

# SCADA SYSTEM FOR OFF-GRID ENERGY SOLUTIONS ON REMOTE ISLANDS

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## Abstract

Remote off-grid energy solutions in the archipelago need to be monitored and controlled from the mainland. This report proposes a solution for how such a supervisory control and data acquisition system could be set up. The proposed solution relies on local systems that can work independently to control the power production on site but that at the same time can be supervised remotely. This is accomplished by letting local systems connect to the Internet using a 3G connection. For this purpose, access to a 3G network has also been verified at one possible location in the archipelago (Mickelsörarna).

## Sammanfattning

Avlägsna off-grid energilösningar ute i skärgården måste kunna övervakas och styras från fastlandet. Denna rapport presenterar en tänkbar lösning för hur ett styr- och övervakningssystem kunde implementeras. Den tänkta lösningen omfattar lokala system ute i skärgården som är tillräckligt avancerade för att hantera energiproduktionen lokalt men som på samma gång även kan övervakas och styras på distans. Denna kombination möjliggörs genom att låta de lokala systemen ansluta till Internet genom en 3G anslutning. För ändamålet så har även möjligheten att ansluta till ett 3G nätverk ute i skärgården verifierats vid ett tänkbart läge (Mickelsörarna).



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# 1 Introduction

SUPERVISORY control and data acquisition systems are vital for ensuring proper operation of machines and processes at remote locations, and these systems are commonly used for monitoring and controlling the electrical grid at a nation wide scale. In a similar fashion, this type of systems could also be used for ensuring proper operation of small scale off-grid energy solutions at remote islands in the archipelago.

Several island groups in the Kvarken archipelago hold nature stations, cafés, and accommodation. These kind of buildings are all in need of off-grid energy solutions to maintain operations, and it would be very useful to have a system that would make remote monitoring and control possible.

This report focuses on different aspects of remote monitoring and control, and presents a proposal for how a supervisory control and data acquisition systems could be implemented for an off-grid energy solution on a remote island, Mickelsörarna, in the Kvarken archipelago. Furthermore, the proposed solution is structured in such a way that it can be easily extended to also cover more island groups in the future. This is accomplished by keeping the system's central parts on the mainland and letting local systems, localized on islands in the archipelago, connect to the central system using a 3G internet connection.

The work was conducted within the project **Pisara meressä** (English translation: A drop in the sea). This was a 3 year project set out to investigate and develop small-scale decentralized solutions for integrating automated renewable energy sources in a sustainable manner. The investigation was divided into different areas regarding production, distribution, and usage of the renewable energy sources, including the profitability aspect of the implemented solutions. Funding was received from the Centre for Economic Development, Transport, and the Environment, and the European Agricultural Fund for Rural Development. The project was run by the *Vaasa Energy Institute* (VEI)

and the University of Jyväskylä in cooperation with the Metsähallitus unit in Vaasa. VEI is a cooperative organisation founded by the University of Vaasa, the Levón Institute, Novia University of Applied Sciences, and Vaasa University of Applied Sciences, with a long term goal to increase local know-how within energy related fields (Vaasa Energy Institute, n.d.; Levón-instituutti, 2012).

## 2 Background

### 2.1 Supervisory control and data acquisition

*Supervisory control and data acquisition* (SCADA) systems are used to monitor and control processes in real time, and to store historical data. These systems can vary in size from a tank level process in industry to a nation wide electric grid (Cegrell & Sandberg, 1994). Historically, SCADA systems have been developed for specific applications, such as the electrical grid or large process plants, where the need for real time control and monitoring have motivated the required investment. These kind of systems are often very expensive, but cheaper SCADA-like<sup>1</sup> alternatives have emerged for building automation applications.

SCADA systems usually consists of the following parts (Cegrell & Sandberg, 1994):

1. sensors and actuators,
2. local systems,
3. a communication infrastructure,
4. central systems, and
5. a *Human-Machine Interface* (HMI).

