VAASAN AMMATTIKORKEAKOULU
VASA YRKESHÖGSKOLA
UNIVERSITY OF APPLIED SCIENCES

Rami Rajamäki

LOAD SHARING COMMUNICATION BETWEEN DIFFERENT ENGINE/GENERATOR CONTROLLERS

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VAASAN AMMATTIKORKEAKOULU
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Uusilla diesel-, kaasu- ja monipolttoainevoimalaitoksilla on käytössä uuden tyyppiset moottorinohjaimet ja jännitteensäätäjät, jotka hoitavat kuormanjaon. Tämän työn tarkoituksena oli selvittää miten uudet ohjaimet ja säätäjät saadaan kommunikoimaan vanhojen olemassa olevien järjestelmien kanssa.

Työn tekeminen aloitettiin tutustumalla sekä vanhaan että uuteen kuormanjakojärjestelmään ja perehtymällä niiden oleellisin eroihin. Oleellisimpien komponenttien ja järjestelmien manuaaleista selvitettiin, mitä eroja ja yhtäläisyyksiä laitteilla ja järjestelmillä on. Vanhoja jännitteensäätäjiä käsiteltiin 3 erilaista ja moottorinohjaimia myös 3 erilaista. 1 uusi jännitteensäätäjä ja moottorinohjain esiteltiin tässä työssä. Kyseiset laitteet on valittu sen perusteella, että ne ovat yleisimmin käytettyjä ABB:n projekteissa. Säätäjien ja ohjaimien eri ohjaustoiminnot on myös esitetty tässä työssä.

Erilaisten kommunikaatiojärjestelmien yhdistäminen onnistuu moottoripuolella konvertterin avulla. Tässä työssä tehtyjen selvitysten perusteella voidaan suositella, että mikäli voimalaitosten laajennuksissa käytetään ABB:n Unitrol 1020-jännitteensäätäjiä, on kuormanjakamisessa käytettävä yhteistä PLC:tä. Vanhempien jännitteensäätäjien yhdistäminen Unitrolin kanssa ei ole mahdollista johtuen erilaisista kommunikaatiojärjestelmistä.

Avainsanat kuormanjako, jännitteensäätäjä, moottorinohjain

VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES
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ABSTRACT

Author	Rami Rajamäki
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New diesel, gas and dual-fuel power plants have new engine controllers and voltage regulators which control the load sharing. The objective of this thesis was to find out how the new controllers and regulators are able to communicate with the old existing systems.

The thesis started by getting to know the manuals of the relevant components in load sharing, including both old and new devices and specially what differences and similarities they had. This thesis includes the presentation of three old voltage regulators and engine controllers. From the new system there is only one voltage regulator and one engine controller. These devices were chosen because they are the most common in projects in which ABB participates. Different control modes for the controllers are also presented in this thesis.

Connecting different communication systems is possible on the engine side through a converter. According to the information gathered in this thesis it is recommended that a common PLC is used for load sharing between the existing power plants and the power plant extension that use ABB's Unitrol 1020. This is because it is impossible to connect the older AVRs with Unitrol due to different communication systems.

Keywords load sharing, engine controller, voltage regulator

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS

AVR	Automatic Voltage Regulator
CAN	Controller Area Network
CCC	Cross Current Compensation
CCM	Cylinder Control Module
DECS	Digital Excitation Control System
IGBT	Insulated Gate Bipolar Transistor
kW	kilowatt
LSG	Load Share Gateway (Woodward)
LSC-10	Load Sharing Converter (Wärtsilä)
MCM	Main Controller Module
MW	Megawatt
PF	Power Factor (cosφ)
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
PPU	Paralleling and Protection Unit
pu	per unit
QPF	Reactive current, cos phi regulator and balancer for Cosimat N+
RDC	Reactive Droop Compensation
UNIC	Unified Controller

VDC	Voltage Droop Compensation
WECS	Wärtsilä Engine Control System

1 INTRODUCTION

This thesis was made for ABB Power Generation to widen their knowledge and to make the new solutions more compatible with the already existing power generation. More power is needed today and in the future, that is why it is important to have the possibility to install new power plants to the existing grid and parallel with other power plants.

Load sharing failure between generators can lead to a total blackout. This will take place, if both active and reactive power sharing fails. If a load sharing failure occurs, protection relays may trip a healthy generator instead of a faulty. /13/

Load sharing has to be equal between two or more generators connected to the same bus. If there is the slightest difference in voltage between two generators, the generator with bigger voltage begins to supply the generator with the smaller voltage (Figure 1.)

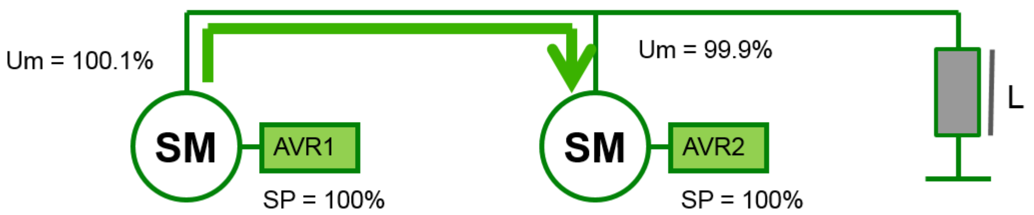

Figure 1. Load sharing problem. /18/

Voltage differences on the bus cause high reactive current because of the low impedance of the bus bar. /18/

Having many engines running in parallel, increases the reliability of the power system, since the failure in an engine does not cause a total loss of the power. One or more engines can also be at maintenance while power is produced, because power is still provided by the other engines. In a worst case scenario a failure in load sharing may cause a total blackout. /13/

In this thesis different control operations for both engine and generator controllers are presented. Also the most common devices for one of the ABB's customers have been introduced. One focus is in showing how the old and the new load sharing system are handled and how they differ from each other. Different possibilities in load sharing communication are presented and explained in this thesis and based on these possibilities the conclusion has been made.

Load sharing communication enables more functions of the controllers. In order to achieve equal load sharing, a proper communication system is needed between the controllers.

Load sharing communication in power plant extensions is possible on the engine side in active load sharing because of the load sharing converters made specifically for the situations. But for the reactive load sharing there is not a similar gateway that would make the load sharing between the old and the new AVRs possible. Therefore, another solution had to be considered and when the communication between the AVRs is needed, a common PLC is necessary.

1.1 Target

The purpose of this thesis was to find out if there is a solution to load sharing communication between the old and new engine controllers and as well as between the old and new generator controllers. As there already is a solution for load sharing between the old and new engine controllers the main focus was to find out a solution for the load sharing between the old and new generator controllers.

2 ABB

ABB is a global leader in power and automation technologies. Based in Zurich, Switzerland, the company employs 140 000 people and operates in approximately 100 countries. /1/

ABB's business is comprised of five divisions that are in turn organized in relation to the customers and industries they serve. /1/

Today ABB is the largest supplier of industrial motors and drives, the largest provider of generators to wind industry and the largest supplier of power grids in the world. /1/

2.1 ABB in Finland

Strömberg was established in Finland in 1889. The product range included electro-mechanical products, such as generators, electric motors and even small power plants. ABB was formed in January 1988 by merging the Swedish Asea who had just bought Kymi-Strömberg's electrical business, and Switzerland's Brown Boveri electric system operations. ABB Oy employs 5400 people in Finland. /2/

2.2 ABB Power Generation

ABB Power Generation business unit is located in Vaasa, Finland. Power Generation is part of the Power Systems –division. Power Generation offers power and automation systems, turnkey project deliveries and services for power plants and water utilities. Power Generation employs more than 70 people in Vaasa. /3/

The unit provides process know-how and references in different power plant areas, such as hydropower, gas and diesel power plants, gas turbines, thermal power and nuclear power. /3/

3 CONTROL MODES FOR ENGINES AND GENERATORS

There are various control modes for both engines and generators. Only one mode can be used at a time. The control mode that is used, is chosen by the need of the operations that it provides. Some control modes can be used only when operating in the island mode and some when operating in the grid mode. Active load sharing is controlled by the engine controller and reactive load sharing by generator controllers.

3.1 Engine Control Modes

In this thesis three sub-control modes are presented for the speed controller which are mainly used by ABB's customers. The control mode that will be used is chosen for each situation separately. For example, when engines are running in parallel, it may be necessary to have one engine running in the speed droop and the others in the isochronous mode. The engine controller controls the fuel supply of the engine. New engine controllers have more functions and possibilities because of the digital communication they are using. These control modes described below are based on how they operate according to Wärtsilä's UNIC.

3.1.1 Speed Droop

The speed droop reduces the governor reference speed as the load increases. The principle of the droop is used by all of the engine controls. It is a basic load sharing mode. When running in parallel, engines share their load by decreasing their internal speed reference proportionally to an increase in the engine load. The speed control is adjusted to approximately 4% speed droop from the governor output (Figure 2.) /16, 23/

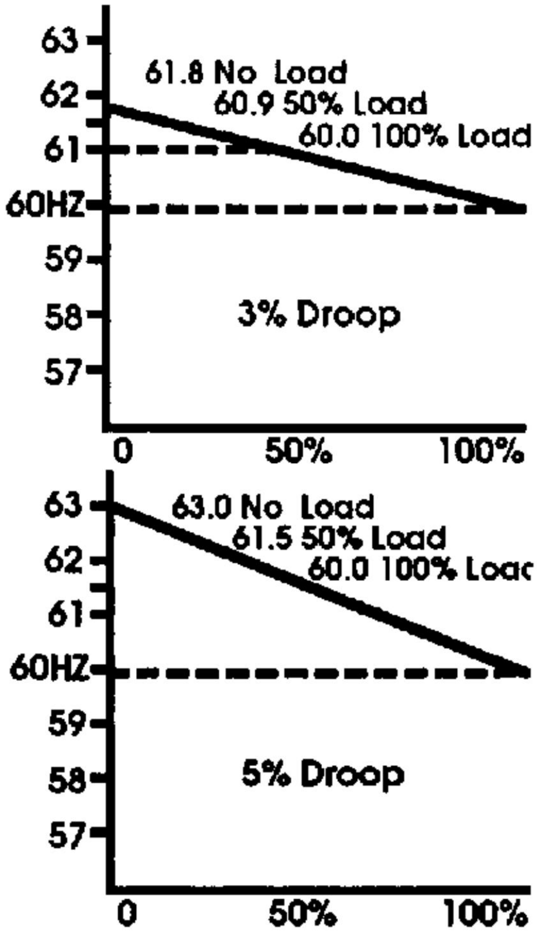

Figure 2. Speed droop with 3% and 5%. /16/

In systems with the speed droop as a primary load sharing method it is necessary to actively transfer load to a recently connected generator from parallel generators in order to achieve an even load on all generators. Before disconnecting a generator, it has to be correspondingly unloaded. Loading and unloading is normally performed automatically by a power management system. The power management system, also known as the controlling system, commonly also corrects the frequency to eliminate the speed droop offset, which is proportional to the system load. The power management system performs load balancing and frequency correction by adjusting the speed references of the individual engines. /23/

The controlling system should not perform adjustments with shorter intervals than the controlled system responds. Therefore, in order to achieve smooth load sharing it is important to implement suitable dead bands in the control. /23/

If the power management system performs continuous load balancing and frequency correction, it should include the following features:

- Pulse length and time between pulses shall be adjustable. If the same control system also handles automatic synchronization, the pulse length, time between pulses and dead band shall be separately adjustable for synchronisation.
- The time between pulses shall be sufficiently long. After a correction it can take up to 30 seconds before the actual adjustment has reached 95% of the set point change. The control system should therefore wait at least 10 seconds before giving a new pulse.
- The control system should preferably determine the length of the pulse based on the size of the desired correction and then wait for 30 seconds or more before performing a new correction.
- A control dead band should be implemented, allowing for an uneven load of minimum +/- 2% of nominal power and a frequency drift of minimum +/- 1%.
- The corrections should not be based on instantly sampled values. The corrections should be based on the average value over several seconds. A suitable time span is 10 seconds. /23/

3.1.2 True kW Control

The true kW control is used specifically for parallel running generating sets. In the true kW control mode, the control loop is a true load control loop. If the kW control mode is entered from the circuit breaker open control mode, the load reference will at first set to the kW base load in order to avoid the risk of reverse power of the generating set. When ramped down, the load reference is always limited to the kW base load level. If the mode is entered from the speed droop or isochronous load sharing mode, the load reference will be at first the generator load and from this level the load will be ramped towards the kW reference according to a predefined rate. /23/

If the engine unload input is activated, the load reference will be ramped down to the unload trip level and when reaching this level the circuit breaker open control will be entered. But if the engine unload is deactivated and the unload ramping is not finished, the load reference will again be ramped to the kW reference. The control will trip to the droop mode if the bus frequency is not within a predefined speed range or if the generator load signal fails. /23/

When the true kW mode is used, the grid must be stable enough to maintain nominal frequency, because the engine does not actively support the frequency.

