Siemens FuseSaver
New half-cycle circuit breaker for rural smart grids to minimize operating costs of feeder and spur lines

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1. Introduction

Rural electricity distribution is less reliable and more expensive to operate than urban networks and generates less revenue.

Long overhead line lengths, inherent high fault frequency and the often considerable time taken to find and access faults, results in long outage duration, poor regulatory performance and, often, financial penalties.

Long lengths of line that generate little income can be financially problematic for utilities even when they operate reliably. Those with a high fault frequency as well as having few customers are *more* than challenging. They require investment to improve reliability performance, but with few customers, it is difficult to justify the capital expenditure necessary to improve them.

This paper proposes ten criteria that represent the ideal network performance of rural overhead spur line protection devices. These criteria are then used to evaluate and compare the rural network performance of three low capital cost protection devices. Two of these solutions are traditional devices, the common fuse and the drop-out sectionalizer. The third is a new compact, intelligent and fast circuit breaker technology recently developed.

2. Rural Network Overview

Rural overhead, medium voltage distribution networks are normally configured as radial networks. A zone substation will have a number of feeder lines emanating from it. Each of these feeder lines will then have tee-off spur lines feeding clusters of customers. There are few, if any, interconnections between feeder lines. Figure 1 provides a typical network topology that will be used for the performance comparisons presented later in this paper.

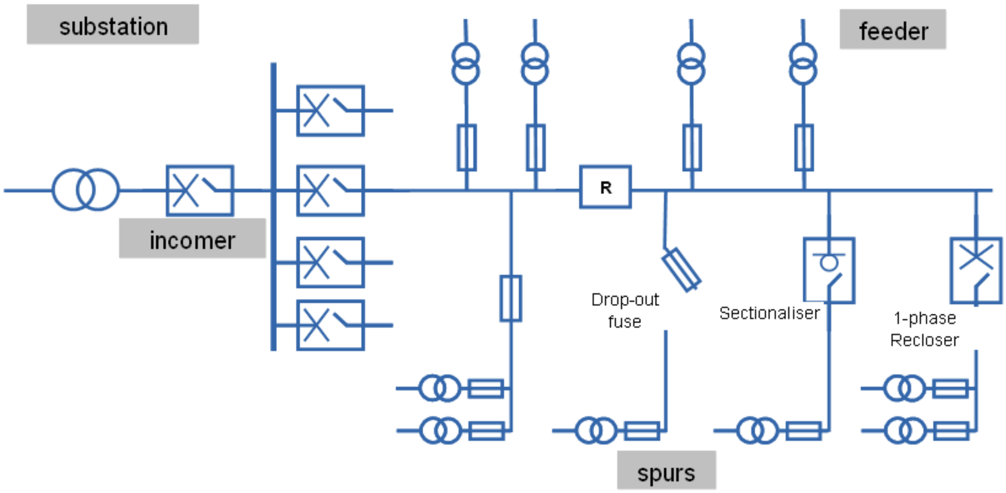

Figure 1. Typical Rural Network Topology

Rural networks also tend to experience high fault rates due to storms, lightning, vegetation and wildlife. A typical fault rate that provides a reasonable guide to network performance and is used in this paper for later comparisons is that a rural spur line will experience 0.02 faults per kilometer per year. [1] For example, a 50km spur line will, on average, experience 1 fault per year.
Fault types can be classified as transient or permanent. A transient fault means that the electricity supply is turned off momentarily and that the fault will be gone when the line is re-energized. A permanent fault infers that the line has experienced permanent damage and the fault cannot be cleared by a momentary interruption to supply. A line crew must physically repair the damage before re-energizing the line. For a rural overhead network, typically 70-80% of faults are of a transient nature. This high proportion of transient faults has implications for optimization of rural network performance.

Rural networks are also characterized by their large geographical size and low customer density. This means that the operating costs to own and run the network are high, especially considering the high fault rates, but that the revenue generated is low. Outages that require line crew attendance incur high operating costs due to the long drive time to find the fault and access the site. In addition, potentially substantial penalties may be incurred from regulators for these long outages. These factors have significant implications on the scale and type of investment that network owners are prepared to make on their rural network. Low cost of purchase, installation and ownership are all key drivers for rural network investment to improve network reliability.

3. Ideal Spur Line Protection Characteristics

As the majority of line length in rural networks is attributed to spur lines rather than the feeder line, this paper will examine the protection options at the spur line level for faults that occur on the spur line. Per Figure 1, this paper will assume the feeder line is protected by a recloser with electronic control.

