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High Reliability Alternatives to Network Systems

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SUMMARY

Historically, secondary network systems have been the distribution grid layout of choice in large cities and areas with expected high load. They provide a high level of reliability to loads that require continuous service under any conditions. Despite the high level of reliability they provide, network systems in many cities have been used for a century and expanded upon to their limit, with much of the equipment reaching end of life. Safety has also proved to be a major consideration for many utilities to move away from network systems due to many companies' dedication to proving power safely to its customers, as well as protecting its workers. Advances in distributed energy resources (DERs) and the demand for cleaner energy from both consumers and governments are pushing utilities to evaluate their existing networks and their ability to handle the connection of stochastic generation. In many cases, existing networks are not equipped to handle connection of DERs. These are just some of the issues presented by existing networks, and these issues are also causing hesitation in construction of new network systems. In this paper, a few high reliability distribution grid alternatives to network systems are presented. Microgrids, spot networks, FLISR, switch source, and automatic transfer switching are explored, along with considerations for each that should be evaluated before implementing in a specific area. While these alternatives have both advantages and disadvantages, they present the future of the modern distribution grid.

KEYWORDS

Network systems, reliability, microgrids, spot networks, FLISR, switch source, distributed energy resources

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I. Introduction

For large cities across the United States and all over the world, network systems have been used to provide highly reliable power in dense load areas. Their level of redundancy and the interconnection of the secondary network makes them ideal to provide power to locations requiring uninterrupted power flow, even in the event of equipment failures, maintenance, and outages on portions of the system. Many large cities throughout the world are still using portions of their network system that were installed a century ago. These networks are aging, leaving many utilities looking for new, modern solutions to replace them. This leaves utilities with the difficult task of evaluating modern alternatives for network systems, while maintaining high customer expectation of reliability. These customers often go years without even a momentary outage that affects their systems. Utilities today also are typically not expanding these systems, relying on alternatives to patch spot networks together. Regulatory decisions to modernize the grid are also driving a need for alternatives to allow for DERs and Non-Wired Solutions (NWS) to be connected to alleviate the need of expensive infrastructure build outs. The push for reliable, cheap, and clean energy is leading many utilities to move to more modern solutions.

II. Overview of Network Systems

a. Historical Uses

Network systems have a rich history, going all the way back to the beginning of the electric distribution system. Low voltage DC networks were used at the start of the installation of distribution systems. The inefficiencies of DC power led to the development and construction of AC networks throughout the United States. In many large cities, newly constructed distribution lines were hung on the same poles as lighting and telegraph lines, leading to a city skyline dominated by hanging wires. Thomas Edison proposed the first use of conduit to house DC wire [2]. After what many know as "The War of the Currents" and the victory of AC current, DC systems were slowly converted to AC. As these conversions took place, many large cities began to slowly interconnect their underground networks, leading to large interconnected secondary networks.

Early network systems presented issues in terms of protection of the primary network due to the need to prevent backfeed onto the primary network. Secondary side cables were often protected with fuses, which protected network transformers from secondary side faults but provided no protection from high side faults. This need helped facilitate the development of the network protector.

The first network system as it is known today began in New York City in 1922 with the installation of the first fully automatic network protectors by United Electrical Company [3]. Around the same time, Memphis, Tennessee, was also working to create a network system with the installation of its first network protector in 1925 [3]. This created a spot network that would later develop into a secondary network system as portions of the system were interconnected. Many other utilities in large cities, such as Georgia Electric Light Co. of Atlanta, Georgia, and Philadelphia Electric Company of Philadelphia, Pennsylvania, were also working to make the conversion from DC to AC, constructing extensive underground secondary networks that would evolve into the modern network systems that these cities use to this day. The expansion of these networks has led to the development of modern grid equipment, such as smarter network protectors and transformers, that are safer and more efficient.

b. Architecture

Network systems make use of redundancy to create a robust distribution system in high-load density areas that require increased reliability. Network systems are three-phase, four-wire systems, with the secondary network operating at 120/208V to service both lighting and power loads, but this secondary voltage can vary depending on utility. Due to their use in large, vertically developed cities, network systems are almost exclusively used underground, with transformers, breakers, and network protectors housed in large underground vaults. Figure 1 depicts a vault, housing equipment typically implemented on a network system.