When operating in the true kW mode, the internal speed reference is constantly calculated and updated to match the equal load level in the speed droop and load sharing modes. /23/

3.1.3 Isochronous Load Sharing

When operating in the isochronous load sharing mode, the speed will be regulated to the speed reference, regardless of the load level of the system. Today, with the new Wärtsilä power plants, load sharing communication in the isochronous mode is done via a CAN bus. All engines are interconnected by a LS-CAN, also known as load sharing CAN. The relative load of the engines is monitored by the other engines connected to the system, the relative system load is calculated. The unit compares its own relative load with the relative system load and biases its internal speed reference until the two loads are equal. The relative load is calculated based on the generator load. /23/

Isochronous load sharing is normally used only when the power plant is operated in the island mode. The frequency is constant, not load dependant.

The system is transferred to the isochronous load sharing mode from the circuit breaker open control mode, speed droop control mode or true kW control mode if the isochronous control enable input and the generator breaker status are true and the LS-CAN communication is healthy. /23/

When a new engine is added to the system, it is always softly uploaded to the load sharing network by using a load sharing ramp. The same goes when unloading an engine from the system. /23/

To offset the load of an engine that is part of an isochronous load sharing system, there is an asymmetric load sharing bias input. The input range for the asymmetric load sharing bias is 4-20 mA. In this range a 4 mA value means equal load sharing with the other engines and a value of 20 mA means that there is no load on that precise engine. A sensor fault will occur when signal is out of range and the engine will trip to droop. /23/

3.2 Generator Control Modes

Nowadays the advanced automatic voltage regulators have also other functions beside voltage regulation, based on several connections (Figure 3.) The most common operation modes used by the customer, for the power plant generator controllers are presented in this thesis. The voltage droop compensation mode is described here based on how it works in ABB's Unitrol 1020 Automatic Voltage Regulator.

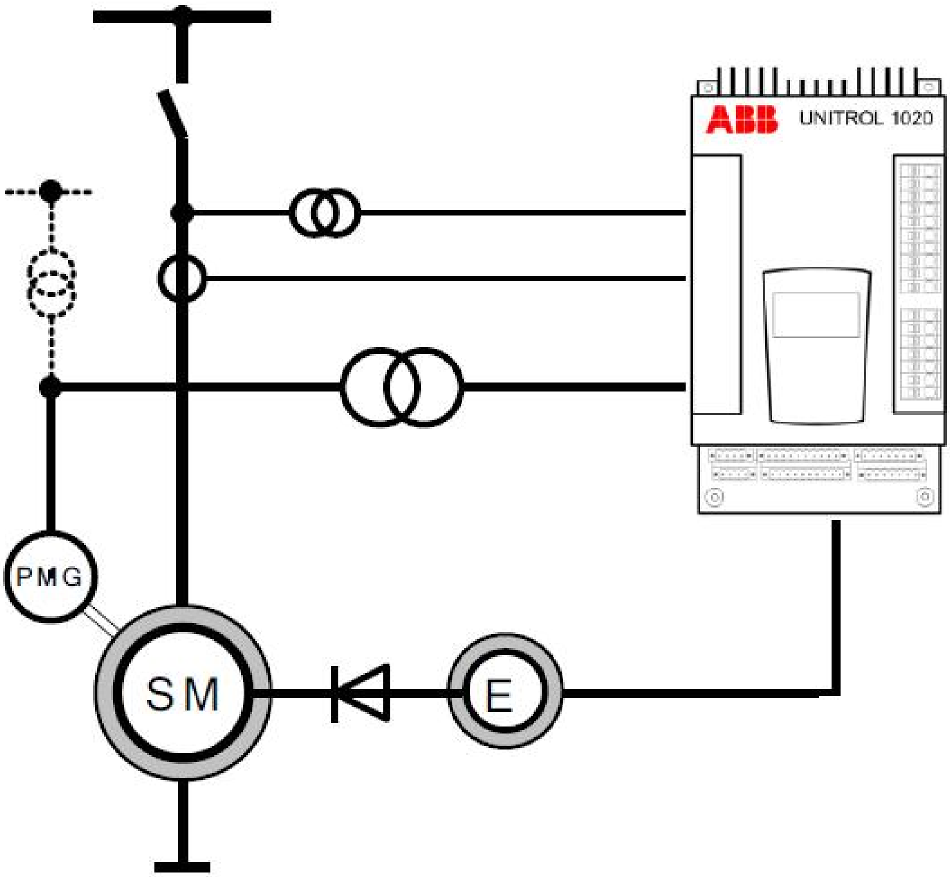

Figure 3. ABB Unitrol 1020 AVR. /4/

3.2.1 Voltage Droop Compensation

In the normal voltage droop mode, the generator voltage will decrease when the reactive current increases. The voltage droop is similar to the speed droop on the engine side. The difference is that in the speed droop the frequency is reduced whereas in the voltage droop the voltage is reduced.

Voltage Droop Compensation or VDC shares the reactive power between the paralleling generators through a RS485 bus between the Automatic Voltage Regulators. VDC uses a proprietary communication protocol specified for Unitrols. When voltage droop compensation is used, all AVRs operate in the auto mode. Regulators share their values through the RS485 bus and the other regulators use this information to calculate a common average MVAR set point and compensate the effect of the voltage droop so that the voltage level on the bus bar will maintain at 100% (Figure 4.) No master is needed for this communication system. The level is not adjustable. To change the control mode in the AVR, the load sharing is activated over a ramp time to get a smooth transition. /4/

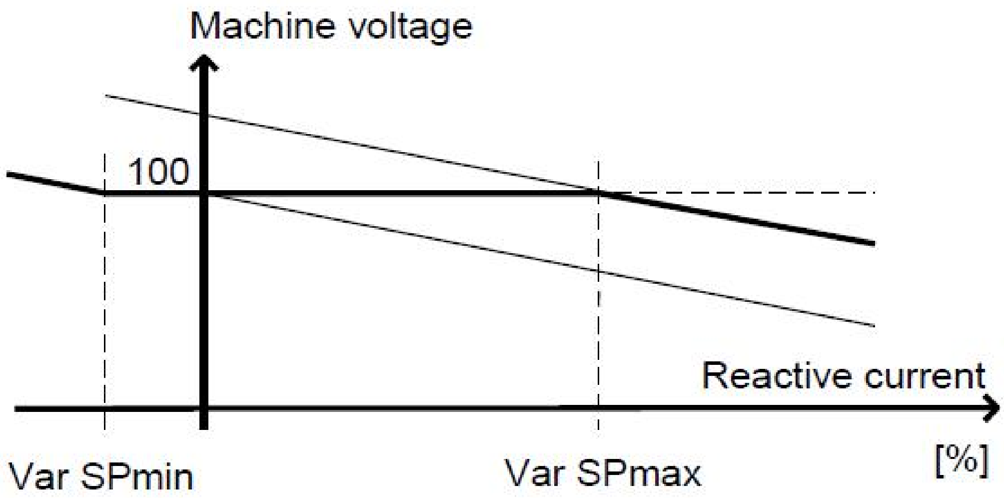

Figure 4. Voltage droop compensation. /4/

VDC is normally used only for the island operation. The voltage is constant, not load dependant. /4/

3.2.2 Power Factor Control

In Basler 100 Digital Excitation Control System, the Power Factor Control mode maintains the generator power factor at a set level when parallel with grid. AVR calculates the generator power factor using the sensed output voltage and current quantities. Then it will adjust the dc excitation current to maintain power factor at the set point. The power factor set point is adjustable between 0.6 lags and 0.6 lead. /7/

Power factor control is used in parallel with the grid. When the true PF mode is used, the grid must be stable enough to maintain the nominal voltage, because generator does not actively support the voltage.

AvK Cosimat N+ has an additional cos phi regulator module which holds the power factor constant irrespective of fluctuations in the system voltage or load changes. /6/

ABB Unitrol 1020 has a PID control algorithm for power factor control (Figure 5.) /4/

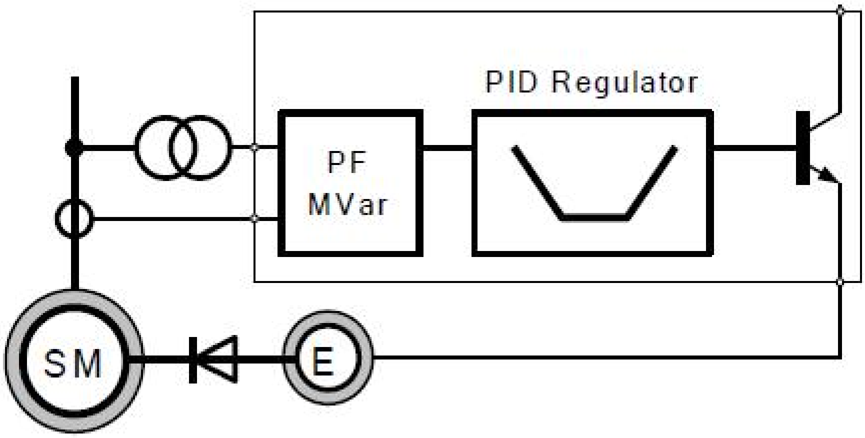

Figure 5. PF mode with PID control algorithm. /4/

3.2.3 Reactive Load Sharing

Reactive Droop Compensation is a feature for droop load sharing in the parallel generator operation. In RDC the reactive portion of the generator load is calculated by the regulator using the sensed generator output voltage and current quantities. The regulator will then modify the voltage regulation set point accordingly. If there is a unity power factor, there will be almost no change in the generator output voltage. If there is an inductive load, the generator output voltage will decrease and if there is a capacitive load, the generator output voltage will increase. /7, 10/

Droop compensation is accomplished through the load compensation equation (Equation 1.) /8/

$$V_{C1} = \left|\overline{V_T} + \left(R_C + \left|jX_C\right)\overline{I}_T\right|\right. \qquad (1)$$

Where V_{C1} is the compensated output voltage, V_T is the measured terminal voltage vector, R_C and jX_C are the compensation impedance values and I_T is the measured terminal current vector. "When the droop percentage is a positive quantity, reactive droop compensation is performed. Droop is the product of the output voltage and the kvar that the generator is exporting. This is equivalent to the above compensation equation with R_C equal to zero and neglecting the real part of the vector I_T." /8/

Another mode for reactive load sharing is Cross Current Compensation, it is used for reactive load sharing between parallel generators. CCC operates with analogue signals. CCC measures currents between the current transformers of the generators. The current transformers are interconnected. The secondary current of the first transformer must match with the other transformers secondary current, so that the load will be equal (Figure 6.) The current flow through the burden resistor will be zero since the secondary currents will cancel each other out. The voltage over the burden resistor is used for generator regulation. /10/

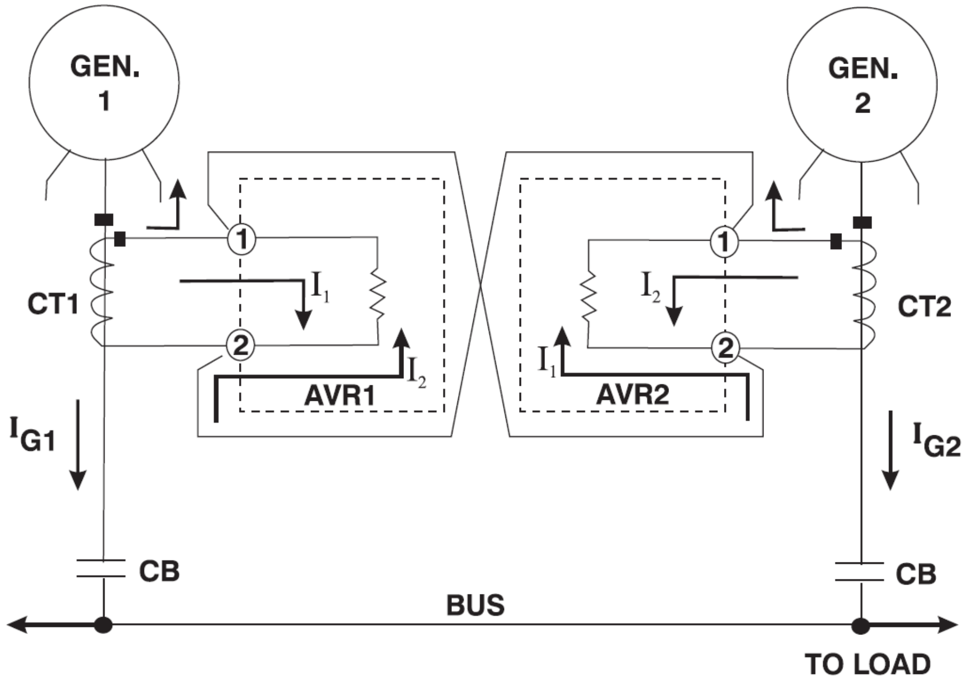

Figure 6. Two parallel generators with cross current compensation. /10/

4 DEVICES

The controlling and monitoring of the engines and generators is done via controllers. Controllers on the generator side are mainly automatic voltage regulators. Four engine controllers and four generator controllers are presented in this thesis. Active load sharing is handled by these engine controllers. Reactive load sharing is handled by the generator controllers.

4.1 Devices for Engine Control

The new engine controller, UNIC, is an automation system. UNIC provides load sharing via its Main Control Module. Four different engine controllers are presented in this thesis, they were chosen because they are most common in projects in which ABB participates.

- UNIC (MCM) (Wärtsilä)
- Woodward 723
- DEIF PPU2
- WECS 8000 (Wärtsilä).

