The ship's electrical network, engine control and automation

by Kari Valkeejärvi, Marine Technology, Wärtsilä Corporation

Electrical power in ships is usually produced by a synchronous generator. Given the essential nature of electrical power onboard ship, several means are used to assure its continuous availability. The main switchboard is divided into two or more sections. Also necessary are a switchboard supplied by an emergency generator as well as an uninterrupted (battery secured) power supply (Figs. 2 and 3), both for reasons of safety and to ensure redundancy.

Dimensioning the electrical network

The first step is to define the ship type. It goes without saying that the vessel's size and purpose are key factors when dimensioning the ship's electrical network. The following illustrate the differing electrical needs of different types of ship:

- Cargo handling equipment plays a dominant role in containerships, and defines the special power requirement characteristics of the electrical network
- In tankers, cargo pumps and possibly compressors are significant factors
- In passenger ships large electricity consumers are air conditioning, the galley equipment, stage equipment and lighting (also called hotel load) and the transverse thrusters for manoeuvring in port
- In ships with electric propulsion, the propulsion machinery itself is the dominating factor.

Both the choice of propulsion machinery and the classification regulations have an impact on the design of the electrical network. The rules of SOLAS (International Convention for the Safety of Life at Sea), the flag state and the harbour authorities specify the basic level of safety, while the classification societies mainly specify the basic navigational regulations. A redundant propulsion, unmanned engine room, a 'green' ship, all set their own requirements.

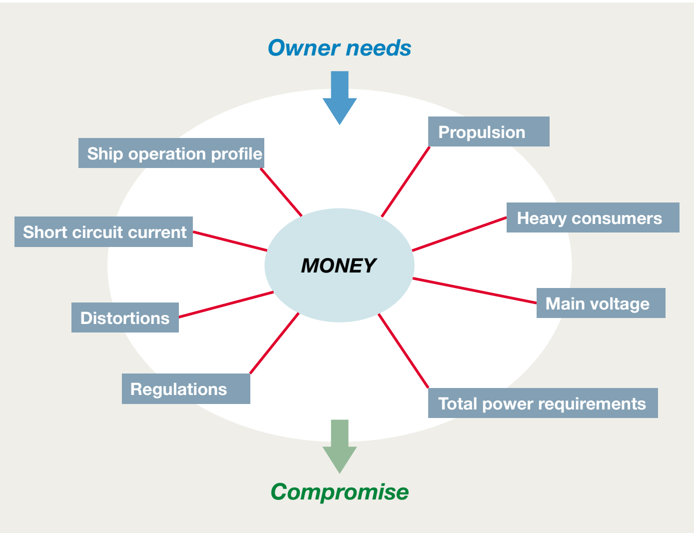

Fig. 1 – Designing a ship's electrical network calls for a careful balance of various critical factors.

Structure of the electrical network

Once the type of the propulsion machinery, diesel-mechanic or diesel-electric, has been selected further clarifications and decisions have to be made, examples of which are the following:

- Maximum electrical power needed to be generated (the load reservation is agreed with the customer).
- Given that information on the ship's electricity consumers can be limited, load calculations are often based on relative values calculated from reference ships. Also, different ship operating modes (sailing, manoeuvring, loading, harbour, DP etc.) will affect the load calculations. It is important that the load calculations are updated while the ship is being built and that the 'final' actual consumption information is received from the shipowner after the ship is delivered.
- Generator size and number
- Selection of main voltage and frequency
- Voltage drop calculation
- Short circuit calculation and network selectivity and structure.

Other electrical networks

Network supplied by an emergency generator

An emergency diesel generator (EG) is used to provide main electrical power should the main source fail, for example as a result of a blackout.

The emergency source must be self-contained and independent of the other engine room systems, with its own independent systems for starting, fuel oil, lubrication oil, cooling and preheating. The consumers supplied by the EG as required by the regulations include emergency lighting, navigation and communication equipment, the steering gear, fire and sprinkler pumps, bilge pump, water tight doors and lifts.

The EG must also be able to start automatically if the main source of electrical power fails to supply the emergency switchboard. In this case the EG is automatically started and connected to the emergency switchboard. The automatic starting system and the characteristics of the prime mover should be chosen to ensure that the EG carries the required load as quickly as is safe and practicable, and within a maximum period of 45 seconds.

The services listed above are then automatically supplied from the emergency switchboard (due to interlocking of the EG and main source breakers) (Fig.2).

Uninterruptible power supply (UPS) network

Where the emergency source of electrical power is a generator, this must be provided with a transitional source of emergency electrical power. The ship type defines the selected uninterruptible power supply (UPS) application.