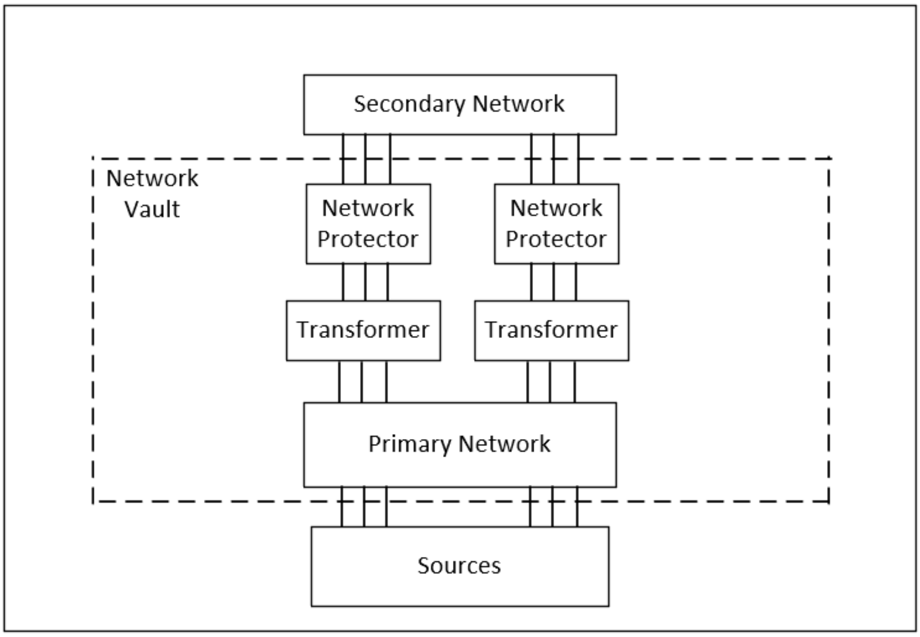

Figure 1. One line diagram of a typical vault

Large-load areas are supplied with multiple feeders of the same voltage in parallel. Primary feeders come from multiple substations, and feed many step-down transformers. Loads are connected to the secondary side of these transformers, which are connected to one another throughout the system providing many parallel feeds to multiple loads. With all loads connected to the secondary bus, any parallel feed can be disconnected via circuit breaker without interrupting service to any portion of the system. The secondary side can be further networked with smaller transformers to increase reliability and step-down voltage further if needed. A one-line diagram of a network system is shown in Figure 2.

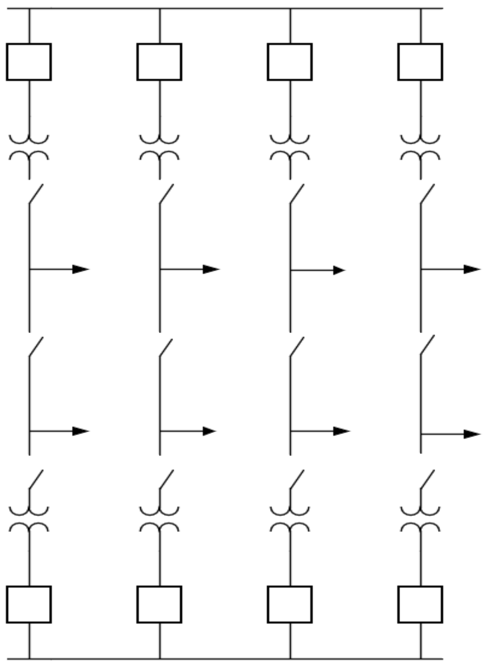

Figure 2. One line diagram for network system.

c. Protection

To prevent damage to the network transformers and high-side equipment in the event current is back fed onto the primary feeders, network protectors are placed between the low side of the network transformers and the secondary bus. Circuit breaker protection typically utilizes ground and phase overcurrent protection, but network protectors on the feeder primary utilize reverse power flow protection. The reverse power flow will be set to look for real power flowing from the network to the feeder from the network to other loads or networks on the feeder, or from the network to supply core losses of the network transformer [4].

While the network protectors will clear faults on the primary feeders, they are not designed to disconnect in the event of a fault along the secondary bus. Protection on the secondary bus typically will include fuses and cable limiters. Cable limiters function similarly to fuses, containing a copper wire that will burn through in a short circuit condition. This protects cable and limits damage due to their fast operation when faults occur, but they are not able to provide protection in the event of overload conditions. Fuses along the secondary bus act as overload protection, as well as limit overcurrent in a fault condition.