Sensors and actuators are connected to local systems, such as *Remote Terminal Units* (RTUs) or *Programmable Logic Controllers* (PLCs). These gather data locally, and they

<sup>1</sup>SCADA-like is here referring to systems that share the supervisory control and data acquisition structure, but possibly lack the strict real time requirements found in traditional SCADA systems.

can also run simpler local control algorithms. Central systems, such as system servers, collect data from all local systems and can also send instructions or control commands to these. The communication infrastructure therefore have to secure a communication channel that allows local and central systems to exchange information continuously. Finally, the HMI allows humans access the central systems by visualizing collected data, presenting current process states in real time, and by letting the user set control parameters.

A SCADA system designed for monitoring and controlling energy solutions on remote islands could therefore utilize the following design:

1. sensors and actuators,
2. one or more local PLCs at each island group,
3. 3G routers connecting local systems to the Internet,
4. a central system server located on the mainland or in the cloud, and
5. an HMI that can be accessed remotely through a web browser or through a remote desktop connection.

Several PLC providers, or providers of similar products, also provide a SCADA solution for their products that include software for the central systems as well as software for creating a HMI. This software is normally licensed and can be quite expensive. A cheaper solution would be to use free on-line services for similar tasks, but our experience indicate that these do not constitute a complete product, and that interoperability issues are a big problem that can make the solution very expensive in the end.

## 2.2 Internet connectivity

The Finnish telecommunications companies Elisa Oyj, DNA Oy, and TeliaSonera Fin-

land Oyj all provide coverage for 3G<sup>2</sup> networks in parts of the Kvarken archipelago. However, based upon coverage maps from different telecommunication companies (see Elisa, DNA, and Sonera), the coverage on Mickelsörarna is questionable. Despite this, the tests performed on site, presented in section 4, still indicate that the 3G reception on Mickelsörarna could be satisfactory.

## 2.3 Dynamic Domain Name System

Each computer or device connected to the Internet is identified with an *Internet Protocol* (IP) address, provided by the Internet service provider. The addresses for the most common IP version, IPv4, are in short supply; devices connected to *Local Area Networks* (LANs) therefore normally share one or several global IP addresses<sup>3</sup> when communicating with other devices outside the LAN. For example, your Internet service provider only assigns one IPv4 address to your home router, and this address is shared among all devices, connected to the router, for outbound communication. This works fine when communication is initiated within the LAN to an external device with a global address, as when visiting websites, but it becomes problematic when a device on the Internet wants to initiate communication with a device inside a LAN (Kurose & Ross, 2010).

Central SCADA systems must be able to initiate communication to local systems; this then corresponds to the previously presented problematic situation as PLCs normally are found within a local system LAN. Furthermore, Internet service providers normally assign addresses dynamically. A device can therefore be assigned a new address from time to time. In order to secure a communication channel, over the Internet and initiated

<sup>2</sup>3G stand for the third generation of mobile telecommunication technology and supports communication rates of at least 200 kbits/s (Wikipedia, n.d.).

<sup>3</sup>A **global IP address** differs from local IP addresses by being globally routable.

by central SCADA systems, the following two problems must be solved:

1. The router connecting a local system LAN to the internet must be reachable on a fixed address.
2. Inbound communication from central systems to a local system LAN must be recognizable and rerouted to the correct device within the LAN.

The first problem can be solved in two different ways: 1) At an additional cost, it is possible to lease static IP addresses from Internet service providers. 2) IP addresses can be linked to domain names, such as `www.google.fi`, and a dynamic IP address can thus be linked to a static domain name (Kurose & Ross, 2010). Free services exist that allows a router (if this service is supported) or a computer to associate their IP address with a domain name. Each time the router's or the computer's IP address changes, it simply announces its new IP address, whereupon the service updates the IP address associated with a selected domain name. Hence, the router or the computer can always be reached using a fixed domain name. A couple of such service providers are: NO-IP, DNSdynamic, Dyn, and ZoneEdit.