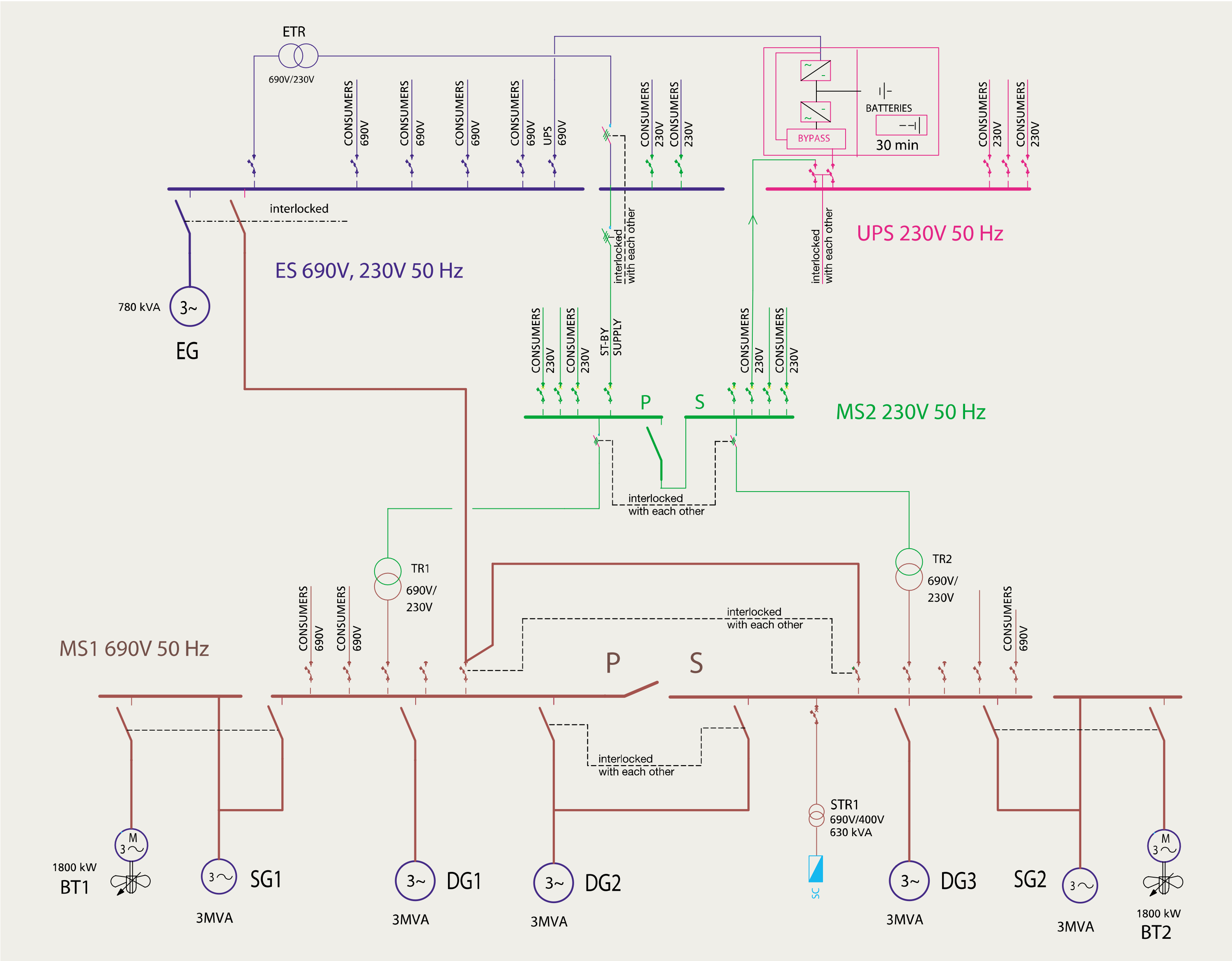

Fig. 2 – Low-voltage 690V network for auxiliary power station: diesel-mechanical propulsion.

A battery or an uninterruptible power supply (UPS) must be provided as a standby power supply with a capacity of 30 minutes. Navigation and safety aspects (required by class) define the use of the UPS, such as automation, navigation, radio and safety announcement equipment, emergency lighting, watertight doors, etc.

In cruise applications and passenger accommodation (comfort requirements) other systems commonly supplied by the UPS are cable TV, telephones, the onboard intercom system, casino, hotel and restaurant, and cash registers.