III. Benefits of Network Systems

The main benefit of a distribution grid network system is its reliability. Unlike radial networks, grid networks are designed with two or more primary feed sources. This results in much greater reliability to the customer as every load has two or more connections to the primary system. If a fault occurs on the system and one of the sources is lost, the loads should not experience an outage due to the systems built in redundancy. Usually, this type of network configuration is found in densely populated areas where the cost-of-service interruption is much higher [5].

An example of one such system is the Hong Kong grid. The grid is split into 11kV and 22kV networks. Between 1997 and 2008 the 11kV network achieved a 99.999% reliability rating. The 22kV system, first energized around 2003, achieved almost 100% reliability in its first five years [6].

Another example to consider is New York City. ConEd serves approximately 3.5 million customers in NYC and Westchester County. Approximately 2.6 million customers are served by a network system while the other 900,000 customers are served by a radial system. Table 1 shows the System Average Interruption Frequency Index (SAIFI) and Consumer Average Interruption Duration Index (CAIDI) scores of the network system compared to the radial system [7]. The data show that the network system is about 17 times more reliable than the radial system, based on the SAIFI score. However, outage duration on the network system is about 4 times what is seen on the radial system. This is largely due to the construction of the radial feeders on ConEd's system. The radial system is mostly overhead, while the network system is underground. Because of this, the radial system will have much more frequent outages, but many of these will be far shorter than the underground fault duration. The short time combined with the higher frequency will drive down the CAIDI numbers.

Metric	2015	2016	2017	2018	2019	5 Year Avg.
Network						
SAIFI	0.027	0.017	0.025	0.023	0.056	0.030
CAIDI	8.39	7.42	7.11	7.29	5.29	7.10
Radial						
SAIFI	0.35	0.49	0.36	0.40	0.53	0.41
CAIDI	1.95	1.89	1.92	1.99	2.73	2.10

Table 1. Network and Radial SAIDI and CAIDI Metrics from ConEd.

IV. Limitations of Network Systems

While network systems provide very high reliability in densely populated areas, they are not an ideal solution in many cases. Historically, they provided cities and utilities with a reliable system that can be expanded upon easily, but with modern day grid advancements and considerations such as cost and safety, utilities are looking for different solutions.

a. Cost

The cost of a network system is estimated to be 175-200% more expensive than radial networks [5]. However, to get a more wholistic cost picture, it is important to consider not only the investment cost of building and maintaining a grid network but also the estimated cost of outages. This task relies on information about the load types, degree of reliability able to be provided by the network, economic cost of outages, etc., to attempt to quantify the total cost/benefit of a given system [8]. A detailed cost analysis is not in the scope of this paper, rather reliability indices will be evaluated, where available.

b. Safety

Prior to work on de-energized conductors, industry accepted practice is to obtain a visual open point in the circuit, ensuring de-energization. With the extensive redundancy on the secondary side of a network system, it can be difficult, if not impossible, to obtain a visual open point prior to starting work. Due to this, any work being done on a network system requires proper hot-line PPE. Hot-line work is inherently more dangerous than de-energized work, especially in enclosed spaces such as underground vaults.

Network systems also experience much higher fault currents compared to other system layouts. This is due to the high number of transformers connected in parallel allowing multiple sources to feed a fault. With the potential for such high fault currents, completing work on network systems requires more PPE with higher calorie ratings to prevent injury if fault conditions were to occur during work. The threat of higher fault currents also requires more extensive fire protection in vaults. When equipment failures do occur on network systems, the resulting arc flash and arc blast are dangerous events that can be very difficult to extinguish. Failures of underground transformers also have been known to blow manhole covers serval feet in the air, endangering passing cars or pedestrians. With safety being of very high concern for many utilities, these threats are leading many to move away from network systems to ensure safety for employees and the general population.

c. Difficulty with DER Integration

As discussed previously, a main component to network system protection is the detection of reverse power flow by network protectors. This creates a problem when attempting to connect DERs onto network systems, particularly when protection devices reclose. Network systems are connected to multiple sources that are all in sync, so generally the protective devices are not doing a sync check since they do not have to worry about connecting to an out-of-sync system. However, if there is enough DERs on the network, it can create an unintentional island condition. When the protective device attempts to reclose, it can connect the two systems out of phase. Because network relays were not previously intended to operate in this condition, it will likely require more than a simple modification of the network protectors to account for it [4].

