A case study of SCADA implementation for small electrical producers in WideQuick

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Abstract

The escalating demand for electricity requires the deployment of reliable, secure, and efficient energy production methods. This master thesis explores the utilization of Supervisory Control and Data Acquisition (SCADA) systems in power plants to meet these requirements. The primary objective is to investigate the specific requirements for implementing a SCADA system in the power production sector, drawing insights from a comprehensive literature review.

Building upon the literature findings, the following phase of this thesis involves assessing the feasibility of incorporating identified requirement specifications into the WideQuick software developed by Kentima AB. To ascertain this, a small-scale demonstration program will be created within the WideQuick environment. This demo program aims to simulate the control and supervision aspects of a small hydroelectric power plant.

The research comprises a two-fold investigation: firstly, an in-depth analysis of SCADA system requisites based on existing literature; and secondly, a practical exploration into the adaptability and functionality of the WideQuick software for SCADA implementation within a hydroelectric power plant context. By integrating theoretical insights with hands-on application, this thesis aims to contribute valuable perspectives in the use of SCADA systems in power production, and software implementation.

Keywords: Supervisory Control and Data Acquisition, SCADA, power production, automation, control, WideQuick, hydroelectric power plant

Sammanfattning

I takt med en ständigt ökande efterfrågan på elektricitet ökar kraven på att hitta säkra, pålitliga och effektiva sätt att producera energi. Detta examensarbete utforskar hur användningen av Supervisory Control and Data Acquisition (SCADA) system används i kraftverk för att möta denna efterfrågan. Det primära målet för rapporten är att utforma en lista med kravspecifikationer vid implementering av ett SCADA system i kraftproduktion. Dessa kravspecifikationer kommer att tas fram efter en omfattande litteratur genomgång.

Vidare kommer möjligheten att implementera ett SCADA koncept i WideQuick, en mjukvara utvecklad av Kentima AB att undersökas. SCADA konceptet kommer utvecklas i linje med de kravspecifikationer som identifierats i litteraturstudien. För att fastställa om WideQuick lämpar sig för uppgiften kommer ett demonstrationsprogram att utvecklas.

Undersökningen är uppdelad i två delar, först en granskning av vilka kravspecifikationer som ställs vid utvecklandet av ett SCADA koncept för kraft produktion baserat på befintlig litteratur. Vidare kommer en demonstations applikation ge en praktisk indikation på lämpligheten av att använda WideQuick vid en implementation av ett SCADA system för kraftverk. Genom detta tvärvetenskapliga tillvägagångsätt syftar avhandlingen till att bidra med värdefulla insikter vid implementering, utveckling samt krav på ett SCADA system inom kraft produktion.

Nyckelord: Supervisory Control and Data Acquisition, SCADA, kraft produktion, automation, kontroll, WideQuick, Vattenverk

Acknowledgements

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David Karlsson

Contents

1

Introduction

The principal objective of this master's thesis is to formulate a requirement specification for a SCADA system tailored to a small hydroelectric power plant. Additionally, the study aims to assess the suitability of the WideQuick software in implementing these specified requirements for the development of a SCADA concept within the context of a power plant.

1.1 SCADA systems

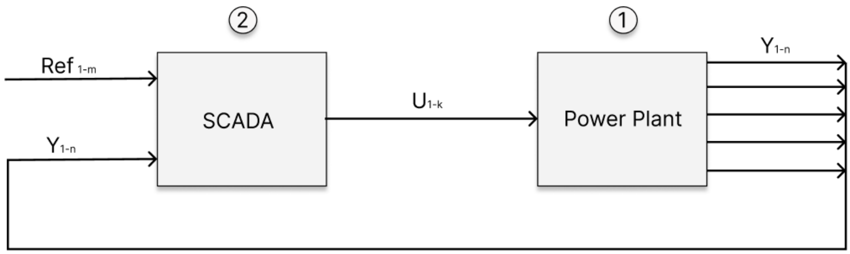

Figure 1.1 System overview

In figure 1.1 an overview over the operational framework for a system is presented. Illustrating the interaction between the power plant and the Supervisory Control and Data Acquisition (SCADA) system. In the power plant sensors or meters will be used to measure vital signals. These signals will be sent to the SCADA system where they will be displayed to the user through a human machine interface (HMI) and stored in a database to be able to view history from the power plant. The SCADA system will also have some reference values Ref_{1-m} of what the measured signals should be, by comparing the incoming signals Y_{1-n} with the reference values the control signals U_{1-k} can be generated in the SCADA system and sent to the power plant. These control signals will be able to control parts of the power plant depending on the correct action.

1.2 Scope

This paper will aim to give an overview of the general use of SCADA systems in power systems. However, it will not delve into specific details about a typical SCADA system in the power sector. However more focus will be on the use of SCADA systems for electricity producers, especially for small hydroelectric plants. As this will be the main focus point of this paper. For the SCADA demo program that will be developed during this paper, will only represent the control and supervision of some key parts of a hydroelectric power plant, with a few selected signals, much fewer than for a fully operational plant.

2

Background

In this chapter an overview of the electricity system will be presented and a brief forecast of the electricity consumption. Then some background on Kentima AB their software suite, and the other software that will be used in this project. Followed by a list of acronyms.

2.1 Electricity outlook

The electricity consumption in the world is at an all time high with an average increase of 2.4% per year in the last decade, and is expected to continue to rise with 1.8 - 2.7 % each year between the years 2030 and 2050 [IEA, 2022].This rise in electricity usage will inevitably lead to an increase in greenhouse gases being released into the atmosphere, hence contributing to warming the planet, unless the way we produce electricity changes. According to [Bala, 2022], a key component in reducing carbon emissions from the usage of electricity is to automate the entire power system. This change from manually operating the power system to an automatic operation is well on its way. Furthermore, with increasing awareness and a will to act against climate change, the share of renewable energy in the power system will increase as the production cost of these power systems goes down [IEA, 2022].This will likely lead to more decentralized electricity generation, with more small-scale producers [H.A.Gabbar, 2017]. To utilize the full capacity of these power producers, they need to be run efficiently. In most cases, a SCADA system installed in the power plant can reduce both the labor time and the maintenance cost [Bala, 2022].

Kentima AB

Kentima AB is a company active in the automation and security sector located in Staffanstorp, Sweden. The company develops and sells many different products. Including HMI-panels, software suites to develop HMI/SCADA/Physical Security Information Management applications along with server racks and more. Today they offer a SCADA concept for Building management systems (BMS), and Kentima AB wants to offer a power SCADA concept to their customers, as the interest for such a product have risen among their existing and potentially new customers. This report aims to see what the requirements for such a SCADA system would be, and if it's feasible to implement in their software collection WideQuick, an explanation to the software is given in section 2.2.

2.2 WideQuick software collection

The WideQuick software collection is comprised by four different programs, WideQuick Designer, WideQuick Runtime, WideQuick Remote client and WideQuick Web client. A brief explanation of these are given below.

WideQuick Designer

The developer tool for designing and commissioning a SCADA application, in figure 2.1 the user interface can be viewed. Here the operator can design the system they want to monitor, while also deciding what should be monitored. In the designer software scripts, tags, schedules and configuration of databases can be done. There is also a built in support for open platform communications (OPC), that will be used in this project, more specifically OPC Unified Architecture (UA).

