment in many jurisdictions has adapted to allow generation to interface directly with the distribution grid. This is causing traditional energy consumers to become energy producers by allowing them to invest in generation such as small roof top solar systems up to mid-size wind farms, or by selling unused generation capacity from co-generation plants back into the grid. This is creating a veritable energy marketplace out of the distribution system that will require a high degree of reliability as

producers seek to make their return on investment (ROI).

B. Plug-In Electric Vehicles

With the ever increasing price of gasoline, consumers are beginning to look for more cost-effective means of transportation. The introduction of partially or fully electric vehicles is seen as one of these lower cost alternatives. Consumers of new electric vehicles will require the supply of sufficient energy to charge their vehicles at their homes and offices. Census data from both Canada and the United States show that 72-75% of commuters drive a vehicle as their primary mode of transportation to their workplace. Sustained outages can have the potential impact of interrupting a consumer's daily commute, leading to absenteeism and greater economic disruption.

II. MEASURING QUALITY OF SUPPLY

Because the distribution system is made up of many different stakeholders such as producers, consumers, traders and network operators, it can often be difficult to determine the basic level of system supply quality and reliability. In North America, this responsibility falls to regional energy regulators. Regulators can entice distribution network operators to meet and even exceed these levels by creating a framework for performance-based rates.

The main criteria for measuring the quality of supply are the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI).

SAIDI measures the average amount of time that consumers are without service per consumer served and is defined by the following equation:

$$\text{SAIDI} = \frac{\sum_i r_i N_i}{N_t} \quad (1)$$

Where N_i is the number of customers affected by an outage, r_i is the restoration time of an outage and N_t is the total number of customers served.

SAIFI measures the total number of outages experienced by consumers per consumer served and is defined by the following equation:

$$\text{SAIFI} = \frac{\sum_i N_i}{N_t}. \quad (2)$$

Where N_i is the number of customers affected by an outage and N_t is the total number of customers served.

Usually outages of less than 1-3 minutes are not counted towards the SAIDI or SAIFI metrics.

III. THE COSTS OF SUPPLY QUALITY

The cost of supply quality can be borne by both consumers of energy and distribution network operators.

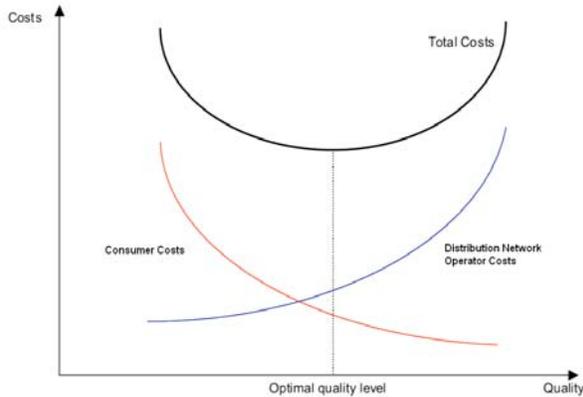


Fig. 1. Costs versus Quality of Supply.

When considering the interruption costs for consumers because of low supply quality together with the costs for distribution network operators to implement supply quality improvements, the optimum supply quality can be found as the minimum cost.

A. Energy Consumers

The cost of an outage for commercial and industrial consumers can have a direct economic impact on their operations.

TABLE I
TYPICAL FINANCIAL LOSS PER OUTAGE

Industry	Cost
Semiconductor Production	\$5,300,000
Financial Trading	\$8,400,000 per hour
Computer Center	\$1,000,000
Telecommunications	\$45,000 per minute
Steel Works	\$500,000
Glass Industry	\$350 000

Source: "The Costs of Poor Power Quality", David Chapman, Copper Development Association, July 2002.

Add to this new demands on our distribution network based on emerging technologies, and the added costs of outages for energy consumers can have even greater economic impact.

B. Distribution Network Operators

Because of the trend in increasing consumer costs due to supply interruption, distribution network operators will be forced to increasingly invest more to maintain the optimal supply quality level. One such solution to increase supply quality is Fault Location, Isolation and Service Restoration (FLISR). This solution can easily help reduce the SAIDI metric by allowing operators to locate and react to outages much more quickly. It can also help to lessen OPEX expenditures by reducing the amount of time crews are required to try and manually locate faults on the distribution network. Further, functionality to automate the service restoration process can restore many customers before the 1-3 minute limit, enabling reduction in both SAIDI and SAIFI.

