Wind Farm Protection Using an IEC 61850 Process Bus Architecture

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Abstract

Wind generation and wind farms are becoming an important part of the generating capacity of the modern utility grid. Protection of wind turbines, and wind farm collector systems, has been the subject of numerous technical papers over recent years, as wind generation grows more prevalent. These papers have focused on the basics of protecting the wind turbines, protecting the wind farm, and modelling of wind farms for stability studies. However, few have focused on practical aspects of protection and control systems when wind turbines and collectors systems are distributed over many square kilometres of surface area. There are design, construction, and maintenance decisions to make for a wind farm, such as where to physically mount protective relays, laying out copper wiring between measurement sources and protective relays, and realistic and affordable maintenance programs for protective relays. Maintenance can quickly become an issue if relays are located at each individual wind turbine. These decisions become much more complicated when the wind farms are located offshore, as the cost of installation, and the cost of maintenance, increase dramatically.

This paper proposes a protection and control (P&C) approach based on IEC61850 process bus architecture. Ruggedized Merging Units (MUs) can be installed at individual wind turbines to acquire AC measurements (as raw sampled values) and status information, as well as provide control points. Data is transmitted via IEC 61850 messages over a fibre optic communications network to a Central Relaying Unit (CRU) which executes P&C functions for a whole wind farm.

1 Introduction

Wind power has become cost-competitive with other conventional means of power generation. It can provide a significant amount of energy from a renewable resource with minimum adverse impacts on the environment and is the focus of “green power” marketing programs throughout the world. Wind generation and wind farms are rapidly becoming an important part of the generating capacity of the modern utility grid. Emerging trends such as government incentives, carbon limits, and decreasing costs of wind turbine technology will all lead to increased number of wind farms in the coming years.

There are two kinds of wind farms: (1) large wind farms located onshore or offshore consisting of numerous wind turbines connected together and distributed over several square kilometres, with a single interface to the transmission system; and (2) a single wind turbine directly connected to the distribution utility’s system. The focus of this paper shall be the large wind farms. Typically modern wind farms consist of 20-150 individual wind turbines clustered into many groups depending on the total number of turbines. The capacity of each turbine is in the range of 0.5 – 3MW, with some turbines as large as 5MW.

A typical wind turbine generator unit consists of the wind turbine itself, an induction generator, turbine/generator control, generator breaker, and step-up transformer. Recently power converters have been employed to permit variable speed operation in order to maximize the output power and provide reactive power. Generation voltage is typically 690V and this is stepped up to 34.5kV. Numerous wind turbine outputs are connected together and tied to the collector bus through a circuit breaker. Multiple collector feeders are combined and fed to a utility transformer, which steps up the voltage to transmission level and transfers the power. Often, reactive power compensation units such as capacitor banks are also provided at the collector bus. There are other modern ways such as the use of FACTS devices or advanced control of induction generator for providing reactive power support.

When it comes to protection and control requirements of a wind farm, the wind power industry has been using conventional and simple approaches. Even though rapid advancements are being introduced in various fields related to wind power such as wind turbine and induction generator design, wind turbine/induction generator control, ride-through ability, and reactive power control, approaches adopted for implementing protection have not seen significant advancement. It is not that protection and control industry has not made technology breakthroughs; in fact there have been remarkable developments. However, there might have been a gap in tuning these to the needs of wind farm application.

The objective of this paper is to present a new approach for wind farm protection and control implementation. Advancements in the protection and control industry have to be brought into the domain of wind farm application to address the specific needs and challenges of this application. This paper begins by presenting an over view of protection and control requirements for a wind farm highlighting the key challenges. A key proposal in the presented concept is the idea of using a Centralized Relaying Unit (CRU) to meet the P&C requirements of the whole wind farm consisting of numerous wind turbine generators, their step-up transformers, and the collector feeder.

It is important to note that the capacity of individual wind turbine generators and wind farms as a whole continue to increase. The simple and basic protection approaches such as fuses will no longer be sufficient to protect these systems. More elaborate protection functions and schemes will be required in order to enhance the availability and reliability of wind farms. The time is ripe for the wind power industry to look at innovative technology that not just meets their protection and control needs, but goes beyond to solve their various other economic, operation and maintenance challenges, while remaining simple and using proven methods.

