YRKESHÖGSKOLAN NOVIA

# Investigation of a Power Plant Distribution System Controlled by PLC

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Degree thesis for Bachelor of Engineering

Degree program in Electrical Engineering

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**BACHELOR'S THESIS**


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**Abstract**

This bachelor's thesis was written for ABB's Energy Industries department in Vaasa. This thesis work is a part of the constant product development going on at ABB.

The main objective of this thesis was to execute an investigation pinpointing the theoretical benefits of integrating a micro PLC in the common control cabinet. This micro PLC would have the purpose of handling the synchronizing, interlock and position signals of the main circuit breakers in LV distribution systems.

Simulation is considered the key method of this investigation, together with meetings with various experts of the department. Several simulations and tests were done, this thesis will present a few of them.

The result of this thesis work is a presentation of the pinpointed benefits and challenges this PLC integration would bring. The result of the investigation is meant to function as a base argument, when deciding on whether it is beneficial to make this future upgrade on this product group. If ABB decides to implement this upgrade, this investigation will function as a base for them to work from.

The investigation and the result of it are considered sensitive material and will not be shared with the public.



Language: English Key words: PLC, power plant, distribution system

**EXAMENSARBETE**

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| Utbildning och ort: | Elektroteknik, Vasa |
| Inriktningsalternativ: | Elkraftsteknik |
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Titel: Undersökning av PLC-kontrollerat distributionssystem för kraftverk

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Datum: 9. april 2019 Sidantal: 32

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**Abstrakt**

Detta examensarbete har skrivits åt ABB:s Energy Industries avdelning i Vasa. Denna avhandling är en del av den ständigt pågående produktutvecklingen som sker hos ABB.

Huvudsyftet med detta examensarbete var att genomföra en undersökning som fastställer de teoretiska fördelarna med att integrera en mikro-PLC i common-kontrollpanelen.
Denna mikro-PLC skulle ha som uppgift att hantera synkroniserings-, interlock- och positionssignaler för huvudbrytare i LV-distributionssystem.

Simulering anses vara den huvudsakliga metoden för denna undersökning, tillsammans med möten med olika experter på avdelningen. Flera simuleringar och tester har utförts, denna avhandling kommer att presentera några av dem.

Resultatet av detta examensarbete är en presentation av de fördelar och utmaningar som denna PLC-integrering skulle medföra. Resultatet av undersökningen är tänkt att fungera som grundargument när man bestämmer om det är fördelaktigt att göra denna framtida uppgradering hos denna produktgrupp. Om ABB beslutar sig för att genomföra denna uppgradering, kommer denna undersökning att fungera som en grund att arbeta från.

Undersökningen och resultatet av den anses vara känsligt material och kommer inte att delas med allmänheten.

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Språk: engelska Nyckelord: PLC, kraftverk, distributionssystem

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**OPINNÄYTETYÖ**


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| Tekijä: | Adrian Ahlskog |
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| Ohjaajat: | Jan Berglund, Tony Bäck |


Nimike: PLC:n ohjaaman voimalaitoksen jakelujärjestelmän tutkimus


Päivämäärä: 9. huhtikuuta 2019 Sivumäärä: 32



**Tiivistelmä**

Tämä opinnäytetyö on tehty ABB:n Energy Industries-osastolle Vaasassa. Opinnäytetyö on osa ABB:n jatkuvaa tuotekehitystä.

Opinnäytetyön päätavoitteena oli suorittaa tutkimus, jossa tutkittiin, mitä teoreettisia etuja olisi mikro PLC:n integroinnilla common-ohjauskaappiin. Mikro PLC:llä olisi tarkoitus käsitellä katkaisimien synkronointi-, lukitus- ja paikannussignaaleja LV-jakelujärjestelmissä

Simulaatiota pidetään tämän tutkimuksen tärkeimpänä menetelmänä, sekä kokouksia osaston asiantuntijoiden kanssa. Useita simulaatioita ja testejä on tehty, ja tämä opinnäytetyö esittelee osan niistä.

Opinnäytetyön tuloksena esitetään PLC-integroinnin edut ja haasteet. Tutkimuksen tuloksen on tarkoitus toimia perustana, kun ABB päättää, jos tämä päivitys olisi hyödyllinen tälle tuoteryhmälle. Jos ABB päättää toteuttaa tämän päivityksen, tutkimus toimii heille pohjana työskentelylle.

