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Multi-Feeder Protection Methodology and New Product Design for Distribution Substations

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SUMMARY

The power system is changing rapidly by introduction of new electrical power generation sources, technologies, ageing of the existing power transmission-Distribution infrastructure and new dynamics in the power grid. This will lead us to take advantage of new developments in hardware and software technology such as processors and Analog to Digital converters as well as utilization of new standards and digital frameworks such as IEC 61850 to equip ourselves for facing the new challenges.

Some of these challenges are as follows:

1. Ageing power grid infrastructure and need for upgrading the existing components/assets.
2. Increase in cost of ownership.
3. Need for resiliency in the network with respect to climate change, electric vehicles, distributed generation and unpredictable nature of loads.
4. Safety aspects for the personnel.
5. Operation and Maintenance challenges.
6. Digitalization of the power system and data access through variety of tools.
7. More accuracy, selectivity and grading of the protection system.

All the above requirements and the fact that protection and control technology require a paradigm shift lead us to investigate more centralized and accurate way of fault clearing and transient detection system. Hence moving towards centralized protection and control system for some special applications seems to be inevitable.

This paper aims to discuss a joint project between EPCOR and Siemens in which a radial network where a combination of short underground cables and overhead lines are used in distribution substation outgoing feeders. It happens quite often that faults on the overhead lines or cables occurring in proximity of the substation take more than 400ms to be cleared due to coordination requirements when conventional Time OverCurrent (TOC) protection is

utilized. Also, sensitivity of detection of fallen conductor which is likely to be left undetected added up to the necessity of looking into alternative/complementing solutions. The constant reach and time delay which is directly linked to distance from the faulty section of the line and need for instantaneous tripping led to the implementation of impedance protection in a single protection device. In this methodology and new product development, a combination of single zone and alarming zone will be used for sections of the feeder. The impedance protection will cover up to 90% of the radial feeders and avoid hazards of undetected ground faults and high-power arc faults happening in cable vaults in downtown area which can potentially cause hazards in some highly populated areas. Also, simulation results, the implemented settings in this project and product development challenges will be discussed. Other important challenges such as the failsafe operation, redundant communication of IEDs, protection data interface, integration into a Supervisory Control and Data Acquisition (SCADA) system and CAPEX vs. OPEX analysis will be presented as part of this paper.
This project led to development of additional functions and features into existing Siemens product platform which will be contributing to the safety, resiliency and accuracy of the protection schemes in different voltage levels and applications.

KEYWORDS

Testing, methodology, Simulation, Intelligent Electronic Device (IED), Grading, Coordination, Supervisory Control and Data Acquisition (SCADA), Smart Grid, Protection Data Interface, Capital Expenditure (CAPEX), Operating Expenditure (OPEX), Time Overcurrent Protection (TOC)

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Introduction

EPCOR Utilities Inc owns and operates the Transmission and Distribution facilities for the city of Edmonton. Urban constraints combined with a strong Transmission system surrounding the city has led to system conditions that lead to high fault levels with potentially large variances depending on system configuration.

Feeders in EPCOR's system typically consist of an "express cable" portion leaving the substation that can in some circumstances be several kilometers long which branches off into either an Aerial/Underground mixture or purely underground network of cables. Due to the high fault levels on the express cable, fast fault clearing times are of the utmost importance in order to mitigate the damage to the public and assets that may happen when manhole faults occur.

Due to the varying source impedances, the 50 element of the feeder protection must be set high in order to coordinate with downstream protective devices. This means, when the source impedance is higher, a large portion of the express cable does not have high speed protection. With DERs on the horizon, this situation could get worse. One solution to this problem for EPCOR's protection and control group, has been to start introducing impedance protection onto feeders. In order to reduce costs, EPCOR protection and control is looking to utilize single multifunction relays to cover this function and others into a single box.

