Integration Of Protection, Control, Monitoring And Remote Communication Into One Intelligent Electronic Device For Small Hydro-Power Plants – Pilot Installations

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ABSTRACT

This paper briefly describes some work done in a project to develop a new Intelligent Electronic Device (IED) containing integrated control, protection, monitoring and communication elements for small hydropower plants. The requirements from two Swedish Electric Power Utilities in this joint project result in two small hydro power-plant pilot-installations. The conceptual requirements and project results will be discussed along with turbine, generator and station control strategies.

I. BACKGROUND AND REQUIREMENTS

Sweden has about 1500 small hydropower (SHP) stations in operation. Most of them were erected during the last century. During the 1990's SHP suffered from low profitability due to low electricity prices and withdrawn subsidies. Consequently about 145 power stations were closed down or paused during the ten-year period from 1989 to 1999. During this period very few investments were made in SHP stations. This trend was recognized as undesirable since small hydro is an excellent distributed renewable energy source as well as a part of the cultural and industrial heritage.[1] In recent years the electricity prices have increased substantially from about 10 to about 30 Euro/MWh. Electricity certificates has been introduced in Sweden to support hydropower units below 1500 kW at an additional contribution of about 25 Euro/MWh.

The interest to renovate power stations in operation and to build new ones has grown with the increased profit of their operation. Interest in running small hydro has also increased as a result of governmental bodies and international organizations such as the European RES Directive 2001/77/EC of the European Parliament and the Council on the promotion of the electricity produced from renewable energy sources in the international electricity market. As the Commission calls for a stronger commitment of Member States to achieve the 2010 targets it is likely that this interest will continue for a good number of years. Still the value of electricity produced from a 1 MW station is modest. E.g. an annual production of 4 000 MWh at 55 Euro equals 220 000 Euro or about 600Euro per day (if the production was the same every day of the year). Profitable operation requires a stable system that is autonomous to a high degree and runs with very few unscheduled maintenance and support visits. Furthermore the systems should have a long lifetime with

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availability of spare parts that preferably are of a standardized design rather than tailor-made. A standardized solution that is easy to service is therefore required.

Even for small hydropower plants (1-10 MW) a relatively large number of functionalities must be included for efficient control and protection. Functionalities such as voltage control, generator supervision, turbine control, water management, start/stop, excitation equipment and an interface to the network operator control central or access via a remote PC are necessary. Generally the requirements to control all these functionalities demand several included “building blocks” in the hydropower plant control system. The complexities and costs to handle these requirements nearly approach those of larger hydropower stations if conventional equipment design is used. Optimized electric energy production is important but a safe water management and protection system is a prerequisite. If the proportion of distributed versus centralized generation units connected to the grid grows in time, the role of the distributed hydro power stations as a source for robust grid operation will further be strengthened. This increases requirements on protection and interfacing with grid control systems. The storage capacity of small hydropower can become an additional asset for the grid operator when balancing other renewable energy sources, such as wind. The demand for more flexible operation of small hydropower stations will therefore increase.

I.1 The project objective and setup

The objective of this project is to show how a standardized Intelligent Electronic Device (IED) can enable autonomous SHP operation and prioritize safe water management. The IED should be cost effective, compact and integrated with the control of electrical and mechanical elements including the flow of water, communication, monitoring and the needed protection system for the SHP plants. The project is jointly realized with one equipment supplier, two electric utilities and the Swedish Energy Authority to focus on (1) a solution with the minimum functionalities necessary to operate the station and (2) the most important requirements for reliable and cost-effective operation with the highest possible availability. Prototypes are scheduled to be installed 2005 in two hydropower plants owned by the participating utilities Mälarenergi AB and Tekniska Verken i Linköping AB.

I.2 Description of the power stations for the two pilot installations

One pilot is going to be installed at the Surahammar power station owned by Mälarenergi AB. This power station was erected 1927. The generating capacity is 1.0 MW. Some parts of the installation have been renovated and updated over the years but e.g. the turbine regulator is in original (Fig 1A) working condition, i.e. 77 years old. The second pilot installation is at the Slattefors power station (Fig 1B) owned and operated by Tekniska Verken i Linköping AB. Slattefors was erected 1962 and has a rated capacity of 0.9 MW. Kaplan turbines drive each synchronous generator and the hydraulic turbine regulators and the excitation equipment will also be replaced as part of the project.