Tutkimus ja sen tulos katsotaan arkaluonteiseksi aineistoksi, eikä niitä jaeta yleisölle.



Kieli: englanti Avainsanat: PLC, voimalaitos, jakelujärjestelmä

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# 1 Introduction

This bachelor's thesis has been written for the Energy Industries department at ABB Finland in Vasa. Energy Industries is a department that designs control and surveillance systems for power plants all over the world.

This chapter will contain a short introduction to the thesis in the form of the background that led to the need of this study, the purpose of the study and lastly a few words about secrecy and disposition.

## 1.1 Background

The idea for this study was brought up on a meeting between project engineers and their supervisors. The topic of the meeting was product development. A question was brought up on that meeting, this was whether there is a simpler way to automate the existing hardwired circuit handling the synchronizing, interlock and position signals for the LV main circuit breakers with less components. And whether it is beneficial making this change at all. This is what led to this study taking place.

It is a fact that global market demands changes as new technology gets researched. The environmental awareness is also a key factory when it comes to building a modern power plant. Combined with a strong focus on customer satisfaction, these two are strong focus points when it comes to designing automation systems for power plants. And with these two in mind it is clear that to be able to keep up with all these new customer demands and competitors on the market, there has to be a huge focus on the product development all the time.

## 1.2 Purpose and challenges of the thesis

The main purpose of the thesis is to investigate the simulation of integrating a micro PLC in the common control cabinet. With the purpose of processing the synchronization, interlock and position signals for the main breakers in the LV distribution system. The investigation is being made on request by the project design engineers and their supervisors. It will be helpful in their everyday product development.

The investigation is meant to be concentrated on the theoretical benefits this kind of upgrade would bring to this product group. The thesis would thus function as a base argument when deciding on future upgrades on products manufactured by energy industries.

The main challenge is the fact that the results of this study will only be theoretical due to the lack of possibility to test this new solution under real circumstances at this point. Another challenging aspect is to figure out whether this solution has a financial advantage or not both time consumption and component price wise.

## 1.3 Employer – ABB

ABB is a result of many company merges, but the one that counts as the start of ABB is the merge in 1988 between Swedish ASEA and Swiss BBC, known as Brown Boveri. These two companies where two of the largest in electrical engineering stationed in Europe in their time, and when they merged, they set the corner stone of the market leading ABB we see today. (ABB, 2018)

Today ABB has its head office in Zurich, Switzerland. The company itself is divided into four different global divisions, Power Grids, Electrification Products, Robotics & Motion and Industrial Automation. These divisions are all leader on the global market in each of their own specialized fields of operation. ABB has over 100 different countries it operates in, with a total of approximately 135 000 employees. (ABB, 2018)

ABB is since 2014 a title partner of the ABB FIA Formula E Championship, which is an entertainment motorsport for its followers, and an excellent way for ABB to be part of the research of new inventions for the electric car industry. (ABB, 2018)

## 1.4 Disposition

Chapter 1. Introduction to the thesis work and the employer.

Chapter 2. Theory used in this thesis presented.

Chapter 3. Presentation of the thesis work.

Chapter 4. Presentation of the result.

Chapter 5. Discussion.

Chapter 6. References

## 1.5 Secrecy

The investigation and the results presented in this study are considered sensitive information, competing companies might find it useful in their own product development. Information considered sensitive will be kept confidential from the public.

# 2 Theory

## 2.1 Synchronization

Synchronization (also shortened Synch) is the name of the process when comparing the voltage, frequency and phase angle of a generator and an already existing power system. Synchronization of two systems makes it possible to control them as a single unit, also making them able to share load and power flows.

There are four key values that must be taken into consideration when attempting to synchronize two AC systems without causing any harm to them or the loads connected to them. Note that it is the oncoming systems whose values must match with the existing system.