Challenges of Urban Utilities

The consistent changes in the load and generation profile leads all utilities to some paradigm shift in their protection and control schemes. Some aspects of such shift can be highlighted as follows:

- With respect to higher penetration of Distributed Energy Resources (DERs) and introduction of more power electronics into the distribution network, varying source impedance has become an inevitable effect on the network which makes utilization of traditional Overcurrent element (ANSI 50) less effective and introduction of some additional protection elements more effective. Figure 1 depicts the challenge due to the large variation in fault levels and use of different current based protection equipment such as overcurrent relays and fuses.
- Most of the distribution feeders are long radial networks with a combination of different conductors such as overhead line and cables. High fault levels near the substation and coordination of the standard ANSI 50 element seems to be a challenge in terms of delayed fault clearing time

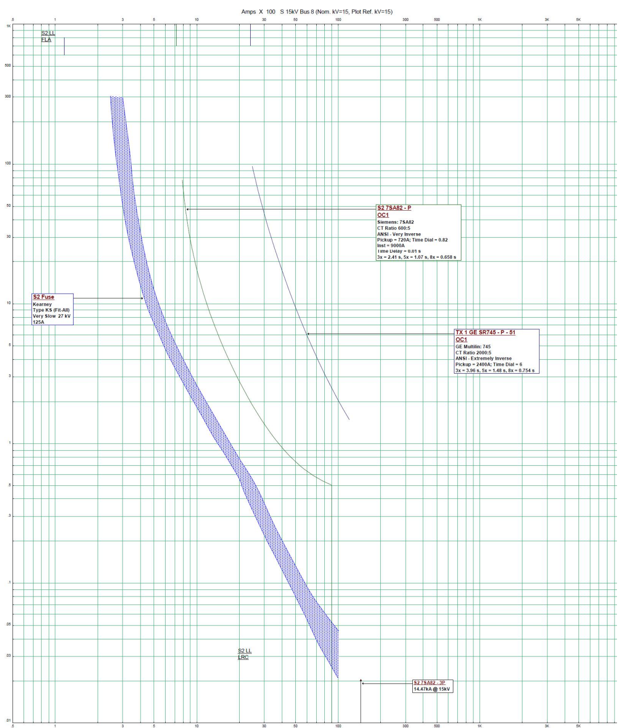


Figure 1: Time Current Curve (TCC)

- Resiliency of the protection system and requirement for backup protection will have a substantial impact on the availability of the power. For example, in case of failure of a feeder protection relay with the standard ANSI 50 protection, the substation bus will be lost. This leads to requirement for some backup planning for feeder protection specially for substations with critical feeders. Also, it is important to keep the cost associated with this and minimize it in a fashion not to impact the functionality.
- CAPEX and OPEX management including training and spare parts management as well as engineering/testing efforts becomes important considering today's economic changes and market dynamics. Considering the early implementation of this solution, detailed OPEX data is not available however, based on the simulation and projection of numbers, we conducted a CAPEX/OPEX analysis and the result was approximately 30% reduction for CAPEX and OPEX combined. This adds up to the viability of the solution on top of its technical benefits.

Methodology

<u>The traditional approach:</u> In this methodology, ETAP modelling has been used to facilitate the setting calculations. Based on the input on the primary equipment, system configuration (SLD) and protection data, the simulation was conducted by EPCOR. In such configuration, the high voltage side of the transformer is not protected by a protection relay. Upstream feeder is protected using fuses and feeder Overcurrent protection at the upstream substation side. The fuse is sensitive for phase fault current higher than 5kA, however it is not sensitive for ground faults happened in low voltage winding of the transformer.