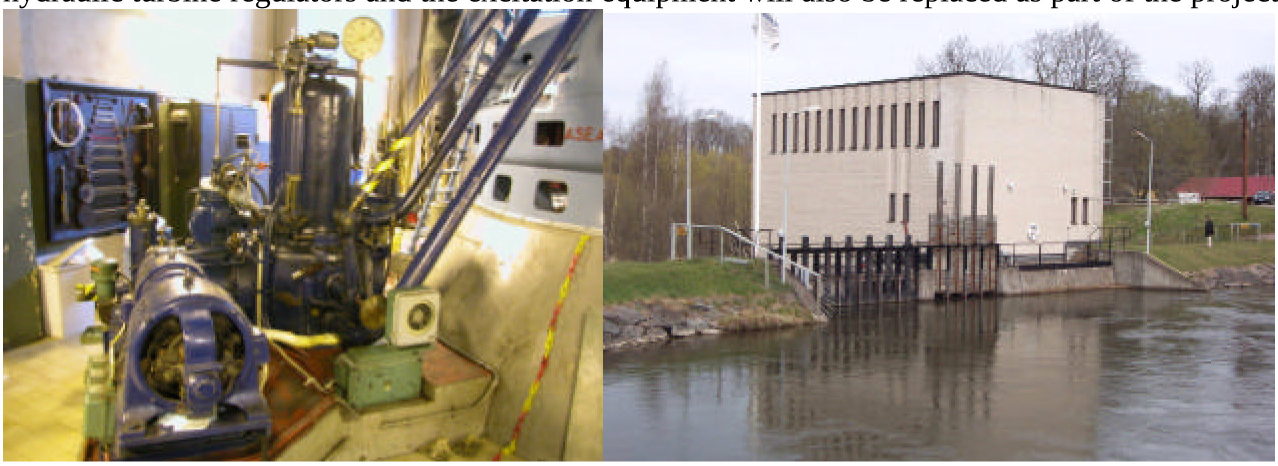


Figure 1A LEFT) The Kaplan turbine hydraulic regulator at the Surahammar power station
Figure 1B RIGHT) The Slattefors power station building

II. THE CONCEPT

The conceptual approach is to integrate station monitoring with the turbine and generator control functionality into one commercial high performance protection and control IED. Voltage and current signals that are used by the protection unit are then also made available to the control system without need for additional wiring. The integration of most of the required functionality into one compact unit was considered key to improve the cost performance. Communication on the other hand is subject to a faster changing technology and separated into a communication module to expedite possible future replacement needs. It is suggested to use communication based on the IEC 61850 standard with optional remote communication to a remote PC or the operator control room.

In the future it is anticipated that several hydropower stations in a common watercourse could also make use of the installed IED's to optimize electricity production by regulating the flow of available water through the system. Software to improve functionality will be further developed over the time of use of these power plants as the economies of electric generation change.

Figure 2A. (LEFT) The front panel of the existing control and protection system at Slattefors
Figure 2B RIGHT) The new compact station control and protection system

By using modern control and power electronic equipment, the size of the station control, protection and communication equipment can decrease substantially for these installations. In Fig.2A the front row of the existing control system for the Slattefors power station is shown for comparison purposes next to the new more compact system in Fig. 2B, equal in size to the pilot system. The protection and control panel at Surahammar is also about 40 years old and similar in size.

II.1 The need for a flexible control and protection package

The configuration flexibility of the IED relay and control terminal needed for this development should enable the implementation of any needed power system protection function available in the existing plants. The freedom of function selection is of particular interest also for the control functions that may require more change depending on the station design and also to enable the benefits of integration into one common platform.