Shaft generator (SG) network

In addition to auxiliary generators an electrical network may also consist of shaft generators (SG) driven by the main engine. In some intallations shaft generators are used only for driving thrusters during manoeuvring while in others they supply the ship's network. For this reason some interconnections are required to avoid overload or damage to the network. The following feeder combinations, for example, are prohibited:

- If the bus-tie breaker is closed, the SG breakers are interlocked in the open position.
- If the SG breaker is closed, the bus-tie breaker is interlocked in the open position.
- If the bow thrusters breaker is closed, the SG breaker is interlocked in the open position.
- When synchronizing the SG in parallel with the diesel generator (DG), the DG breaker has to be open with a time delay.

Interlocking and every auxiliary power station (switchboard) must be defined separately.

When the SG is connected and supplying the ship's network, a constant speed mode for the main engine must be selected. This means a pre-selected network frequency.

In constant speed mode, the propulsion must be controlled by pitch adjustments to the controllable pitch propeller (CPP). The main engine can run the SG when this is disengaged from the main propulsion line by a clutch. In this case the main engine runs as an auxiliary engine, for example to feed large consumers during loading or unloading in harbour.

Diesel-mechanical propulsion

The electrical network in a ship with 'traditional' diesel-mechanical propulsion is called an auxiliary power station and is powered by an auxiliary engine.

The auxiliary power station normally consists of three or four (minimum two) synchronous generators, two of which typically run in parallel during sea operation.