2 Protection & Control Requirements of a Wind Farm

A wind farm has many protection zones from the traditional P&C perspective. Figure 1 illustrates the various protection zones in a typical wind farm. This structure remains similar whether it is an onshore or offshore wind farm. Each protection zone has one or more protection relays and at times other means of protection such as fuses depending on the size and arrangement of a wind farm. The disconnecting switches are not shown in the diagram. The wind turbine generator, which is normally an induction generator with its associated power electronics converter and control, is protected by a separate wind generator protection relay. The step-up transformer has normally a fuse at the MV side. However for larger transformers (>1MW), a separate transformer protection relay is used. The collector feeder is protected by a separate feeder protection relay, while the collector bus uses a bus bar protection relay. The high voltage transformer is always protected by a transformer protection relay while the transmission line has a distance or current differential relay.

There are specific challenges in a wind farm protection that are worth mentioning. There exist different topologies for connecting wind turbine generators to the collector feeder. Radial, Bifurcated radial, Feeder-Subfeeder and Looped feeder are the different types of topologies used. Each topology has its advantages and disadvantages. Some provide the opportunity to isolate the faulted area and continue running the rest, while other topologies have lower cost. However whatever may be the configuration, the MV side of wind turbine generator step-up transformer has normally a delta winding. So the entire collector feeder depends on the ground of the High Voltage transformer. This may lead to a situation where a collector feeder with all its wind generators runs as an island without a ground. This may result in transient or sustained over-voltages and wind turbine generator relays won't be able to see MV ground faults. The behavior of the power converter and associated controls can act to produce voltage transients due to neutral shift. Thus, sometimes a grounding transformer is installed on each feeder circuit. Even then, it is not desirable to run the collector feeder as an island due to safety reasons. Various communications based transfer trip solutions are used to trip the wind turbine generator breakers if the collector feeder breaker trips [2]. In addition new approaches to identify faults in different areas of a collector feeder will be a blessing since specific areas can then be easily isolated while rest of the system could continue to run.

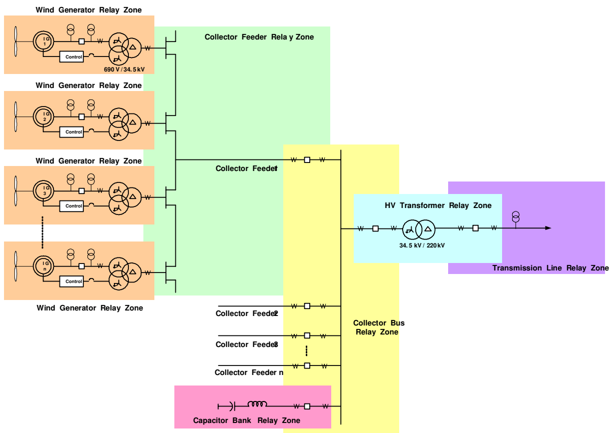

Figure 1: Protection Zones in Wind Farm

The fact that the protection relays for wind generators are located at the base of the tower brings in several challenges associated with commissioning, operation, and maintenance. Monitoring of a wind farm protection system from a central location means interconnecting all the individual protection relays and configuring each relay to access required information. This could be an elaborate process. For example, a wind farm with 36 wind turbines on a single collector feeder would have 36 relays minimum. To install, configure, test, commission and maintain these individual relays distributed over a wide area and that too located at the base of the wind turbine tower could be quite expensive in terms of labor, time, and resources. Any new technology for wind farm protection should address these challenges associated with installation, commissioning, operation and maintenance.

4. Protection and Control System Based on IEC 61850 Process Bus

At a time when the protection industry is looking at what should be the next step in the evolution of protective relays, it should be recognized that merely enhancing the capabilities of numerical relays will not be sufficient to meet the real challenges facing the utilities such as dealing with huge copper cabling installation, scarcity of workforce, reduction in available time for new or retrofit project executions, labour cost and cyber security threats etc. Thus a holistic approach taking into account the business expectations of the utilities is essential. This section presents one such protection and control solution based on the IEC 61850-9-2 process bus. This implementation is based on the concept of distributed data acquisition units interfacing with various primary apparatus and exchanging information with numerical relays over fiber communication.