The remainder of this paper will focus on evolutionary FLISR strategies that can be implemented by distribution network operators with increasing CAPEX investment, as needed, to meet increasing supply quality requirements.

IV. FAULT PASSAGE INDICATORS

The traditional method for locating faults on the distribution network can be a very tedious task. Crews are dispatched to the faulted feeder and try to predict the fault location. Using a hit and miss method of isolating sections of the faulted feeder, crews will reclose the substation breaker, or other network protective devices, such as reclosers, to validate that the faulted feeder section is downstream from the isolation point. This can create unnecessary wear on protective equipment on the feeder being tested, resulting in decreased equipment life and increased time required for maintenance. It also increases the risk of creating additional faults on the feeder as weak isolation points are stressed. Multiple faults on a feeder can create

additional complexity for the crew as they try to locate the faulted section.

One solution to help crews locate a fault and rule out healthy sections of a feeder is the addition of fault passage indicators (FPI) at strategically located points along a feeder. Solutions for fault passage indication exist for both overhead and underground networks. One such solution for overhead networks is FPIs that can clip-on to overhead lines. The FPIs operate by monitoring the current at a specific point on the line. To detect a fault, they monitor the line for a loss of voltage following a sudden high impulse current (dI/dt) over a 30ms period, or an overcurrent condition set to a preset value. Upon detecting a fault downstream from the FPI, the FPI will provide a visible indication by flashing a set of high-intensity LEDs. The crews can then follow the feeder and the flashing FPIs until they locate an inactivated FPI (one that has not activated the flashing LEDs). The crew will then know that the fault is located between the last active and first inactive FPI, allowing them to focus their efforts on a much smaller feeder section.



Fig 2. Overhead clip-on fault passage indicators.

SAIDI values can be significantly reduced by helping crews locate faults and reducing the time required for diagnostic testing. Maintenance costs for protective devices in the network can also be reduced by eliminating the need to repeatedly close onto faults. FPIs can easily be added to the distribution network with very minimal CAPEX investment, making them an excellent starting point for helping operators to improve their quality of supply. The ROI for adding FPIs can usually be realized in 6-12 months.

V. ADDING COMMUNICATIONS

Typically, communications has only extended to the distribution substations, allowing operators the ability to detect faults that trip feeder breakers only. This leaves consumers to report outages caused by faults that operate other protective devices outside the substation fence, such as reclosers or fuses. This means that the time it takes to detect a fault is reliant upon the consumer.

Deciding on the right communications medium depends on many unique factors, such as physical or geographical limitations that are specific to different distribution network operators. Some of the many choices for communication mediums include licensed/unlicensed radio, cellular technology, broadband over power line, fiber optic cabling or even piggy-backing on mesh networks that are being implemented for Advanced Metering Infrastructure (AMI). Adding communications capabilities to distribution network devices outside of the substation fence can lead to improvements in real-time situational awareness and even allow for some remote control capabilities. Devices exist today that can easily communicate to a network operator's **supervisory control and data acquisition (SCADA)** system using standard protocols such as DNP3 or MODBUS. Some of the benefits are specifically related to communicating fault passage indicators and protective/isolation devices such as reclosers and sectionalizers.

A. Communicating Fault Passage Indicators

Communicating FPIs operate along the same principles as non-communicating FPIs, except that upon the loss of voltage on a feeder; the outage can be immediately reported to the distribution network operator. Because the communicating FPIs can also transmit information if they have detected the passage of a fault current, the operator can determine the general location of a fault. The operator can quickly dispatch a crew directly to the faulted section of the feeder, significantly reducing the time it takes to report and locate the fault on the feeder, while also having a minimizing effect on the operator's SAIDI value. The ROI for communicating FPIs can be realized in 1-2 years.

As an added benefit, communicating FPIs can also provide metering information on average, minimum and maximum current values for the line. This information could be used to help optimize an operator's asset management program or to help detect distribution network irregularities.

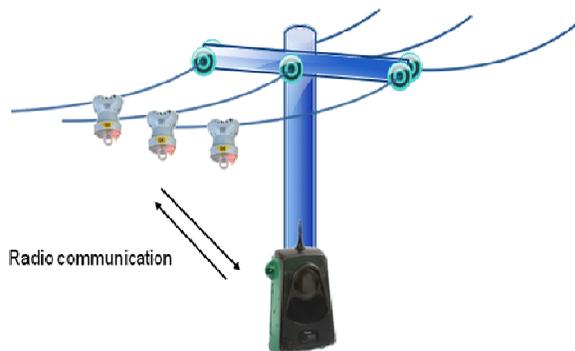


Fig 3. Overhead communicating fault passage indicators.

