Intelligent application

Applying intelligent equipment to bring increased benefits to power distributors and residential customers

PETR GURYEV, ENRICO RAGAINI – Stockholm Royal Seaport is one of the first large smart grid projects in Sweden. An urban area of three districts, including the port, will be rebuilt based on new smart city criteria. Local generation of renewable energy, life in smart houses and the use of electric vehicles (EV) are only some of modern technologies which will be used for the sustainable city. ABB is working together with Fortum, one of the biggest Nordic heat and electricity production and distribution companies to help redesign the approach to power distribution. Fortum is exploring the different possibilities for this project which now exist because of the smart grid. A typical need in projects such as this is for a cost/benefit analysis, in this case, of smart grid technologies which can be used to improve network reliability and reduce downtime. Such analyses show that the benefits of intelligent equipment in terms of reduced profit losses and penalties justify the capital investment expenditure.

With changes to legislation in Sweden and regulations becoming stricter generally across Europe, distribution companies must now solve outage problems in the distribution networks more quickly. The frequency and length of power interruptions are typically measured using the system average interruption frequency index (SAIFI) and system average interruption duration index (SAIDI) reliability indicators. The fewer and shorter the power interruptions, the lower the indexes are and the less penalties and compensations a distribution company has to pay.

Design criteria for the Stockholm Royal Seaport project include improvements of the power supply quality and reductions in power interruptions. In the development of the project, the following requirements were used:
– Load shedding to avoid blackouts when the power system is in a critical condition
– The possibility to avoid outages due to overload

Title Picture
Artist's impression courtesy of City of Stockholm and Aaro Designsystem

1 Comparison of LV substation solutions

Summary	Traditional design (no supervision, no redundancy)	Breakers/switches with supervision /control	Redundant feeders with advanced selectivity and supervision/control
Simplicity	+	-	-
Initial investment	Very low	Moderate	High
Time for fault identification	Long	Short	Short
Time for power restoration	Very long	Long*	Very short
Remote monitoring	–	+	+
Remote control	–	+	+

* - depends on the configuration of the circuit breaker, use of parallel breaker and type of the outage

Remote monitoring and remote control of equipment brings a significant reduction of outage time in many situations.

- Minimum consequences from short circuit outages
- Minimum cost of ownership (including initial equipment purchase, operation, maintenance and malfunction compensation)
- Short payback period

Improving on the traditional

Traditional low voltage (LV) installation designs have inherent advantages and disadvantages. The traditional design of a medium voltage (MV) and LV transformer station for non-industrial customers is typically based on fuses, which protect each of the outgoing LV feeders, and generally radial feeders are used. The advantages of this design are the low cost and reliable protection from short circuits and overloads. On the other hand, due to a lack of remote supervision and control, manual power restoration is required which can sometimes take a long time. In fact, that a fault has occurred may remain unknown to even the operator for several minutes or even hours.

Alternative design schemes employ electromechanical circuit breakers instead of fuses, which in some cases results in better coordinated protection. Larger stations may use two transformers instead of a single one. All such "traditional" designs can also suffer the consequences of manual fault management and a lack of supervision.

However, traditional designs can be improved by modern technologies, particularly in the field of electronics and communication. In smart grid applications, such as at the Stockholm Royal Seaport, LV network design employs apparatus and switchgear with remote monitoring and remote control. In addition, power system design is based on redundant feeders with advanced protection coordination.

Remote monitoring and remote control of equipment brings a significant reduction of outage time in many situations. In case of a short circuit, information about the fault is immediately transmitted to the operator, who can then take action. Transmitted information can include data about fault currents and voltages, which are useful to locate the fault. In addition, remote supervision allows optimized operation of the power system. In case of overload or in a situation close to a blackout, when power consumption becomes too high, some loads can be disconnected. Power produced by renewable sources, such as solar panels, can be monitored in real-time.

Remote supervision allows optimized operation of the power system.

A wide range of ABB products are available for the remote control and supervision of LV networks, such as power meters that can communicate, which can be installed together with electromechanical breakers or fuse switches. Such a solution is especially good for retrofitting existing substations. One innovative solution, which offers the maximum compactness, is the circuit breaker with integrated power measurement unit. The

2 ABB's Tmax XT4, designed for smart grid applications

unit includes protection, measurement and communication all in a single item.