This IEC 61850 process bus architecture uses merging units to collect CT/VT signals and circuit breaker/process control and status signals. The IEC 61850-9-2 output of each merging unit is connected via pre-terminated fiber cable to a patch panel that directs the appropriate signals to each relay.

In reference to Figure 2, the system includes merging units mounted at the primary apparatus, relay, pre-terminated cables, and fiber patch panels for cross-connecting the merging units and relays.

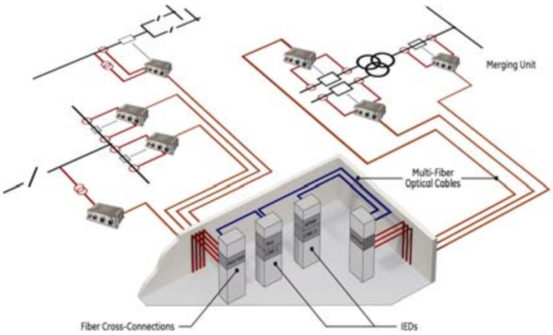

Figure 2: Protection & Control System using IEC 61850 Process Bus

The merging units are designed to interface with all signals typically used for substation automation and protection as close to their respective origins as practical, including AC currents and voltages from instrument transformers, breaker status and alarms, breaker control, disconnect switch status and control, temperature and pressure readings, etc. The merging units are designed for harsh environments including temperature extremes, shock and vibration, electromagnetic compatibility, sun load effect, pressure washing and exposure to salt and other harsh chemicals.

Each merging unit contains multiple independent digital cores each composed of a microcontroller with individual bi-directional (bi-di) fiber links providing dedicated point-to-point communications with a single relay. Sampled value communications used conform to IEC 61850-9-2, and GOOSE communications to IEC 61850-8-1.

All cables are connectorized and pre-terminated for ease of deployment and replacement using standard military/avionic grade components. Rugged outdoor fiber cables connect the merging units in the field to the patch panels in the control room.

The process bus architecture presented above brings in numerous benefits to the end user in terms of reduction in total installed cost, ease of engineering, installation, commissioning, operation and maintenance. The rugged merging units with pre-fabricated/connectorized cabling and highly reliable point-point fiber communication makes this approach suitable for wind farm applications as explained in a later section.

Patch panels are used to land and organize the outdoor cables. Standard patch cords are used to accomplish “hard-fibering”, making all the necessary IEC 61850 connections between the relays and the merging units as dictated by the station configuration on a one-to-one basis, without the use of switched network communications as detailed.

Each relay provides protection for one basic zone, conforming to established protection philosophies. It receives the signals to perform its function over a secure and dedicated network consisting of direct hard-fibered links to each of the associated IEC 61850 merging units. Due to the completely deterministic data traffic on these dedicated links, a simple and robust method is used for synchronization whereby each relay controls the sample timing of the connected merging unit cores over the link without relying on an external clock for process bus data synchronization. Figure 3 depicts how the classical numerical relay hardware platform presented in the previous section has been modified to adapt to the process bus based system. The process bus relay has the process bus interface card but does not have the conventional DSP and Contact I/O modules as these functionalities are moved to the merging units.