V. Alternatives to Network Systems

Utilities are considering multiple options as alternatives to network systems due to cost, aging infrastructure, safety, and regulatory decisions. These regulatory decisions are often tied to DER deployments, net-zero energy targets, and NWS that require energy to flow to and from the customer point of interconnect. Equipment is also becoming harder to source as manufactures move on from the basic components that are required to operate networks efficiently. In addition, the space required for these types of systems is becoming harder to site due to the highly urbanized locations of the network systems.

a. Microgrids and Distributed Energy Resources

As much of the world is looking to move away from an unsustainable dependency on traditional fossil fuel energy sources, renewable energy sources connected as microgrids are being explored as alternatives to the traditional grid. They provide an integration platform for micro-resource based distributed generators, energy storage equipment, loads and voltage source converters with the ability to maintain the voltage and frequency to the end user within an allowable range and a compact size [9].

According to the U.S. Department of Energy, a microgrid is defined as a group of interconnected loads and DERs within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. Microgrids can be made up of both renewable and traditional generation. These generation sources can include wind turbines, photovoltaics, tidal power, fuel cells, combined heat and power (CHP), biogas plants, hydroelectric power units, geothermal heat, and biomass power. Depending on the method of grid connection, they can be fully autonomous and self-supporting or still maintain a connection to the main grid. When operated autonomously, the microgrid operates independently, providing 100% of the connected demand. When still connected to the grid, the microgrid can help reduce the overall demand of the connected load on the main grid, while also providing voltage support to the main grid. In addition, microgrids can help to improve the response of the network to voltage and current transients during short circuits, as well as transients caused by the stochastic behavior of photovoltaic and wind power [10].

Microgrids also have the ability to be networked much in the same way as network system secondaries. Networked microgrids are groups of microgrids tied together, giving them the ability to support one another. This gives the added reliability of multiple microgrids tied together with their own generation and storage available to one another. Figure 3 shows some types of microgrids and how they can be networked together.

One way DERs are leveraged to provide cost savings is their deployment as NWS. NWS make use of DERs that are lower emission and maintain high system reliability instead of expanding on the existing distribution grid with infrastructure investments. In some cases, NWS can be cheaper to implement instead of conventional grid upgrades. One of the most well known NWS is the ConEd deployment of DERs to defer the need for construction of an additional substation, distribution feeders, and transmission line with a total estimated cost of $1.2 billion, while the projected cost of implementing the NWS is around $200 million [1].