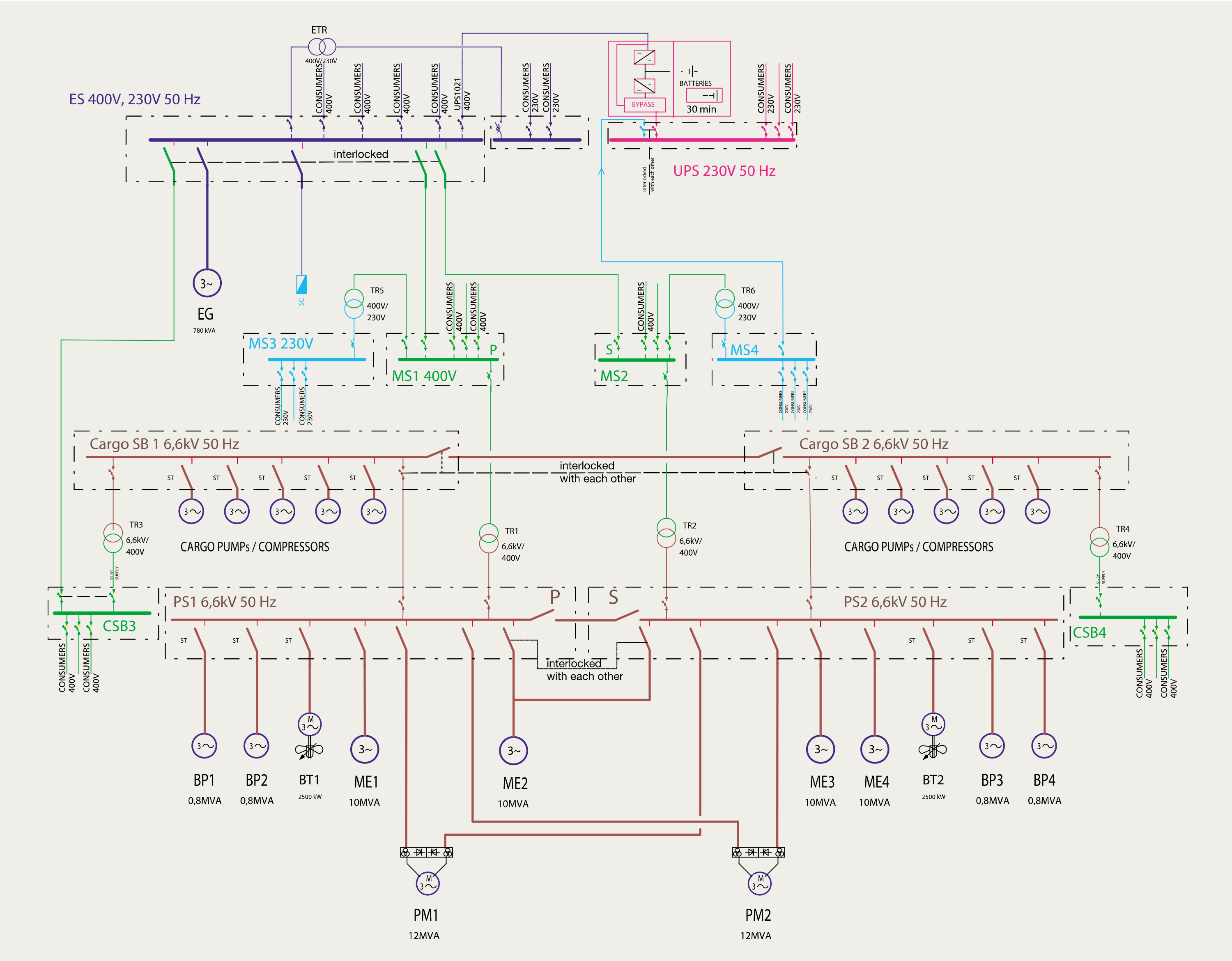

Fig. 3 – Medium-voltage 6.6kV network for a main power station: electric propulsion of an LNG tanker.

Given the wide variety of ship operational conditions and load variations it is often a good idea to select different sizes of generators (two small and two big, for example), although such arrangements set higher demands on generator protection design. When running big and small generators in parallel, an unexpected stop of a bigger generator could create a blackout without a quick and well managed load reduction system (e.g. two-step preference trips for non-essential consumers).

Diesel-electric propulsion

The market share of diesel-electric propulsion systems in ships for a wide range of uses has substantially increased in recent years. Due to their flexibility and versatility, diesel-electric propulsion systems are highly adaptable to a wide range of applications.

The diesel-electric concept is gaining favour in newbuildings, especially the cruise ship market.

In this case the power to the propulsion machinery is supplied by the same generators as supply the other electrical consumers. Here, the diesel engines are called the main engines (ME) and the classification requirement must be followed as stipulated for MEs.

In typical applications, four or six equal-sized generators supply the main switchboard. These are connected symmetrically each side of a bus-tie breaker (Fig. 3.). The overall solution will largely depend on the increasing demand for reliability (redundancy) and the desired level of power availability.

Prime movers

The most common prime mover for generator applications is still the diesel engine. Smaller engines are installed with the generator on a common baseframe. In larger diesel-electric applications both have their own baseframe and are connected with a flexible coupling.

Diesel engine speed control

The governors used to control engine speed are usually hydraulic/mechanical or electronic. Electronic governors are used in more complex applications. The speed governor controls the engine speed (generator frequency) and active load sharing either by **speed droop** or in an **isochronous** (zero droop) mode.

Speed droop control is still the most common method of engine load sharing. In this method, the speed reference of the engine speed governor is reduced in proportion to the generator load. To take an example: an engine rated speed of 500 rpm driving a 50 Hz generator at no load. The droop setting is 4% (usually 3-5%). The total decrease in engine speed is 20 rpm from 0 to 100% load. An external speed setting commands ‘increase’, while a ‘decrease’ from