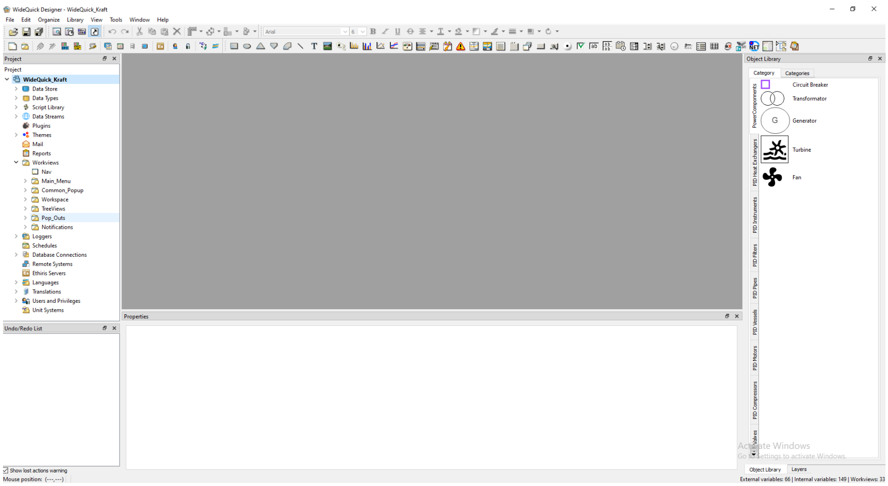

Figure 2.1 WideQuick designer user interface

WideQuick Runtime

Runtime is the software that runs the application of the user, on either a server the HMI-panel, Linux or windows machine. Essentially, it serves as the interface through which operators in the plant or control room interact with the system

WideQuick Remote Client

Is a user application that uses native protocols to connect to a runtime application or service that allows remote connectivity for one or more users and projects to link with a target system. This software empowers the configuration of these systems from a distance.

WideQuick Web client

Allows the operator to interact, and run the application developed in WideQuick designer though the use of any web browser as a client to WideQuick Runtime.

2.3 Other software

Integration objects OPC UA server simulator

Integration objects has developed a OPC UA server simulator that allows multiple clients to connect to the same server, enabling the user to both read and write values in real time to variables located in the server. The user can configure the server variables, both by name and type to create server variables that is fitting for the specific use. In essence the server simulator resembles the communication a PLC or another controlling unit would have in a real use situation.

Matlab

Matlab is a high-performance programming language and environment primarily used for numerical computing, data analysis, algorithm development, and visualization. With the add-on Industrial Communication Toolbox, it is possible to communicate to an external server using OPC UA, this is something that will be used in this project.

2.4 DB Browser

DB Browser is a open source database management system, that sets up a database, and is based on SQLight. It will be used in this project to store relevant data in a database, as it is easy to set up and use.

2.5 Acronyms

Acronym	**full length word**
IED	Intelligent electronic device
RTU	Remote terminal units
PLC	Programmable logic controller
SCADA	Supervisory control and data acquisition
HMI	Human machine interface
EMS	Energy managment system
ACG	Automation generation control
MTU	Master Terminal unit
CB	circuit breakers
DMS	Distrubution managment system
EDC	Economic Dispatch Calculation
ITS	Interchange Transaction Scheduling
OPC	Open Platform Communications
OPC UA	Open Platform Communications Unified Architecture
RPM	Rounds per minute

Table 2.1

3

Method

In this chapter the method used in this paper will be described. To see if it is possible to implement a SCADA system for power generation, a list of requirements need to be set up. Leading from this, a demo of a SCADA system will be created in WideQuick designer, using simulated data to represent a small scale power plant. This is done to determine if WideQuick is a suitable software to implement a SCADA concept for the power generation sector.

3.1 Requirement specification

Before any development can be made with the demo program, a list of requirements need to be defined for hydroelectric power generation. This will be done by an extensive literature review, taking into account what is used in industry today, and what is required for a SCADA in the power sector. It's important to note that this list will include the most vital functions for a SCADA in the power generation, however this does not limit more functions being added when implementing the SCADA concept in the industry.

3.2 Data simulation

The data will be simulated using Matlab and sent to WideQuick using OPC UA tags. The data will be simulated to represent certain aspects of a small hydroelectric power plant, with the main focus on simulating signals to and from the generator. Additionally, some parts of the turbine will also be simulated. This will be done by a combination of collection data from commercially available products, and the literature review.

3.3 SCADA program

Leading from the list of specifications, a demo will be set up where the crucial parts of a hydroelectric plant will be monitored, although this will not be the full representation of a real hydroelectric power plant, the demo with a few chosen sensors will work as a proof of concept, if it's feasible to implement a SCADA concept for power generation in WideQuick. The data to the sensors will be simulated through a OPC UA connection, as described in the previous section.

4

Literature review

This literature review will be divided into three different parts, first the concept of SCADA will be presented, the history and where it is currently being used, followed by an explanation of the common components in a SCADA system. Then the benefits of using a SCADA in power systems, and more specifically for electricity generation will be presented.

4.1 SCADA

Supervisory Control and Data Acquisition (SCADA) systems have been used in industry since the 1960s, as the need to control and monitor different industrial processes grew as the industries became larger and more effective. At this time, the SCADA systems were more basic and not the complex system we can see in present time. Today however, a SCADA system can contain thousands of sensors and measurement points, and are growing more and more complex. [Ujvarosi, 2016] SCADA systems are today used in a wide variety of industries, as the system gives the opportunity to collect and analyze many industrial processes, and control parts or the whole operation remotely[Hieb, 2008]. This is useful, especially for systems that are spread out on a large geographical area such as power systems, more on this in section 4.2. The architecture of SCADA systems has crystallized into a relatively stable and well-defined structure. Compromised of several devices, and while it's possible to add more components in a system the basic components are: Programmable Logical Controller (PLC), Remote terminal units (RTU), Telemetry system, Human machine Interface (HMI), Data acquisition server, historian service, and a supervision center.[Ujvarosi, 2016]

Programmable Logical Controller

A Programmable Logic Controller (PLC) can be compared to a robust and durable industrial computer. It is frequently used in automation processes and tasks characterized by repetition, time sensitivity and real-time operation, such as assembly lines. The extended lifespan and resilience of PLCs make them well-suited for operation in challenging and harsh environmental conditions.[Apar Agrawal, 2019]

Remote terminal units

The primary function of the Remote Terminal Unit (RTU) is to convert data obtained from field sensors within a SCADA system into digital signals. Subsequently, the RTU transmits this data through the telemetry system to the central supervision and control center.

Telemetry system

This refers to the communication protocol and the connection used by the SCADA system for communication between stations, substations, and the central supervision and control center.

Human machine interface

The human machine interface is the physical device that display the data, and the system, so that a human operator can oversea the system.

Data acquisition server

The data acquisition server serves as a crucial component within the SCADA system, responsible for gathering data from both the substations and the RTUs. Its primary role is to transmit this collected data to the central supervision and control center, effectively functioning as the communication bridge in the SCADA system[Society, 2007]

Historian service

Is the part of the SCADA system that can store data to a database. This is a crucial part of a SCADA system as it allows the user to look back at the operation over a certain time period. This can be represented by graphs, table or other practical ways to present the data

Supervision control

This is the main part of a SCADA system, and is also called Master Terminal Unit (MTU). It is the part that can communicate with all different parts of the system, and also control them. This is generally a central computer, that is the main "brain" of the system. [Ujvarosi, 2016]

4.2 OPC UA

In many industrial plants the communication protocol is spread across many hierarchical layers, and are not unified. Therefore to allow different parts of the plant to communicate with one another, a unified communication protocol is needed. The Open platform communications unified architecture (OPC UA) is a communication standard, that is independent of the platform. With extensive capabilities to handle the communication in a plant, regardless of the different communication protocols each individual component has.