The second problem can be solved by leasing a fixed IPv4 address for the server running the SCADA program. As the SCADA software is communicating through a fixed *Transmission Control Protocol* (TCP) port, local system routers can use port forwarding to route traffic from a specific IP address and TCP port to a specific device within the LAN. Hence, communication between local and central systems over the Internet require at least one static global IPv4 address, and if dynamic domain names can not be supported for the local systems, then another static global IPv4 address is needed for each local system as well.

### 3 System specification

THE currently implemented electric system at Mickelsörarna is depicted in Figure 1. Conceptually, the electric demand should be covered with wind and solar power, but in practice this is not the case and generators are used during such circumstances. A local control system on site should therefore be able to control generator usage in order to make sure that power is always available. Additionally, the local systems should monitor total electricity demand and production, as well as the radiator based heating system.

In order to comply with the above purposes, it was here determined that the local system should monitor:

**Temperatures** outdoors, inside the cafeteria, at the top and bottom in the hot water tank, and in the ingoing/outgoing water pipes to the radiator system.

**Voltages** for both the generator batteries and the battery bank.

**Power** production by the generator and power demand for the cafeteria, the accommodations, and for the whole site.

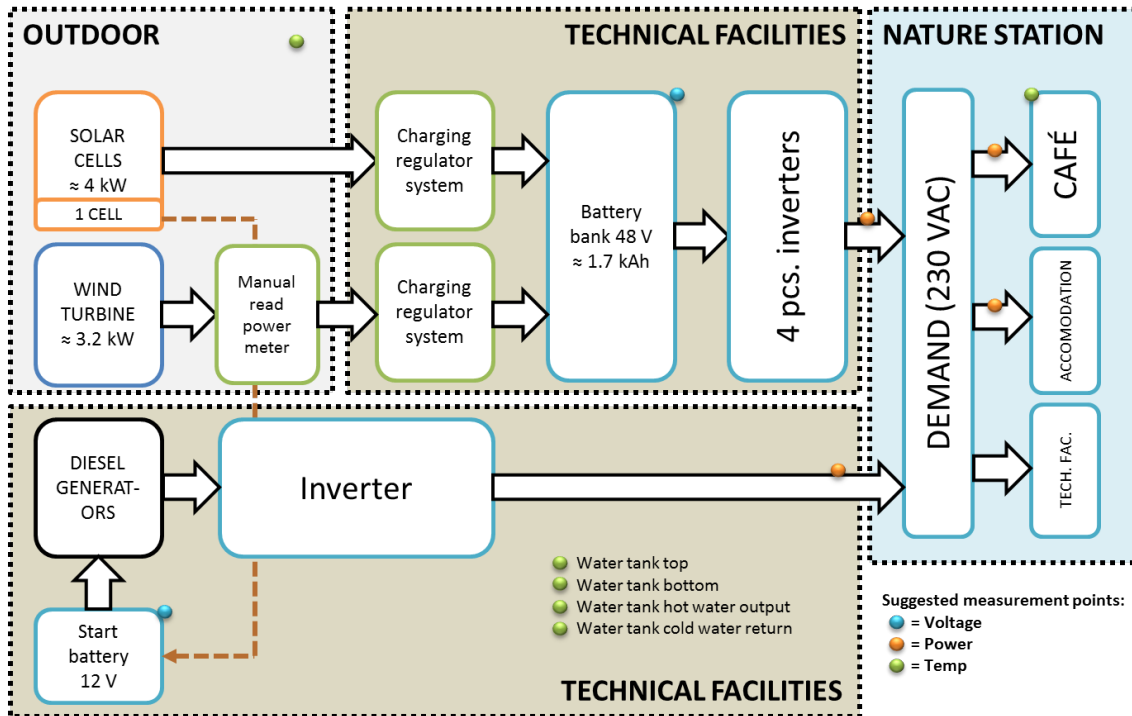
**High and low levels** for the fuel tank.