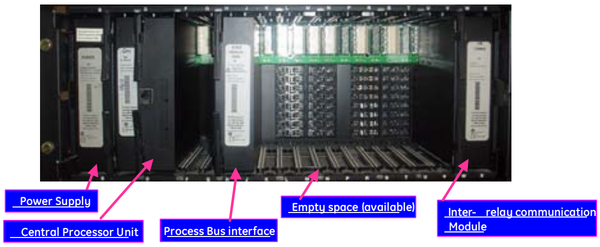

Figure 3: Hardware Architecture of a Process Bus Based Relay

3 Integrated Protection and Control System

Knowing that numerical relays are built on a common hardware platform and in fact have the software programming required for various protection functions hosted within the same unit, it is practical to think about integrating all the protection and control requirements of a substation into a single numerical relay. There could be two challenges to this approach to begin with: (1) the capability of the processors used in numerical relays, (2) the need to bring all the copper wire based signals from the whole station into a single relay. The former challenge is easily addressed by ever increasing capabilities of the processors and perhaps by various other architectural considerations. The distributed processing and the all-fiber numerical relay architecture presented in the previous section resolve the second challenge. Before delving into this idea, it is worth recapturing some of the efforts in the past that were invested in similar lines.

6. Wind Farm Protection & Control Using IEC 61850 Process Bus

The present practice using conventional numerical relays or process bus based relays is to use an individual protective relay dedicated to each zone of protection. If the same approach is adopted, one relay will be needed for each wind turbine, and collector feeder protection. However, use of the integrated protection and control system allows for one protective relay to acquire signals from multiple zones of protection, and provide protection for multiple zones, further reducing maintenance and installation costs. Protection and Control requirements of the whole wind farm can be met by a single protection relay with distributed merging units.

Referring to Figure 4, this system has merging units placed at the wind turbines and feeder breaker. They are brought to the Central Relaying Unit (CRU) using point-to-point fiber communication. The CRU is essentially an all-fiber numerical relay and has multiple process bus interface cards to connect to the numerous merging units out in the field. Each process bus interface card connects to a pre-defined number of merging units and each CRU has a fixed maximum number of process bus interface cards it can support.

The CRU implements the parallel processing approach. The CRU uses multiple processors running in parallel to execute the protection and control functions of the whole wind farm. Each process bus interface card in turn consists of multiple processors that have the power and ability of a single numerical relay. So it can be said that the CRU essentially contains multiple relays. The protection functions of a whole wind farm are distributed among the different process bus interface cards and the main processor card.

Figure 4 also shows the application of this integrated protection and control system in the typical wind farm example explained in Section 2. Each wind turbine generator has a merging unit as part of its generator breaker, which can easily be installed, wired and tested by the breaker manufacturer before even shipping to site. This merging unit acquires current, voltage and breaker signals. Similarly each feeder breaker merging unit is installed as part of it to acquire CT and breaker interfaces.

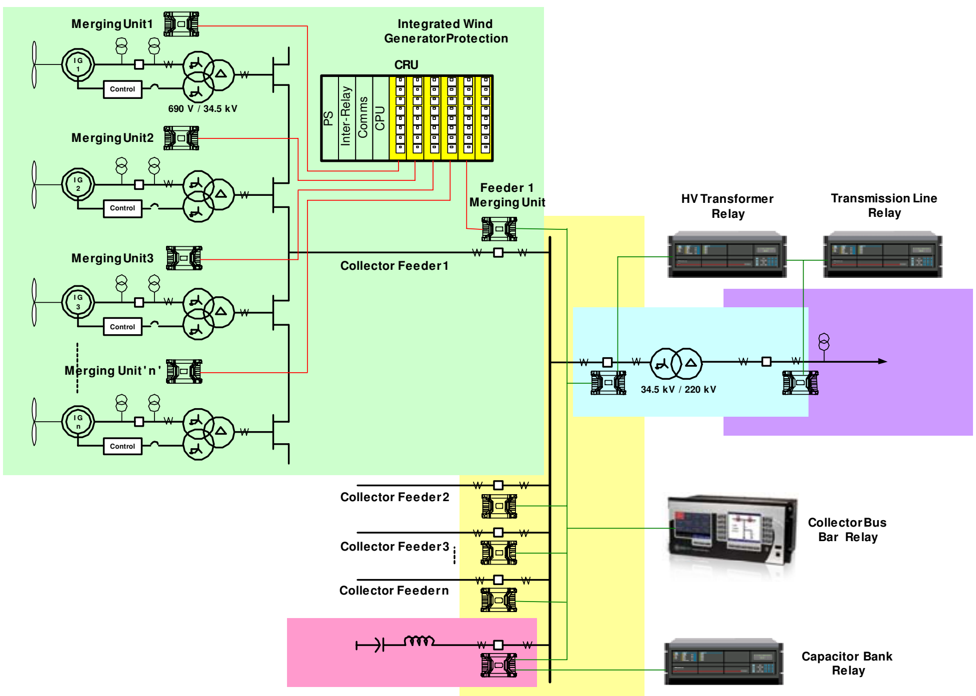

Figure 4: Wind Farm Protection using IEC 61850 Process Bus and Integrated P&C System