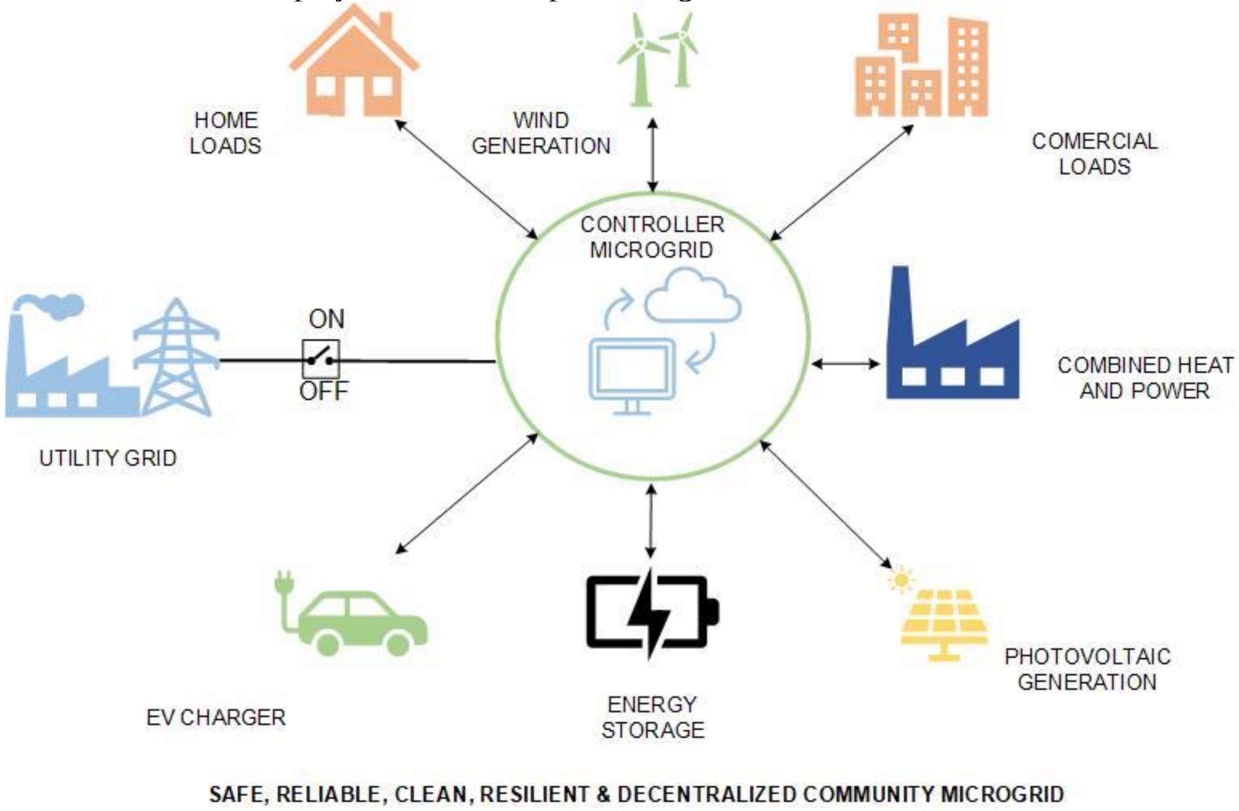

Figure 3. Structure diagram of a microgrid community system

i. Implementation Considerations

The implementation of microgrids and DER requires local generation and storage that can take many forms. While great strides are being taken to make it economically feasible to implement things such as battery storage, wind, and solar generation, technology is still lagging in terms of large-scale manufacturing methods and access to affordable materials. Manufacturing of solar panels is an expensive process, and the expensive investment of installation of wind turbines makes them difficult for some utilities to justify. While a breakeven point is in reach, technological advances are still needed to reach an obtainable breakeven point for cost of installation and return on investment within a reasonable amount of time. Large-scale battery storage, a necessary part of microgrids due to the stochastic behavior of wind and solar, is still an expensive investment because large batteries are expensive to produce in relation to their overall energy capacity. In 2020, the approximate capital cost of 4-hour lithium ion battery storage was $345 per kWh, and the median projected cost in 2050 is around $150 per kWh, with that value fluctuating some depending on which year is used as a reference point [12]. The price reduction over time as this technology matures will make it more obtainable to implement at the utility scale.

When battery storage is implemented, DERs and microgrids do provide very high reliability for connected customers. In the event of a utility experiencing an outage, microgrids with islanding capabilities can disconnect from the utility system and use local generation and storage to maintain service. This layout is being deployed on many military bases, college campuses, and hospitals to ensure continuity of power in large outage events, like hurricanes and ice storms.

The addition of some renewable energy sources, such as wind turbines and solar panels, also require the use of specific equipment, such as converters and sensors, that are not only expensive but introduce grid operation challenges. DC/DC and AC/DC converters can introduce transients onto the grid, along with creating voltage and current instability. As stated previously, these generating methods are stochastic in nature, leading to further system operation challenges. Specialized equipment and controls are needed to regulate these issues, another added expense.

Government red-tape is also posing a challenge for microgrids and DER penetration. Regulatory support at the federal, state, and county levels is imperative to helping DER grow on the distribution system. Much of the policy pertaining to microgrids and DER is still in development, leading to long wait times for approvals for things such as interconnection agreements and protocols for energy exchange. The threat in many states to end net-metering programs also makes the construction of new DERs less than appealing for some companies. For faster deployment of DERs, restructuring of the market, as well as establishment of clear policies, is needed to make them economically appealing to investors and beneficial for utilities.

b. Spot Networks

Also common in densely populated and metropolitan areas, spot networks are architecturally similar to network systems. Network transformers are interconnected on the secondary side, with network protectors used to provide protection from backfeed. Different from secondary networks, spot networks are typically limited to only two to four transformers networked together as compared to many transformers on a traditional secondary network. Multiple feeders are used to supply the network transformers. This means that an outage on one feeder does not necessarily interrupt service, but this depends on the number of interconnected transformers and the load requirements. If the load only requires supply from one transformer and it is sized to carry one hundred percent of load, no interruption of service would result in the event of losing one feeder. Spot networks are most commonly used to supply large commercial buildings with high load, such as hospitals and large office buildings, that require higher reliability. Many utilities are utilizing this solution intermediately to prevent large expansions of their network systems, while still offering enhanced service to their new or rebuilt customer locations.

i. Implementation Considerations

Like secondary networks, spot networks provide high reliability with redundancy provided by multiple supplies from network transformers. They provide a more cost-effective solution compared to a traditional network system due to being contained to a smaller area and reduced secondary side networking. The reduced level of redundancy in the system could decrease reliability, but the smaller footprint of a spot network reduces the duplicate equipment needed. Maintenance can also be carried out without service outage due to the parallel feeds to transformers, as long as the remaining transformers are designed to carry the extra load.