Taken together, the above requires local system PLCs to have the capacity to handle the signals listed in Table A-1 (Appendix A).

Central systems located on the mainland should gather data from the local system on site, provide an overview of the heating system as well as the current electricity demand and production, allow for remote control of the electricity production, and store gathered measurement values in a database. Additionally, the control and monitoring offered by the central systems HMI must be accessible remotely.

### 4 Network accessibility tests

COVERAGE maps for different network operators indicate that access to a 3G net-



**Figure 1:** Simplified flow-chart of the electrical system on Mickelsörarna with local system measurement points marked, adapted from (Puig et al., 2012).

work on Mickelsörarna might not be guaranteed. For this reason, a connectivity test was carried out on site (coordinates 63.4604, 21.7731 on Google maps). The test equipment consisted of a Huawei USB 3G-modem, provided by Saunalahti (owned by Elisa Oyj), and a laptop. This equipment was placed inside the coast guard station (main building) at its highest point. From this location, both the 2G:EDGE and 3G:HSPA+ networks were reachable, and both were subsequently tested with a separate ping and speed test.

A ping test sends a packet of predefined size to a remote web service, in this case to cosm, and measures the delay between transmission and received response (response

time). Here, the test was performed with the Axence NetTools software, using a packet size of 1024 bytes and a threshold time of 5000 ms (max response time before a packet is considered lost). The results from a 5 min long ping test for both networks are shown in Table 1. Package loss for the 3G:HSPA+ network was 0 % and the average response time was 290 ms. Corresponding numbers for the 2G:EDGE network were 5 % and 1094 ms respectively.

The speed test utilized is a common web service speed test. This test measures download and upload rates to a close by internet server and hence provides an estimate of the speed of an internet connection. Results obtained from this speed test are shown in

**Table 1:** Results from 5 minute long ping tests with different network connections and using the Axence NetTools software

Network	Packets			Response time (ms)		
	Sent	Received	Lost	Avg.	Min	Max
2G-EDGE	334	316 (95 %)	18 (5 %)	1094	678	4646
3G-HSPA+	282	282 (100 %)	0 (0 %)	292	261	423

**Table 2:** Measured download and upload rates for the two network connections

Network	Download	Upload
2G-EDGE	0.08 Mbit/s	0.55 Mbit/s
3G-HSPA+	2.88 Mbit/s	1.45 Mbit/s

Table 2. The 3G:HSPA+ network performed great with a download rate of 2.88 Mbit/s and an upload rate of 1.45 Mbit/s, whereas the 2G:EDGE network performed significantly worse with a download rate of 0.08 Mbit/s and an upload rate of 0.55 Mbit/s. However, contrary to the ping test, this test does not show the amount of lost packets during a specific time.

Even if the above tests indicate that a 3G internet connection could connect devices on Mickelsörarna to the Internet, the reliability of such a connection should also be taken into account. The implemented tests were performed during midday on one day only. It is therefore possible that the network could perform worse during evenings, weekend, or during days with different weather conditions. In order to rule out such events, it would be recommended to redo the connectivity test under a longer time period before a decision to use a 3G network is taken.

## 5 Proposed solution

WE propose a SCADA system based on the structure in Figure 2 for control and monitoring of the off-grid energy solution at Mickelsörarna. This structure allows local systems to operate independently and also offers good possibilities for extending the SCADA system to other island groups in the future. That is, similar local systems as the one suggested for Mickelsörarna can be installed on other sites and supervised from the same central system. This is made possible by letting the complete system use the Internet as its communication channel.

Below follows a more detailed description of the local systems, the central systems, the HMI, and possible products.