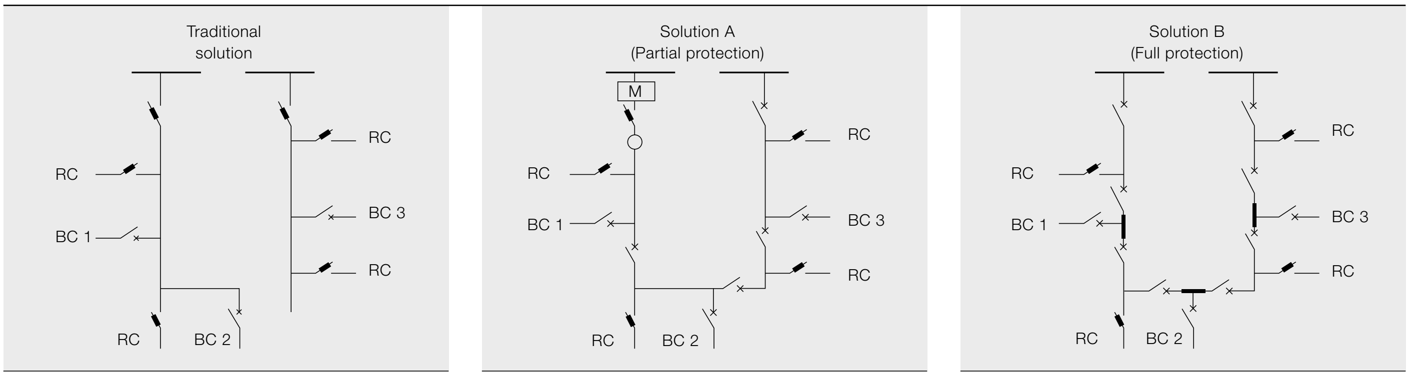
Remote monitoring can reduce detection time and time to power restoration. However, in case of a short circuit power may not be restored until a repair crew has identified and removed the cause of the fault. In a traditional design, radial feeders offer no redundant path for power: if a fault occurs in one portion of the feeder and is then cleared by the relevant protection device, all of the downstream part of the feeder is disconnected from the power, potentially blacking out several customers. Since it is now also required that the number of customers affected by the fault be minimized, a specific design strategy based on new technologies such as redundant feeders and advanced circuit breaker protection can be applied to achieve this. Significant improvements can be achieved if redundant feeders are used in the design of the LV network because two alternative paths become available to connect any given customer to the power system. Plus, each feeder is split into sections, separated by breakers or switches. Only the sections where the fault occurs will be disconnected from the power. Together with the advanced selectivity schemes implemented by intelligent circuit breakers, this design makes it possible to restore power in a very short space of time to all the loads which are not directly connected to the faulty section of the feeder → 1.

Redundant feeders are normally used in MV distribution, where feeders designed as rings that can be fed from both ends are common. Each feeder is split into segments, separated by circuit breakers or switch-disconnectors. The feeder can be operated as a closed loop, ie, with all breakers closed, or as an open loop ie, with one of the breakers open, which actually creates two radial feeders, each fed by one of the end stations. When a short circuit is detected, depending on the fault location,only a defined subset of circuit breakers open, so that the faulty section of the feeder is disconnected from the power system, while keeping all the other loads connected.

Closed loop operation provides the maximum operational advantage in terms of reduced outage time. It makes it possible to automatically identify and disconnect the faulty section of the feeder, without any power interruption

Significant improvements can be achieved if redundant feeders are used in the design of the LV network.

3 Traditional and suggested designs for the LV substation and distribution network



4 Share of outage consequences in comparative scenarios

Outage type	Expenses in case of outage %	Traditional solution	Solution A	Solution B
Overload	Compensation to residential customers	50 %	0 %	0 %
	Compensation to business customers	50 %	0 %	0 %
	Repair crew work	100%	0 %	0 %
Short circuit	Compensation to residential customers	50 %	33 %	33 %
	Compensation to business customers	50 %	33 %	0 %
	Repair crew work	100%	100%	100%

Breakers are able to identify where a fault has occurred and disconnect only that specific part of the network.

to all the remaining sections of the feeder. This requires protection elements with directional sensing, which is becoming more and more common in MV installations.