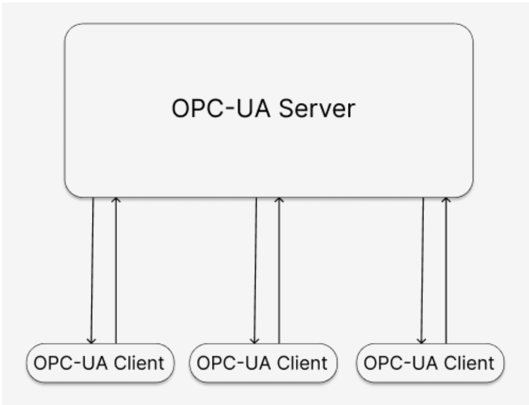

Figure 4.1 OPC UA hierarchy

OPC UA work on top of established transport protocols such as Ethernet, and therefore works like a middle ware. In figure 4.1 the hierarchy of the OPC-UA communication is shown. The connected clients can both recive, and send information to the server. Allowing the clients to communicate with one another though the server, and therefor the same protocol. An OPC UA server also allow the clients to subscribe to a variable on the server, on per example when a variable changes value. [Bauer et al., 2021]

4.3 SCADA in Power systems

SCADA systems are used in all parts of the power system, from generation and transmission to distribution. The reason for this is that there are several advantages in automating parts or the whole power system. However, the following list highlights the advantages of implementing a SCADA system in a power plant

- Minimizing the operational cost, as a larger part of the operation is automated, requires fewer personnel to manage the system.

- Lower the maintenance cost for the system, since the maintenance can be done more effectively, and the need for maintenance can be overseen by the system. This leads to a effective handling of the equipment, which lowers the overall maintenance cost.

- Shorter downtimes in case of a power surge, as the faults can be detected faster, and action can be taken immediately.

- Better control over reactive and active power, as the values can be quickly and correctly calculated by the system, and the correct action can be taken.

- An overall faster decision making, as the logic of the system can make split second decisions, where a human operator would need time to consider what actions need to be taken for a specific situation.

- The reduction of human error, since the SCADA handles both the reading and control of the machines.

- An increase in safety is observed for system operators and maintenance personnel. Given the high voltage levels, the capacity to control components remotely, along with faster fault detection and correction, significantly enhances overall safety.

[Mini S. Thomas, 2015] [Hieb, 2008] [Bala, 2022] While the basic functions of a SCADA in the power system, are as described for a general SCADA in the previous chapter. There is also more advanced functions to a SCADA used in the power system. This can be illustrated in figure 4.2,Where SCADA is employed to manage a substation at the distribution level

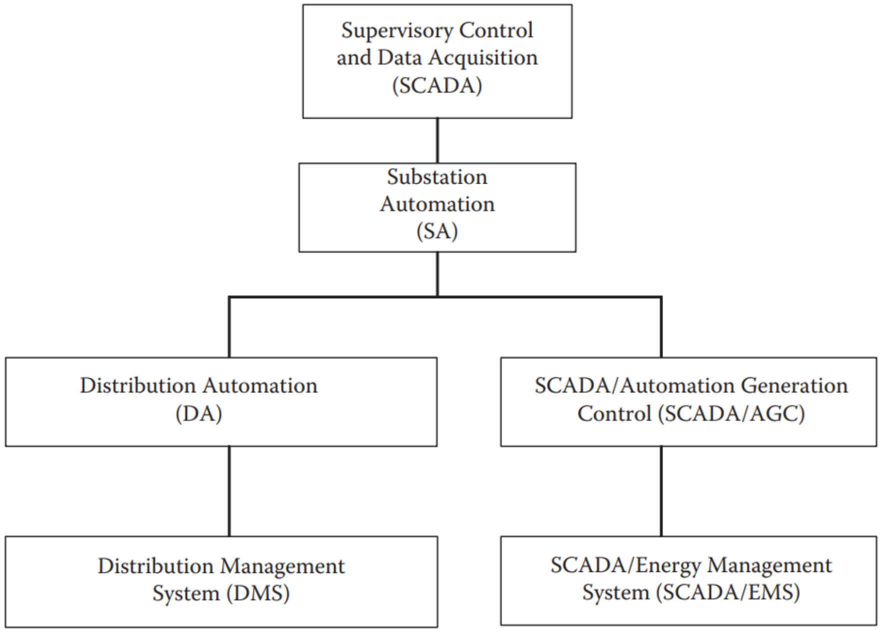

Figure 4.2 Hierarchical representation of SCADA for a distribution-level substation.

The right side of the figure represent the SCADA/AGC (Automation Generation Control), this is the part that is placed at the generation control center, and it is mainly this part that will be the focus point for this paper, with some of it's most important tasks being the following.

- Automated generation control: a collection of software and hardware that oversee and control the frequency, and interchange of power from the generation unit to the power grid.
- Economic Dispatch Calculation (EDC): Efficiently planning the allocation of power from various available sources while keeping costs as low as possible without compromising security or safety
- Interchange Transaction Scheduling (ITS): Guarantees that there is an adequate supply of energy and capacity to meet the demands and requirements of the load
- Hydro-thermal coordination: The power scheduling from the available sources in a way to minimize costs withing the limits of the water reservoir.

[Mini S. Thomas, 2015] Further down on the right side of the figure the SCADA/Energy Management System (EMS) can be seen. This is a type of software used in the control center of a power grid, either in the transmission and/or generation. The primary purpose of the software is to oversee and enhance the efficiency where it is used.[Perez, 2010] The complexity and cost of the different parts increase the further down they are in the figure. With the substation automation, being the least complex and cheapest. and the Distribution Management System (DMS) and SCADA/Energy Management System (SCADA/EMS) being the most complex and most expensive components of a SCADA in a power system.

Reactive and Active power

The control of active and reactive power is important for the power sector. As an increase of reactive power does not contribute to more apparent power, i.e power that can be utilized by the user of the grid. Instead the $R \cdot I^2$ losses will be increased without any gains in the available power, as the reactive power cannot be transported over large distances. The deciding factor for how much active and reactive power is present in a system is the phase angle (θ) between the current and the voltage this is represented in 4.3.