In investigating the performance of rural spur lines, ten performance criteria have been introduced that, when implemented in a protective device on the spur line, provide the optimal network performance. [2] These ten criteria are listed and explained in Table 1.

Performance Capability	Explanation
Interrupt Fault Current	The rural spur line protective device must be able to interrupt fault currents appropriate for this part of the network. An additional aspect of this is for the device to have adequate protection reach to pick up relatively low level faults.
Only Spur line customers experience an outage	For any fault that occurs on a given spur line, only customers on that spur line should experience any outage, either momentary or sustained.
Transient faults should not cause a sustained outage	If a fault is transient, it should be cleared in a way such that power is automatically restored to the spur line customers after only a momentary outage.
Provide a visual indication of a permanently faulted line	If a line has a permanent fault that has caused the spur line protection to operate, the protective device should provide a clear visual indication to line crews driving by as to which is the faulted spur line.
Record information about fault and line operation history	The rural spur line protective device must record historical information about events that have occurred on the spur line. This event history should include information about when events occurred and in particular details about faults such as phase and magnitude of fault current.
Provide a visible point of isolation	During some network maintenance activities that cannot be carried out live-line, spur lines may need to be electrically isolated and have a visible point of isolation to comply with network safety requirements before work can be commenced.
Improve safety of live line crews	The spur line protective device should be able to improve the safety of live-line crews when working on energized spur lines. This should be achieved by having very fast and sensitive protection to clear faults in the case of accidents.
SCADA integration capability	To facilitate a real smart grid, all protective devices should have the capability of being integrated into the network SCADA system. This provides the following key benefits: • Device status information reported in real time to control center to allow notification of faults and outages. Allows efficient management of line crews during storm events. • Remote switching of devices • Remote reconfiguration of devices • Remote access to event records
Low capital cost of equipment	The purchase price of devices for rural spur line application must be low to provide an attractive return on investment to utilities.
Quick, easy and cheap to install	The installation cost of devices for rural spur line application must be low to provide an attractive return on investment to utilities. This means quick installation times, using live-line techniques with no additional lifting equipment required.

Table 1. Performance Criteria for optimal spur line protection.

4. Evaluation of Spur Line Protection Solutions

Currently, the most common devices used for the specific protection of spur lines are a traditional drop-out fuse or a drop-out sectionalizer. This paper evaluates each of these devices and compares it to a new, intelligent fuse-saving circuit breaker. The authors acknowledge that other devices are also available for spur line protection including the use of reclosers. These have not been included as in most cases the cost justification for use on rural networks is not possible.

Traditional Drop-out Fuse

Most rural medium voltage networks are configured with the primary feeder protected by a circuit breaker or recloser, whilst a fuse protects the spur line (refer Figure 1).

Figure 2. A traditional Drop-out fuse. [3]

When a fault occurs on the spur line the fuse operates to clear the fault. When the fuse protection is graded correctly with the upstream recloser, the recloser will never need to operate on a spur line fault. This means only the customers on the faulted spur line experience an outage. The problem with this configuration is that the fuse blows on all faults, both permanent and transient, causing downstream customers to always experience a sustained outage and always requiring a line crew to replace the fuse incurring substantial operating costs for the network owner. In most cases this sustained outage is unnecessary as the fault is transient.

A fuse that has blown will drop down and provide a visual indication to passing line crews as to the faulted line. When in the dropped down position the fuse provides a genuine electrical isolation due to the large air gap.

A fuse has no electronics or intelligence and therefore no capability to record historical data about fault events or reliability data. Without communication functionality, it cannot communicate device status remotely. It makes no contribution to the formation of an intelligent grid.

When a live-line crew is working downstream of a fuse, the operating time of the fuse is dependent upon the fault level. As such, normal practice is to use the feeder line recloser with a hot line tag setting as the protection for the live-line crew. Even the fastest recloser protection will allow 2-3 cycles of current to flow, which is adequate to cause significant burns to an operator in case of an accident.

Whilst fuses possess a low capital cost, up to 80% of fuses blow unnecessarily. Whilst fuses are quick and easy to install on-site, a line man or crew, in an average rural environment may take hours to travel, patrol the line for potential fault, search for and repair the blown fuse, costing the utility in the order of R10 000 for a single fuse operation. This represents a substantial cost of ownership if a line has frequent faults and is therefore a false economy.