With fewer connected network transformers, a spot network would experience lower fault currents when compared to a traditional network system. This would make it safer for maintenance personal and the general population, but it would still experience higher fault currents than a radial system, making safety a concern for this system layout. Spot networks are also constructed in vaults like networks, creating the need for increased fire protection.

c. FLISR

Self-healing or self-restoration of power delivery systems enables the identification and isolation of the system due to a fault and to more advanced functions such as automatic load transfer and loop sectionalizing. Fault Location, Isolation, and Service Restoration (FLISR) is one of the grid modernization concepts driving the implementation of self-restoration schemes. FLISR has become one of the key distribution automation applications, which can significantly reduce outage time to the end-customers. Figure 4 gives a visual representation of how FLISR can reduce outage times.

When a fault occurs, protection normally trips the required protective devices creating an outage for most, or all, of the customers on the feeder. The operation of a system without FLISR is conducted manually to isolate the faulted area and restore services to customers where possible after the fault has been cleared. On the other hand, a system utilizing FLISR will be able to isolate the fault and restore customers automatically.

The first step for the FLISR application is to detect the fault on the distribution feeder and determine the approximate location. Typically, the faulted section is a portion of a feeder between two switching devices. The FLISR system can determine the approximate location by communicating with the devices on the feeder and checking which device(s) targeted for the fault. Providing a rough location of a fault reduces the time required for fault investigation and patrolling. Additionally, circuit reconfiguration by closing normally open tie switches could transfer loads that are downstream of the fault section, reconnecting customers to a healthy section of the system. The service restoration portion of FLISR is designed to prevent reconnection to healthy feeders that do not have enough capacity to carry the additional load because this could lead to overloading those circuits and further deterioration in operation.

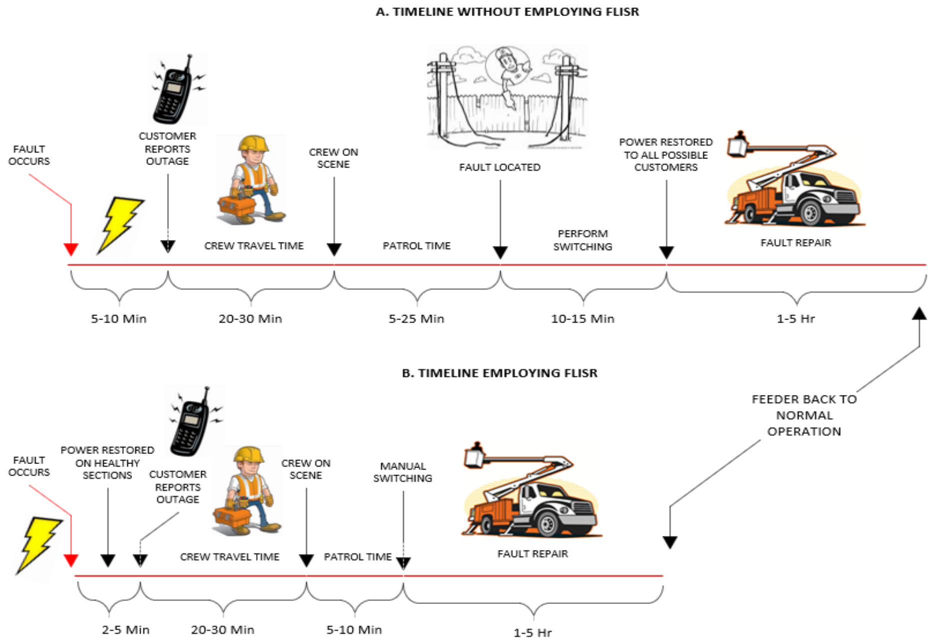

Figure 4. Comparison of reliability improvement with/without employing FLISR, adapted from [11].

i. Implementation Considerations

Some of the functional benefits of FLISR include reducing the outage duration and the number of customers interrupted, thereby improving the system average interruption duration index (SAIDI), the system average interruption frequency index (SAIFI), and other reliability statistics. A study of five utilities with FLIRS capability by the U.S. Department of Energy found that the number of customers interrupted (CI) could be reduced by up to 45% and the customer minutes of interruption (CMI) by up to 51% [6, 7]. Some of the economic benefits are:

- Reduce customer cost of outage due to faster restoration of the power
- Additional revenue from “premium quality” customers
- Reduce operators’ and crews’ workload
- Achieve regulatory incentives (when available)