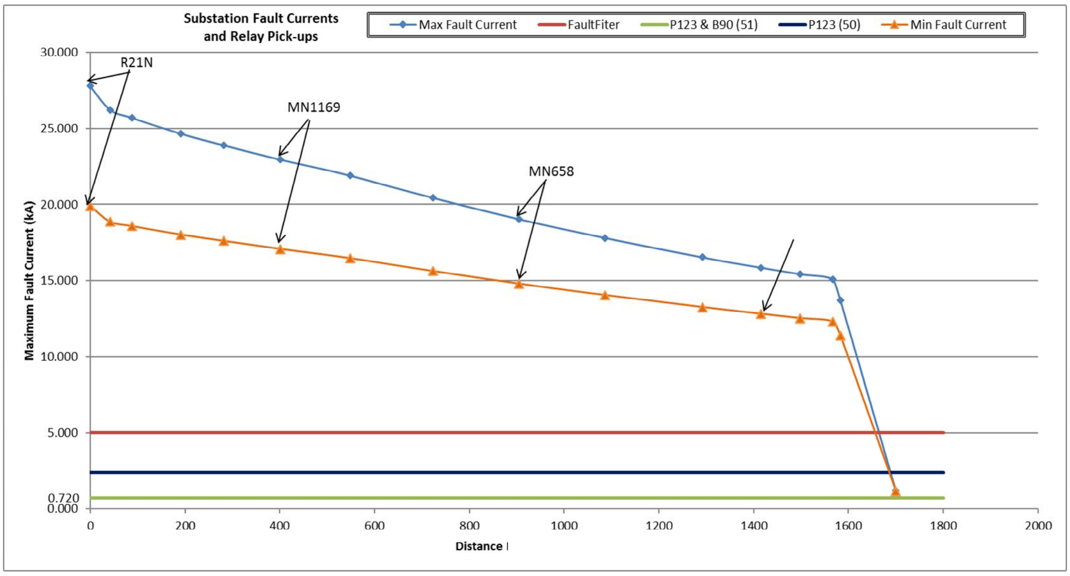


Figure 2: Substation Maximum Fault Current (Radial Feeders)

In the traditional approach, Substation relays are used as a backup for fuse protection. The relays are more accurate and cover the fuse protecting zone and go beyond the distribution transformer at the low voltage side. With reference to figure 2, all protection relays will detect faults in the transformer zone and upstream and clear all faults within minimum 5 cycles. Although the coordination between the relays/fuses downstream seem to be accurate and a workable solution, the high fault current close to the substation makes the system prone to high energy arc flash faults closer to the substation. In this philosophy, ground faults on the LV side of network transformer will remain undetected by the relay.
Additionally, an accurate coordination between fuses and overcurrent relay is not achievable.

Figure 3 explains the coordination requirements and delay in fault clearing.