Drop-out Sectionalizer

Drop-out sectionalizers are used in place of the spur line fuse and are partnered with the feeder line recloser. When a fault occurs on the spur line, the drop-out sectionalizer does not have a fault interrupting capability of its own and relies upon the recloser to clear the fault. If the fault is transient then the recloser will clear the fault, however in doing so it will give *all* customers downstream of the recloser a momentary outage, not just those on the faulted spur line. If the fault is permanent, the sectionalizer monitors the fault current and the reclose sequence, and opens during the dead time of one of the reclose operations according to the configuration set. Essentially, the feeder line recloser is used to clear transient faults and the sectionalizer is used to isolate a permanently faulted spur line. Unfortunately, the majority of spur line faults are transient.

Figure 3. A typical drop-out sectionalizer [4]

As the recloser protection settings must take account of the load currents generated from all downstream customers, the pick-up current can be much higher than is ideal for spur line protection where the fault has actually occurred. This means that low level faults at the end of a spur line may not trigger the recloser protection at all. This can result in serious safety events such as pole top fires or downed conductors that are still energised.

A sectionalizer that has operated provides line crews with a visible break at the site of the operation, but without fault interrupting capability, offers no rapid or sensitive fault protection to line crews. Again, the upstream recloser hot line tag must be applied. Therefore drop-out sectionalizers do not improve the safety of line crews.

Furthermore, the sectionalizer has no internal fault memory capable of maintaining a record of outage events. No event log or line history exists to assist the network operator to understand the reason for the outage, nor maintain an accurate record of the length of the outage for performance reporting purposes. It cannot be integrated into a network’s SCADA system and has no capacity for remote control and does not enable operators to transition to an intelligent network.

The purchase price of the sectionalizer is relatively low, and the device itself is simple to install and replace.

Fuse-Saving Circuit Breaker

This newly developed device is a self-powered, electronically controlled, single-phase fault-interrupting device that is installed in series with a fuse (refer Figure 4) to protect the fuse from transient faults. This ‘fuse-saver’ detects, opens and clears a fault in as little as a half-cycle which, for most rural spur line faults, is less time that it takes for the fuse to melt. It then automatically closes after a configurable dead time.

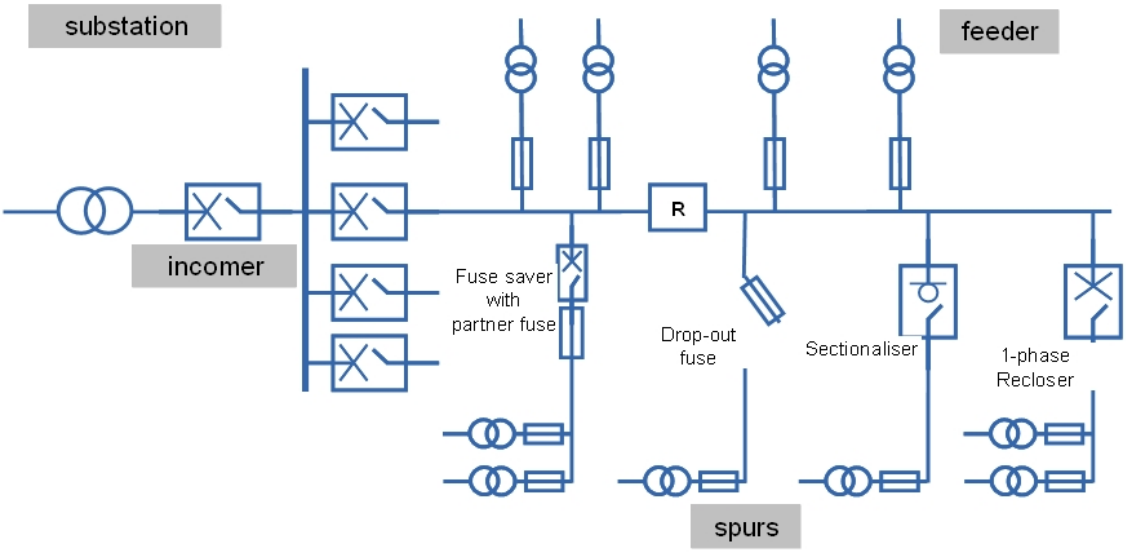

Figure 4. The fuse-saver and fuse partnered on spur line

If the fault was transient, then only the spur line customers have experienced a momentary outage. If the fault is permanent, after closing, the fault current will flow again and the fuse will now operate to clear the fault. The fuse drops down providing a visible flag to line crews of the permanently faulted line and electrical isolation. Again, only the customers on the faulted spur line experience an outage.