Woodward and DEIF controllers are equipped with a built-in load sharing possibility. DEIF needs a speed governor for speed control. WECS needs a PLC (Figure 28) for load sharing (Table 1.)

Table 1. Engine control modes and communication.

Engine Controller	Control modes			Communication	
	Speed droop	true kW control	Isochronous LS	CAN	Analogue
UNIC/MCM	X	X	X	X	
Woodward	X	X	X		X
DEIF	Governor	Governor	X		X
WECS 8000	X	X	Additional controller		X

4.1.1 UNIC

Wärtsilä Unified Controls is an automation system for all power plant and marine solutions with Wärtsilä dual-fuel or spark ignited gas engines in the newest model of UNIC C3. In case of Common Rail engines, the system has control algorithms for the fuel injection. Features in UNIC are basic safety, engine monitoring, engine control and electronic fuel injection control. UNIC itself consists of seven different modules:

- Local Display Unit (LDU)
    - External Ethernet communication
    - Local parameter display
    - Engine tuning and software download
- Local Control Panel (LCP)
    - Push buttons for local engine control
    - Indication of the most important engine measurements
- Engine Safety Module (ESM)
    - Safety functions
    - Shutdown latching
    - Signal conversion
- Main Control Module (MCM)
    - Speed/load control
    - Engine management
- Power Distribution Module (PDM)
    - Filtering
    - Protection
    - Earth fault detection
- Cylinder Control Module (CCM)
    - Injection control
    - Cylinder measurements
    - Fast measurements (knock, pressure)
- Input Output Module (IOM). /17/

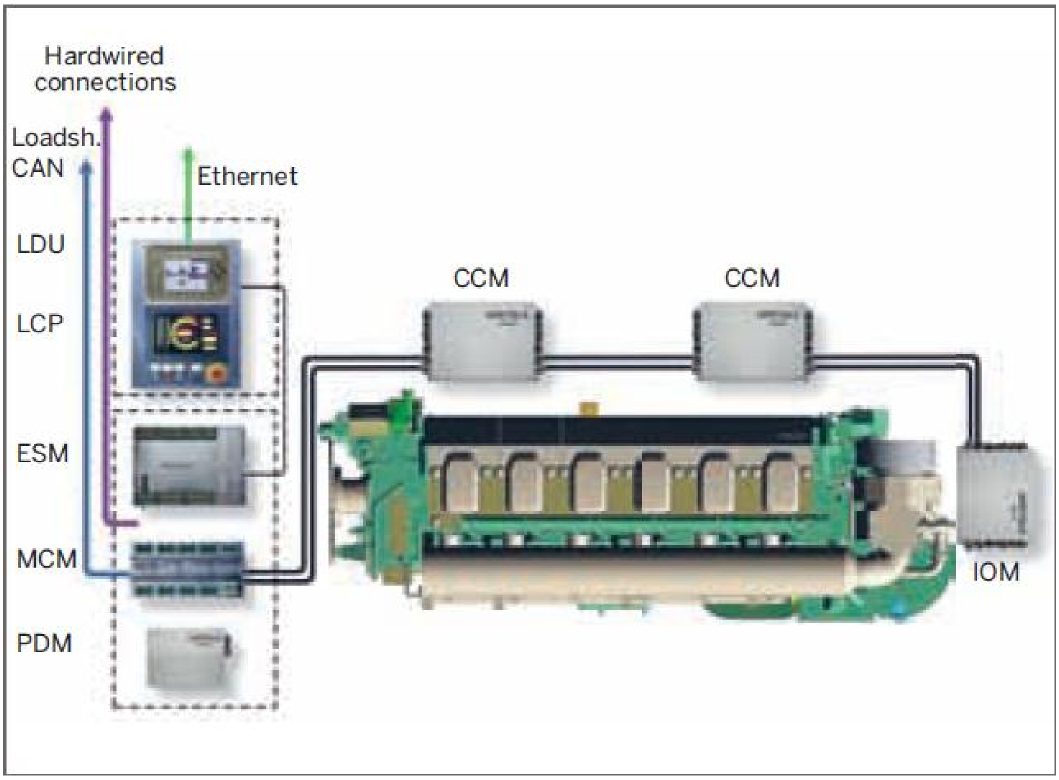

Figure 7. General layout of the UNIC C3 system. /14/

Local display unit communication is done by the Modbus TCP/IP connection. Load sharing is handled by MCM via a load sharing CAN bus. MCM is also connected to CCMs and IOM with a dual CAN bus. External power is connected to PDM (Figure 7.) The internal modules communicate with each other over a CAN protocol bus. /14/

Wärtsilä have presented three versions of UNIC C1, C2 and C3. They have only added more engine applications to the newer versions while remaining the existing ones (Figure 8.) /14/

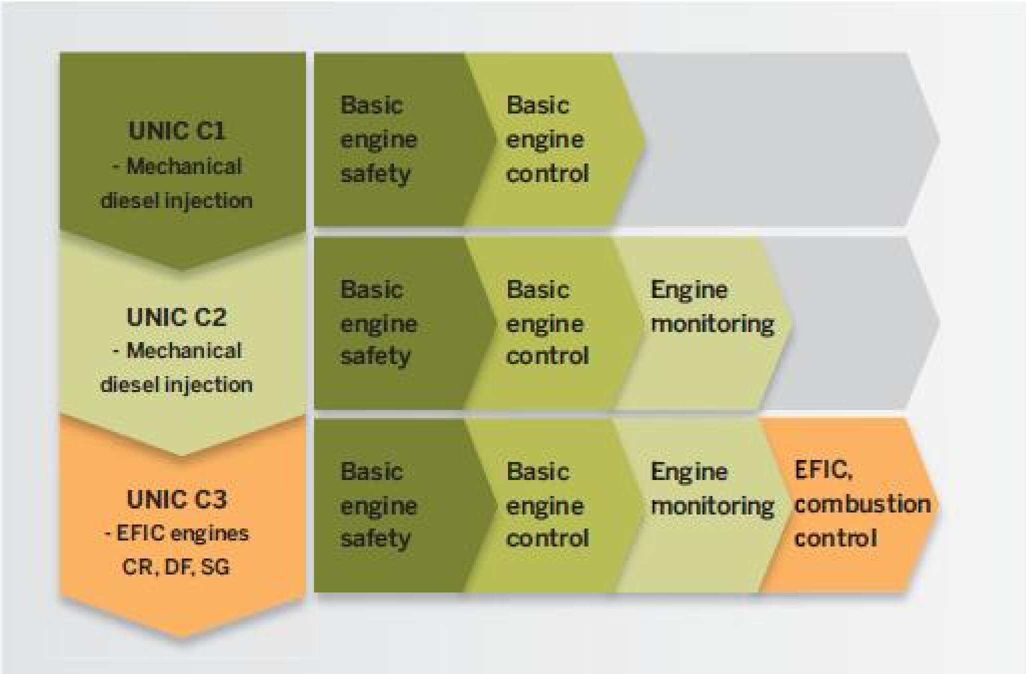

Figure 8. UNIC features for engine applications. /14/

UNIC has the major control and monitoring systems for the engine. Engine start and stop management includes:

- Starting and stopping of the engine
- Start blocking and automatic shutdown of the engine
- Load reduction request
- Local control through local command buttons. /23/

The control of the speed and load is handled by UNIC. Several measurements and signal processing are followed through UNIC, for example engine and turbocharger speed, monitoring and safety sensors. Measurements will be readout on a local graphical display. The alarm and monitoring system of the power plant is communicating with UNIC over Modbus. UNIC has terminal strips for external connections. The protection class is IP54. /23/

The Main Control Module handles all strategic control functions of the engine such as start/stop sequencing and speed/load control as well as the load sharing so for this thesis it is the main part of UNIC. The UNIC speed controller is a software module in MCM, it provides four different sub-control modes:

- Circuit Breaker open control mode
- Speed droop control mode
- Isochronous control mode
- True kW control mode. /23/

4.1.2 Woodward

The Woodward engine controller model that is presented here is 723PLUS Generator Control for Wärtsilä. Woodward controller has three different control modes:

- Droop control on a 4-20 mA MW transducer input, or the actuator position.
- Isochronous load sharing with soft loading/unloading and automatic generator open command once the engine has unloaded.
- MW control with soft loading/unloading and automatic generator breaker open command once the engine has unloaded. The reference may be adjusted by increase/decrease contacts or by analogue reference 4-20 mA or Modbus. In addition an internally tuneable MW reference value can be used. /19/

The MW control mode is corresponding to the true kW control mode and useful for applications where the grid is weak and large frequency excursions are expected. Under these circumstances, operating in the droop mode is not practical, because large variations in load would be experienced, due to the frequency shifts of the grid. In MW control, the speed of the engine is maintained by the grid and the load on the generator remains constant throughout the frequency excursion. /19/

The Woodward controller provides a closed loop speed control, with a torsional filter and a notch filter to eliminate problems caused by low frequency oscillations due to engine and generator inertias and flexible couplings. Start and maximum fuel limiters and a charge air pressure limiter are provided. A load limiter provides load de-rating during frequency excursions. If the frequency excursion becomes too large, an additional protection is offered to open the grid breaker or the generator breaker. /19/

Woodward has the following ports for signals:

- 8 Digital Inputs
    - 8 mA at 24 VDC
- 4 Analogue Inputs
    - 4-20 mA or 1-5 VDC
        - MW Transducer
        - MW Reference
        - Unit/System Synchroniser
        - Reactive Power Transducer/Charge Air Pressure
- 3 Analogue Outputs
    - 4–20 mA or 0–1 mA to meter or computer
    - 20–160 mA or 4-20 mA
        - Actuator Position
        - Engine Speed
        - Engine Load
        - MW Reference
        - Speed Input #1
        - Speed Input #2
- 1 Actuator Output
    - 20-160 mA or 4-20 mA
- 1 Programmer Communication Port
    - RS-422, 9-pin D connector, 1200-19200 baud (1200 baud only to handheld programmer), full duplex
- 2 Communication Ports
    - RS-232, RS-422 or RS-485, 9-pin D connector, 1200 to 38400 baud, full duplex. /19/

4.1.3 DEIF

Engine controller presented here is Protection and Paralleling Unit Multi-Line 2 made by DEIF. The DEIF controller contains three different applications: stand-alone, parallel with other generating sets and parallel with the mains. The PPU is a microprocessor based control unit containing functions for protection and the control of a synchronous/asynchronous generator. PPU is suited for PLC-controlled systems and the interfacing can be done via binary and analogue inputs and outputs or via serial communication. /12/

There are four different operation modes available in DEIF: fixed frequency, fixed power, droop and load sharing (Table 2, Figure 9). /12/

Table 2. Effects of modes on values.

	Freq.	Power
Fixed freq.	x	
Fixed power		x
Droop		x
Loadsharing	x	x

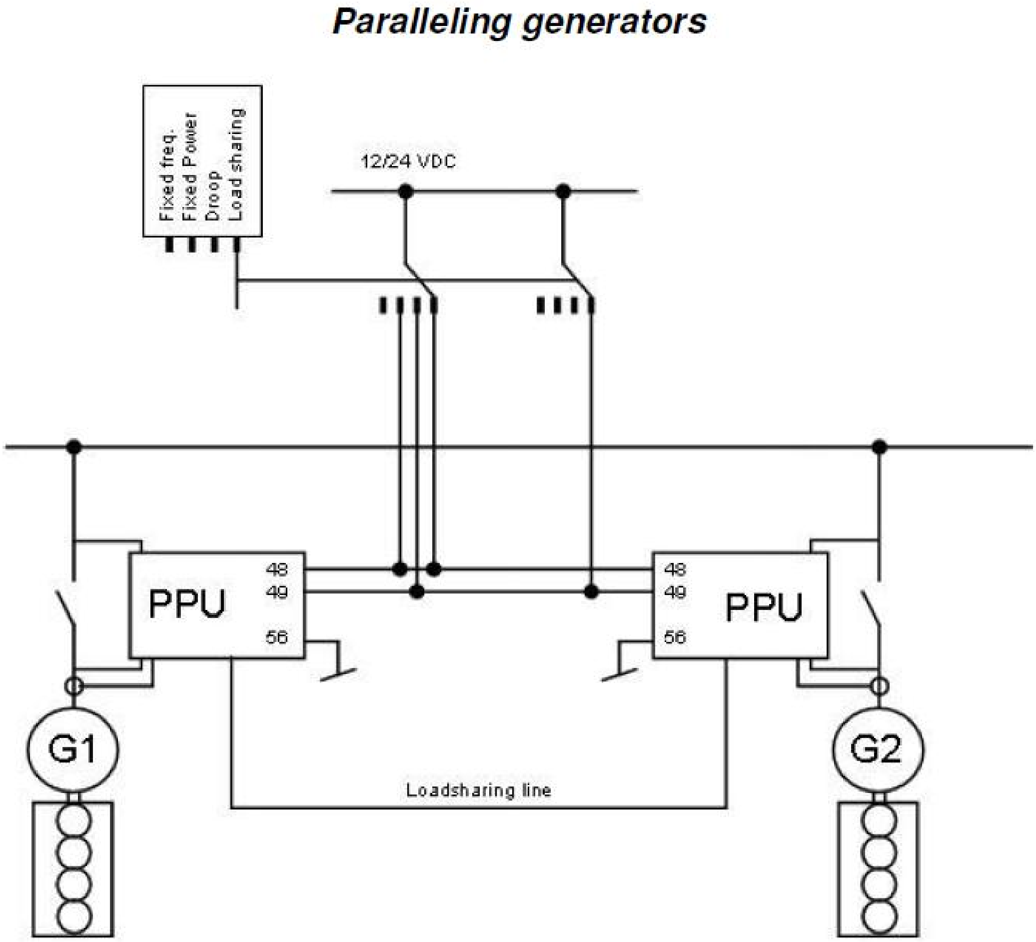

Figure 9. Load sharing between two generating sets with DEIF controllers. /12/

PPU contains 8 different slots for connections:

- Slot 1
  - Power supply
- Slot 2
  - Serial communication
- Slot 3
  - Load sharing
- Slot 4
  - Regulation outputs (relays)
  - Voltage/var/PF control

  - Analogue controller outputs
  - Combination outputs
  - PWM output (speed + droop)
  - PWM output (speed)
- Slot 5
  - Measuring
- Slot 6
  - PWM output (speed + droop)
  - Analogue transducer outputs
- Slot 7
  - 2 Engine interfaces
- Slot 8
  - Engine communication
  - I/O extension cards. /19/

DEIF is usually combined with a speed governor to control the engine speed. The speed governor can be connected directly with DEIF through +/- 20 mA signal or by using a resistor through +/- 5 VDC signals. The speed governor is controlled by DEIF. Slot 4 is for speed governor connection. The speed governor is an analogue controller. DEIF makes the load sharing possible between the governors by using the speed droop with DEIF controller, the droop will be isochronous load sharing.