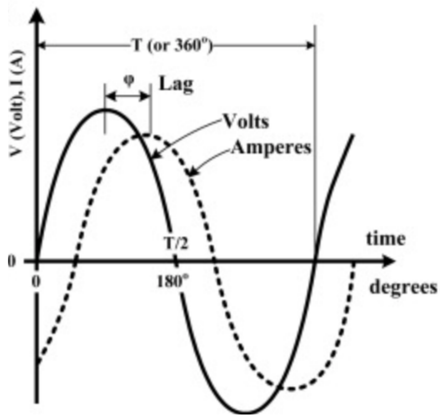

Figure 4.3 Phase angle, the lag between current and voltage

The amount of reactive and active power in the system as described in equations (4.1) & (4.2) from these equations it is clear that the reactive power will increase as the value for sin(θ) increase, with the maximum amount of reactive power being generated when the phase angle between the current and voltage is 90°. While the active power instead depends on cos(θ) leading to a maximm value while the voltage and current a completely in phase, having the phase angle 0°

$$P_{Active} = P \cdot cos(\theta) \tag{4.1}$$

$$P_{Reactive} = P \cdot sin(\theta) \quad (4.2)$$

However while it is generally true that the reactive power is kept at a low level, for a generator of a smaller size that is synchronized and connected to a larger power system, a certain amount of reactive power is needed to keep the voltage from the generator constant. While also avoiding any over current in the generator, that might destroy or damage the generator.[Singal et al., 2023]

Circuit breakers

A circuit breaker is a unit with two operational states, closed or open, during normal operation or when a fault occurs. It is designed in such a way that, during normal operation it can be closed and opened manually, this is something that is useful when performing a maintenance in the system. However when a critical fault occurs, the circuits breakers should open automatically, to protect the components in the system, and any eventual humans that is in proximity to the fault. [Mariesa L. Crow, 2004]

Alarms

The ability to monitor the signal values from integral parts of the plant, e.g generators, turbines etc, is vital. Along with the monitoring, alarms should be in place to signal the operator if a certain value is avoiding from the ideal value. If the measured signal deviates to much, certain actions should be automatically deployed.

Monitored value	**Action taken**
Too low	trip
Low	Alarm
High	Alarm
Too high	trip

Table 4.1

A combination of alarms and circuits breakers or the ability to shut down a process can be useful in the system.[Power and Society, 2022] This combination of the two components is illustrated in table 4.1, where the "trip" action is the opening of the corresponding circuit breaker.

4.4 Electricity producers

Electricity generation facilities exhibit considerable diversity in terms of both scale and energy sources. This diversity encompasses a broad spectrum, ranging from smaller micro-producers with the capacity to generate only a few kilowatts (kW) to expansive facilities capable of producing several gigawatts (GW) of electricity. Moreover, the sources of energy utilized by these facilities span a wide array, encompassing conventional fossil fuels such as coal, oil, and gas turbines, as well as renewable energy sources like wind power, photovoltaic (PV) panels, and hydroelectric power.

In order to provide context for the subsequent discussion pertaining to the application of the SCADA system, this section will commence by offering a succinct overview of small-scale electricity producers. Subsequently, it will delve into a more comprehensive examination of hydroelectric power plants

4.5 Small electricity producers

According to the International Energy Agency (IEA) a small electricity plant, is a plant that has less than 10MW installed power.[IEA, 2016] The amount of small scale electricity producers have gone up in recent years, as the share of renewable energy has increased in the electricity mix, and a lower price for solar PV, and wind power. Leading to a more decentralized market, with an increase of small scale plants. This increase is expected to continue, with the added benefit that decentralization of the electricity generation in many cases leads to climate benefits. These benefits come both from the fact that electricity can be produced closer to the end user leading to a lower impact on the distribution grid, and lower losses. A vast majority of the smaller plants installed today, generate electricity from renewable sources.[Karger and Hennings, 2009]

4.6 Hydroelectric power plants

Hydroelectric plants, are often seen as the worlds most mature technology for generating electricity from renewable sources. Hydro power is generated by moving bodies of water, led to the generation station by a funnel or channel. There the water hits the ends of a turbine, or wheelhouse making the shaft to rotate. The kinetic energy can then be converted to electricity, by connecting it to a generator, which can be both asynchronous and synchronous depending on the plant, more on this in the the next chapter. Hydro electric plants stand for about 97% of all electricity generated form renewable sources. In Sweden hydroelectric power plants is the largest source of electricity, producing 43% (70.6 TWh) of the total electricity generation in Sweden 2021.[Langlet, 2022] Approximately 1,900 small hydroelectric power plants are in operation in Sweden, and while the total amount of electricity generated from these smaller plants are limited accounting for about 1-2% of electricity generated world wide, even so they play a role to keep up the grid stability where they are installed. [Manzano-Agugliaro et al., 2017]

Asynchronous or Synchronous generators

Both synchronous and asynchronous (induction) generators can be used in a hydro electric plant. The main difference between these, is that the synchronous generator, keeps the same frequency as the grid when connected. This is because the generator is connected directly to the grid, with no gears. This means that the speed of the turbine needs to be constant, when synchronised to the grid. However the opposite is true for asynchronous generators, where the speed of the generator can vary. This is made possible by the use of gears in the generator. Generally if a hydroelectric power plan has less than 2 MW output usually asynchronous generators are used in the generation of electricity. Also the most cost effective voltage level for hydro power plants of this size is 400V [Singal et al., 2023] However for a larger plant between 3-10MW, synchronous generator are most often used, and the most cost effective voltage of from the plant is 6.6kV. The higher rating will be used in this project.

4.7 Requirement specification

A rigid and well defined requirement specification is important in the development of a new SCADA application. Not only to the end user, so stability and standards can be met safely, but also in the development in it self. To be able to know for sure that the developed program meets the demands, and expectations from the industry. The following list have been based on a literature review, and is specific for hydroelectric power plants, however with small modifications, can be applied to many other small power plants.

- Protection of turbine. Monitors the turbine, to be able to create reports if the turbine malfunctions, if the error is severe, the turbine should disconnect, not to hurt personnel or the equipment.
- Control, and monitoring of reactive and active power. This is done by algorithms in the SCADA software
- Continuous monitoring of frequency, to be sure it is the same as the grid, when connected.
- Continuous monitoring of current and voltage output.
- Planning of generation operations, taking into consideration the load of the system at the specific time.
- Monitoring of the water levels in a damn, applied only to hydroelectric power plants, with a dam present.
- Fault detection and fault reporting.

- Circuit breakers (CB) control on/off
- Collection and display of historical data

[Sayed, 2017] [Power and Society, 2022] [Bala, 2022] With these conditions met, a safe, reliable and effective SCADA could be developed using the SCADA concept in WideQuick. More functions might be desired to fit the needs of a specific plant, and this requirement specification does not limit the additions of other features. It should rather be seen as a foundation with the most fundamental features for a SCADA in power generation.

4.8 How to collect/simulate data?

The simulated data will represent a small scale hydroelectric power plant, this part will represent the power plant in the system overview showed in figure 1.1, refer to figure 4.4 as it shows the highlighted part of the system.

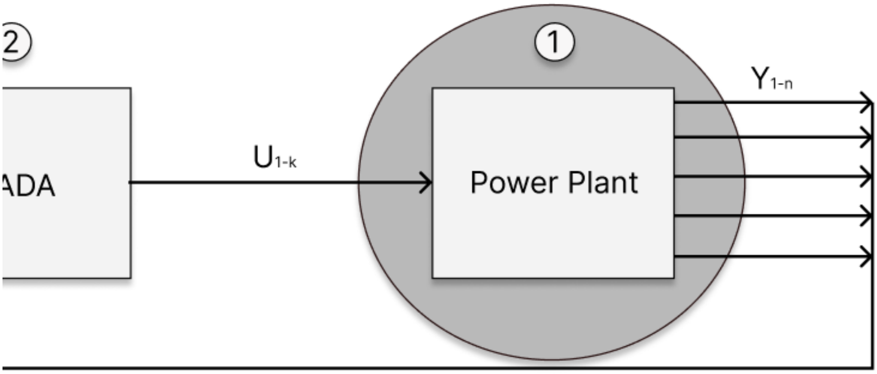

Figure 4.4 Focused view of a power plant within a broader SCADA system

The simulation will be conducted in Matlab, with the primary focus on signals to and from the generator, including current, voltage, and the phase angle between them. Additionally, data from the turbine will also be considered. More information about the data is provided in the next section. The data will be communicated to WideQuick using OPC UA in appendix A, the Matlab code used in the simulation can be viewed. where the data to the different variables, representing the values from the sensors on a power plant. For some of these variables the value will be changed in such a way that their values go from the ideal values to either to low, or to high values. These fictional data points are chosen in such a way that the SCADA concept will be able to showcase the functionality, when the data is outside the specified interval. These Data intervals will be showcased and discussed briefly below, however it is of importance to note that the actual intervals when applying this SCADA concept to a real world situation, can be chosen any way the operator seem fit. The flexibility in this regard is very important as different sized plants inherently have different ideal operation conditions, and also how large of a safety margin is needed.