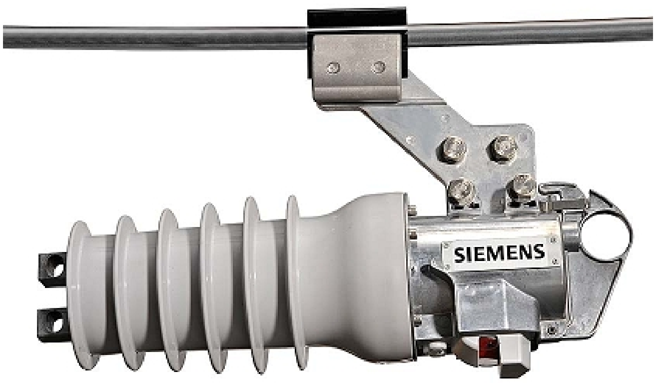

Figure 5. The fuse-saving device

When line crews are working downstream, the device's protection functionality can be changed to a single shot to open mode with instantaneous protection by pulling down the "protection off" lever. This means that all faults will be limited to a half-cycle duration and the consequences of accidents during live-line work are greatly reduced and survival chances increase.

This device has on-board electronics with memory that contain an event history, including information on fault characteristics. A short-range wireless communication module is easily attached to each device allowing connection to a custom PC application. This enables an operator to view live data on the status of each installed device, including the time, type and magnitude of the most recent fault. Event logs from multiple spur line fuse-saving devices can be retrieved and analysed to determine the worst performing spur lines and allowing network owners to take preventative action in a cost effective manner. Furthermore, a utility can gather accurate, reliability data on their network performance for use in regulatory reporting, leading to financial savings.

Using the short-range radios, the devices on multi-phase sites can communicate and work as a team to further improve network performance. Synchronous manual tripping and closing is possible to

avoid ferro-resonance issues. Also, when one phase experiences a permanent fault the devices on the adjacent phases can be instructed to trip and to provide a three-phase lock-out to protect three-phase machinery from damage.
A proprietary, purpose-designed remote control unit is available, enabling this device to then be integrated into a network's SCADA system, providing rapid access to data and remote access to devices from the central control center. This includes receiving fault alerts and gathering reliability data.
Like traditional spur line protection options, this technology has a low capital cost, and is quick and simple to install, saving operational budget. Payback can be achieved in as little as a year, subject to fault frequency and reliability penalty schemes.

5. Comparison of Rural Network Performance

A comparison of the three solutions examined in this paper using the ten network performance criteria listed in section 3 is presented in Table 2.

Performance Criteria	**Fuse**	**Sectionalizer**	**FuseSaver**
Improve operator safety	No	No	Yes
Interrupt fault currents	Yes	No	Yes
Only spur line customers affected by fault	Yes	No	Yes
Transient fault only cause momentary outage	No	Yes	Yes
Point of visible isolation of line	Yes	Yes	Yes
Visible indicator of permanent fault on line	Yes	Yes	Yes
Provides data on fault and line operation	No	No	Yes
Communicate location of fault	No	No	Yes
Event history for the line	No	No	Yes
SCADA integration	No	No	Yes

Table 2. Network performance comparison

6. Conclusion

A comparison of the performance capabilities of the three solutions examined in this paper immediately shows that the fuse-saving device is the only one that meets all of the criteria for the optimal protection of rural spur lines.
Fuses, whilst the lowest cost option, are inadequate as they create a sustained outage for all faults when the majority of rural faults are transient. Drop-out sectionalizers require a much larger customer base to experience an outage to clear a spur line transient fault. Neither a fuse nor a sectionalizer has any smart grid functionality and certainly cannot be integrated into a SCADA system.
This evaluation finds that the new fuse-saving device is the only technology that can improve rural performance and cost, whilst building an intelligent grid for the future. It addresses all of the key performance capabilities required for an achievable, improved rural network performance today and a financially sustainable future.

7. References

[1] Robert E. Goodin, "Distribution reliability using reclosers and sectionalizers", Jan. 1999
[2] Brett Watson, D. Murray, K. O'Hare, "An evaluation of the impact of cost-effective, new fuse-saving circuit breakers on rural network performance", EEA Conference & Exhibition June 2012, Auckland, NZ
[3] http://www.diytrade.com/china/pd/8209383/OUTDOOR_AC_HIGH_VOLTAGE_DROP_OUT_FUSE.html
[4] http://www.akpowersolutions.com/index.php?page=sectionaliser-links