4.1.4 WECS

There are different WECS controllers for different size engines. Similarly to the new UNIC, WECS also consists of MCM, CCMs and IOMs. WECS communicates with external systems via Ethernet or Profibus. Internal communications are done via a CAN bus (Figure 10.) /5/

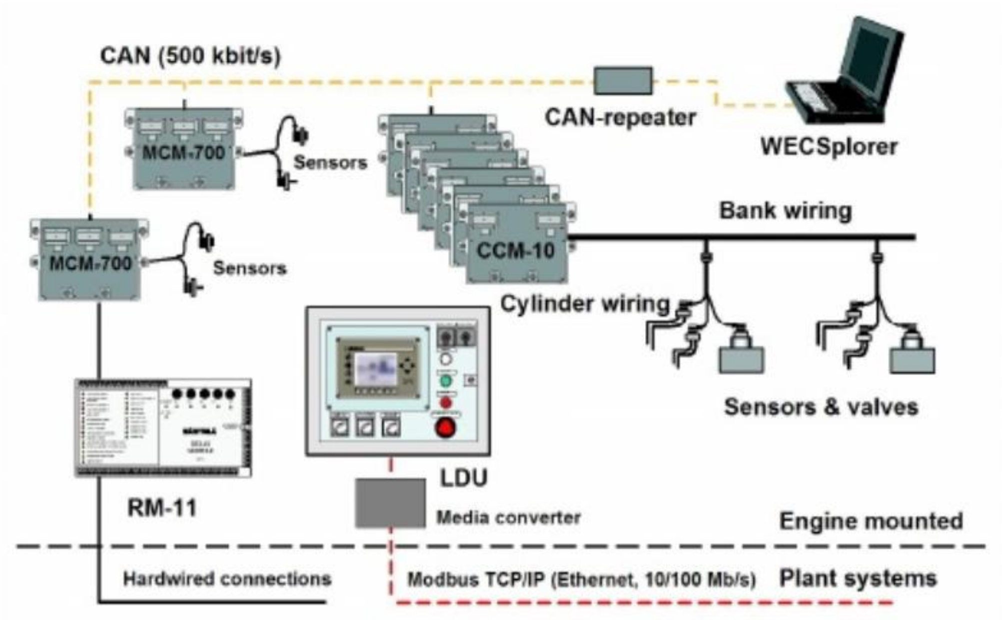

Figure 10. WECS 8000 communication and signals. /22/

WECS cannot handle load sharing by itself, but load sharing can be done for example by Woodward controllers. A load sharing controller is connected to a PLC, which handles the communication between WECS and the additional controller for load sharing (Figure 11.) Load sharing on WECS engines can also be handled by a common PLC, but when load sharing is done with PLCs, isochronous load sharing is not possible (Figure 30.)

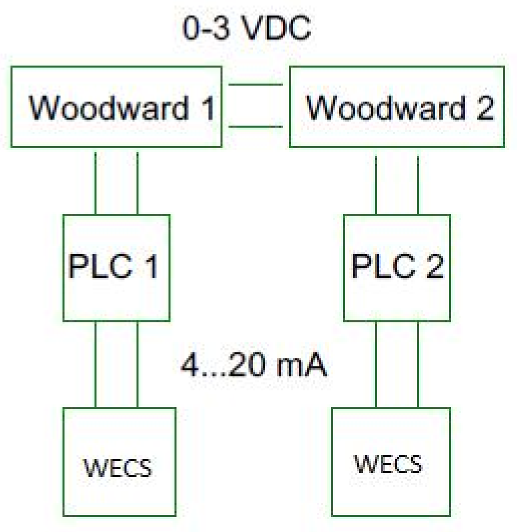

Figure 11. WECS load sharing with Woodward controllers.

The specific WECS presented in this thesis is WECS 8000 engine management system. It handles all necessary monitoring and strategic control features needed on a dual fuel and gas engine. WECS 8000 contains the following functionality categories:

- Engine slow turning, start and stop sequences
- Changing of fuel modes
- Instrumentation and communication
- Speed measurement
- Engine safety
- Speed and load control
- Gas pressure and gas admission control
- Pilot pressure and pilot injection control
- Air and fuel ratio control
- Cylinder balancing and knock control
- Diagnostics. /22/

For interconnections and cabling WECS has a Cabling Interface Box. CIB is an interface between the control modules and external devices. /22/

WECS 8000 controller includes a frequency fine tuning control mode, which is similar to the speed droop. Frequency fine tuning is a droop compensation, which keeps the frequency stable. WECS includes also the true kW control.

4.2 Devices for Generator Control

All of the devices for generator control presented in this thesis are automatic voltage regulators. The new AVR is ABB's Unitrol 1020 and the old ones are Basler 100, 200 and AvK's Cosimat N+. Four different AVRs are presented in this thesis, they are chosen because they are most common in projects where ABB is involved. Unitrol 1000, the older version for Unitrol 1020, is not presented because the communication between Unitrol 1000 and Unitrol 1020 is similar to the communication between two Unitrol 1020 AVRs.

- ABB Unitrol 1020
- Basler DECS-100
- Basler DECS-200
- AvK Cosimat N+.

Different control modes are available in different AVRs (Table 3).

Table 3. AVR control modes and communication.

Generator Controller	Control modes			Communication	
	Voltage droop	PF control	Reactive LS	Digital	Analogue
Unitrol 1020	X	X	X	X	
Basler 100	X	X	X		X
Basler 200	X	X	X		X
AvK	X	Additonal	Additional		X

4.2.1 Unitrol 1020

ABB's Unitrol 1020 is an automatic voltage regulator, it is presented in this thesis as a new generator controller. Unitrol is a microprocessor based AVR and contains

IGBT semiconductor technology. All operations are effected through the panel on the unit. /4/

Unitrol 1020 includes the following signal and communication ports:

- 8 digital outputs
- 12 digital inputs
- 6 analogue inputs
- 6 digitally assigned analogue inputs
- 4 analogue outputs
- RS-485 serial interface
- CAN bus
- USB
- Ethernet. /4/

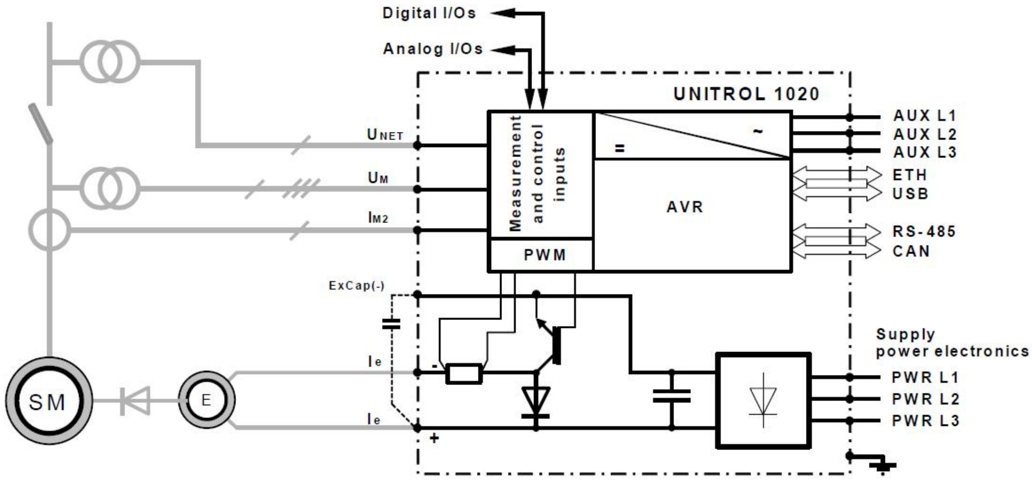

Figure 12. Unitrol 1020 connection diagram. /4/

Signals and communication as well as other connections are shown in Figure 12. Unitrol 1020 has five different operation modes:

- Auto mode, which means automatic voltage regulation
- Manual mode, which means field current regulation

- Open loop, which is a control with a fixed output signal
- Power factor and Var regulation
- Voltage droop compensation for load sharing between parallel units. VDC is a function in auto mode. /4/

CMT1000 is software for remote control of the Unitrol. To use CMT1000 Unitrol must be connected to a PC either via USB or Ethernet which are both also ports for remote access. Remote access is possible also via Modbus to RS-485, but the RS-485 port is also meant for VDC and only one can be operated with the RS-485 interface at the same time. In this situation remote access is connected over Modbus TCP to the Ethernet port and VDC over RS-485. The Ethernet connection allows monitoring and controlling from a remote location. Basic features of the CMT1000 are:

- Configuration of parameters and I/O signals
- Measurement reading
- Trending function for controller optimization
- Parameter file upload or download
- PID tuning, Set point step and other commissioning tools. /4/

4.2.2 Basler 100

Basler 100 Digital Excitation Control System, DECS-100, is a microprocessor based control device. DECS-100 regulates the output voltage of a generator by controlling the current into the generator exciter field. DECS-100 has four different control modes:

- Automatic Voltage Regulation
- Field Current Regulation
- Power Factor Regulation
- Var Regulation. /7/

For generator paralleling, DECS-100 uses reactive droop compensation and cross current compensation which are controlled through analogue signals. DECS-100 contains following connections (Figure 13.):

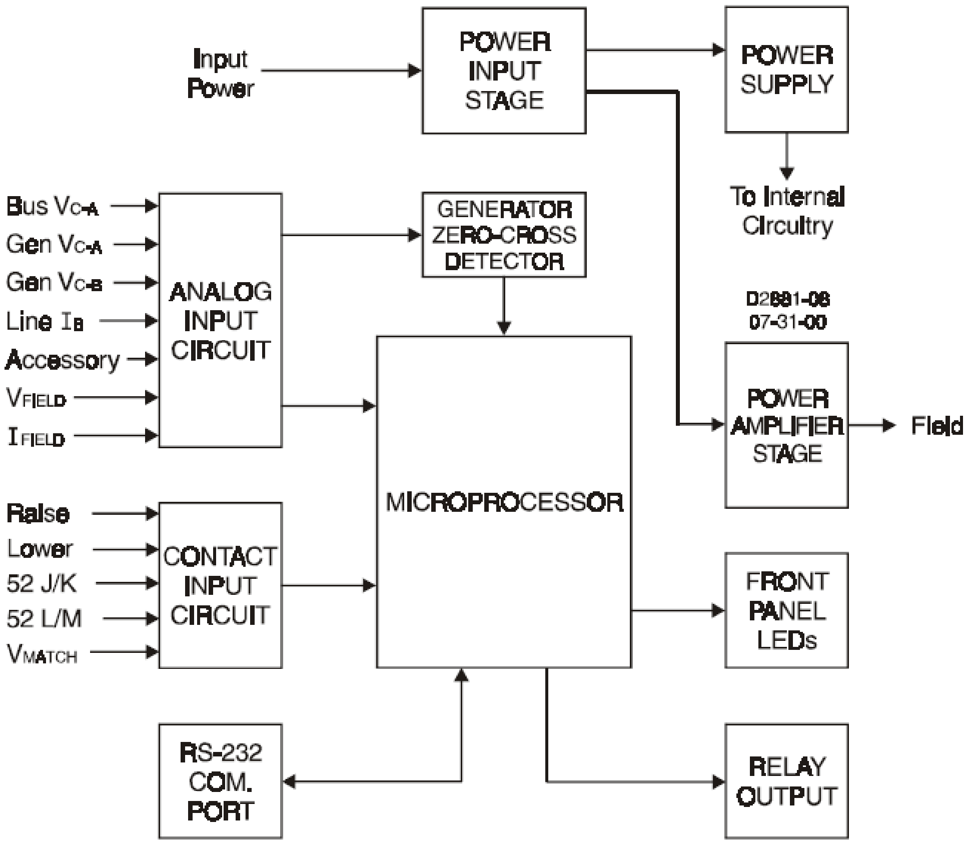

Figure 13. DECS-100 block diagram. /7/

The communication port for the DECS-100 is a RS-232 connector. The programming of the device is done through the communication port. Programming is done by a PC that contains BESTCOMS software which is supplied with the DECS-100. /7/