These key values are:

- Phase sequence
- Voltage amplitude
- Frequency
- Phase angle

If the values of both systems match and the synchronization is done right, it results in positive benefits brought to the system such as:

- Disturbances to the two systems are kept at a minimum
- Both electrical and mechanical stress upon the generator are kept low
- Electrical equipment will last longer in both systems
- Generator will provide and distribute power more quickly

If the two systems get disconnected from each other their ability to share load and power are canceled until they are resynchronized to each other. (Ransom, 2014)

### 2.1.1 Phase sequence

The order of how the different phases are connected is called phase sequence. For instance, it can be 1-2-3 or 1-3-2. Note that it is the oncoming systems whose phase sequence must match with the existing system. When the two systems have the same phase sequence they are in phase. (Ransom, 2014)

### 2.1.2 Voltage, Frequency and Phase angle

Every time a generator is connected to a system these key values have to be controlled and adjusted to match. In theory the circuit breaker should get closed at the time when all the key values match perfectly. In practice though, getting all these values to match completely is impossible. When performing a synchronization, the target is to get the values to match as close as possible, but it is not required to match them completely perfect. The better the two systems match together, the smaller the disturbance is at the connection moment.

There is an acceptable tolerance window for each of these values when it is acceptable to close the circuit breaker. For instance, a common range of the tolerance window for frequency measured in Hz can vary between 0.05-0.5 Hz depending on the system. (Ransom, 2014)

The figure below (Fig. 1.) shows the synchronization window.

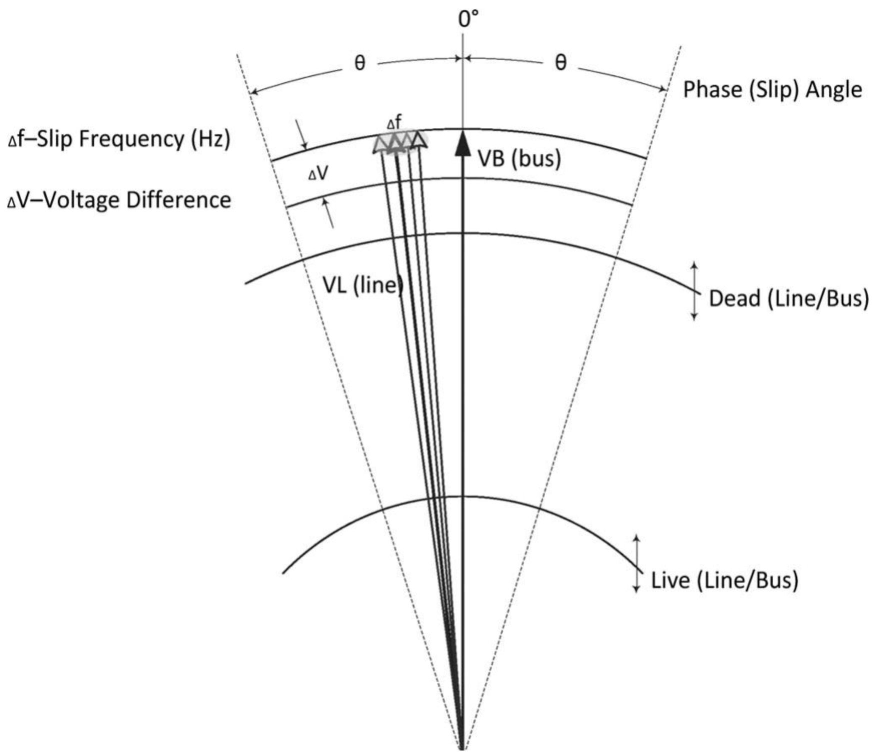


**Figure 1: Synchronization window. (Ransom, 2014)**

## 2.2 Synchronization methods

There are three different methods when synchronizing a generator to the grid, manual, assisted manual and automatic synchronizing. This thesis builds upon the usage of automatic synchronization.

### 2.2.1 Manual Synchronization

To be able to perform a manual synchronization it is necessary to have skilled personnel that possess the necessary knowledge for this type of process. Because it is the personnel that manually do all the adjustments and manually matches the source to the existing system.

The figure below (Fig. 2.) shows dark lamp synchronization. This method can aid the personnel which adjust the excitation and speed of the oncoming generator. There are lamps connected between the same phases on the bus and generator on each side of the circuit breaker. These are used as indication so the personnel know when to close the breaker between the lines. If the bus and generator voltages are not synchronized it will result in a potential difference, thus making the lamps illuminate. When synchronized the potential difference will be 0 volt making the lamps go dark. (Ransom, 2014)