In order to gain similar advantages for LV feeders, circuit breakers with directional protection and logic interlocking can be used. Each breaker recognizes the direction of the fault current and sends a trip block signal, ie, a signal that prevents opening, to the upstream breaker. The blocking signal is then propagated from one breaker to the next, all the way up to the feeding station. The breaker directly facing the fault receives no blocking signal, hence it immediately clears the fault. If the feeder is powered from both ends, the same occurs in both directions. The final result is that the two breakers immediately facing the fault open, while all the other breakers remain closed, maintaining power to all loads not directly affected by the fault. LV breakers with directional protection and logic interlocking are technology that is exclusive to ABB. Originally designed for critical power applications such as marine installations, this technology is now finding new applications as a building block of smart grids. Integrated directional protection is available in all of the ABB LV air circuit breakers, such as the Emax E1 to E6 and X1, with a minimum rated current of 630A [1].

The most critical requirement to reduce unnecessary blackouts and minimize the consequences of any faults, is selectivity. In other words, the ability of breakers to identify where a fault has occurred and disconnect only that specific part of the network. The is a very challenging requirement, particularly for smaller feeders, where molded case circuit breakers are typically preferred, due to their compact size , reduced interruption time, and more efficient limitation of fault energy. Until recently, no zone selectivity system existed for such devices. In order to prevent breaker trips, fault detection and signal processing should take place in less than 1 ms, which was not feasible for existing embedded protection units.

A recent major breakthrough in LV technology was the development by ABB of a dedicated protection system with fast interlocking, which allows breakers to automatically identify and disconnect the faulty section of the feeder in less than 5 ms. This protection, called early fault detection protection (EFDP), is available on Tmax moulded case circuit breakers T4 to T6, rated 250A to 1000A → 2. When EFDP breakers are used, zone selectivity is ensured. Each breaker which detects a short circuit sends a trip block signal to the upstream ones, ensuring that only the breaker directly facing the fault will open. In turn this reduces, as much as possible, the portion of the network which is disconnected from the power system.

Business case and payback time

During the pre-study phase of the Stockholm Royal Seaport project, ABB developed a decision tree of several business case scenarios for feeder automation solutions based on customer profiles and the functionality required.

To illustrate one of the business case scenarios, show its benefits and estimate the payback period, the following assumptions were made about outage related expenses. These expenses can be partially or fully avoided:

Compensation to business customers

Assuming that a business customer is either a corner shop or a small restaurant the normal working day of the business customer will be at least 12 hours. This means that it can have a maximum amount of 12 hours power loss a day. The compensation to business customers will be among the biggest of all the potential expenses, which can be partially or fully avoided by the solution.

> If the outage can be avoided, repair crew work will not be necessary.

Compensation to residential customers

Assuming that there will be residential customers that will require compensation according to the legislation of Sweden, this applies if the outage is longer than 12 hours. The value of the compensation for residential customers is fixed and moderate in the scope of the overall avoidable expenses.

Maintenance crew work

If the outage can be avoided, repair crew work will not be necessary. The value of the repair crew work is moderate, but accumulates for every hour of the outage length and is the second biggest cost in the range of overall avoidable expenses.

Advanced feeder automation for LV substation and distribution network

To meet the requirements set by the project, two possible designs for the LV substation and distribution network were suggested → 3. The suggested designs have the lowest possible price and meet the set requirements.

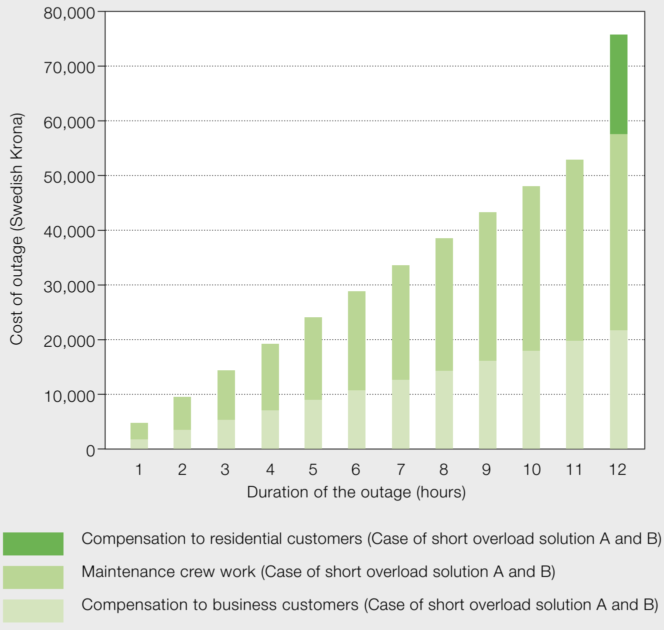
The traditional scenario is used here as a comparison against the advanced feeder automation solutions A and B. Three business customers are shown in the traditional scenario, which are located in two non-redundant feeders. A distribution company is not required to compensate for outages caused by customers, but has to compensate if it was a result of a damaged cable supplying the customer. If a short circuit or overload happens in any section of any feeder, the average compensation a distribution company will pay is 50 percent of overall compensation if all three business customers lose power.