### 5.1 Local systems

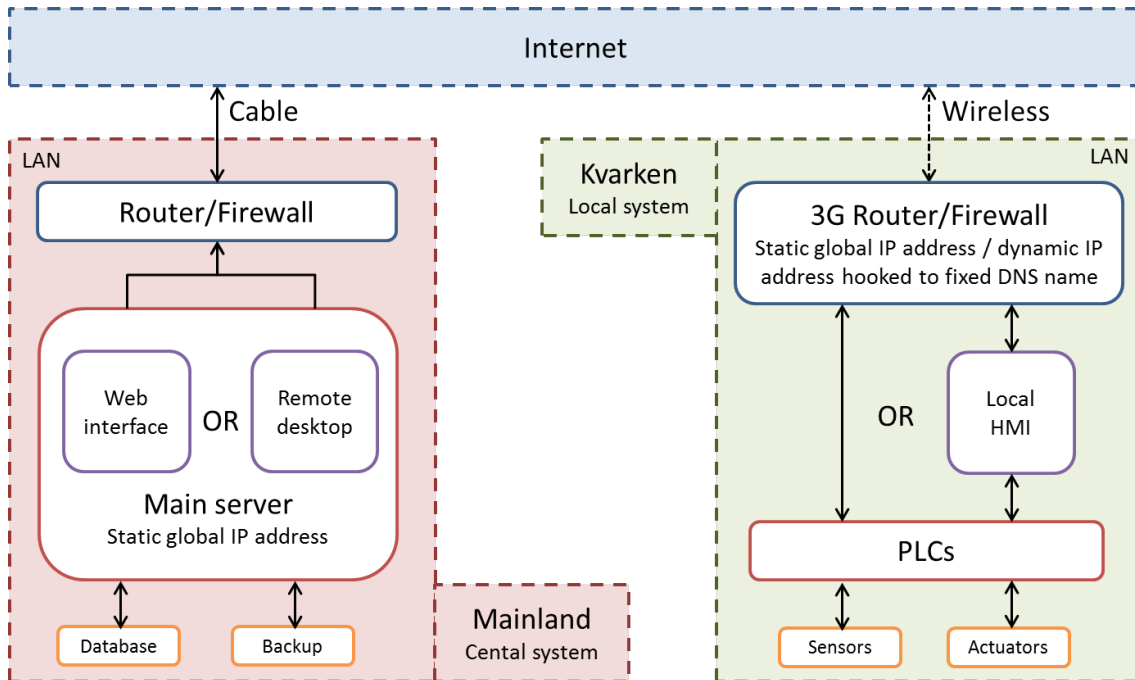
The local system consists of one or several PLCs (or other similar devices). These collect data from sensors and send control signals to actuators. Local PLCs can, for example, be programmed to start the generators automatically when the voltage in the battery bank drops below a certain threshold. Similarly, alarms can also be generated in response to a low fuel level.

If needed, a computer or a touch screen can be used to provide a local HMI. This could be useful for presenting local sensor readings and for controlling certain aspects of the energy solution manually. Depending on the hardware, this local HMI could be connected directly to the PLC or via the router. The local HMI together with local control algorithms then makes it possible for a local system to function independently. That is, the local system will continue to work normally even if the connection to central systems is lost.

Internet connectivity is required for communication with the central systems located on the mainland. The local system should therefore be equipped with a 3G router that connects the local system LAN to the Internet. As presented in subsection 2.3, this router needs to be reachable using a static global IP address or with a domain name. However, only certain routers support dynamic domain name services and this have to be checked in advance. Additionally, not all SCADA software support replacing IP addresses with domain names and for these reason it might be better to lease a static IP address.

In order to avoid unnecessary devices for translation between different communication protocols, it is recommended that the used PLC supports TCP/IP communication. If several PLCs are needed in order to comply with the I/O list in Table A-1 (Appendix A), these might have to be connected in a master slave like fashion using a product specific protocol. This makes sure that all IO channels can be accessed from the master PLC. The 3G router can only port forward traffic





**Figure 2:** Proposed SCADA solution for remote monitoring and control of off-grid energy solutions at remote islands.

from central systems to one device within the local system LAN, and it is therefore important that all IOs are accessible from this device.