While increase in reliability indices makes FLISR an attractive, high-reliability option to replace a network system, the up-front investment in grid modification to implement FLISR should be weighed in the balance. FLISR can be implemented with either a centralized or decentralized scheme. Both schemes have advantages and disadvantages. A decentralized FLISR scheme is limited to communication between equipment in the field, which typically leads to the fastest restoration times. This is more often the cheapest application since it does not require communication back to a substation and to an operation center. With limited communication, decentralized FLISR is difficult to scale to large portions of the grid since it requires programming at the equipment level for many different responses to outages. While more expensive to implement, centralized FLISR is more versatile than decentralized. All equipment makes use of network communication to communicate with one another, as well as back to a central location such as a substation. Equipment and grid statuses are reported back to operation centers, allowing for restoration schemes to be executed using real-time data. Centralized FLISR can be implemented on large portions of the grid since restoration schemes are executed at the Distribution Management System (DMS) level. Centralized implementation does require a robust communication network system for equipment to communicate with one another, as well as back to a central point. Different communication methods can be used, such as radio, cellular, and fiber. Many factors must be considered when determining the best communication to implement for FLISR, such as customer count, terrain, range, and available infrastructure. Regardless of the FLISR solution chosen, customers can still experience momentary outages with the implementation of FLISR, which may be a rough transition from network customers who only experience voltage dips occasionally. Momentary outages could also pose issues for more sensitive loads.

DMS and Outage Management Systems (OMS) also require upgrades and reconfigurations in order to integrate FLISR into an existing grid and protection scheme, another added expense to consider. These can further be integrated into an Advanced Distribution Management System (ADMS), which can utilize large system models to make the best decisions based upon active load flows and state estimations.

Beyond hardware and software consideration, FLISR is considered very safe for workers compared to other reliable system layouts. When integrated into ADMS, some protection schemes can be disabled, such as automatic reclosing, when hot-line work is being conducted, so in the event of a fault, lines are de-energized as quickly as possible and stay de-energized. This prevents further injury if an accident were to occur and reduces the potential for faults affecting crews while they work.

d. Switch Source

Switch source systems involve multiple sources that are tied together through a Soft Open Point (SOP). The SOP would replace the Normally Open (NO) point between two radial circuits. Several devices including Back-to-Back converters (B2B), Multi Terminal DC Systems (MT), Unified Power Flow Controllers (UPFC), STATCOMs, static series synchronous compensators (SSSC), and Transformer-less Unified Power Plow Controllers (TUPFC) can be used to turn a NO into an SOP [13]. Under normal conditions, the primary power source of each feeder is used as the main supply the for the circuit. However, the SOP device can act as a bi-directional power flow control allowing for the source of each circuit to serve the other. This results in several potential benefits:

- Increased demand capability
- Increased DER hosting capacity
- Increased reliability

Figure 5 depicts a system layout making use of a SOP with two different feeders, Feeder A and Feeder B. Consider this layout while each of the benefits of switch source are evaluated.

Increased demand capability: If circuit A has increased demand that would normally require system upgrades, those upgrades can be delayed because part of the load will be able to be served by feeder B through the SOP thereby alleviating the loading upstream on feeder A. This will of course only work if feeder B is capable of picking up the additional load. The components on circuit A that are nearing overload will also limit the ability of circuit A to pick up any load on circuit B. For these reasons this set up will not be able to mitigate the need for system upgrades all together [13].

Increased DER hosting capacity: The ability to have bi-directional power flow between circuits A and B allows for more DER capacity. This is because feeder A is no longer required to host the entire new amount of generation. During periods of lower loading on feeder A some of the power can be sent to feeder B through the SOP. This can potentially alleviate much of the overloading, voltage, or reverse power flow issues that would otherwise be seen.

Increased reliability: If a fault were to occur upstream on feeder A, feeder B can pickup the effected customers. This system layout can provide additional reliability by allowing for multiple sources to feed the connected circuits. In this case, the SOP would act similarly to a NO in a FLISR system. Consideration would need to be taken in protection system operation as the fault current will be affected based on the chosen SOP device.