4.2.3 Basler 200

Like the DECS-100, Basler 200 Digital Excitation Control System is a microprocessor based control device that contains the same four control modes. An addition to the device functions has been made from DECS-100 to DECS-200, including protection functions, soft start capabilities and limitations. Load sharing is still done with reactive droop compensation and cross current compensation. Most significant changes in DECS-200, considering this thesis, are the number of signal and communication ports (Figure 14.) /8/

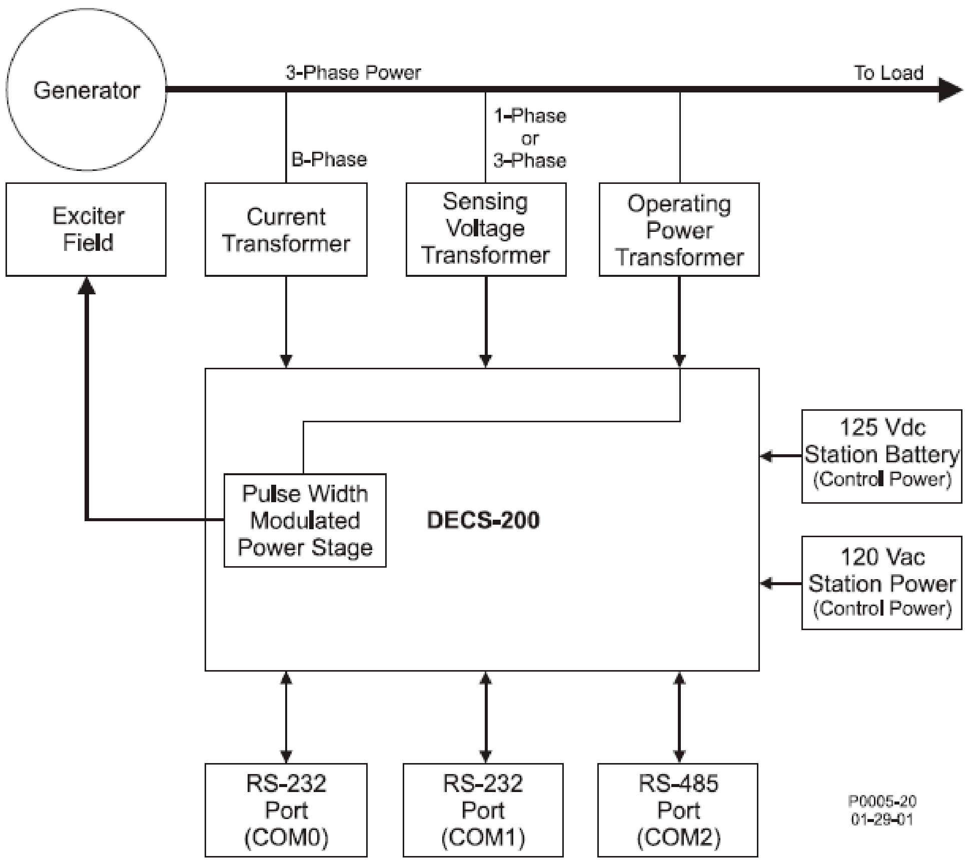

Figure 14. Block diagram for a DECS-200 application. /8/

Two communication ports have been added, one RS-232 and one RS-485. The front RS-232 port is for communication with a PC for BESTCOMS software. The other

RS-232 is for communication with a redundant DECS-200. The RS-485 port is for communication with a remote terminal. The RS-485 port includes The Modbus protocol. /8/

The operating mode used in DECS-200 is dependable of the generator operating mode. If the generator is operated as a single unit or stand-alone, the AVR mode is active. If the generator is operated parallel to the utility grid or islanded with two or more generators, the droop mode is active. If the generator is parallel with the utility grid, the Var/PF mode is also possible to be used. /8/

4.2.4 AvK

The AvK voltage regulator model presented in this thesis is Cosimat N+ (Figure 15.) When Cosimat N+ is in single operation, the alternator voltage is held constant irrespective of power, frequency and temperature. When operated in parallel with the mains or with other alternators, a stable reactive power is produced. For generator control AvK Cosimat N+ uses the droop control. Additional modules can be added to widen the field of operations. Reactive load sharing and power factor control can be handled by these additional regulators. /6/

When a generator is operating in parallel, voltage regulation is no longer possible because the system voltage is fixed. A fluctuation in the system voltage would lead to the generator producing reactive current. To stabilise the generator reactive current, it is necessary to have a measured variable which is dependent on the reactive current and incorporates the magnitude of the current and the reactive power. This measured value is introduced at the addition point of the amplifier circuit. This produces a static droop control characteristic, which represents the relationship between the generator voltage and generator current in relation to their nominal values. The droop effect can be adjusted from 0 to 6 % using the potentiometer R7 on the device. /6/

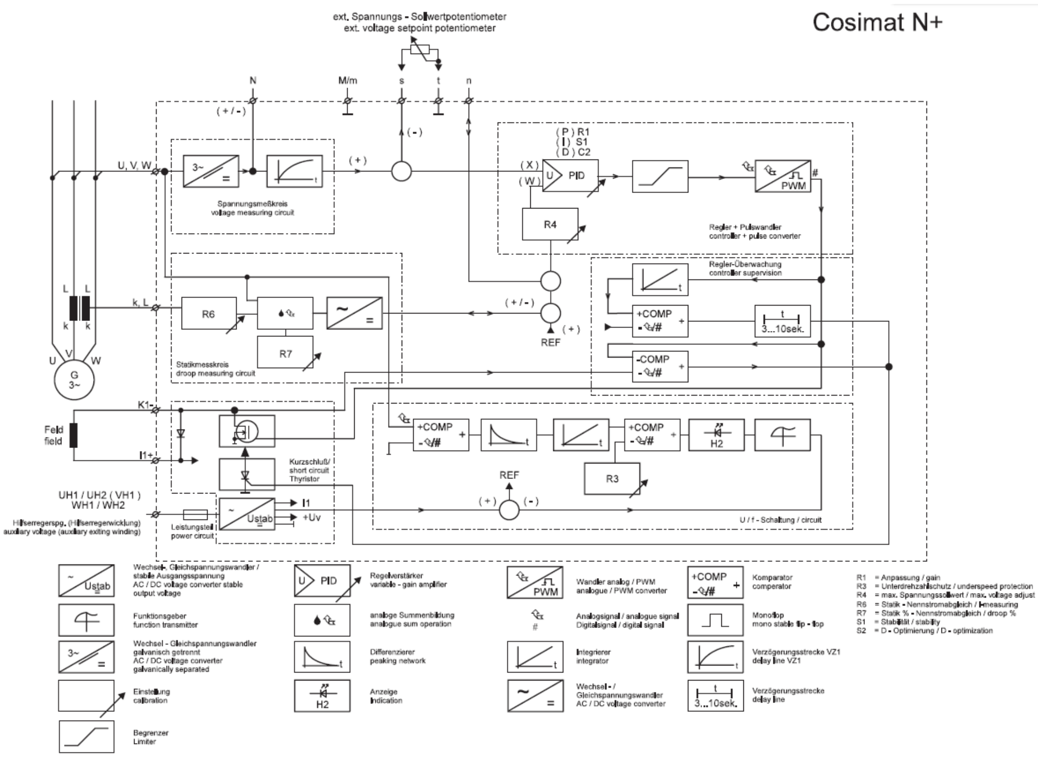

Figure 15. Cosimat N+ block diagram. /6/

In parallel operation, regulation of the synchronous generator is made possible by the droop sensing signal. The droop sensing signal in the Cosimat N+ influences the desired value and is produced by means of a geometrical addition of the external conductor voltage U-W and a current dependent voltage signal from the V phase. The droop sensing system of the Cosimat N+ is matched to the nominal current of the generator by the potentiometer R6. The droop current sensing signal is between 3…7 VAC. /6/

An additional QPF module is needed for parallel operation. The QPF regulator is connected to the Cosimat N+ and individual QPF regulators are interconnected. The QPF regulator makes power factor and reactive power regulation possible. QPF measures the generator voltage and generator current in phase. When generators are in parallel operation, the QPF regulator is encoded in a certain way for the reactive power to be balanced automatically. The QPF load sharing signal is within 4…20 mA (Figure 16.). /6/

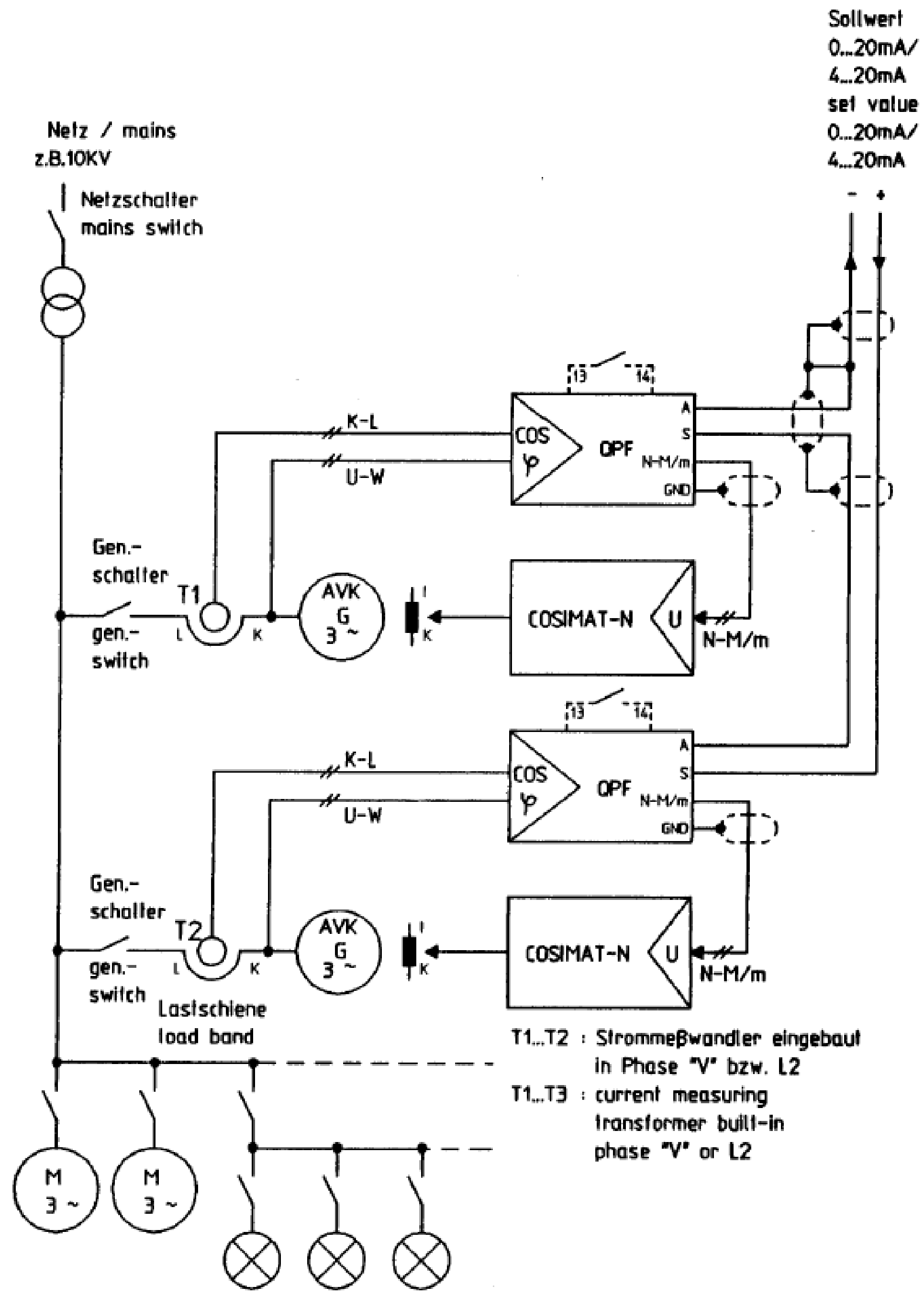

Figure 16. Reactive current or power factor of generators in parallel with grid. /6/

4.3 Devices for Load Sharing Communication

A certain device between different load sharing lines is sometimes needed in order to achieve load sharing communication between generating sets with different engine controllers and different regulators. This is especially relevant in power plant extensions, because of the long physical distances between the power plants. Because of the distance, it is not possible to use the analogue load sharing line between the power plants. Active load sharing between parallel engines already have these kind of devices from different manufacturers. LSC-10 is Wärtsilä's Load Sharing Converter, it is presented in this thesis because of its relevance to ABB Power Generation.

