DEMONSTRATION OF ADAPTIVE OVERCURRENT PROTECTION USING IEC 61850 COMMUNICATIONS

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ABSTRACT

This paper contains a description of an adaptive protection scheme that has been implemented and demonstrated in a hardware in the loop simulation environment using commercially available protection hardware and IEC 61850 communications. The implementation is based on an actual 11kV system which includes distributed generation and network automation.

IEC 61850 communications offers several benefits for the implementation of adaptive protection, but also presents some limitations which are discussed in the paper. An alternative approach to overcome a number of the limitations is also presented.

INTRODUCTION

Following privatisation and re-structuring of the UK electricity supply industry in 1990 [1] electricity distribution networks have changed from being passive to active in nature, with an increasing penetration of generation connected to the distribution network. Furthermore, utilities have introduced automation schemes in response to regulatory system performance targets, to automatically re-energise parts of a circuit that are unaffected by an initial fault.

The presence of distributed generation (DG) and the operation of automation schemes affect both fault levels and fault current paths, and have been demonstrated to affect the operation of protection systems. The authors of [2-6] showed that DG affects the sensitivity and the operating time of overcurrent relays (OCRs), while the authors of [7] proved that changes in network topology compromise grading between OCRs.

Another potential threat to the operation of protection systems is islanded operation. At present, islanded operation is normally not permitted, but it may become desirable as DG penetration increases in the future, making sustained islanded operation viable. The impact of islanded operation was analysed in [8, 9], where the authors assessed the amount of fault level reduction during islanded operation and proved that it increases operating times and can cause non-operation of OCRs.

To overcome the problems caused by the growth of DG, especially in weak rural networks, and the introduction of automation, it is required to change the protection grading practice. Protection systems should adapt to changes in the substation or power system configuration and should recognise the connection status of DG, whilst maintaining optimum clearance times in the interests of security of supply.

Adaptive protection, which was initially developed to solve distance protection problems [10], has since been proposed by several researchers to address other protection problems. For example, the authors of [9, 11] have proposed an adaptive overcurrent protection scheme with two setting groups – one for grid connected, and one for islanded mode – and analysed how it may improve the performance of the protection system. The authors of [12] have developed an adaptive protection system for low voltage networks using two circuit breakers (CBs) equipped with ABB protection relays and an ABB Remote Terminal Unit (RTU) using Modbus communications.

This paper tackles the problem of how to implement and test adaptive protection for distribution networks. In particular, the practical implementation of an adaptive protection system using commercially available, IEC 61850-compliant protection hardware (using equipment from a variety of vendors) is presented and described.

The adaptive protection system has been implemented in a Hardware In the Loop (HIL) simulation environment, with a section of the 11kV network of the Power Networks Demonstration Centre (PNDC) [13] at the University of Strathclyde used as the basis for the simulation. This proves the concept, which will subsequently be implemented using a Power Hardware In the Loop (PHIL) demonstration at the PNDC.

The remainder of the paper is organised as follows: first, the section of the PNDC network that has been used for this work is presented; second, the HIL simulation environment and the implementation of the adaptive protection system are described; finally, the advantages and limitations of using IEC 61850 for implementing adaptive protection are discussed.

TEST CASE NETWORK

The power system model used in this investigation, comprises two 11kV feeders protected by Auto-Recloser CBs (AR 1 and AR 2) and Pole Mounted Auto Reclosers (PMAR 1 and PMAR 2), as shown in Figure 1.

The network topology is radial and may be modified by shifting the Normally Open Point (NOP), i.e., by changing the position of the network switches. In Figure 1, Switch 2 is the NOP.

Two DG units are connected to the 11kV network through step up transformers. Interface protection relays are installed at CB A and CB B, which provide overcurrent and Loss Of Mains (LOM) protection in accordance with G59/2 [14].

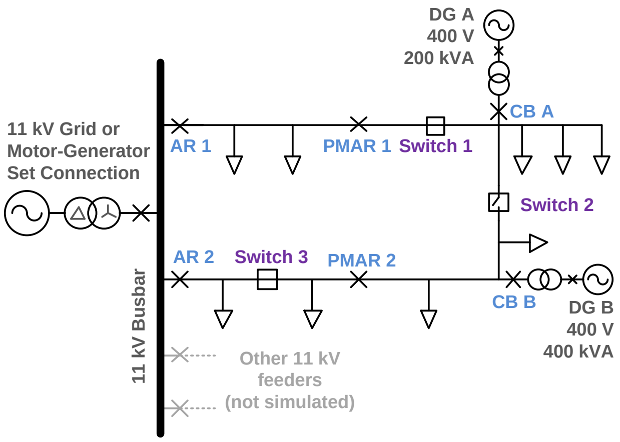

Figure 1: PNDC Network Schematic

Phase and earth faults can be applied at various positions in the network using several values of fault resistance. DG units can be connected or disconnected and the network topology can be changed by shifting the NOP, which changes the fault current magnitude and/or fault current path. These factors affect the tripping time of the protection system and in some cases cause mal-operation.