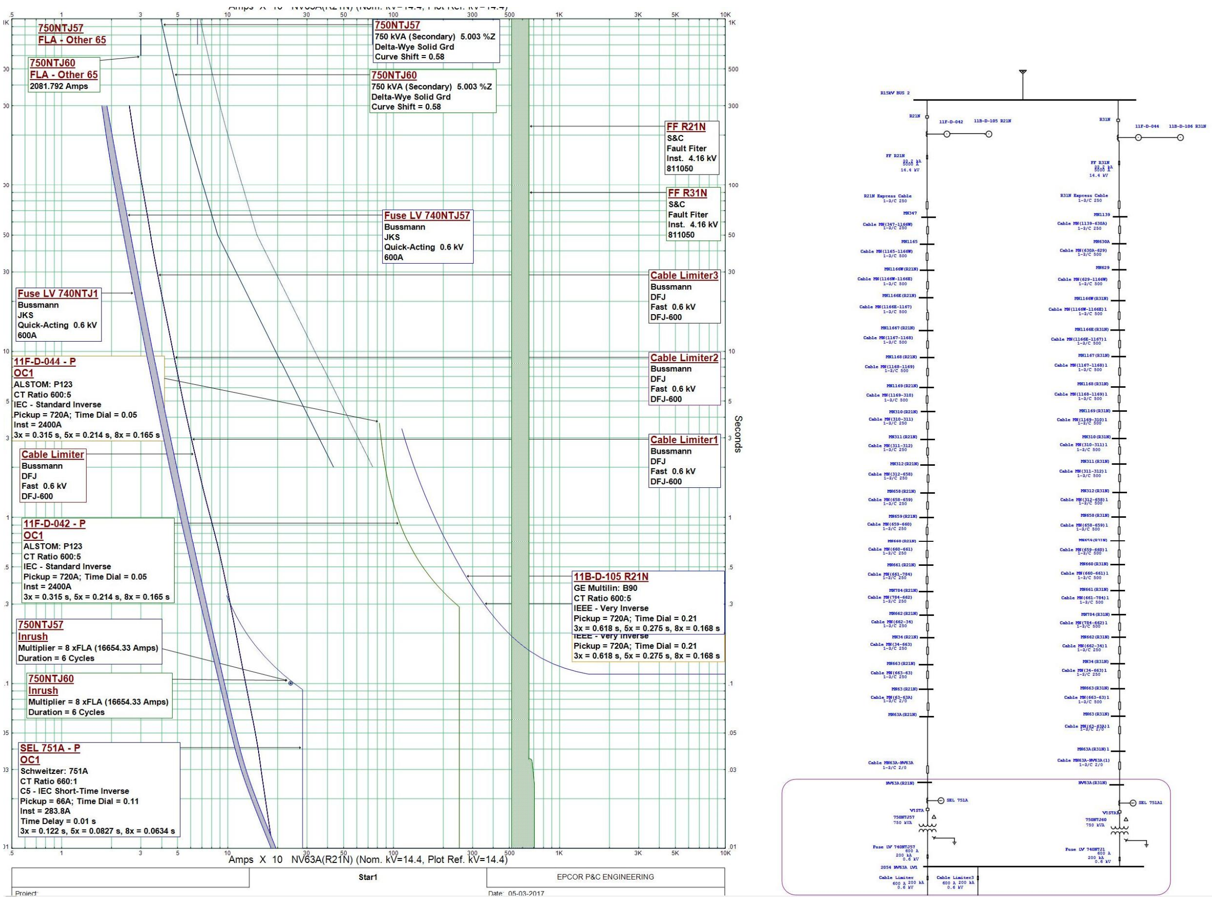


Figure 3: example of the overcurrent characteristics used

New Philosophy: In this method, addition of a simple impedance protection will rectify deficiencies of implementation of 50/51 only protection scheme.

In this method we used 7SS85 multifunction bus differential, feeder overcurrent and impedance protection device. The simulation was done using an OMICRON relay simulation module for comparison of tripping times between 50/51 and 21 function for a typical substation illustrated in Figure 3. Phase to phase faults and phase to ground faults were considered as two possible scenarios. Figure 4 and 5 illustrate the comparison of fault clearance time for the same feeder in the phase to ground fault (A-N) scenario using 50/51 vs 21 elements respectively. Also, Figure 6 and 7 illustrate the same comparison in phase fault scenario (A-B-C). The X-Y axis shows the infeed and

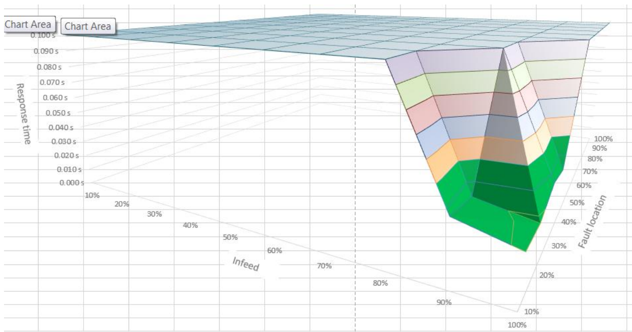


Figure 4: A-N Fault with 50/51 Protection Only

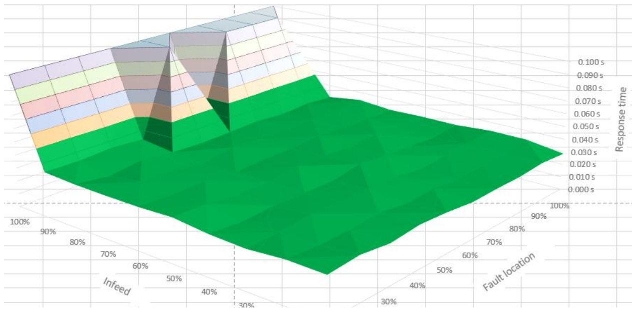


Figure 5: A-N Fault with 21 Protection Only

fault location and the Z axis shows the fault clearance time which is between 0 to 100ms with 10ms increments. The desired tripping time is less than 50ms which is highlighted in green in figures 4 to 6. In each fault simulation, using of impedance protection element led to significant improvement in fault clearance time. Observation was made that use of a single zone impedance protection can enhance the selectivity and fault clearing time. This resulted in thinking towards use of a simpler impedance protection element as an integral part of a multifunction relay such as transformer differential protection relay (7UT87) and bus differential protection (7SS85). The initial pilot started by use of impedance protection element of 7UT87 which led to the accuracy of 100% within 90% of the express cable for detection and clearing of faults. After successful pilot, single zone impedance protection was developed within 7SS85 bus differential relay due to its capability of handling of multiple analogue inputs and high performance of the CPU. Figure 8 provides additional information on the configuration scheme developed in DIGSI 5 relay setting tool. In order to be able to assign the combination of feeder and busbar differential protection in one device additional development on 7SS85 platform was performed. The new firmware contained the additional function groups and capability to assign the impedance protection to all feeders using the modified library of the relay in DIGSI 5 tool.