One such overhead communicating FPI solution today employs a pole mounted remote terminal unit (RTU) that communicates with three or more FPIs through radio communications. There are some additional solution health benefits from using an RTU as a receiver, such as the ability to monitor FPI signal strength or battery level. This information can be reported back to an operator who can schedule maintenance at the first sign of potential trouble. The RTU can also be used to concentrate the FPI sensors to help optimize communication costs by reducing the number of cellular subscriptions or radio units required.

B. Reclosers and Sectionalizers

SCADA communications can also be extended to many existing reclosers and sectionalizers in the distribution network by interfacing communications technology such as radios to the existing controller. This will not only allow improved situational awareness by reporting switchgear statuses, currents and voltages, but also allow for remote control operation of the switchgear.

In some cases, legacy recloser controls may not have the capability to communicate through conventional means or, in the case of some sectionalizers, not be equipped with a controller. In these cases an integrated RTU (iRTU) can be retrofitted to the switchgear either through an output contact to an existing controller or directly. Some iRTUs contain backup power supplies that can provide enough power to operate sectionalizers and allow for control of the switchgear during an outage. Other iRTU features include the ability to include current transformer (CT) and voltage transformer (VT) inputs for metering, and integrated communications technology such as radios or cellular communications.

Like the monitoring of the feeder breakers at the substation, adding the communications infrastructure outside the substation allows distribution network

operators to immediately be informed when one of the protective devices, such as reclosers, has operated. Data reported by the switchgear controllers and iRTUs on the feeder, along with FPIs can aid in quickly locating fault occurrences. With the operator's ability to control the feeder switchgear, the operator can manually isolate the faulted area of the feeder by sending control commands to reclosers and sectionalizers. Once the faulted area on the feeder is isolated, the operator can remotely restore service to the remainder of the feeder consumers by closing the breaker or recloser upstream of the isolated segment and by closing any possible normally open points downstream of the isolated segment. While communicating with reclosers and sectionalizers does aid in fault location, the added value can be realized in remotely isolating the fault and restoring service to some of the consumers on an affected feeder, while quickly minimizing the impact on consumers and the distribution network operator's SAIDI metric.

VI. ADDING REGIONAL DISTRIBUTED INTELLIGENCE

The next step after installing communications capabilities to the many intelligent devices on the distribution network is to add some distributed intelligence at a regional level. One such method for accomplishing this is to place an intelligent controller at the distribution substation level. This regional controller can contain a real-time data model with data collected from the intelligent devices on the feeders connected to the substation, distributed generation and neighboring substations.

The intelligent controller would be reliant on communications to regional devices to adequately manage the region, while the controller should be able to act independently and not have reliance on any centralized intelligence from the distribution network level. Because of the regional awareness the intelligent controller possesses, it can easily assist in better determining fault location, making some automatic switching decisions and managing distributed generation connections.

A. Fault Location Determination

Many rural feeders are radial and cover long distances. This means the distance between the placement of FPIs on the distribution feeder can be large, requiring crews to spend greater amounts of time searching the feeder to locate the fault. Since regional intelligent controllers have awareness of real-time data such as voltages and currents collected from protective devices inside and outside the substation, they can help to more accurately predict the location of the fault using the fault current method. The fault current method for detecting the location of faults uses the magnitude of

the short-circuit current during the last cycle before the protective device operates and the type of fault detected. From this information, a fault simulation can be performed using the pre-programmed parameters for the feeders to predict the location of the fault. In urban areas, this method of fault location prediction should be used in conjunction with fault passage indicators due to the added complexity of the network and various feeder branches which could lead to the fault current method predicting multiple fault locations.

B. Automatic Switching

After determining the location of the fault on the feeder, the intelligent controller can take some actions to issue controls to sectionalizers to isolate the fault as tightly as possible. Once isolation is completed, the controller can restore service to consumers upstream of the isolated feeder section. In some cases the controller could even automatically restore service to consumers downstream of the isolated section by closing a normally open point between two adjoining feeders. Care should be taken before allowing this type of operation to ensure there is no possibility of overloading the adjoining feeder.

C. Distributed Generation Management

With the new regulated requirement of distributed generators connecting to feeders, multiple supply sources need to be disconnected from the feeder when a fault occurs. Since the intelligent controller is aware of the status of all protective elements along a given feeder, it can issue disconnect commands to distributed generators downstream from the operated device as per the distribution network operator's grid code.