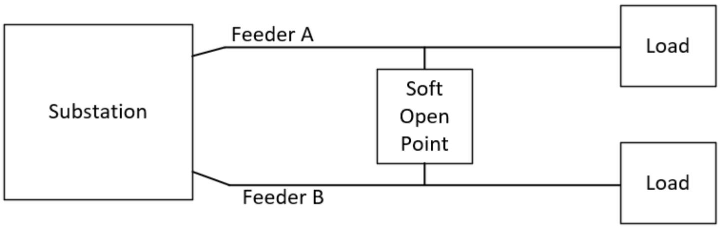

Figure 5. Possible configuration with use of UPFC.

i. Implementation Considerations

While this system configuration seems quite promising, devices such as UPFC and STATCOMS have traditionally been used on the transmission system, but they are still new to applications on the distribution grid. As new technology emerges and they become more economic for distribution level deployment, some of these devices might become good options to implement on existing radial systems with normal open points. More studies and testing are needed to figure out how these devices will perform on a distribution system.

e. Automatic Transfer Switching (ATS)

Automatic transfer switching, also known as selective service, system layouts could be compared to spot networks, but instead of networked secondary, multiple sources are tied together at the bus through an automatic transfer switch (ATS). A primary source and an alternative source, sometimes also called an emergency source, can carry the full required load. Under normal conditions, the primary power source is used to supply the load. If a fault were to occur up-stream on the main feeder, an ATS can autonomously or manually switch to serve the load from an alternative source. Figure 6 shows a typical layout for an ATS system layout. An ATS can perform either a break-before-make transfer or a make-before-break transfer, depending on the requirements of the load. A break-before-make transfer, or open transition, is the most common. This system layout provides the advantage of full redundancy, with multiple available source to feed the load. ATS is commonly used to feed large loads that require high reliability, such as hospitals or data centers, just as a spot network is used. While the use of just two sources, a primary and an emergency source, is the most common layout, three or more sources can be used. A three-source layout would provide an emergency back-up, to be used in case of failure on the alternative source. The use of three sources requires the use of two ATS, with layout determined by the priority of each source. The sources used could be either a direct utility connection or a generator, with generators commonly used as alternative or emergency back-up sources.

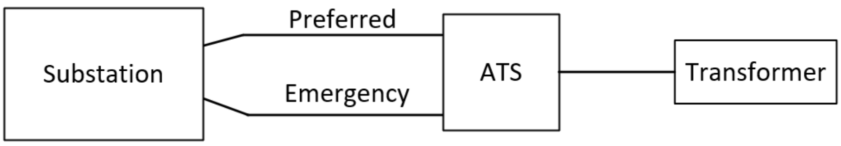

Figure 6. Typical selective service layout with ATS.

i. Implementation Considerations

ATS configuration to service critical loads is highly reliable due to the redundancy in sources, and it reduces the amount of redundant equipment needed since only one transformer is needed, making it a cheaper option compared to a network system. Reliability can be increased even further by using a preferred and an alternate source from different substations. For ATS systems to perform as intended in the event of a fault, selective coordination should also be applied. Overcurrent protection devices, such as fuses and breakers, up and downstream from the ATS must be properly coordinated to ensure that minimal load is affected by a fault. If coordination equipment does not open and/or close in the proper sequence, the ATS could be prevented from opening and a greater number of customers would be affected by an outage. Routine maintenance is also required for automatic transfer switches, just as it is required for network protectors, so this is an O&M expense that needs to be considered when constructing an ATS configuration.

VII. Conclusion

Network systems have proved to be highly reliable grid layout, but cost, safety, aging equipment, and many other factors are leading utilities to seek out modern solutions that still provide high reliability, while also being economically appealing. Table 2 presents some key metrics for comparison of the alternatives discussed. Each solution should not be considered a blanket solution to replace an existing network. Rather, each alternative has certain application requirements that should be considered when evaluating whether they are the proper solution for a certain situation. Not all these alternatives will be economic or even feasible for a given area

Utilities will be faced with difficult decisions in the future when determining which of these solutions to implement in place of constructing new networks or expanding on existing ones. Further advances in technology will only improve upon these grid solutions and make them more accessible and economical. These solutions are the future of an efficient, reliable, and safe grid.

Solution	Cost	Reliability	Safety	Maturity	Other
Microgrids	High-Very High	High	Medium	Low-Medium	Integrations/Protection Complexity
Spot Networks	Medium	High	Low-Medium	High	Easier Transition Known Technology
FLISR	Medium	Medium-High	High	Medium-High	Highly Deployed Modernization Projects, Momentary Outages
Switch Source	High	Very High	High	Low	Few Large Scale Deployments, Solves Momentary Outage Issue for FLISR
ATS	Medium	Very High	High	High	Highly deployed, can be implemented on radial systems

Table 2. Comparison of Alternatives to Network Systems.

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