Solution A illustrates the design of the redundant feeder, with junction boxes used for the connection of redundant feeder sections. This solution gives full protection from overload and partial protection to business and residential customers from short circuits, meaning that outages can happen in one of three sections of the redundant feeder and only residential and business customers in this section will lose power. Thus the average compensation paid to both residential and business customers will be only 33 percent of the potential total compensation if all customers had lost power.

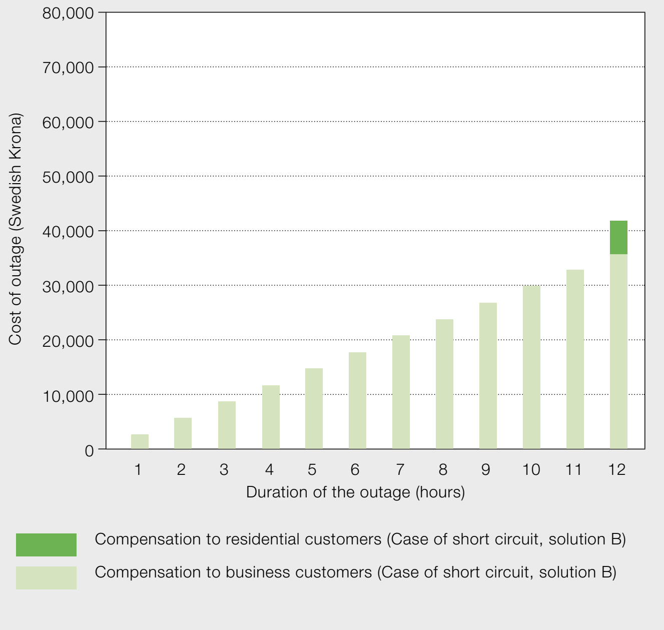
Solution B illustrates the design where business customers are connected to the redundant feeder by means of small kiosks with bus bars. Two infeed circuit breakers are used in each kiosk, allowing each busbar to be supplied in both directions. In addition, intelligent breakers with directional protection are used all the way to the feeder station. This solution also gives full protection from overload, partial protection from short circuits to residential customers, and full protection to business customers. The possibility of a short circuit on the busbars inside the kiosk is

> Breakers using EFDP send a trip block signal to the upstream ones, ensuring that only the breaker directly facing the fault will open.

5 Cumulative expenses which can be avoided if outage lasts from 1 to 12 hours, when applying solution A or B



6 Cumulative expenses, which can be avoided if outage lasts from 1 to 12 hours, when applying solution B



Selection of the appropriate solution is based on the likelihood of the different kinds of faults, and on the amount of compensation to be paid in each case.

generally very low. If a short circuit happens in one of three sections inside of redundant feeder, the distribution company will pay to residential customers an average of 33 percent of the potential total compensation if all customers had lost power and no compensation at all would be payable to business customers.

A summary of the outages and compensation paid by a distribution company applying different solutions are shown in figure → 4.

Selection of solution A or B for a specific installation is based on the likelihood of the different kind of faults (overloads versus short circuit), and on the amount of compensation to be paid in each case. In case of a short circuit, solution A will result in much longer outage times for business customers on average, compared to solution B, so solution B may be preferable. While both solutions are substantially equivalent for overloads. If the network has a low probability of short circuit because, for example, the cables are installed in conduits with physical protection, and probability of overloads is high, solution A can be advised. These factors have to be weighed against the cost of the equipment, which is lower for solution A.

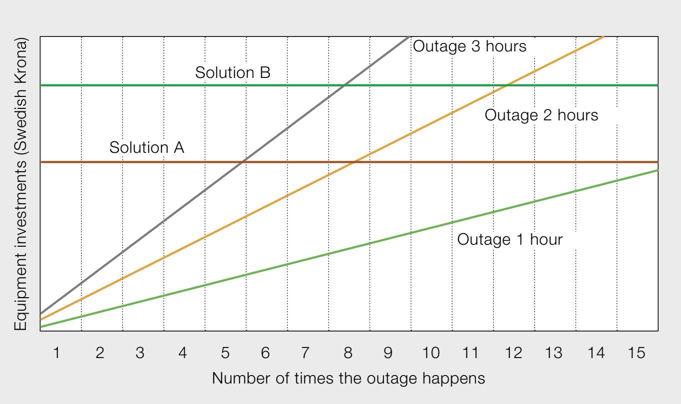
According to the business case assumptions, a summary of cumulative expenses which a distribution company can avoid in case of overload, applying solutions A or B in comparison to the traditional solution, are shown figure → 5.