VII. ADDING CENTRALIZED INTELLIGENCE

Centralized intelligence, such as a distribution management system (DMS), can be implemented with a real-time awareness of the complete distribution network. All decisions are made based on the current state of the network instead of using a worst-case, pre-engineered solution. Detailed models also provide load simulations that can assist with detecting faults in the distribution network. The DMS is aware of pre-fault loading plus outage duration and can predict the "cold load pickup" current expected when re-energizing the feeder section. This allows for enhanced isolation and service restoration algorithms which can be executed as a "man in the middle" approach with the SCADA operator interacting with the suggested restoration steps, or fully automatic with the restoration steps executed in a closed loop control method using fully SCADA-controlled equipment. The DMS can produce restoration switching steps as a result of a fault or can

be used to implement and restore service after planned outages.

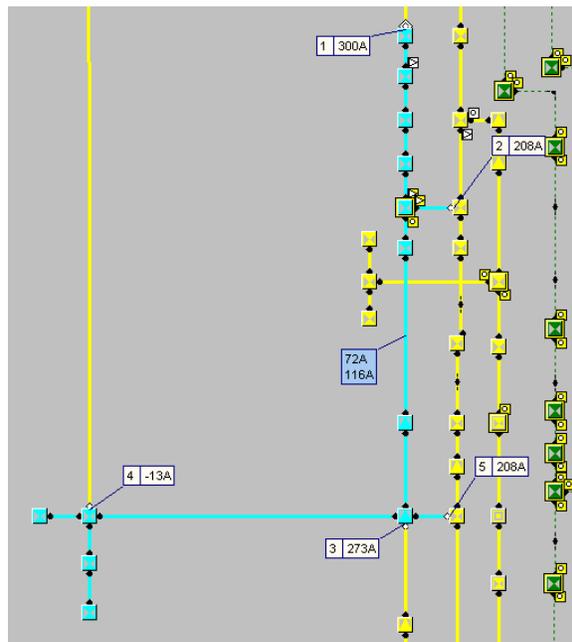


Fig 4. Predicted restoration load and options for resupply.

A. Fault Location

For protective devices that are difficult to monitor, such as fuses, simulation of the expected loading on a feeder can help to predict when and where these devices have operated. This, along with data from customer reporting calls and information on planned outages, can be used to help operators hone their ability to locate faults.

B. Fault Isolation and Service Restoration

With the DMS system having a global overview of the entire network, the system can easily determine optimal switching routines that can restore the maximum number of consumers while taking into consideration priority customers and the rating of specific feeders. This global view is important to ensure the transfer of load from one feeder to another does not cause overloading on the feeder that is picking up the load. For feeders that contain isolation devices that don't have remote control capabilities, the DMS can provide a list of switching operations that can be performed manually by the dispatched crew. The DMS system can also compute a list of alternative switching scenarios for operator selection.

The FLISR algorithms of the DMS can be initiated manually by the operator to reconfigure feeders due to planned outages or scheduled maintenance work.

When feeders are operating in non-standard configurations that are outside of normal operations, the

DMS system can block the distributed automatic feeder reconfiguration at the regional level and issue switching orders from the DMS level only. The result is fully coordinated, central-decentralized intelligence.

C. Future Considerations

Many of the intelligent devices in place today in the distribution network have the ability to record wave form captures of detected distribution network faults. Future DMS systems will have the capability to collect and analyze these wave form captures and predict the cause of different types of faults based on specific fault signatures. For example, based on the fault signature of a tree branch falling on a feeder, the operator would immediately know that he also needs to dispatch a forestry crew to a specific fault location.

Future prediction tools will provide an analysis of trends of transient events to help predict future failure modes. Distribution network operators can then use this information to provide warning of future outages and schedule maintenance before an outage or fault occurs.

VIII. CONCLUSION

With new technologies and consumer requirements placing greater demand on the distribution grid, additional pressure from consumers and regulators is being felt by distribution network operators to improve the level of power supply quality. Providing greater reliability can be accomplished by implementing different Fault Location, Isolation and Service Restoration strategies which can be measured by a relative reduction in the operator's SAIDI metric. This paper highlights some of the FLISR solutions that can be used to help reduce the SAIDI metric with varying degrees of CAPEX investment. Investments in FLISR can easily evolve over time and are scalable in terms of cost and complexity as new requirements demand. Additional operational and maintenance efficiencies can also be recognized from investments in FLISR strategies that can also help justify the CAPEX investments.

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