## 5.2 The central system and its HMI

The central system consist of a server with a static IP address running the SCADA software together with backup systems. The server will collect measurements and variable data from local systems and store these values in a database. This makes it possible to keep a historical record on, for example, generator running times, electricity production and demand, and temperatures. The central system also has access to local system IOs, which allows for a remote start of the generator in response to an increased anticipated demand or for adjustments of other control signals.

Present states, alarms, historical data, and possible control measures for all local systems are presented using a HMI connected to the central systems. A human operator can therefore get an overview of all connected

local systems and also set control parameters for these. As this HMI is running on the central system server, the human operator have to be localized at the server or access it remotely. Depending on the SCADA software used, this can be accomplished trough either a web interface or a remote desktop connection. Hence, assuming internet connectivity, it becomes possible for a human operator to access the HMI remotely from anywhere in the world.

## 5.3 Products and costs

Both Regin and National Instruments have suitable product families and accompanying SCADA software that would fit the requirements for the proposed solution. Regin offer two PLC like devices (EXOflex and EXOcompact) that are used for building automation systems, whereas National Instruments have a PLC like device called compactRIO.

The hardware and software cost for implementing the proposed system will amount to 10 000 – 15 000 €. Additional installation costs will also derive from installing all systems, programming the PLCs, and from

setting up the SCADA system. Once installed, there might further be yearly fees for some software licenses and for static IP addresses.

## 6 Summary

Some remote islands in the Kvarken archipelago are equipped with nature stations, cafés, and accommodations possibilities, and these buildings require off-grid energy solutions in order to maintain operation. This report has presented a possible structure for a SCADA system meant to centralise control of such off-grid energy solutions. The solution consist of a central server, located on the main land, that can gather data and send control signals to local systems on remote island groups over the Internet. Each local system is responsible for controlling the local energy solution, and it is also capable to do so if the connection to the mainland is lost. As no wired Internet connections are available in the archipelago, each local systems connects to the Internet using a 3G connection. Network coverage varies in the archipelago, but a promising connectivity test was carried out on Mickelsörarna. At present, the system was specified for only one local system, on

Mickelsörarna, but the proposed SCADA system can be scaled up to handle local systems on multiple island groups.

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## A I/O list for local system PLCs

**Table A-1:** Suggested I/O list for local system PLCs on Mickelsörarna

I/O	Type	Range	Location/Description
AI-01	Temperature	-30 °C – 30 °C	Cafeteria
AI-02	Temperature	-30 °C – 30 °C	Outdoors
AI-03	Temperature	-30 °C – 100 °C	Water temp. (to radiators)
AI-04	Temperature	-30 °C – 100 °C	Water temp. (from radiators)
AI-05	Temperature	-30 °C – 100 °C	Water tank temp. (top)
AI-06	Temperature	-30 °C – 100 °C	Water tank temp. (bottom)
AI-07	Voltage	0 – 60 VDC	Battery bank
AI-08	Voltage	0 – 24 VDC	Generator battery
AI-09	Power	230 VAC, 0 – 60 A	Cafeteria demand
AI-10	Power	230 VAC, 0 – 60 A	Accommodation demand
AI-11	Power	230 VAC, 0 – 60 A	Total demand
AI-12	Power	230 VAC, 0 – 60 A	Generator supply
DI-01	Low level	ON/OFF	Fuel level (Fuel tank)
DI-02	High level	ON/OFF	Fuel level (Fuel tank)
DO-01	Switch	ON/OFF	Main power
DO-02	Switch	ON/OFF	Battery bank
DO-03	Switch	ON/OFF	Fuel pump
DO-04	Switch	ON/OFF	Generator
DO-05	Switch	ON/OFF	Water pump

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