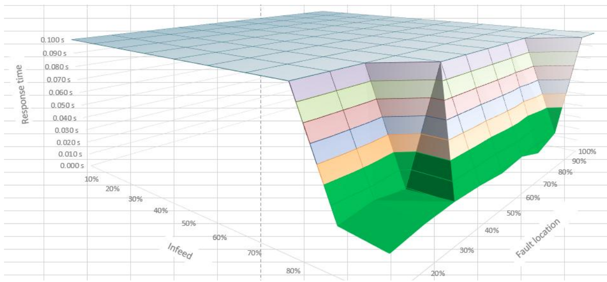


Figure 6: A-B-C Fault with 50/51 Protection Only

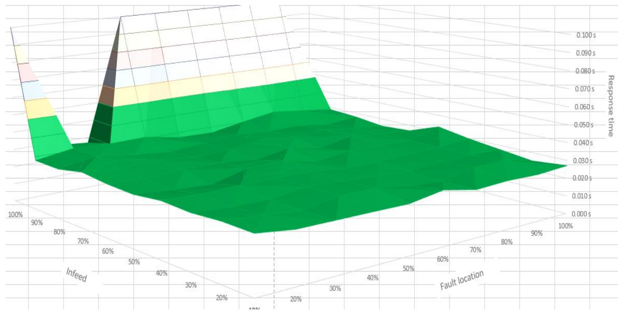


Figure 7: A-B-C Fault with 21 Protection Only

Busbars and transformers as important parts of the distribution system require their protection and use of the same multifunction relay to accommodate impedance element would certainly add more value for the entire engineering, operation and maintenance tasks. Additionally, this would eliminate the use of a fully online distance relay which is in use at EPCOR network. This elimination saves cost for the utilities due to elimination of need for a fully online distance protection relay which is not necessary for this application. Hence, 7SS85 platform was utilized for this development due to the CPU and memory capacity as well as capability to accommodate multiple analogue inputs.

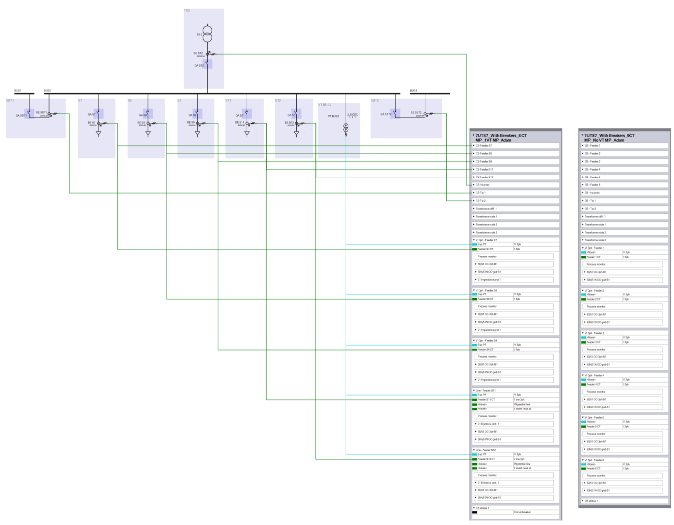


Figure 8: DIGSI 5 configuration of the Relay and functions assignent

Development Challenges

After solution optimization and consideration of the best practice exercises, the decision was made to consider the variants of the device which fits into most distribution substations topologies. Figure 9 depicts the initial function group assignment and prototyping. The following minimum requirements were defined for implementation of impedance protection within 7SS85 platform:

- Busbar differential protection 87B for up to 10 feeders.
- Overcurrent Protection 50(N)/51(N) for up to 6 feeders
- Earth fault protection 50EF for up to 6 feeders
- Impedance protection 21T for up 6 feeders.