One example of mal-operation is when the NOP is shifted from Switch 2 to Switch 3 and there is an earth fault between Switch 3 and PMAR 2. Considering that the protection settings of PMAR 1 and PMAR 2 are identical, both of the PMARs are likely to trip simultaneously in this case, because the fault current measured by PMAR 2 is normally very similar or even higher (due to DG fault current contribution) than the fault current measured by PMAR 1.

To avoid mal-operation, the proposed adaptive protection scheme monitors the network topology and DG connection status, and adjusts the protection settings if required. Considering the above example, the delay times of the earth fault protection functions for AR 1, PMAR 1 and PMAR 2 are amended to ensure correct grading.

HARDWARE IN THE LOOP SIMULATION

The relays in the HIL simulation receive voltage and current inputs from the RTDS and send tripping signals to the RTDS to open CBs when faults are detected. The protection relays used in this simulation are the Alstom MiCOM P145 and ABB REF615 overcurrent protection relays, and the substation computer used to host the adaptive protection software is the ABB COM615.

Figure 2 illustrates the architecture for the adaptive protection demonstration system, including the IEC 61850 and DNP3 communications and the use of OLE for Process Control (OPC).

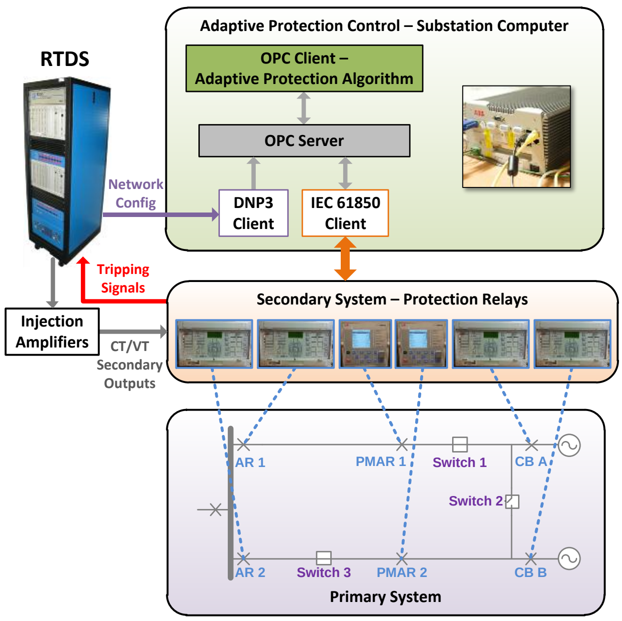

Figure 2: Adaptive Protection System Architecture

The adaptive protection algorithm continually monitors the network configuration. The configuration data are gathered from the power system simulation using the DNP3 protocol. When the network topology or DG status changes, the overcurrent protection characteristics are amended to guarantee selectivity and to optimise the relay trip times.

IEC 61850, specifically the Manufacturing Message Specification (MMS) protocol, has been used for communications between the adaptive protection controller unit (the substation computer) and the protection relays.

The use of OPC hides the complexities involved with each communications protocol, which simplifies the client applications. This approach provides the adaptive protection algorithm with access to data available from both IEC 61850 and DNP3 sources (and potentially from other sources), via a common OPC-based interface.

IEC 61850 COMMUNICATIONS

The use of IEC 61850 communications for the implementation of adaptive protection offers several benefits:

1. The standardised data model ensures that each Intelligent Electronic Device (IED) shares a common "vocabulary" for data representation, which formalises the organisation of data within each IED. Therefore, each different implementation should conform to the same data model.
2. Interoperability of data exchanged between different IED vendors, which means that the presented adaptive protection system or other protection scheme can be composed of IEDs from different vendors. Furthermore, it allows relays to be replaced during the lifecycle of a substation, regardless of the vendor.
3. The configuration of each IED is self-describing and is formally defined using a standardised XML-based language, which greatly help the system configuration process.

A number of practical limitations to this approach have been ascertained during the implementation of the adaptive protection system, including:

1. Despite complying with IEC 61850, each vendor uses different conventions for: Logical Device organisation; Logical Node names; minimum/ maximum/increments for protection setting values; and units for setting values (e.g., ampere or per unit) [15]. These differences impede the configuration process of any multi-vendor adaptive protection scheme.
2. Proprietary configuration software is needed for each protection relay type and for the substation computer, which adds complexity to the configuration process and increases the implementation time.
3. The relays used in this demonstration do not expose direct access to individual protection setting values, such as: protection characteristic, pick up threshold, time multiplier setting, and time delay. Instead, the relays provide four setting groups, with configurable settings for each protection function, and allow changing of the active setting group through IEC 61850 communications.