The CRU executes all protection and control requirements for a specific collector feeder and all the wind generators connected to it. This means the CRU instantiates a copy of all the protection functions mentioned as part of Wind Generator Zone in Section 2 for each of the wind generator in that collector, and also instantiates the collector feeder zone protection functions. Therefore, a single relay has the visibility into the whole of that collector section in the wind farm. The success of such a system is as dependent on the user interface for the system as the hardware and firmware. The software for such a system must consider various aspects such as intuitive appearance, simplicity of configurations, ease of navigation, transparent monitoring screens and one-shot view of the connected system.

One CRU shall be used for each of the collector feeders. The collector bus shall be protected by a single bus bar protection relay that has access to the merging units from all collector feeders and the HV transformer breaker merging unit. The capacitor bank protection relay, HV transformer protection relay, and transmission line protection relay all shall access appropriate merging units to execute the respective protection elements. It is possible to integrate all these into the collector bus bar protection relay, or a different CRU, as well. Such an arrangement will result in one CRU for each collector feeder and a CRU for collector bus bar, capacitor bank, HV transformer and transmission line protections.

This integrated protection approach for the whole wind farm makes the installation and commissioning easy as the merging units come installed and tested with the breaker. Further the need to configure and test individual relays have been eliminated and only a single relay - CRU needs to be configured, tested and maintained. Further, procedures such as transfer trips will no longed be needed as the CRU can issue trip signals to the feeder breaker and all the wind generator breakers simultaneously.

The advantages of the integrated wind farm protection and control system over the conventional ways of protecting the wind farms are summarized below:

- Rugged merging units, suitable for outdoor installation and fully connectorized for ease of installation and maintenance.
- Significant part of site tests could be done in factory.
- Merging units have no settings or firmware identity, essentially dumb units and so ease of maintenance.
- Eliminates the need for separate relays for each wind generator and the need to set, configure, test, and maintain the individual relays.
- One setting file for the whole collector section and so ease of engineering.
- Eliminate the need for transfer trips as simultaneous trips to feeder and generator breakers possible as the CRU has both feeder and generator breakers access instantly.
- Possibility of new operational schemes within the collector section for fault location and to automatically isolate faulty sections and restore operation of rest of the system.
- Monitoring the whole collector section is configuration free as CRU has all the information already.
- Disturbance recording at each wind turbine and single sequence of event recording.
- Easy integration and exchange of data with other collector feeders or interconnection systems.
- Last but not the least, use of a widely accepted open standard protocol – IEC 61850.

The integrated protection and control system explained here find its application not only in wind farms; it can easily be applied for large bus bars with numerous feeders, MV switchgears with multiple feeders and incomers. In fact, it is also possible to have the protection and control requirements of a whole HV substation met by this integrated protection system.

7. CONCLUSIONS

Wind energy is a rapidly growing environmentally friendly generating means. The technology around wind energy is also growing very fast. However the protection and control requirements of a wind farm are still met using conventional means of protective relaying only. The protection industry is evolving at its own rate with breakthrough next generation P&C systems that addresses key challenges facing the utility industry today. This paper briefly presented the protection and control requirements of a wind farm and discussed the evolution of technology in protective relays. An Integrated Protection and Control System for Wind Farms is presented that uses the concepts of IEC 61850 process bus and a centralized relaying unit with parallel processing ability. The application of this system in a wind farm brings in significant improvements such as reduction in P&C system total installation cost; ease of installation, commissioning and maintenance; ease of configuration; faster and reliable transfer tripping schemes; and new approaches to identify and isolate faulty sections and restore operations.

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