Data

The data will be chosen to resemble what the actual data could be in a small hydroelectric plant with a synchronous generator. To get the most realistic values a commercially available synchronous generator by [Leroy-Somer, 2024] for hydro electric plant is used as a reference. The generator has a rotation speed of 750 rounds per minute (rpm), and power output of 3.5 MW. Using the rule of thumb for the calculation of voltage level for a synchronous generator covered in the literature review, the appropriate voltage level for a 3.5 MW generator is 6.6kV. The relation between voltage, current and power in a three phase system, is given by the equation 4.3, where P_G is the power output from the generator, V the voltage and I the current.

$$P_G = \sqrt{3} \cdot V \cdot I \rightarrow \frac{3.5MW}{\sqrt{3} \cdot 6.6kV} = 306A \tag{4.3}$$

from equation 4.3 the current from the generator is 306 A if the generator is outputting the nominal power. However to not overload the generator the turbine is usually has a 10% lower maximum power output than the generator [Singal et al., 2023]. Therefore the current peak for each phase will be set to 275 A during maximum production.

The following numbers are taken from the literature review as well as the commercial generator unit, the default value will be the following:

- Voltage - 6.6 [kV]
- Current - 275 [A]
- Frequency - 50 [HZ]
- Turbine speed - 750 [RPM]
- Power - $U \cdot I$ [VA] = 3.5 [MVA]
- Phase Angle θ = 0-90°
- Active power = $\sqrt{3} \cdot V \cdot I \cdot cos(\theta)$ [W]
- Reactive power = $\sqrt{3} \cdot V \cdot I \cdot sin(\theta)$ [VAR]

When connecting the synchronous generator to the grid, the following conditions must be met. with the general accepted margin of error. During the operation of the SCADA these values will need to be monitored continuously.

- Same phase count
- Same phase sequence

- Same voltage $\pm$ 5%
- Same frequency $\pm$ 0.1Hz
- same phase angle $\pm$ 10°

5

SCADA program

5.1 Program in WideQuick

In this chapter the demo program that incorporate the SCADA concept for power generation in a hydro electric plant will be presented.

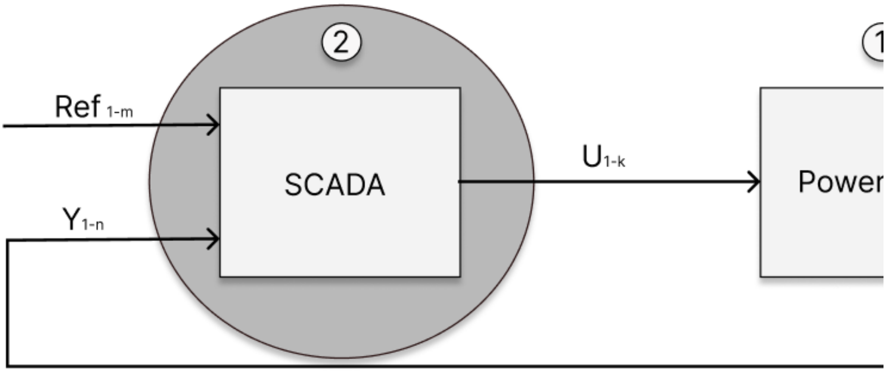

Figure 5.1 SCADA

The program will represent the highlighted, SCADA section in figure 5.1. Firstly a background on the layout will be presented, followed by the different parts of the program. It's important to note that the modules that are a part of the SCADA concept are built in consideration to the the discoveries made in the literature review, what is important, and needed in a SCADA concept. However while a fully functioning SCADA program in real use, could have hundreds of sensors, this number will be heavily limited, as this only will work as a proof of concept.

5.2 Program foundation

The foundation of this program will be based on a masters thesis written for Kentima, about a SCADA concept for waste water treatment written by [Kvist, Markus and Vikstrand, Johan, 2022]. However, even if the foundation, and layout will be similar the concept of using it for power generation is unique, and the program will have to be modified to work as intended.

5.3 Object library

In WideQuick an object library with graphical objects, that also may have embedded scripts can be created, and will be for this project. The object library will have some of the symbols that will be needed to make a SCADA system for power generation. Some of the more important components, and that will be used in this master thesis is included in the following list. Below each component is the list with signals that will be monitored.

Generator

- Oil level
- temperature
- fan speed
- Active/Reactive power
- Voltage/Current in each phase.

Turbine

- Temperature
- Fan speed
- Rotation speed
- Water flow to the turbine

Transformer

- oil level
- fan speed
- temperature

5.4 Alarms

For the operator to get an overview over potential faults or malfunctions in the system, alarms will go of when a sensor reads a value outside the expected range. When an alarm has gone off, the option to send it via email, or text message to the operator will be present. To see all of the alarms, the SCADA will have a alarm page, that displays all of the alarms. If need be, the operator can also acknowledge any old alarms, that have already been taken care of. The operator can also choose to which sensors the alarms should be triggered by, along with the limit values when the alarms should trigger.

5.5 Maintenance

In the maintenance section tasks for maintenance can be created by the operator. The task can either be cyclic, i.e recurring with a certain time interval, this can be useful when it comes to changing the oil in the generator, as an example. But also the option to add a single maintenance, to a component. When adding the maintenance, the user can choose for what component the maintenance should apply to, what type of maintenance and the deadline for the maintenance. All created tasks will be stored in a database, and will be able to be displayed in the maintenance page.

5.6 History

The ability to display and read historic data is an very important part of a power SCADA. On the history page of the program relevant data is to be shown to the operator though graphical and numerical representation. The following list states what will be shown on the history page.

- Electricity production over some historic period
- Historic Alarms
- Historic maintenance tasks.

To show the historical power production, a logger is used to register all the power produced in the generator. This data is saved to a database, and can be displayed to the operator. The operator have different choices for what time span they want to display, one day, one week, one month or one year.

5.7 Graphic representation

A graphic representation of a hydro electric power plant will be shown in this page, as different plants will be inherently different, the operator will have to build a representation of the specific plant, with all parts that is relevant. There will be ready to use symbols, for all the relevant parts of the system that can be used to illustrate the plant. Each graphical object will be associated with a component used in this project, i.e the generator, transformer etc.