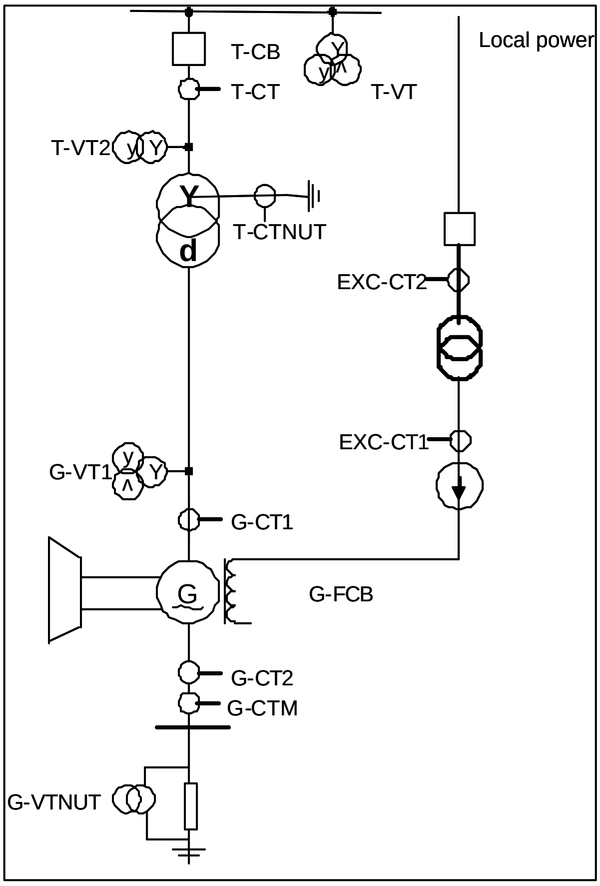
A standardized microprocessor based modular platform hardware used in more than 25 000 installations worldwide and installed in power networks with rated voltage up to and including 750kV was therefore selected for the project. The main property of the IED is the possibility of combining the protection, monitoring and control functionality. Low power consumption especially in the measuring circuits adds flexibility of application. The IED must easily adapt to user's practice regarding protection functions to be included and the number of current and voltage inputs required. 10 or 20 analogue current or voltage inputs were specified as a requirement to be able to handle these SHP installations. The investigation led to the requirement of 2*16 binary input and 24 contact outputs needed for plant operation. The possibility of doubling this was also required.

Different customer requirements for tripping and external signaling as well as the need to locally indicate IED unit status and start of the protection, tripping and other functions must also be met.

II.2 Protection Method

Generators are designed to run for a large number of years at a high load factor and also to permit certain incidences of abnormal operating conditions. The protective relay functions quickly initiate disconnection of the machine from the system in case of a fault and initiate the complete shutdown of the generator. No international standard exist regarding the needed configuration of the protective schemes for different types and sizes of generators. Manufacturers provide recommendations and guides are given by various Standards. The protective scheme configurations may vary from country to country and also between power companies in the same country. There are also different needs to consider depending on the specific machine construction. For those reasons the generator protective schemes must be flexible.

In this project the generator and the step up transformer are protected by common equipment. There are also back-up protections for faults outside the protected zone. In practice, there are many mechanical and thermal protection devices that help avoiding damage to the power-generating unit. Their output signals typically come to the protection panel as potential-free contacts or mA or voltage signals and incorporated in the overall tripping and alarming scheme via inputs to the terminal.



Protection functions available (ANSI Device No)

- Generator differential (87G)
- Generator restricted EF (87GN)
- 2-stages, 80% stator EF (59N), 3Uo internally calculated
- CB failure protection for generator breaker
- Loss of excitation (40)
- Reverse power (32) with minimum setting of 3%
- Stator thermal overload (49S)
- 4-stages, 3ph over and under voltage protection (59 & 27)
- 2-stages, over and under frequency protection (81O & 81U)
- Overexcitation (V/Hz) protection (24)
- Negative sequence overcurrent protection (46)
- Undervoltage with overcurrent seal-in (27/51)
- Turn-to-turn (generator split star point overcurrent) protection
- Generator 3Ph overcurrent protection

Optional protection functions available

- Rotor EF, AC 50/60Hz injection via RXTTE 4
- 95% stator EF (59N) connected to generator neutral point VT
- 80% stator EF (59N) connected to generator open delta VT1 winding
- Rotor thermal overload for static excitation (49R)
- 3ph overcurrent protection (50/51) for excitation transformer
- 3ph overcurrent protection (50/51) and earth-fault protection (50N/51N) for auxiliary transformer

Figure 3. A typical SHP generating station single line diagram and a list of available IED protection functions.

II.3 Implementation of protection, monitoring and control functions into the IED

All protection and control functions are software IED modules presented to the user as functional graphics blocks. Visual indication of operation is provided via a programmable multicolor 18-LED panel. An integrated disturbance and event recorder provide up to 40 seconds of monitoring and recording of analogue and binary signals to aid the analysis processes during the plant life. Alarms can be provided via voltage free contacts and local LED indication or remotely via communication for selected functions e.g.:

- ◊ Generator frequency deviation (frequency outside pre-set band around rated i.e. ±0,5Hz)
- ◊ Generator voltage deviation (voltage outside pre-set band around rated i.e. ±5%)
- ◊ Generator loaded/not-loaded
- ◊ Generator negative sequence over-current or over-voltage alarm
- ◊ Generator over-excitation alarm
- ◊ Generator loss-of-field alarm
- ◊ Generator reverse power alarm
- ◊ VT fuse failure alarm
- ◊ Loss of injection voltage for rotor earth fault protection

The functionality required for the control of a small hydropower station is implemented in function blocks. [2] The scope includes:

- ◊ control of the water level – with various modes of operation
- ◊ normal operation at specified power, water flow, or guide vane opening
- ◊ logic for the timing of start and stop sequences
- ◊ synchronization including required speed control as well as the actual closing of the breaker
- ◊ control of a gate, the guide vanes, and the runner blades by means of increase/decrease signals for each actuator
- ◊ Control of the excitation is done with a controller that is interacting with the IED equipment. An additional operator display is provided for settings and process monitoring.