The cost of new IEC 61850-compliant IEDs and the communications infrastructure to allow the implementation of adaptive protection can be a barrier. However, it is important to consider that this infrastructure would facilitate a number of other desirable applications, such as: power flow metering, fault location, power quality measurements, and remote data retrieval after faults. At present, these are not available or must be installed using dedicated devices and communications links.

DISCUSSION

Setting groups

At present, relay manufacturers normally do not permit remote access to individual protection settings via IEC 61850. This is one of the main limitations encountered during the implementation and it restricts the adaptive protection system in that it can only use protection setting groups.

The protection relays used in the demonstration have four protection setting groups. Therefore, the adaptive protection system is limited to cater for only four network configuration scenarios. However, with the introduction of DG, ANM schemes, and possibly islanded operation, the number of network scenarios that the adaptive protection system has to consider is significantly more than four.

A possible solution is to increase the number of protection setting groups. There are protection relays now available that have up to eight setting groups. However, in some cases this would still not be enough. Furthermore, such an approach may unnecessarily increase the number of data points (which are duplicated in each setting group) in each protection relay, rendering the configuration and management of the protection settings more difficult and time consuming. For these reasons, a better approach would be to allow full control of the individual protection settings, as necessary, using IEC 61850.

Alternative approach

In the adaptive implementation presented in this paper, data are accessed by "polling" the OPC server, rather than using an event-driven mechanism. Therefore, the scheme is relatively slow – in the order of a few seconds, depending on the number of devices in the system – to react to changes in the network configuration. This can be acceptable for an adaptive protection scheme, but limits the use of an OPC-based architecture for other applications.

An alternative approach involves removing or upgrading legacy devices, and the adoption of IEC 61850 GOOSE messaging for all communications.

The use of a single, common communications protocol thereby removes the motivation for using OPC. With this approach, each IED must be configured to publish the appropriate data required by the adaptive protection algorithm, and any other protection or control schemes.

This alternative approach is compared with the OPC-based approach in Figure 3. With an event-driven architecture, the protection or control scheme can quickly respond to network events.

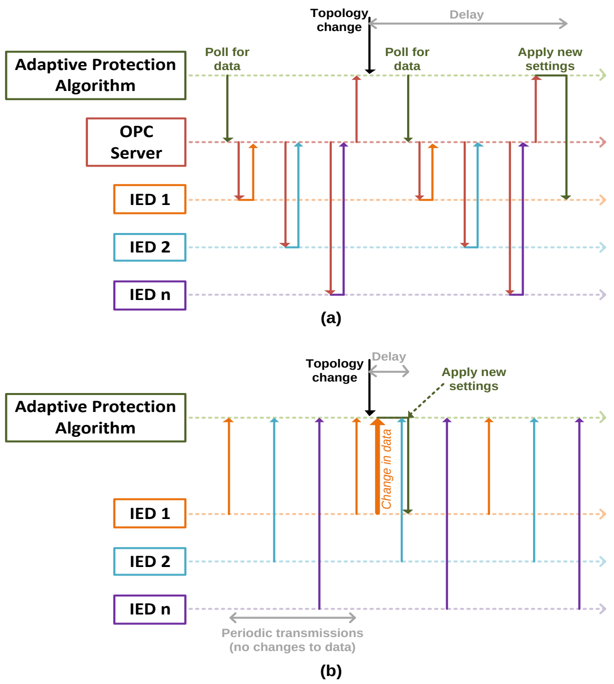

Figure 3: Comparison of (a) polling with OPC server and (b) event-driven communications

CONCLUSIONS AND FUTURE WORK

This paper has presented an HIL simulation of an adaptive protection system for distribution networks, using commercially available protection hardware from different vendors. IEC 61850 communications has been used for the communications between the adaptive protection controller and the protection IEDs.

The HIL simulation has demonstrated that adaptive protection can be implemented with commercially available hardware, and that the scheme improves the performance of the protection system.

A number of limitations were encountered in the implementation of the adaptive protection scheme, in particular, the limited access to protection settings. Alternative solutions have been presented and discussed.

Further work will integrate the adaptive protection system with primary system hardware at the PNDC, including ground-mounted and pole-mounted auto-reclosers. The investigation will also be extended to consider other scenarios, such as spurious tripping due to un-balanced conditions of the network, or as a result of temporary interconnections between primary substations.

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