5.8 Control and regulation

The ability to control and regulate parts of the power plant is a central part of a SCADA system. Therefore some selected processes will be controlled and regulated in this proof of concept program. One of the parameters that will be regulated is the temperature, of different components in the system. The regulation will be devised in the following way, when the component is under load, the temperature will increase linearly. However when a certain threshold value for the temperature has been surpassed, a fan will start leading to a decrease in temperature. The fan can have different speed settings depending on the temperature in the active component. Another aspect that can be regulated is the active and reactive power of the system. The regulation of these signals will possible though the control of the phase angle, between the current and voltage of the system. Lastly it will be possible to regulate the power output from the generator. This will be done by opening or closing the water gate to the turbine, if the gate is closed no water is running to the turbine, generating mechanical power to the generator. The changing parameter in the generator will be the current, that will rise and fall, with the opening and closing of the gate. To further showcase the width of control the SCADA system offers, the operator will be able to manually change these parameters, or let the SCADA system automatically regulate the system.

6
Result

In this section, the finished results from the three main parts of the program will be showcased, starting with the literature review, followed by the data simulation and lastly the demo program.

6.1 Literature result

From the literature review, it is clear that the standards for SCADA systems are very rigid, and can be recreated for a newly developed SCADA.

- History, the ability to review the history is one of the integral parts for any SCADA system used in a power production plant. By knowing the history of power production from previous years can give a strong indication of the amount of power that can be produced in the future, both at specific times and the total amount over the year. The history that should be available is not limited there, the maintenance history is another important aspect that needs to be documented.
- Automatic control, leads to an increase in the safety of the plants in case of a critical error. However not just safety is increased but also the life length of the components can be extended by automatically shutting down, or disconnect components in the event of a critical error, such as over voltage.
- Continuously monitoring, it's important to get continuously updates for important signals in the power plant. This is key for the automatic control to work as intended, but also the triggering of alarms and the display of current production values to the operator.

6.2 Data Simulation

The data simulation, was as previously mentioned implemented using Matlab, and communicated with the SCADA system using OPC UA though a OPC UA server, by integrated objects. Since OPC UA is used widely in a large amount of industries, and the use is increasing, the simulated values can be communicated, much like the values from sensors in a real power plant. The data simulation program, is designed in the following way: firstly the variables, such as fan speed, temperature and current are declared. Then all the nodes in the OPC UA server simulator is coupled with a node in Matlab. Then a loop is run, for a set amount of time, in which all the nodes with values that should be changed continuously, is updated with a new value. A total of 24 signals are simulated, and communicated to WideQuick from the Matlab script. For further detail of the simulation program in Matlab, see appendix A.

6.3 Demo program

under this section, every part of the program will be discussed separately, with figures showcasing the functionality and design of the different views. All the

Overview

The overview page is the starting page displayed on the HMI panel when the SCADA system is started.

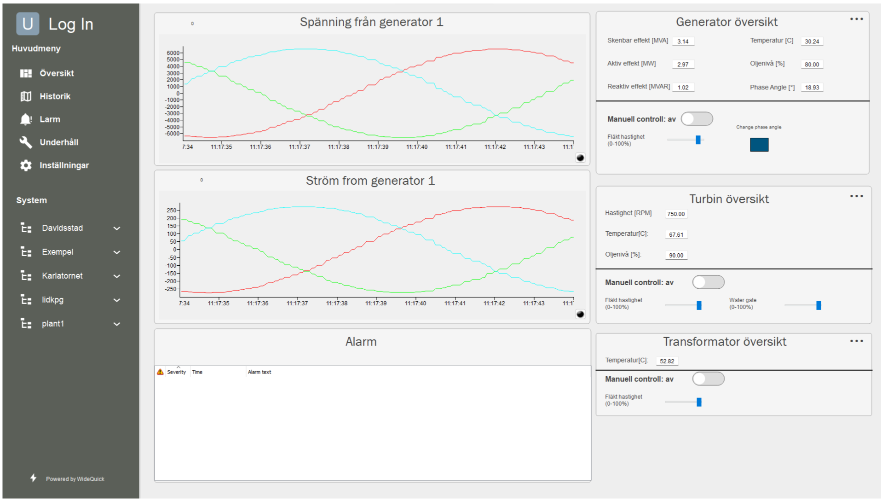

Figure 6.1 Overview page in WideQuick Runtime

As can be seen in figure 6.1 you can get an overview of many parts of the program using the overview page. The graph in the top left corner represents the three phase voltage from the generator, and the graph below represents the three phase current. On the right hand side of the figure, more information is available for the generator, transformer and turbine. The information includes temperatures, generated power, phase angle along with other values. It's also here that the operator can choose automatic or manual control, details about this can be read in the next chapter about control and regulation.

control and regulation

The manual control of the parameters in the generator, turbine and transformer can be done on the right side in the overview page displayed in figure 6.1. Figure 6.2 shows the control of the generator and turbine in a larger view.

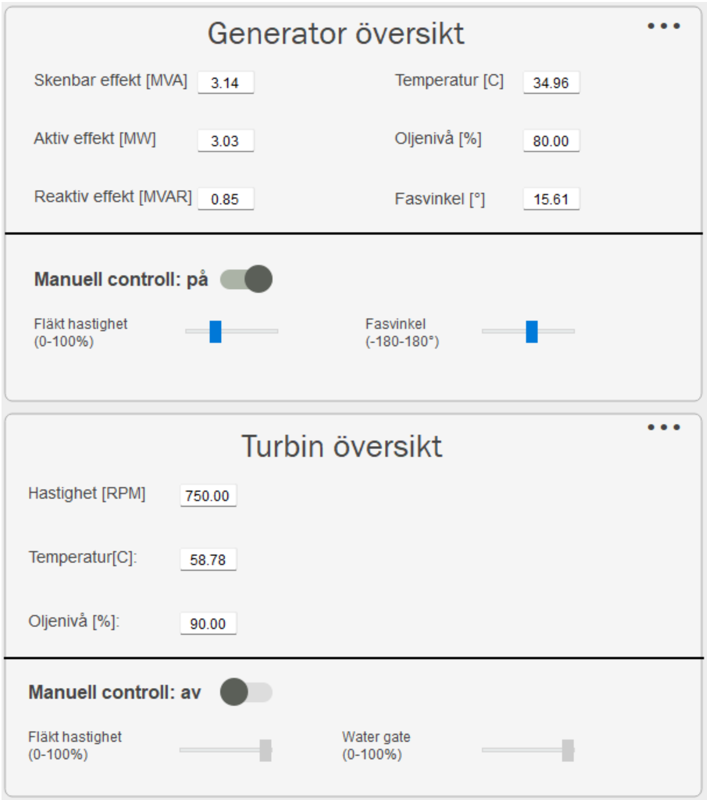

Figure 6.2 generator and turbine overview, with manual or automatic control

As seen in the figure manual control can be toggled on or of by the operator, and if manual control is switched on, the parameters such as fan speed and phase angle can be controlled by moving the sliders next to the corresponding variable.

If the automatic control is activated the fan speed is regulated as stated in equation 6.1, where F_g is the fan speed of the generator, and is always a number 0-100, if 0 the fan is standing still, and at 100 the fan is going in 100% of the maximum speed. T_g is the temperature, and IT_g is the ideal temperature for the generator.

$$F_g = F_g + \frac{T_g - IT_g}{4} \tag{6.1}$$

This closed control loop is affected by both the ideal temperature, and the current temperature. in equation 6.2 the temperature regulation based on the fan speed is described.

$$T_g = T_g + 0.1 - 0.12 \cdot \frac{F_g}{100} \tag{6.2}$$

The full closed control loop is represented in figure 6.3, when automatic control is chosen, this control loop can apply not only for the generator, but to the turbine and transformer as well.