4.3.1 LSC-10

LSC-10 is a Load Sharing Converter designed by Wärtsilä. LSC-10 enables UNIC controller to be connected to some of the existing load sharing lines (Figure 17.) /15/

The power plant extension has a separate plant MCM to which the LSC-10 can be directly connected to. LSC-10 can be mounted to the existing power plant, this will enable more distant location for the power plant extension because of the hardwire communication between the LSC-10 and the plant extension MCM of the new power plant (Figure 18.) /15/

LSC-10 is an interface between UNIC engines that use CAN bus communication for load sharing and other controllers for example Woodward that uses analogue 0-3 VDC load sharing lines.

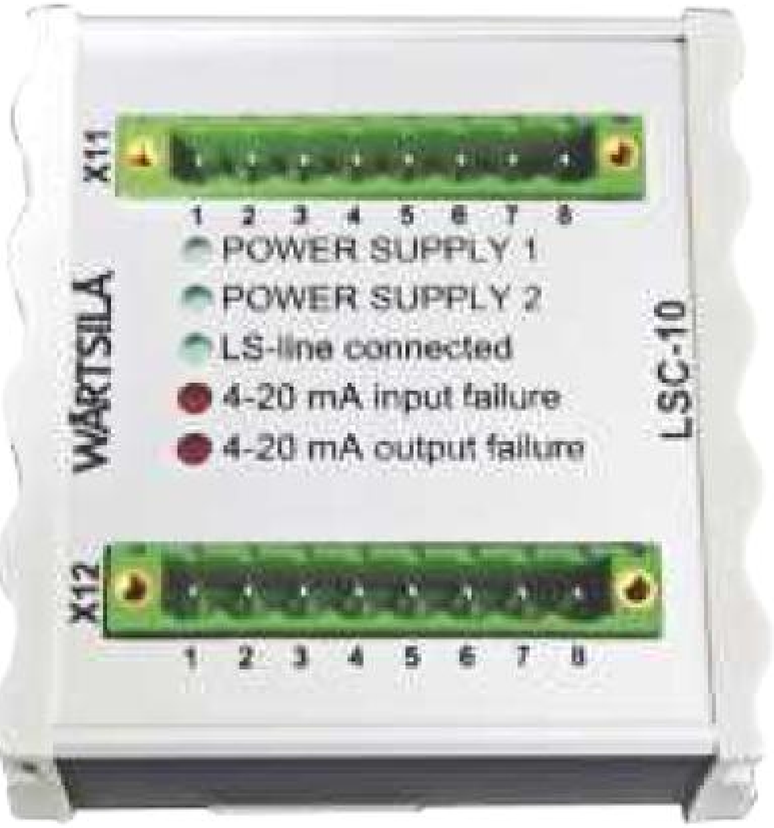

Figure 17. LSC-10, Load Sharing Converter. /15/

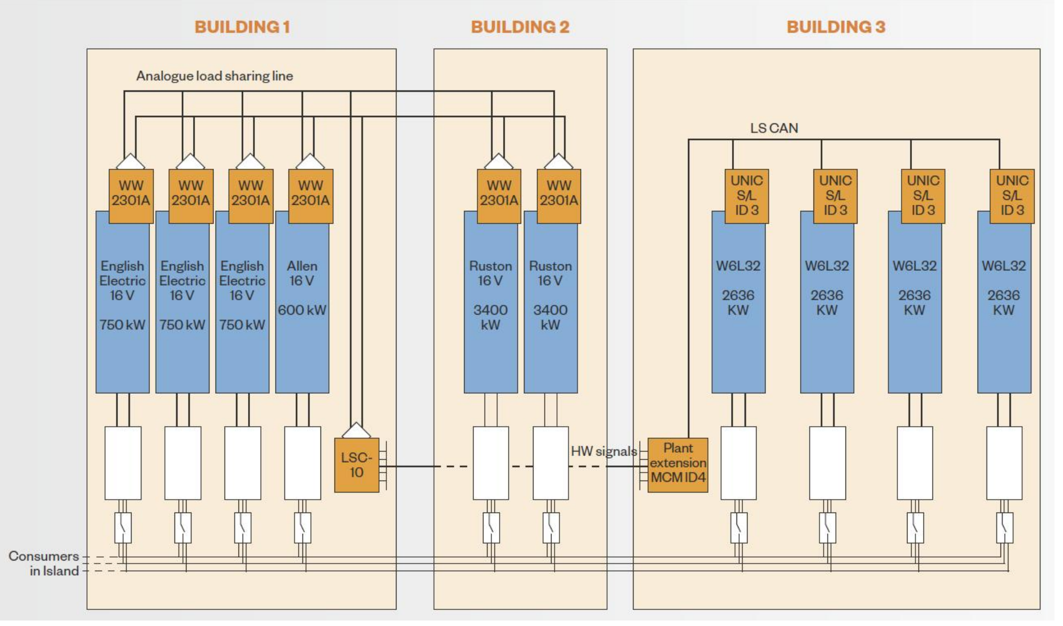

Figure 18. A single line diagram of the generating sets running in parallel. /15/

4.3.2 LSG

Load Share Gateway is a load sharing converter designed by Woodward. LSG is designed to make load sharing possible between legacy devices and Woodward easYgen 2000/3000 series devices. Woodward easYgen is corresponding to UNIC with CAN bus load sharing. The idea is similar to LSC-10, with the LSG converter, coupling of a RS-485 or an analogue load sharing line with a CAN bus is possible (Figure 19.) /21/

LSG is compatible with several analogue devices because of the different voltage ranges, the converter supports. LSG is a converter for both active and reactive load sharing, but the problem is that it needs a CAN bus, that is why it can't be considered to operate between Unitrol 1020 and an analogue device (Figure 20.) /21/

Figure 19. Load Share Gateway. /21/

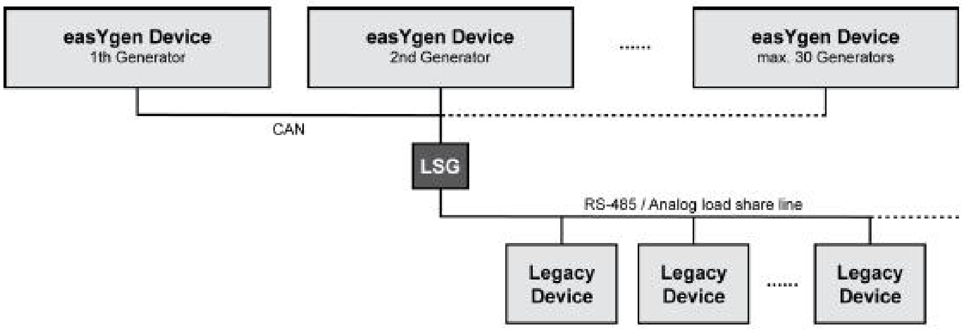

Figure 20. LSG between CAN bus and RS-485 or analogue load sharing line. /21/

5 LOAD SHARING SYSTEMS

Load sharing systems have evolved from analogue load sharing to digital. On the engine side this means jumping from voltage signals to the CAN bus and on the generator side, jumping from small current signals to the bus interface with serial communication ports.

5.1 Old System for Load Sharing

Both active and reactive load sharing are communicating via analogue signals in the older systems. Basically the active load sharing signals are of DC voltage type and the reactive load sharing signals have small current values as in cross current compensation.

5.1.1 Old Active Power Load Sharing

Old power plants have analogue load sharing lines. In an analogue load sharing line, each engine writes its own load signal to the line, which is then converted to the system load. Engines connected to the common load can then measure the system load from the load sharing line in order to perform isochronous load sharing. Communication is a direct measurement. Load sharing line signals are typically 0-3 or 0-4 VDC (Figure 21.)

Analogue load sharing is not possible with long physical distances, because of the voltage decrease due to electrical resistance as a function of the distance of the conductor and the transmitted data is altered. The cable for the load sharing is a shielded twisted-pair cable. The analogue line should be continuous from control to control without any devices between. Relay contacts on controls must be designed for low power signals. /15, 20/

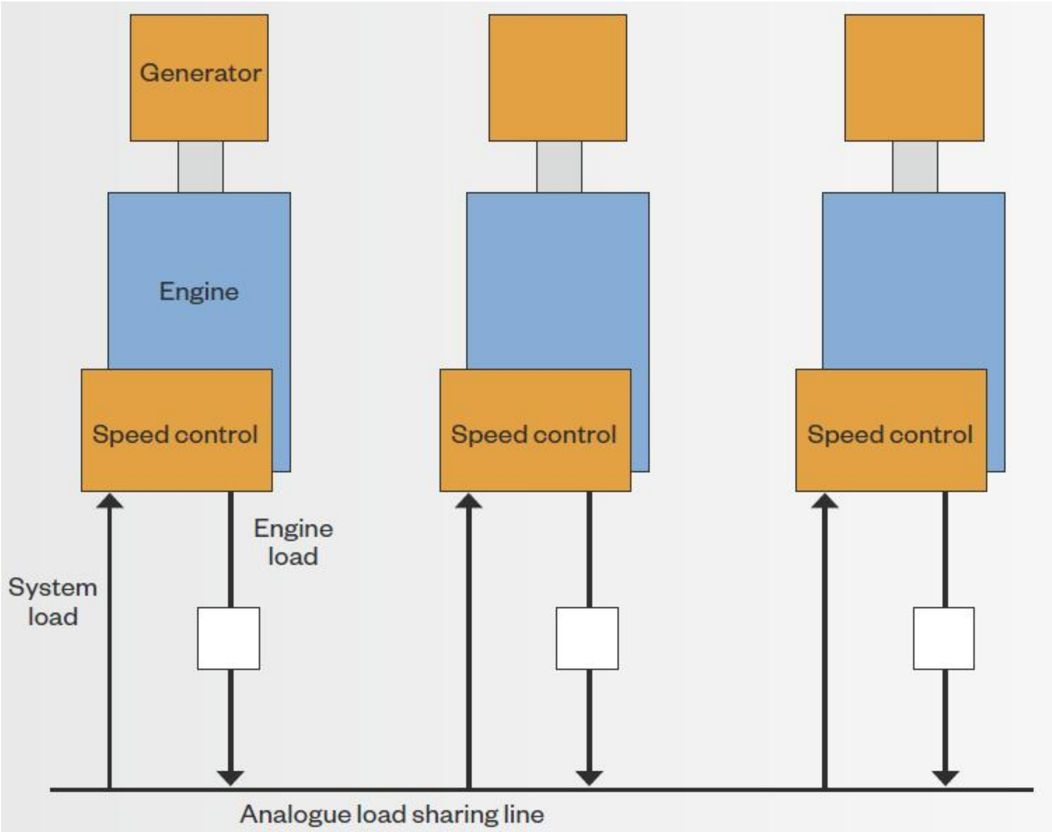

Figure 21. Isochronous analogue load sharing. /15/

5.1.2 Old Reactive Power Load Sharing

Old systems for reactive load sharing are reactive droop compensation and cross current compensation. In cross current compensation, additional current transformers are needed because they are wired as a loop to perform load sharing. In CCC all generators also need to have the same burden resistor setting in the AVR paralleling circuit. This insures that if an imbalance exists in the generator, the current that flows in the cross current loop will setup a proportional voltage across each burden resistor, that will balance the reactive load of the generator system (Figure 22.) /10/

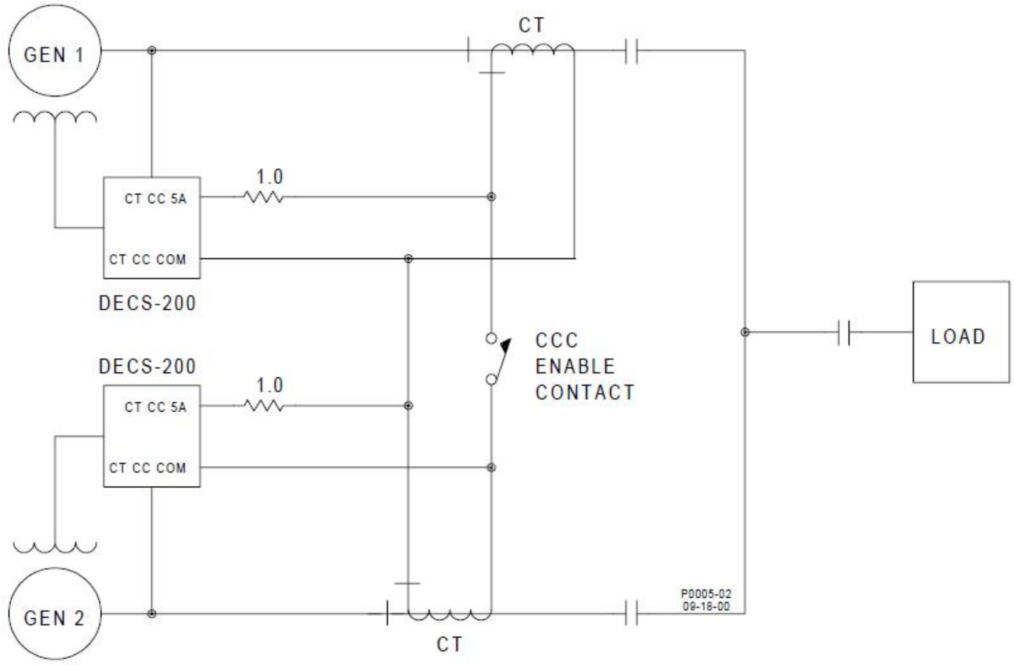

Figure 22. Cross current compensation in Basler 200. /8/

Old reactive load sharing is operated with hardwire signals between the voltage regulators. An analogue signal does not have as much information as a bus cable so less functions are available because of the less data each AVR is getting.