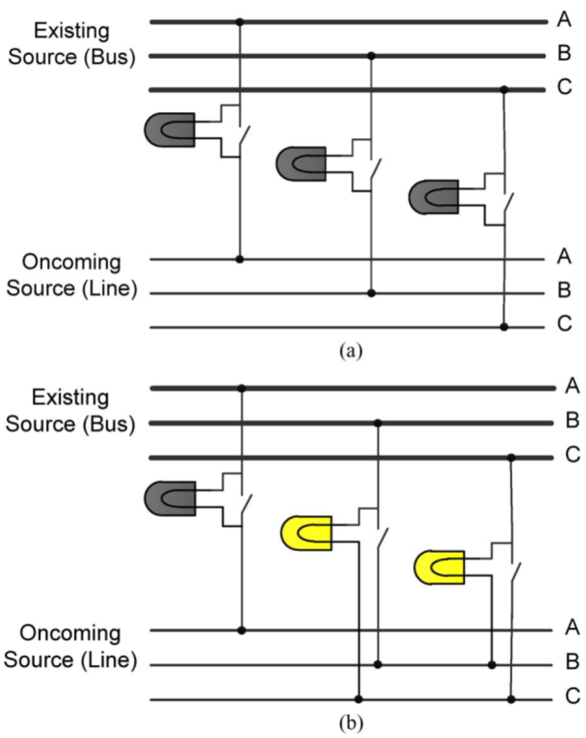


**Figure 2: Dark lamp synchronization (a) All phases in synch. (b) Partly synched. (Ransom, 2014)**

### 2.2.2 Assisted Manual Synchronization

The second method used for synchronization is assisted manual synch, basically the same process as for the manual synch with the exception that a sync-check relay has been added to the circuit. The purpose of the sync-check relay is to monitor the key values on both side of the circuit breaker, with the purpose to prevent human error that would lead to closing of the circuit breaker at the wrong time. This is prevented by the relay because it does not allow the breaker to close outside the synchronizing window. Operating personnel is still needed for the manual adjusting of generator voltage and frequency, also to operate the circuit breaker. (Ransom, 2014)

### 2.2.3 Automatic Synchronization

The automatic synchronizer is a device that measures and does the adjustments of the oncoming generator voltage, frequency and phase angle. Working together with a synch check relay, the auto synchronizer also operates the circuit breaker. When the synchronizing process is initiated, the synchronizer starts of adjusting voltage and frequency of the generator. This is done until they and the phase angle match with the bus, when that occurs the synch check relay contact closes and the synchronizer is enabled to send the close signal to the circuit breaker. (Ransom, 2014)

The figure below (Fig. 3.) shows a connection diagram with a synchronizer.

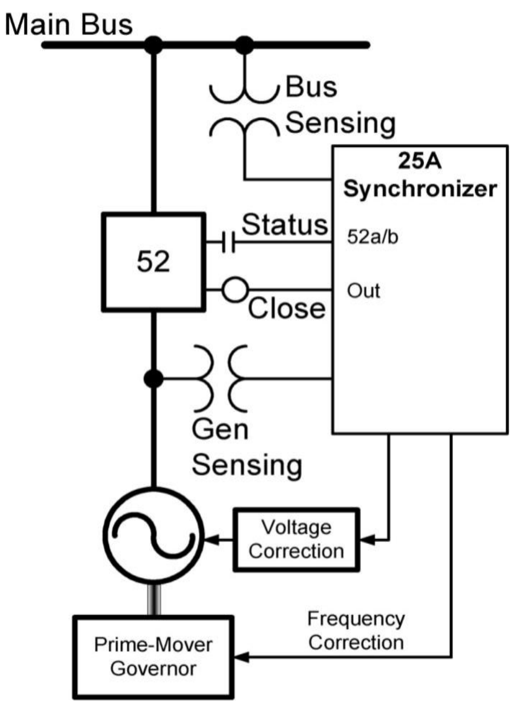


**Figure 3: Connection diagram with a synchronizer. (Ransom, 2014)**

The process order of the auto synchronizer is listed below:

1. Voltage comparison
2. Frequency comparison
3. Adjustment of the generator voltage to match the bus
4. Adjustment of the generator frequency to match the bus
5. Phase angle comparison
6. Send out a close command to the circuit breaker

In case of an emergency or some other kind of major fault where a power outage has occurred it is important to be able to restore the power output as quickly as possible, therefore an auto synchronizer should be used for each separate generator. These synchronizers should all be monitored by a single automation system. (Ransom, 2014)

## 2.3 Automation Systems

This chapter introduces several automation systems. These systems being the Distribution Automation System (DAS), Distributed Control System (DCS) and the Programmable Logic Controller (PLC).