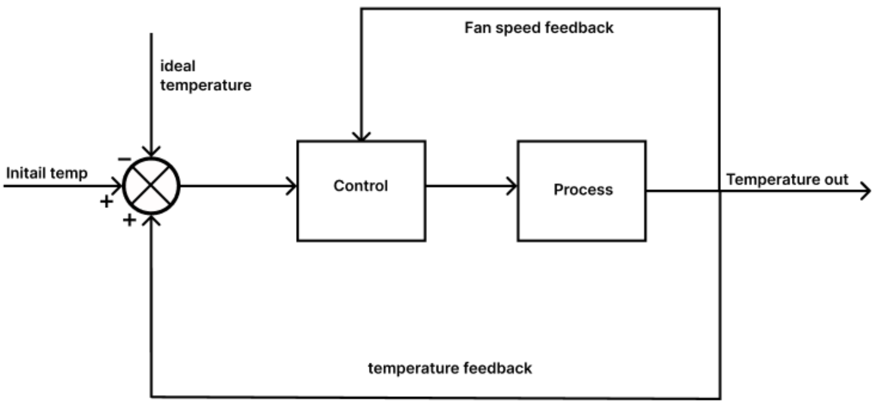

Figure 6.3 Closed control loop, for temperature regulation

Alarms

On the alarm page there is several instruments for the customization of the way alarms are displayed. The alarms can be filtered on severity, time or name, along with the ability to change font size, and column size.

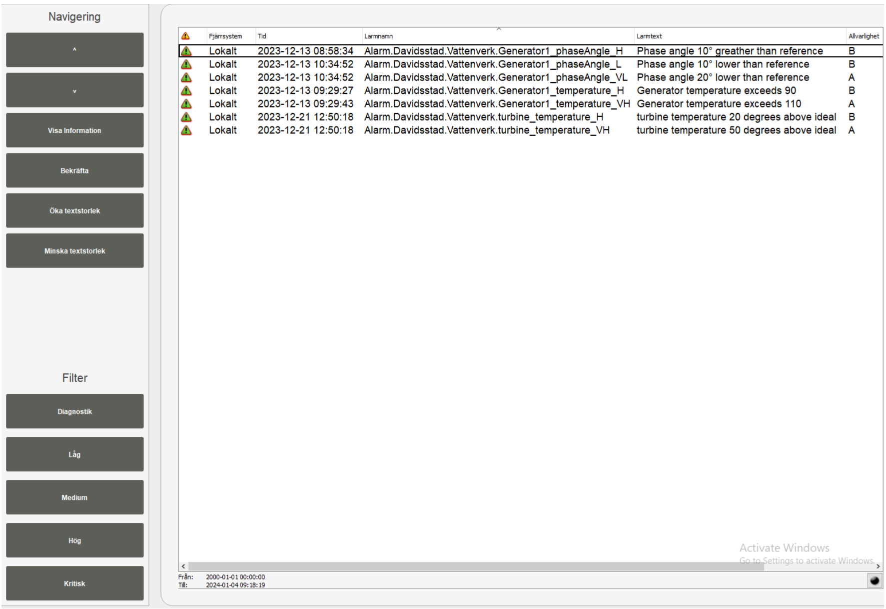

Figure 6.4 Alarm page in WideQuick Runtime

In figure 6.4 the alarm page is displayed, on the left hand side of the figure the filter, and navigation menus are located. In the list of alarm the most crucial information about each individual alarm can be viewed, such as location, time, what caused the alarm and the severity. The ability to acknowledge alarms are also available on the page.

Maintenance

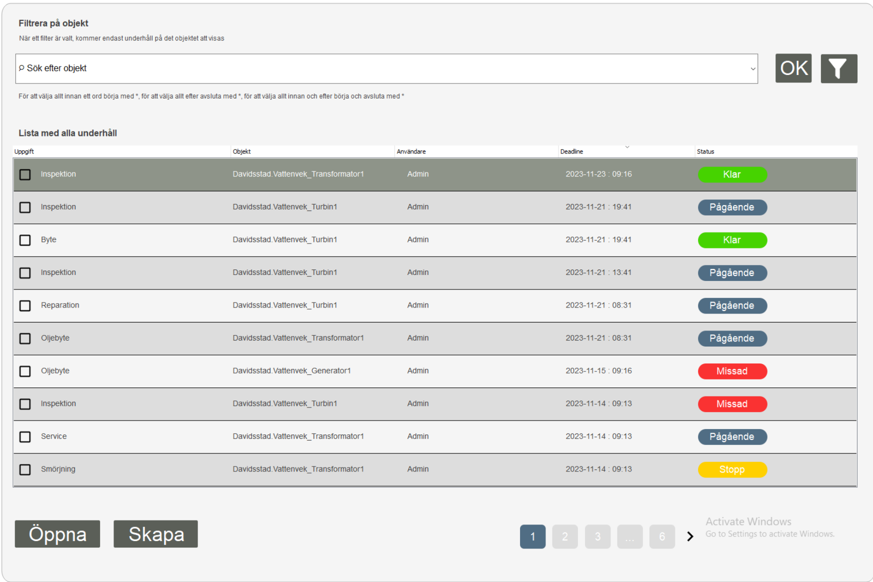

Figure 6.5 Maintenance list in WideQuick Runtime

In figure 6.5 the maintenance list is displayed. The operator can create new maintenance tasks and also edit the existing ones. As seen in the figure, each maintenance has a different status symbol. These are in reference to if the task has been done before the deadline, after the deadline, if it's still ongoing or if it has been stopped by the operator.

History

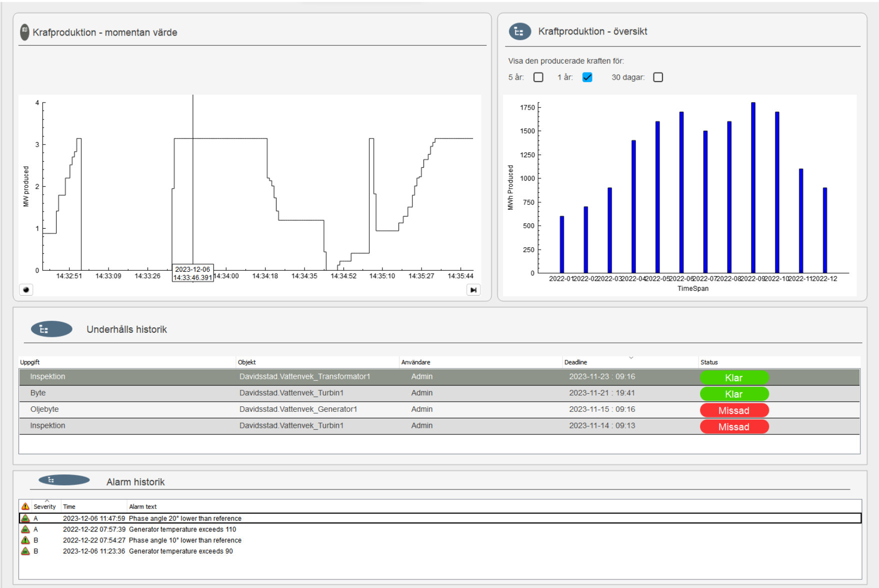

Figure 6.6 History page in WideQuick Runtime

In figure 6.6 the history page can be seen, with the historic power production being the bar chart in the top right.