Cumulatively avoidable distribution company expenses that can be gained from applying solution B, in the case of a short circuit, when compared against the traditional scenario, are shown in figure → 6. If the network has no business customers, or business customers who are only due small compensation in case of power loss, the recommendation is to apply solution A.

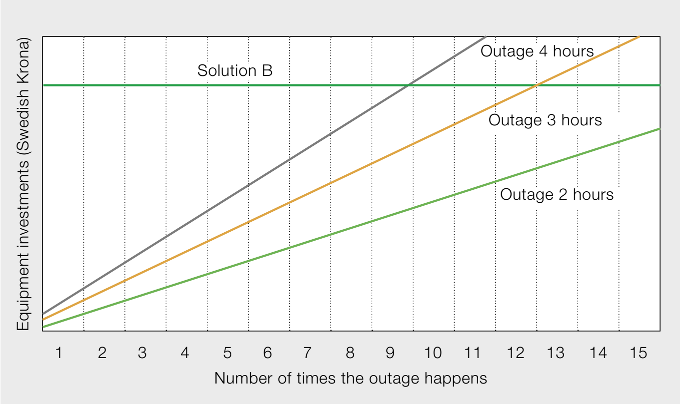
Payback period

To assess the payback period of the equipment it is important to bear in mind that the business case is based on the risks factors of if and how often a certain type of outage can happen. For existing networks with low power quality indexes, a historical record of outage types and lengths can be used to understand the expected payback period. In this case, by applying solution A or B, a distribution company will have as many outages as in the past but will reduce the financial consequences. The overall payback period of the equipment depends on frequency and length of the outages, which occur in a particular redundant feeder in case of overload → 7. The payback period for applying just solution B in case of short circuit is different when compared

7 Payback period of solutions A and B by avoiding overloads of different lengths and frequency



8 Payback period of solution B by avoiding short circuits of different lengths and frequency



to evaluating solutions A and B together because of certain unavoidable losses → 8. The illustrated payback periods depend on the number and type of customers located on the redundant feeder and price of the equipment. The assumptions made about customers are considered to be typical for the Swedish market. The assumptions also use list prices for the equipment which means that the overall payback period could decrease significantly depending on any discount that a customer negotiates when purchasing the equipment. A decision to apply advanced feeder automation solution A or B is always based on an outage risk assessment. However, when it is appropriate to apply solution A or B, the offered solution brings "insurance" to the distribution company, that in case of any outage, compensation, penalties or expenses will be either avoided or significantly reduced.

Applying intelligent technology in the scenarios considered for the Stockholm Royal Seaport project brings savings and reliability advantages for the power distributor.

The suggested advanced feeder automation solutions have a relatively short payback period and can significantly increase the power quality indexes of existing LV distribution networks. Such solutions fit very well to the needs of smart grids, allowing remote monitoring and control together with high reliability and minimum consequences from outages. This type of solution is recommended for grids with a high probability of overloading and high compensation costs to business customers in case of outages. The equipment has a life time of 20 years, which makes it a worthwhile and significant improvement for LV networks, and with a relatively fast payback period which is not typical for this type of power distribution equipment. Applying intelligent technology in the scenarios considered for the Stockholm Royal Seaport project brings savings and reliability advantages for the power distributor, but of course enables residential customers to go about their lives and businesses with the minimum of power supply disruption.

Petr Guryev
ABB Global Trainee Program
Zürich, Switzerland
petr.guryev@ch.abb.com

Enrico Ragaini
ABB Low Voltage Products
Bergamo, Italy
enrico.ragaini@it.abb.com

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[1] Viaro, F. Breaking News: User-Friendly products that satisfy new customer requirements and reduce environmental impact. *ABB Review* 3/2004, 27–31.

Further reading

More information on EFDP protections is available in ABB Technical Application Paper, "Low voltage selectivity with ABB circuit-breakers", document number 1SDC007100G0204.