5.2 New System for Load Sharing

The new system for active load sharing is droop load sharing and isochronous load sharing, which are the load sharing modes in Wärtsilä's UNIC. For reactive load sharing system, the new system is voltage droop control, which is the load sharing mode for ABB's Unitrol 1020.

5.2.1 New Active Power Load Sharing

For engine load sharing, the new isochronous load sharing systems have provided new possibilities through the CAN bus communication including soft loading, load sharing profiling and bus bar synchronisation. Digital communication enables longer physical distances between the power plants and larger amount of data to be transferred through load sharing line, which enables more complex load sharing functions. The new engine control system has two load sharing concepts for speed control: droop load sharing and isochronous load sharing (Figure 23.) /15/

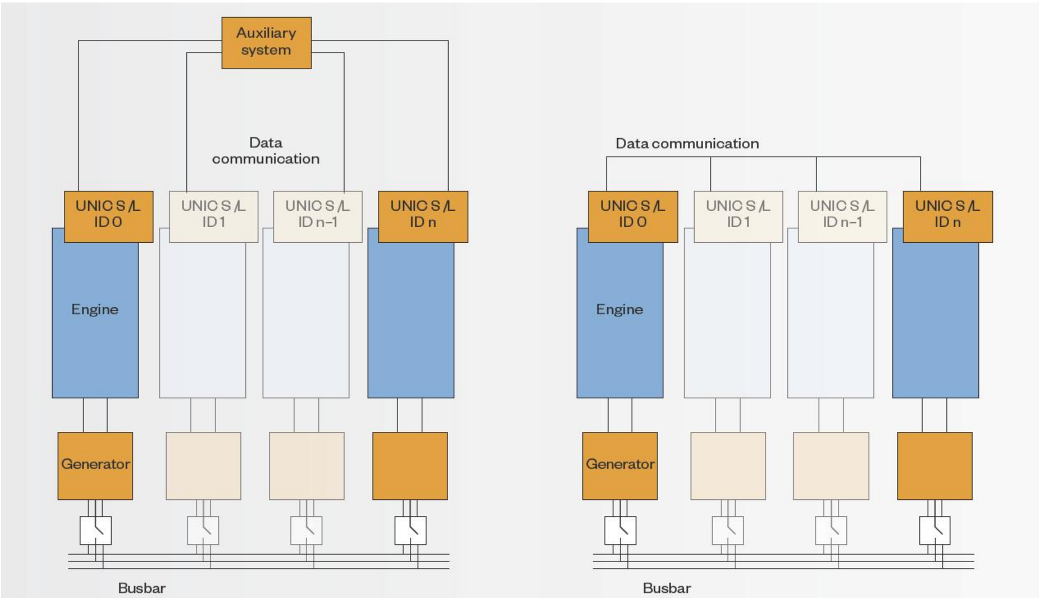

Figure 23. Droop load sharing (left) and isochronous load sharing. /15/

Engines running in the droop load sharing mode cannot maintain a fixed frequency by themselves. For example, a power management system is needed to work as an auxiliary system. /15/

5.2.2 New Reactive Power Load Sharing

Load sharing with Unitrol 1020 devices is done via RS-485 ports with a proprietary protocol. If the load sharing line consists only from Unitrol 1020s, the maximum length is 500 meters, but if the line has also other AVRs, including Unitrol 1000, the maximum length is 250 meters. A total of 31 devices can be in one bus (Figure 24.) /4/

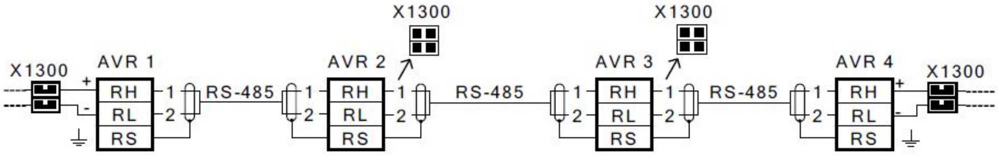

Figure 24. Wiring in RS-485 interface. /4/

VDC is not able to work properly if there is any device in the bus that is not compatible. Each AVR has its own AVR-ID number through which it can be configured and identified on the bus. VDC communication refers to the data transmitted over the RS-485 bus and it is enabled by the AVR. The data on the bus is used for the regulation. VDC communication allows the cabling connection and communication to be tested. The status of the communication can be monitored from the CMT100. /4/

Voltage droop compensation can be done in two different ways, either by bus bar configuration or by ring configuration. In bus bar configuration the AVRs can operate in one of three pre-determined island grids called Primary and Secondary Nets. The Secondary Net is configured using a digital input. This input determines whether the used data is from the Primary or Secondary Net. Four different net IDs depending on two digital inputs are selectable by the user. The load sharing takes place between the AVRs with the same net ID (Figure 25.) /4/

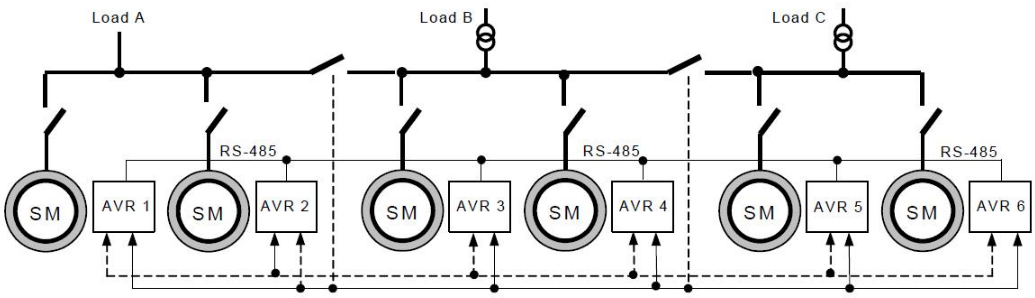

Figure 25. Bus bar configuration for six machines and two nets. /4/

In ring configuration the ring can be split up and the AVR automatically shares load with the connected machines. The ring is based on segments with a left and right breaker. The amount of the machines is not limited inside a segment, maximum is the same, 31 machines. The status of the breakers is wired to digital input of the AVR (Figure 26.) /4/

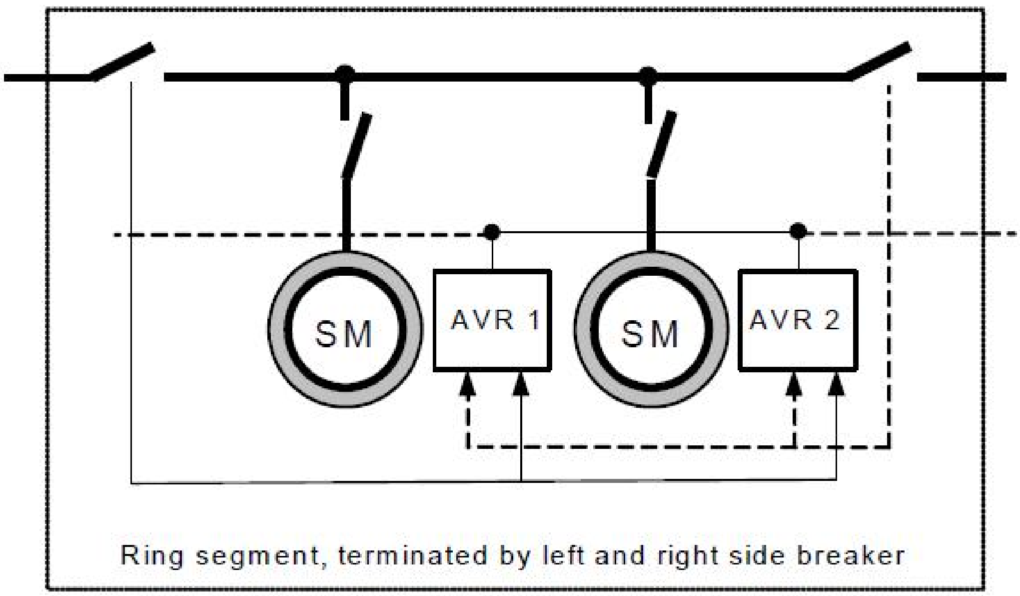

Figure 26. Ring segment. /4/

The auxiliary contact of the breaker is wired only inside of the segment. To select the right machines for load sharing, each AVR gives information of the segment breaker and their own position over the RS-485 bus to other AVRs. Each AVR collects all status information of the ring tie breakers in order to select the right load sharing group. In case of separated segment the load sharing is done by the remaining ones and separately on the isolated segment. /4/

Load sharing via Ethernet communication is also possible in some AVRs, for example in Basler DECS-250. Ethernet communication has advantages compared to the older Basler load sharing with cross current compensation and reactive droop compensation. Zero voltage droop with Var sharing and no possible wiring errors are the benefits of Ethernet communication. /9/

6 LOAD SHARING POSSIBILITIES

Because of the load sharing converters for engine controllers in active load sharing, this part will focus on how reactive load sharing would be possible between AVRs from different manufactures. Different AVRs have been presented in this thesis and the main point in load sharing between them and the problems in load sharing are different paralleling cables and signals.

Cross current compensation is not possible in Unitrol and since the AVRs that are using cross current compensation are capable of sharing the load only with other devices that include the CCC possibility, it is not possible to handle load sharing with the CCC in extension projects.

Voltage droop compensation is used in Unitrol via RS-485 port, an own protocol is made for Unitrol connections. Since load sharing via buses and serial communication ports is not possible in the older devices presented in this thesis, VDC is not possible in extension projects, either. VDC is possible between Unitrol 1020 and Unitrol 1000, but the maximum length is only 250 meters.

AVRs that have analogue load sharing have also the possibility to be paralleled with AVRs from other manufacturers, but the AVRs that use digital load sharing do not have the same possibility. Due to these reasons, different possibilities are considered and presented.

6.1 Active Power Load Sharing Possibilities

The main control module is able to handle load sharing for both existing power plants and plant extensions. The solution is the device presented in this thesis before, LSC-10. LSC-10 is able to convert analogue signals to CAN bus compatible. If the existing plant has some other signal type for the load sharing line, an additional signal converter is also possible to be combined with the LSC-10. The load sharing line between the plant extension MCM and LSC-10 is a 4…20 mA signal via 6 x 1.5 mm^2 cable (Figure 27.)

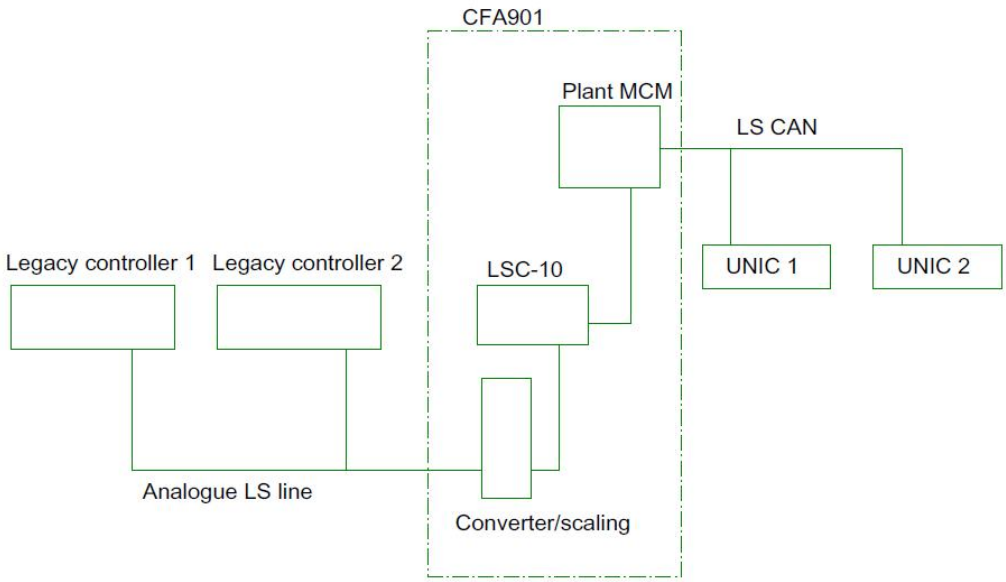

Figure 27. LSC-10 combined with another signal converter or scaling device.

Woodward and DEIF controllers can be connected directly to LSC-10. If some other controller has another signal, for example larger voltage, it can be scaled to a desired value. The connection could be similar to the one presented in Figure 18.

Load sharing between WECS 8000 and UNIC controllers can be done via a common PLC. The active power effect is transferred from the engines to the common PLC. An analogue load sharing line is used for communication. Communication between an engine PLC and the common PLC is done via Ethernet. An active power average is calculated in the PLC and a set point value is sent to WECS 8000 controlled engines based on the active power average. The set point is a kW value, if all engines are the same type or a percentage value if there are different type engines. Engines that are controlled by UNIC handles load sharing through isochronous load sharing. WECS is in droop mode, kW control mode or in frequency fine tuning mode, but only in one at a time (Figure 28.)