The historic power production is implemented through the logging of data into a database and subsequent display on a SCADA page, this system transforms raw data into a format tailored for specific cases. For instance, power generation is initially measured in megawatts (MW). To facilitate a comprehensive view of power production on an hourly basis, the power generated at a specific time (in MW) is converted into the total power produced over an hour (in MWh). This adaptable system enables the display of data for various time intervals, as outlined in the accompanying table 6.3.

Total production during each:	**To see the production during the time period a:**
Hour	Day
Day	Week
Day	Month
Weak	Year
Month	Year
Year	Years

It is important to note that, due to the absence of historical data, the displayed information consists of simulated values.

On the lower side of the page, maintenance tasks that are no longer active are shown. Along with alarms that has been acknowledged and are no longer active.

Object library

In WideQuick interactive and graphical objects can be added to a library, allowing the operator to more easily build up a representation of a power plant. For this demo program the following objects was added.

- Turbine
- Fan
- Generator
- Circuit breaker
- Transformer

The design of these components and how the design of the simulated plant can be viewed in figure 6.7

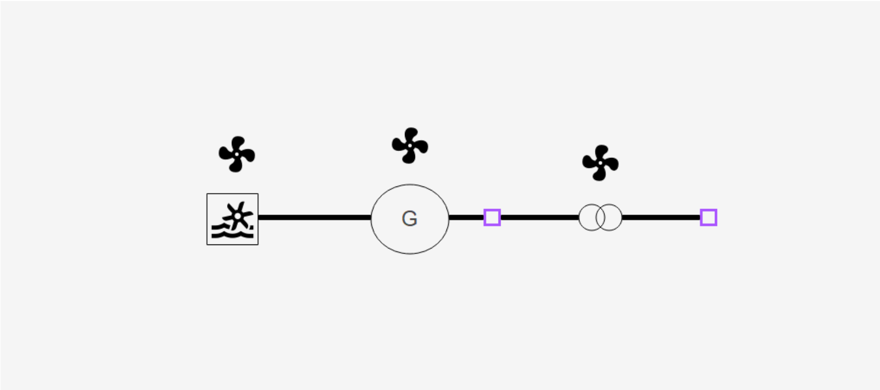

Figure 6.7 Graphic representation of the power plant, in WideQuick Runtime

7

Discussion & conclusion

In this concluding chapter, the initial focus will be on a discussion of the results and the methodology employed in this master's thesis. Following this, the conclusions drawn from the study will be presented, and finally, potential avenues for future research and enhancements to the current work will be outlined.

7.1 Discussion

Literature review

The literature concerning SCADA implementations in power systems, especially within power plants, is an established field with a wealth of existing and ongoing research. Despite its longstanding presence, there is a continual stream of recent studies contributing to the body of knowledge. As a result, a substantial amount of literature, containing both earlier and more recent research, provides a comprehensive understanding of the historical evolution of SCADA systems in power plants, their current applications, and the emerging standards in the field. However to get an even broader view of the field, and how the aspects of the SCADA system is applied in the industry, interviews with operators of power plants could have been conducted. This is also something that might have been valuable to do before the literature review to know if more focus should have been around certain aspects of the SCADA system.

Data simulation

The data simulation in Matlab proved to be effective for the objectives of this master's thesis, particularly in demonstrating a robust and dependable connection through a server using OPC UA. As previously noted, OPC UA is extensively employed in the industry, with a growing number of stakeholders adopting this technology.

Demo program

The communication successfully functioned in both reading incoming signals and sending signals to the OPC UA server. The demo program demonstrated competence in handling maintenance, alarms, history, and executing regulation and control tasks for the simulated power plant. Given that the primary objective of the demo was to establish a proof of concept rather than a fully operational SCADA system, it can be considered as meeting its intended goal. It is crucial to emphasize that this program provides only a glimpse of the comprehensive SCADA concept and falls short of representing the entirety of its potential functionalities.

7.2 Conclusion

The extensive literature review, combined with the ability to articulate essential aspects of a SCADA system tailored for small power plants, particularly in the context of a small hydroelectric power plant, marks a significant achievement. The successful integration of OPC UA communication in WideQuick, along with the demonstration of key components in the program, not only fulfills the primary objective of formulating a requirement specification but also leads to the conclusive determination that WideQuick is a fitting software platform for the development of a SCADA concept in this context.

7.3 Future work & improvements

While this master's thesis has concluded that implementing a comprehensive SCADA program for a power generation plant in WideQuick is highly feasible, there remains room for improvement and future work. Key areas for further development include:

- One avenue for future work involves the implementation of a closer-to-full-scale power plant, whether it be hydroelectric or another type, using Matlab or any other suitable simulation software. By doing so, the increased complexity arising from a larger number of sensor values and their intricate interactions could provide a more definitive assessment of the suitability of WideQuick for SCADA system implementation. This expanded simulation would contribute to a more thorough understanding of the platform's performance in handling the intricate dynamics of a comprehensive power plant environment.

- Conducting a more intricate simulation would offer significant benefits, particularly in running the program for an extended duration. This prolonged simulation period is crucial for ensuring that historical data, continuous control, and maintenance operations function as intended. This approach mirrors the operational dynamics of a real power plant where the SCADA concept operates over an extended period, providing valuable insights into the system's long-term reliability, stability, and performance.

- The graphical interpretation of the plant, coupled with the object library, is an aspect that requires substantial further development before reaching a finalized SCADA concept. Enhancements in this area are pivotal for refining the user interface and ensuring a comprehensive representation of the power plant's components. A more advanced object library would contribute to a more intuitive and user-friendly SCADA system, facilitating efficient monitoring and control of the power generation plant. Further refinement in this graphical representation is imperative for the overall success and usability of the SCADA concept.

The points mentioned above can be implemented either individually or in combination, depending on the desired scope and objectives. Each idea addresses a specific aspect of the SCADA system implementation, and combining them would result in a more comprehensive and detailed program. The flexibility to pursue these enhancements individually or collectively allows for a tailored approach to refining the SCADA concept, ensuring that each aspect is developed to meet specific requirements and goals.

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7.4 Appendix A - Matlab data simulation

https://github.com/DavidPEKarlsson/MatlabSimulation

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Title and subtitle

A case study of SCADA implementation for small electrical producers in WideQuick

Abstract

The escalating demand for electricity requires the deployment of reliable, secure, and efficient energy production methods. This master thesis explores the utilization of Supervisory Control and Data Acquisition (SCADA) systems in power plants to meet these requirements. The primary objective is to investigate the specific requirements for implementing a SCADA system in the power production sector, drawing insights from a comprehensive literature review.

Building upon the literature findings, the following phase of this thesis involves assessing the feasibility of incorporating identified requirement specifications into the WideQuick software developed by Kentima AB. To ascertain this, a small-scale demonstration program will be created within the WideQuick environment. This demo program aims to simulate the control and supervision aspects of a small hydroelectric power plant.

The research comprises a two-fold investigation: firstly, an in-depth analysis of SCADA system requisites based on existing literature; and secondly, a practical exploration into the adaptability and functionality of the WideQuick software for SCADA implementation within a hydroelectric power plant context. By integrating theoretical insights with hands-on application, this thesis aims to contribute valuable perspectives in the use of SCADA systems in power production, and software implementation.

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