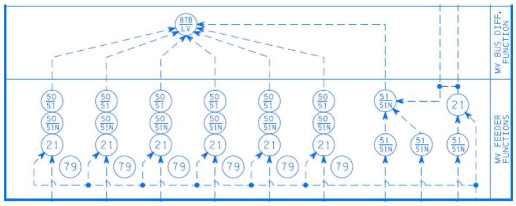
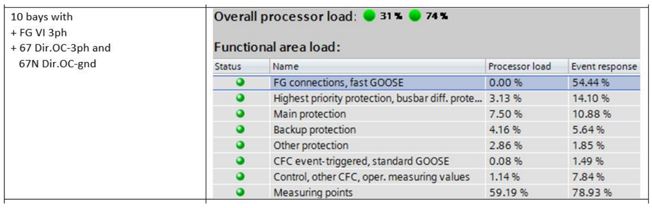


Figure 9: Function Group Scheme

In addition to the protection functions, Electromagnetic Compatibility (EMC), Environmental aspects, Mechanical Requirements, Cyber Security and mandatory certification such as UL/cUL certification for any product development had to be considered. This was a key factor for use of an existing powerful platform and made the development more efficient from time and cost point of view.
In summer 2018 Product Lifecycle Management and development department at Siemens Headquarters got involved and development began. Considering the time constraints and use of existing platform brought the following immediate challenges forward which were tested and rectified during development and testing:

- Available maximum CPU performance and memory capacity: Addition of each protection function to the relay increases the CPU load specially for Impedance Protection functions which requires the CPU to perform some extra arithmetic functions and derive the impedance and characteristics. Also, the added protection functions require additional memory capacity. In this case both Dynamic RAM for all variables during runtime and Static RAM for necessary static settings are necessary.



10 bays with
+ FG VI 3ph
+ 67 Dir.OC-3ph and
67N Dir.OC-gnd

Overall processor load: 31 % 74 %

Functional area load:

Status	Name	Processor load	Event response
	FG connections, fast GOOSE	0.00 %	54.44 %
	Highest priority protection, busbar diff. prote...	3.13 %	14.10 %
	Main protection	7.50 %	10.88 %
	Backup protection	4.16 %	5.64 %
	Other protection	2.86 %	1.85 %
	CFC event-triggered, standard GOOSE	0.08 %	1.49 %
	Control, other CFC, oper. measuring values	1.14 %	7.84 %
	Measuring points	59.19 %	78.93 %

Figure 10: Hardware performance and Load Modeling Tool

- Analogue and Digital Inputs/Outputs: In order to protect and control multiple feeders with various protection functions, multiple analogue current and voltage inputs and binary signals are required. This makes use of a modular and scalable platform with the capability of expansions inevitable.
- Engineering for multi-feeder protection / centralized protection: Due to complexity of the design and multi-function and multi-feeder protection application, a relatively user-friendly, flexible and intuitive relay setting software is required. This makes the system design, configuration and function assignments more efficient. Also, utilization of IEC 61850 data modelling helps utilities to standardize the approach. Figure 10 provides an example of the resource consumption and performance testing of the 7SS85 platform.

Although 7SS85 platform offers busbar differential and feeder protection as well as breaker failure function for the maximum of 20 feeders, the addition of Impedance protection for multiple feeders posed a critical challenge to the development process due to its heavy

algorithm and extensive relay resource consumption. Soon it was realized that the same number of feeders cannot be protected if the combination of Overcurrent, busbar differential and impedance protection are implemented; hence the number of bays was reduced to 10 in case impedance protection is utilized. This challenging optimization task was done by testing and considering all other essential backup functions such as supervision functions, operational values, HMI, communications etc. It must be pointed out that the number of Impedance Protection functions on the relay has an impact on the selection of number of feeders. At this stage the VI functions are limited to the maximum of 10; however, reduction of VI functions to 8 increases the capacity of the relay to protect a maximum of 13 bays.
The allowed combinations are monitored by the so called "load model" application in the SIPROTEC5 system for the user.

Conclusion:

The use of this method provides multiple benefits for power transmission and distribution owners and operators. Some highlighted benefits are listed below:

- Cost effective solution; elimination of need for additional protection relay. One-Box solution reduces both hardware and operational costs.
- Provision of redundancy in distribution feeder protection without need for additional hardware.
- Redundancy of the One-Box solution can be achieved by use of protection data interface on each relay.
- Use of an existing high capacity hardware platform (e.g. SIP5 7UT87 or 7SS85) for the extra development reduces the development costs and complexity.
- Future proof solution; Having all these elements in one box allows for potential consolidation of elements into a single box. This aspect enhances the safety-by-design and makes the solutions ready for IoT platforms.
- Integration to the SCADA system or any other control centre will require less hardware and effort and use of IEC 61850 data modelling will create some templates which makes the entire engineering, documentation and troubleshooting efforts extremely efficient.

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