The function blocks have parameter settings for adaptation to particular power stations. The start sequence is configured via use of logic function blocks. Apart from automatic start and stop as in intermittent operation, it is of course possible to manually start or stop and to adjust set point values and limits for the operation.

II.4 Communication Hierarchy

The station network is based on electrical or optical 10/100Mbps Ethernet media. The station network is designed, like a standard office network, around one or more Ethernet switches to enable easy connection to all station devices of miscellaneous types: the protection and control IED(s), the local HMI panel, a PC for e.g. maintenance work or e-mail, Internet phone, web cameras and other devices. The station network uses optical links in areas subject to severe electrical interference while electrical links can be used elsewhere. The Ethernet switch also serves as an interface between optical and electrical Ethernet links. The IEC 61850 compliant protection and control IED(s) allows other Ethernet based devices to co-exist in the station network. The IEC 61850 permits use of peer-to-peer communication i.e. sharing of process data between IED's operating in the same network e.g. when there are parallel machines. Optimizing the output of such stations require such information and interaction. A communication gateway is required to enable secure and reliable communication with the SCADA remote control center(s) using relevant communication protocols. The gateway interfaces the station network to the remote control center(s) through a public or private network, e.g. GSM or rented phone lines. The gateway also serves as a firewall. Some extra server functionality in the gateway may be used to enable a local graphical HMI or using a standard web browser for display. A Web browser can also be installed in a permanently mounted operator panel or touch screen or alternatively on a laptop PC used during visits to the station. Such a solution can also serve as a straightforward lower cost solution for private SHP owners with only one or a few stations not connected to utility network central operator control rooms.

II.5 Excitation equipment retrofitting in old SHP stations

The described SHP protection and control concept should be applicable to any plant design. SHP stations installed over a period of more than 100 years display many technology variations of excitation equipment for synchronous generators. Handling of asynchronous generators should also be possible. The many different solutions that exist today do not make it possible to come up with one standard solution for excitation control. The development project therefore aims to provide one integrated solution and one additional solution with a clean interface to existing excitation equipment. In the pilot installations the excitation control is presently a separate function.

II.6. Modeling of the station and turbine control systems

As a means to verify the intended control solution and to illustrate its behavior, an implementation study was made by using a Simulink model. A reservoir model was added, and simulations were run according to the different modes of operation – continuous level control, level control to within limits, and intermittent operation. Ref [2]

II.7 Benefits

With a standardized integrated concept, significant cost savings can be achieved during installation, operation, maintenance and analysis of the plant. Additional benefits are derived from autonomous operation, communication and the new functionality discussed. Fig. 5 attempts to quantify this.

	Installation	Operation	Maintenance	Analysis
Completely integrated	**50%**	**20%**	**20%**	**10%**
Autonomous	**10%**	**10%**	**10%**	**5%**
New functions	**5%**	**10%**	**10%**	**10%**
Communication	**-**	**10%**	**-**	**50%**

Figure 4. Cost reduction benefits with a standardized integrated concept

III. ACKNOWLEDGEMENT

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IV. REFERENCES

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SUMMARY

This paper summarize some work done in a project to develop a new Intelligent Electronic Device (IED) containing integrated control, protection, monitoring and communication elements for small hydropower plants. The requirements from two Swedish Electric Power Utilities in this joint project result in two small hydropower plant pilot-installations scheduled to be installed in 2005. The conceptual requirements and project results along with turbine, generator and station control and protection and communication strategies are outlined.

The pilot installations demonstrate how a standardized Intelligent Electronic Device (IED) can enable autonomous operation of small hydro power plants and safe water management. The solution provides cost effective, compact integration with the highest possible availability of the control of electrical and mechanical elements including the flow of water, communication, monitoring and the needed protection system for the SHP plants.

The project is jointly realized with one equipment supplier, two electric utilities and the Swedish Energy Authority to focus on (1) a solution with the minimum functionalities necessary to operate the station and (2) the most important requirements for reliable and cost-effective operation.