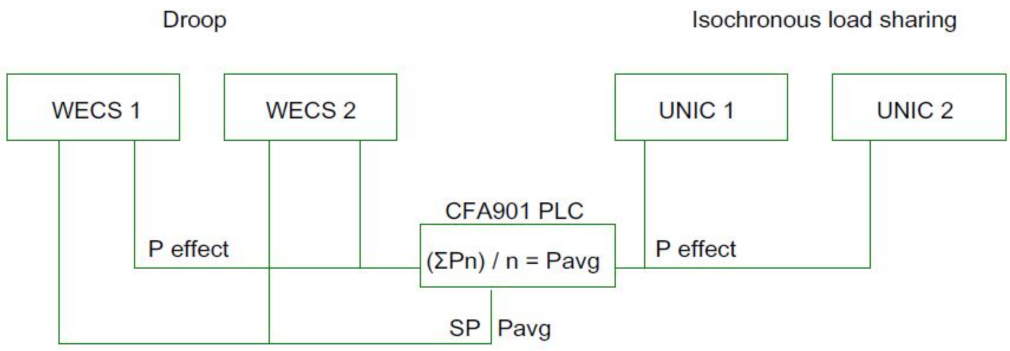

Figure 28. Load sharing between UNIC and WECS 8000 controllers.

An algorithm for set point calculation with blocks for the PLC is already existing. It is based on load sharing between WECS controlled engines.

6.1.1 Load Sharing without UNIC

Some plant extensions can be done without UNIC and MCM. To make an analogue load sharing line it is best to have a load sharing converter between the power plants, if there already are engine controllers that provide load sharing, such as Woodward. Combining load sharing line for Woodward controllers and the load sharing line that has other controllers is also possible through LSC-10.

LSC-10 can be used to enable load sharing between two old plants. In this case converters are needed for both plants. If one plant has Woodward controllers and the other has WECS 8000 controllers or PLCs, the plant with Woodward controllers require one converter, as with the UNIC extensions. The other plant with PLCs needs one converter for the plant and one converter for each engine (Figure 29.)

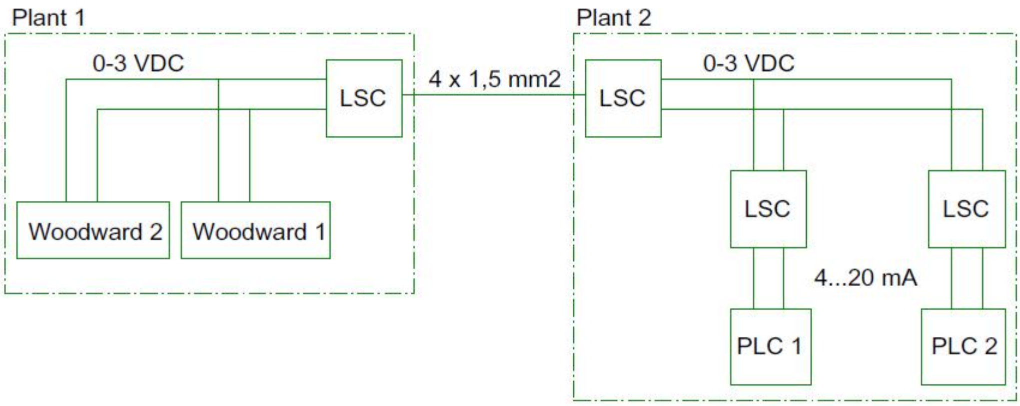

Figure 29. Load sharing between two LSC-10 converters.

Load sharing lines have signals between 0-3 VDC, but the line between the plants has 4…20 mA signals. The signal between the plants is the reason why an additional converter is needed to the plant with the PLCs because the signals between LSC-10 and PLC are also 4…20 mA.

6.2 Static Droop

Voltage control between different AVRs can be handled by static droop. Static droop is available on all AVRs and it does not need any information between the AVRs. A disadvantage in static droop is that the bus voltage is dependent on load. When generators are connected in parallel, the voltage regulation is not possible because of the possibility of the measurement error in system voltage. The slightest fluctuation would cause the generator to produce reactive current. The change in the reference voltage is equal to the error in the measured voltage, which is dependent to reactive current (Equation 2.) /6, 18/

$$\Delta Uref = Iq * Kq = Um_{error} \tag{2}$$

Where ΔUref is change in voltage reference, Iq is reactive current, Kq is droop or compensation percentage and Um_{error} is measurement error in voltage. The Kq must always be negative for reactive load sharing. Static droop is also used for VDC backup, if a failure occurs in the VDC mode, all AVRs affected by the failure are automatically forced to the static droop mode. /18/

6.3 Common PLC

In order to achieve load sharing communication between AVRs from different manufacturers a common PLC is needed between the existing power plant and the extension plant. The basic idea of the common PLC load sharing is that the nominal voltage from the common bus and the reactive power from each generator is brought to the common PLC. According to these measured values a new voltage offset and reactive power set points are given to AVRs. From these values each will either increase or decrease the reactive power and nominal voltage. Increase and decrease values are hardwire signals. Measurements will be gathered from a power monitoring unit, for example VAMP 260 (Figure 30.) Measurements from PMU are normally taken from a bus between the common control panel and PMU. A PLC algorithm for the common PLC load sharing does not exist, so it has to be made and tested.

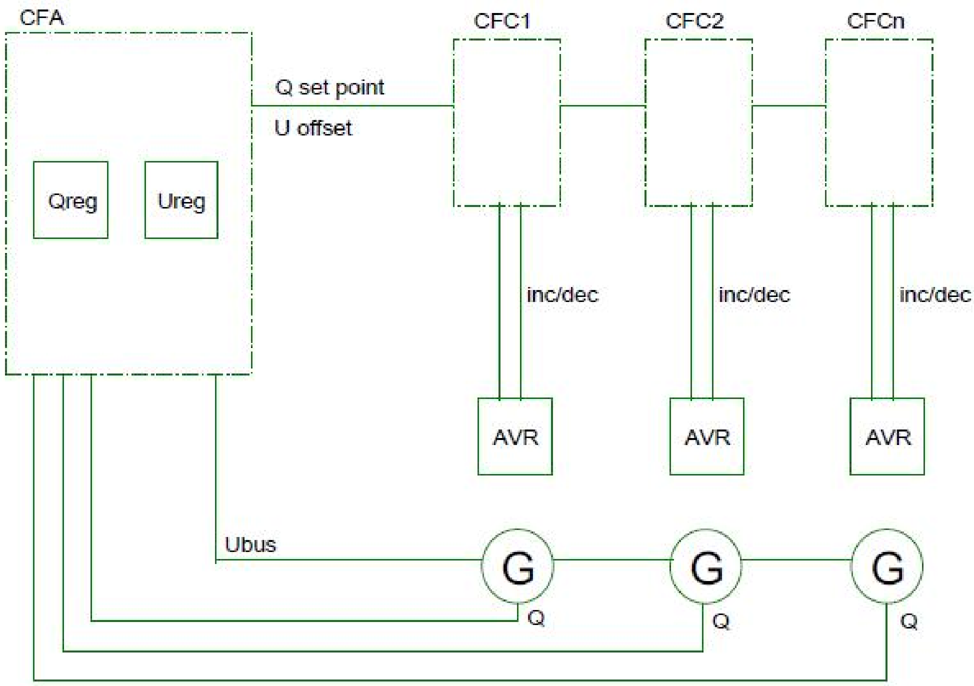

Figure 30. Common PLC load sharing.

From the old AVRs, the information will be transferred as analogue signals as it has been in CCC as well.

6.4 Upgrading the AVRs

Because of the application field that Unitrol 1020 provides, it is a good option to upgrade from the existing AVR to Unitrol. Digital communication allows more data to be transferred and no additional hardware is needed for generator load sharing. Difficulties in load sharing between Unitrol and older AVRs are a problem because of the different communication systems. A solution for the problem would be to have only Unitrols or devices that operate in the same communication system. The AVR upgrade is an advisable choice if a modern communication is wanted. The cost of a Unitrol 1020 is not significantly large if the VDC is necessary.

7 CONCLUSION

The conclusion of the thesis is that a load sharing converter is needed for active power load sharing between UNIC and legacy devices, if the legacy device is not also made by Wärtsilä. Load sharing between UNIC and WECS 8000 engine controllers is possible to be done via a common PLC (Figure 28.) LSC-10, the load sharing converter made by Wärtsilä, allows a load sharing CAN to be connected with an analogue load sharing line (Figure 18.) LSC-10 also enables load sharing between two analogue load sharing lines (Figure 29.) Different load sharing communications between UNIC and the legacy engine controllers are listed in Table 4.

Table 4. Load sharing communication between UNIC and legacy engine controllers.

UNIC	Woodward	DEIF	WECS 8000
Load sharing communication	LSC-10 (Figure 18)	LSC-10 (Figure 18)	PLC/LSC-10 (1 (Figure 28)
Additional modules	No	X (3	No (2

1) The load sharing communication for WECS 8000 can also be done through LSC-10, but a PLC is still needed between WECS and LSC-10. Load sharing with LSC-10 converters would be more expensive. But LSC-10 enables isochronous load sharing via a load sharing line.
2) If the load sharing is done with a PLC, no additional modules are needed but neither a load sharing line will be available. An additional module for WECS 8000 can also be a Woodward controller which will also enable the isochronous load sharing for engines, through a load sharing line.
3) The additional module for DEIF controller is a speed governor. A speed governor does not affect the load sharing.

For reactive power load sharing, the conclusion is that if communication between Unitrol and the legacy devices is needed and upgrading the AVRs is not possible, load sharing must be done via a common PLC. Between Unitrol 1000 and Unitrol 1020 the proprietary protocol for ABB can be used for load sharing communication. When load sharing through a common PLC, reactive power effect and bus voltage are measured by the power monitoring unit, a reactive power set point and voltage offset are calculated by the common PLC based on the measured values. The calculated values are then sent to the generator PLCs and an increase or a decrease value is sent to the AVRs from the PLC. A suitable algorithm in the PLC has to be made for the calculation (Figure 30.) Different load sharing communications between Unitrol 1020 and the legacy generator controllers are listed in Table 5.

Table 5. Load sharing communication between Unitrol and legacy generator controllers.

Unitrol 1020	Basler 100	Basler 200	AvK	Unitrol 1000
Load sharing communication	Common PLC (Figure 30)	Common PLC (Figure 30)	Common PLC (Figure 30)	VDC proprietary RS-485 protocol (Figure 24)
Additional modules	X (1 (Figure 22)	X (1 (Figure 22)	X (2	No
AVR functions 4)	No (4.2.2)	No (4.2.3)	No (4.2.4)	X (3

1) Additional current transformers have to be installed to perform the cross current compensation with Basler 100 and 200 regulators. But when the load sharing is done through a common PLC, no additional current transformers are needed.
2) Additional regulators can be added to AvK Cosimat N+ for more load sharing possibilities. But when the load sharing is done through a common PLC, no additional regulators are needed.
3) The communication between Unitrol 1020 and Unitrol 1000 is done through a proprietary protocol and that enables the use of the VDC. Using the load

sharing protocol enables also the functions of the voltage regulators. In the common PLC load sharing, these functions will be lost.

4) When the load sharing is done through a common PLC the AVR functions will not be utilized.

REFERENCES

/1/ ABB website. Accessed 28.1.2015 http://new.abb.com/about/abb-in-brief

/2/ ABB website. Accessed 28.1.2015 http://new.abb.com/fi/abb-lyhyesti/yhtyma

/3/ ABB inside. Accessed 28.1.2015

/4/ ABB Unitrol 1020 Manual. 3.2012

/5/ Ahnger A. 1998. Gas Engine & CHP Plants. Wärtsilä.

/6/ AvK Cosimat N+ Regulator Descriptions.

/7/ Basler DECS-100 Instruction Manual. 8.2001.

/8/ Basler DECS-200 Instruction Manual. 11.2007

/9/ Basler Electric. DECS-250 and DECS-250N Digital Excitation Control System.

/10/ Basler Electric. Voltage Regulator and Parallel Operation. 2009

/11/ DEIF Multi-line 2/version 2-GS Installation instructions.

/12/ DEIF Protection and Paralleling Unit Multi-line 2 Data Sheet.

/13/ Det Norske Veritas As. Failure Mode and Effect Analysis (FMEA) of Redundant Systems. 01.2012

/14/ Pensar, J. & M. Storbacka. 2007. UNIC – The reliable solution for robust industrial controls. Wärtsilä Technical Journal. 2. 40-44.

/15/ Saikkonen, A. & T. Kaas. 2012. Analogue isochronous load sharing and UNIC. Wärtsilä Technical Journal. 2. 9-16.

/16/ Speed droop and power generation. 1991. Woodward.

/17/ UNIC C3 Engine Control System – Sales Leaflet LR. 2013

/18/ Unitrol 1010, Unitrol 1020 Reactive load Sharing. ABB Group.

/19/ Woodward 723 PLUS Application and Hardware Manual. 2005

/20/ Woodward Installation and Operation Manual. 1999

/21/ Woodward Load Share Gateway. 04.2011

/22/ Wärtsilä Automation for W50DF. 27.09.2007

/23/ Wärtsilä Installation Planning Instructions 1. Automation System. 11.4.2008