### 2.3.1 History

There was a time before the computers changed the whole world regarding process automation systems. Back then process engineers monitored a wide variety of instruments to keep track of temperature, pressure, voltage and so on, depending on the process. Adjustments in the process were done by manually operating different regulation valves or circuit breakers.

DCS is a microprocessor-based control system which were taken into service shortly after the world's first microprocessor was launched in the 70's. Around the same time the PLC, which has its roots in the relay technology appeared on the market.

These two options were both developed through the years and the technology used today still has its origin from these two systems. (Ramebäck, 2003)

### 2.3.2 PLC

PLC (Programmable Logic Controller) is a control system designed for industrial automation. PLC is used when a process of any kind is automated. An example of a typical process that is automated with a PLC system is production lines in different factories. The PLC gathers process information from sensors and other input devices inside the process. It then processes the information gathered and depending on the preprogrammed process code, it activates different outputs. (Unitronics, 2017)

The following figure (Fig. 4.) shows a simplified image of the PLC build up.

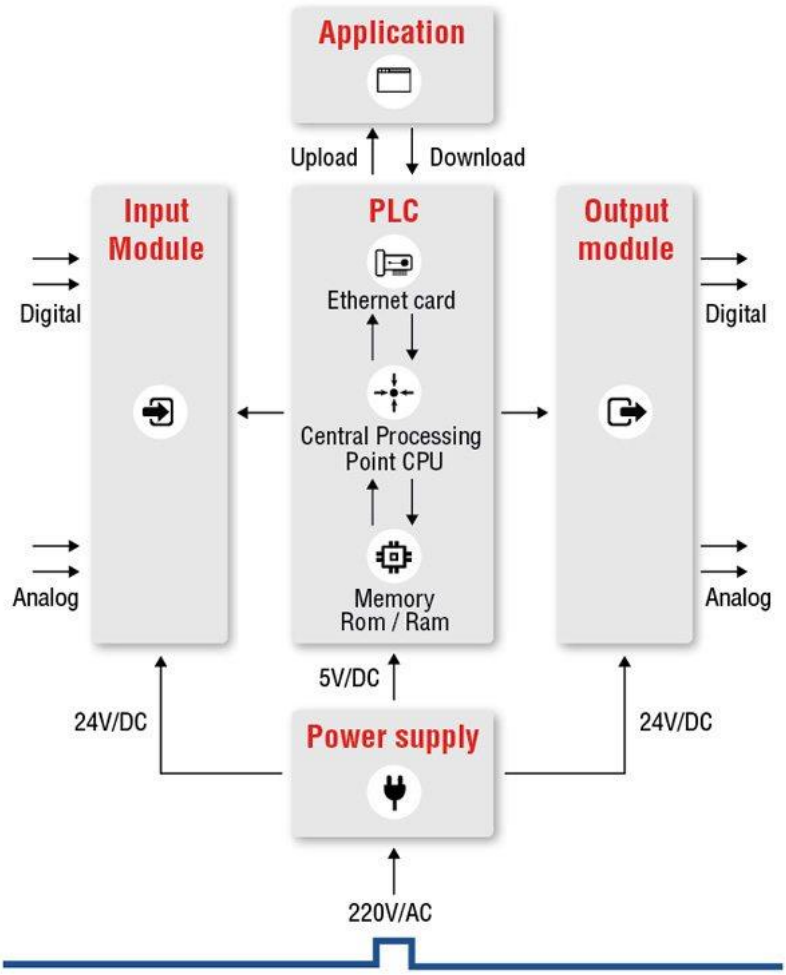


**Figure 4: PLC build up. (Unitronics, 2017)**

### 2.3.3 PLC Types

There are a wide variety of different PLC types when it comes to shapes, sizes and characteristics. There are two major categories that they are divided into, compact and modular. The modular built PLC contains of several different modules linked together. This makes it possible to only exchange one module instead of the whole PLC in case of failure or if different PLC characteristics are needed. The compact PLC type is also built by several modules but are fitted into one single case by the manufacturer, meaning that the characteristics are set permanently.

When it comes to size, they are divided into three categories, large, medium and small (also called micro) size. The difference is mainly their I/O signal capacity. The small / micro PLC is mainly used to replace hardwired relay logics. The medium sized PLC is mainly used if the process is somewhat small or as a sub device for a large main PLC. The large sized PLC is used whenever a high capacity in terms of I/O signals, memory and communication is needed, for example in a power plant distribution system. (Agarwal, 2019)

### 2.3.4 Distribution Automation Systems (DAS)

DAS is a system were an electric utility device monitor, coordinate and operate distribution components in real time from a remote location. It is based on integrated technology. It gathers data and analyzes the data to be able to make control decisions in the field, it gathers feedback information to be able to verify that the desired result is achieved. The location where control decisions are initiated is called distribution control center (DCC). (Davood Mohammadi Souran, 2016)

When a DAS is implemented it enables the ability to pick up one or several standalone sub-systems. These subsystems are linked together which makes it possible to monitor and control them from a single DCC. The DAS is a complex mixture of different hardware and software components. The systems itself can be customized according to what kind of functions the process requires. DAS have a big advantage in form of that it is easy to make changes if the process changes in form of functionality. This can easily be done simply by changing the control code on the modular part that actually operate that particular function.

A typical DAS contains of one or several PLCs that processes the needed information gathered inside the process. The information processed by the PLC is then transferred to the DCC. The information exchange between the PLCs and the DCC in a DAS is done via a communication network. (Karin Eckert, 2011)

The following figure (Fig. 5.) shows how the communication network is connected thus enabling the information exchange between the central station (read DCC) and the PLCs. The figure shows five different PLCs connected to the DCC. If the communication network is connected to each of the PLCs, they can communicate with each other thus enable them to share functions (in the figure referred to as applications) in the process.

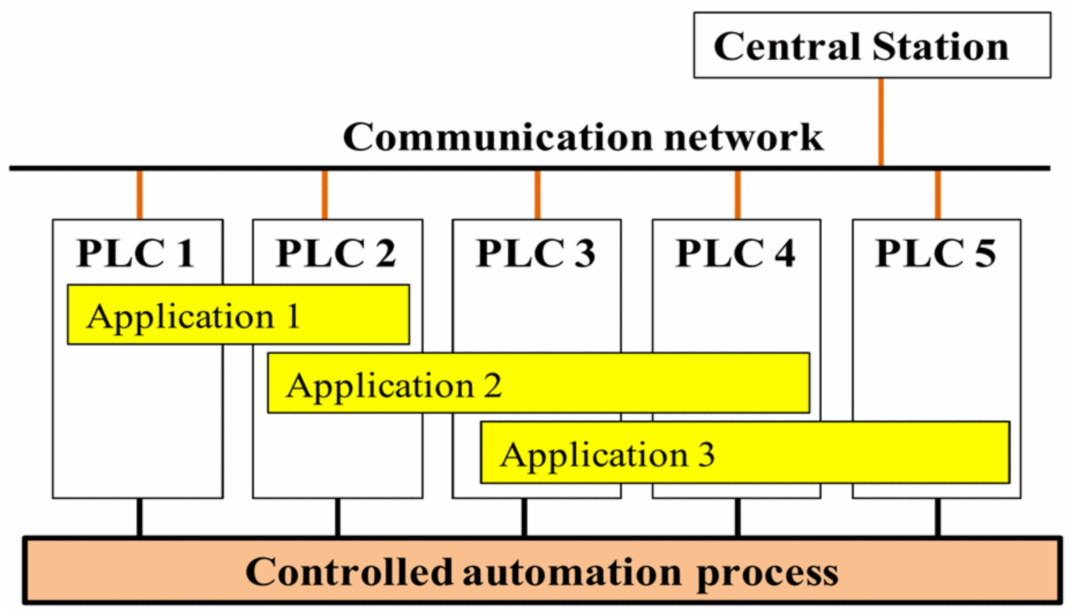


**Figure 5: Communication network. (Karin Eckert, 2011)**

### 2.3.5 Central and Distributed Automation System

The automation system can be divided into two major categories, central and distributed. In the central version there is only one central station that contains the whole process control code. Meaning this method is very vulnerable for complete system failure. Such failure could occur if the communication between the central station and the system process is lost or due to a single component failure. (Karin Eckert, 2011)

The following figure (Fig. 6.) shows how the automation process is connected to the central station, in a centralized automation system.

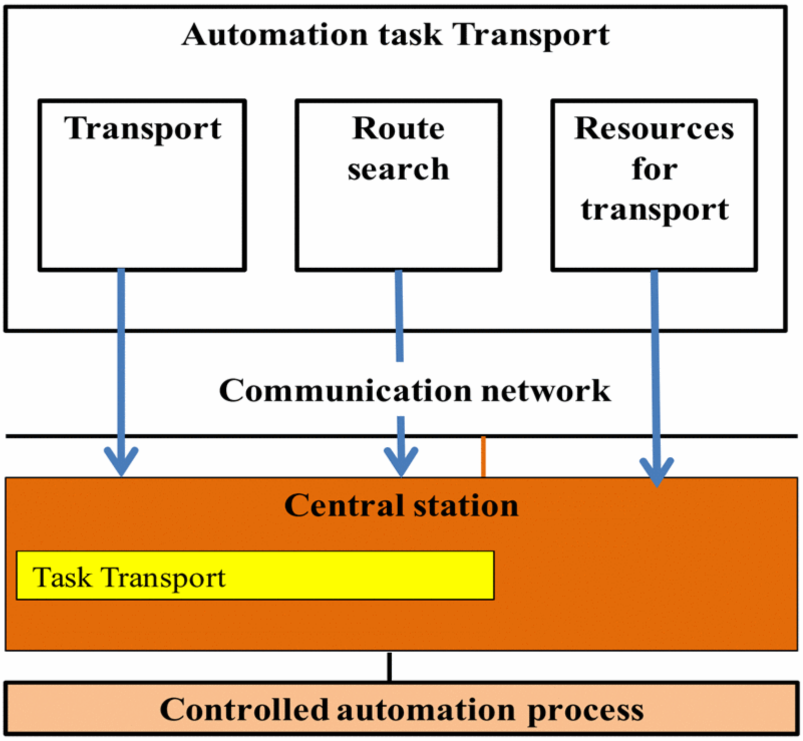


**Figure 6: Central version of the automation system. (Karin Eckert, 2011)**

The distributed version has the control code on various PLCs which enables them to communicate directly with each other not having to go via the central station. This is an advantage compared to the central version, because it makes the distributed system less vulnerable to complete system failure. If there would occur a minor component failure or the communication is lost on a single PLC, it may not necessary result in a complete shutdown of the system. This is achieved through modular construction of the system, where it is possible to divide the process into smaller modules meaning they can work undisturbed by the others. The modular construction also holds an advantage when it comes to expanding the DAS. If changes in the process is needed it can easily be done in the affected module without having to shut down the rest of the process. (Karin Eckert, 2011)

The following figure (Fig. 7.) shows how the automation process is connected to the central station and the different PLCs, in a distributed automation system.

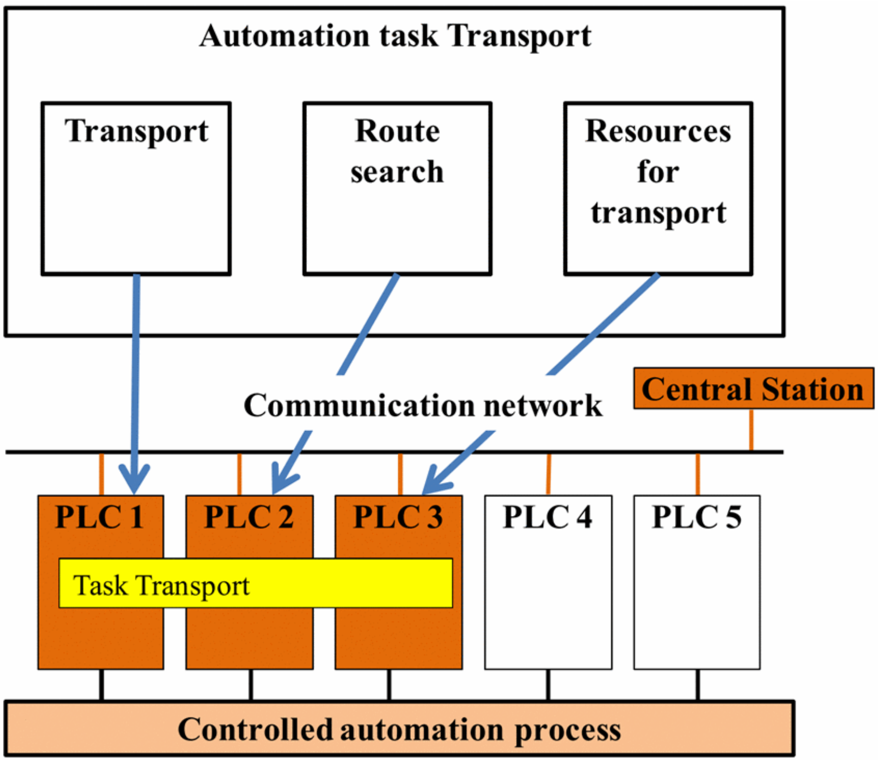


**Figure 7: Distributed version of the automation systems. (Karin Eckert, 2011)**

## 2.4 Interlock

Interlocking is a method used when the goal is preventing undesired action in electrical systems. Interlock is described as several demands that together acts as a safety precaution. An interlock is a certain condition that must be met before another process can be initiated. (Colburn & Wiley, 1964)

In automation systems the interlocks can either be electrically interlocked via hardwired relays or logically interlocked via a PLC.

## 2.5 Genset

The setup when a combustion engine is used as the main actuator for a generator it is called a genset. These gensets are typically driven by either a diesel or a gas engine, there are also multifuel engines that enables the usage of both diesel and gas as fuel. As the engine burn its fuel and air mixture it transforms it into a mechanical rotary force which in its turn drives the generator. The frequency, voltage and power angle characteristics of the electric power output by the genset is depending on how the engine is running. Ideally the engine should run the generator with a constant speed no matter the load on the generator. (Bryan M. Fore, 2012)

## 2.6 E3.cable

E3.cable is an engineering program provided by ZUKEN used for electrical wiring and control systems. E3.cable is capable of both 2D and 3D designing. (Zuken, 2019)

E3.cable is the design platform used by the energy industries department at ABB when designing circuit diagrams for their control systems.

The following figure (Fig. 8.) shows an example of a circuit diagram designed in E3.cable

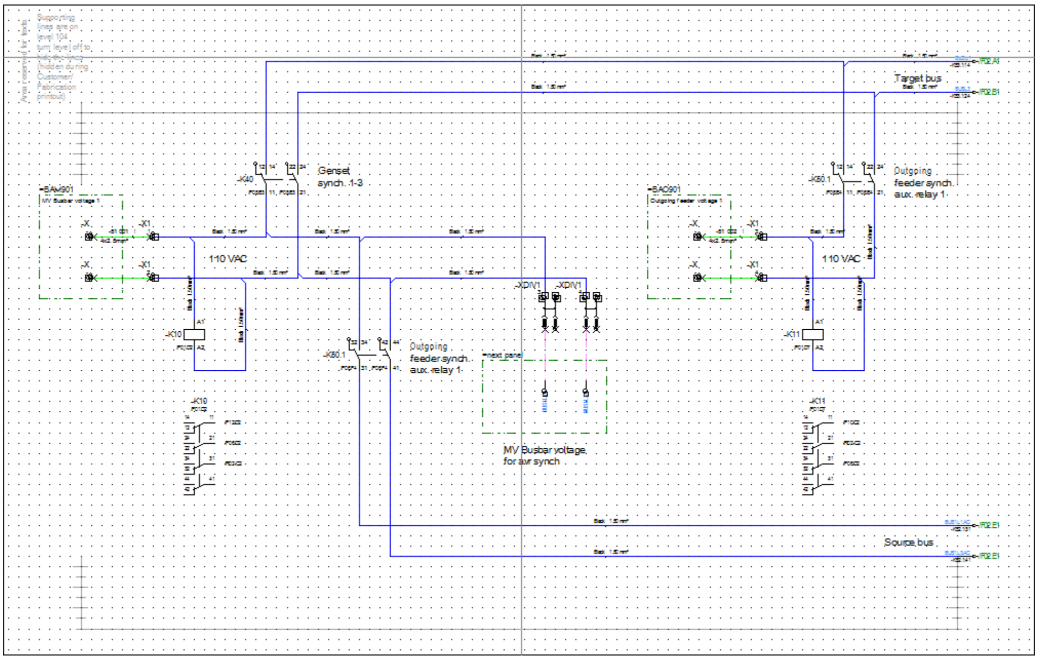


**Figure 8: E3.cable circuit diagram. (ABB, 2019)**

# 3 Investigation (Confidential)

# 4 Result (Confidential)

# 5 Discussion (Confidential)

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