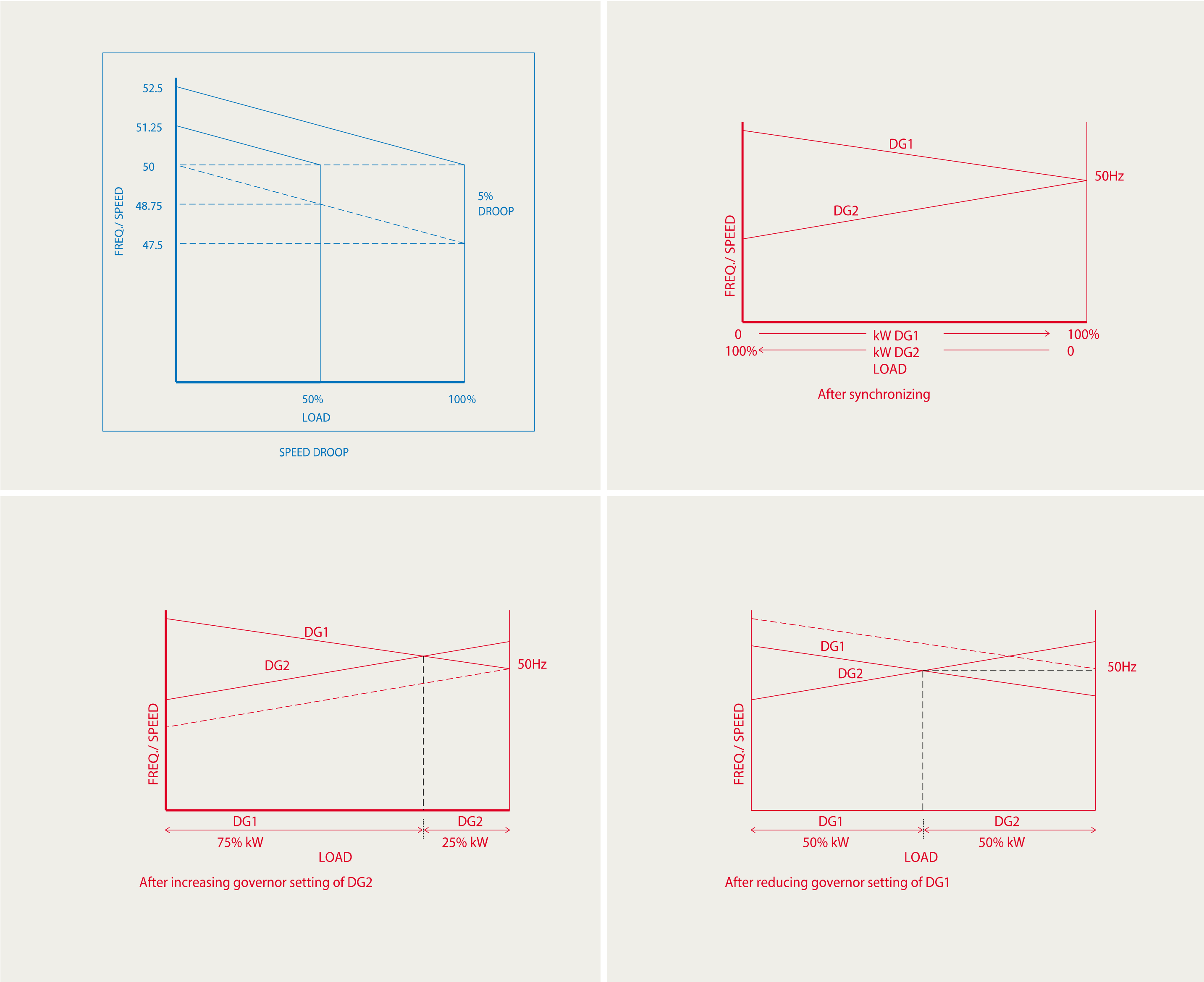

Fig. 4 – Load sharing in speed droop mode.

the power management system (PMS) compensates for the speed droop effect. Engine control governors do not have to be uniform in this control mode.

Isochronous load sharing enables generators to share load very accurately, maintaining a constant system frequency. Isochronous load sharing is possible only if the diesel generators are equipped with the same make and type of electronic governor.

Electronic control governors need to communicate with each other in order to make the load comparison. Control of all parallel generators (ramp-up and ramp-down, load sharing) is automatic without the intervention of any external device or system (PMS).

Control of electric propulsion

The propulsion control system determines the power consumption of the whole ship network. Propulsion can represent about 80% of the total load and large and rapid load variations are possible.

A modern high-output diesel engine requires effective scavenging and the turbocharger needs time to accelerate. The propulsion control system treats prime movers in an acceptable way when the given engine loading curve (Fig.5) is not exceeded (see also section on load increase control).

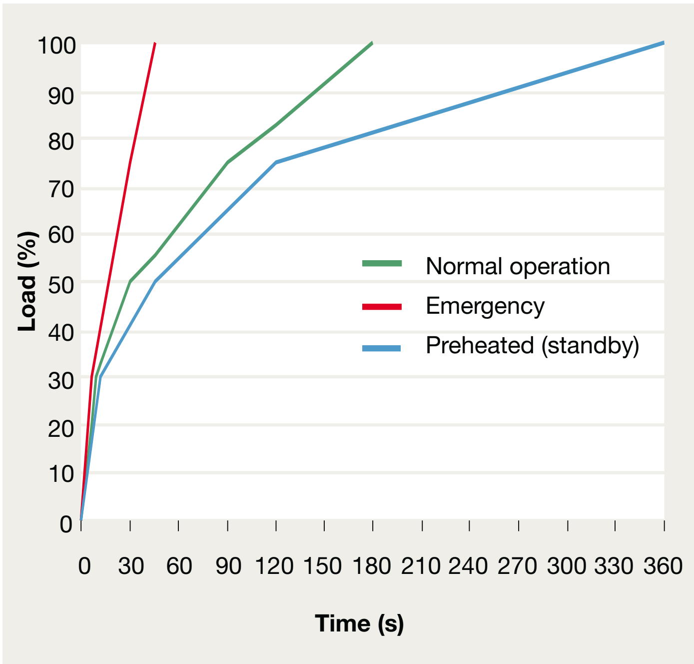

Fig. 5 – Typical engine (Wärtsilä 46) maximum loading

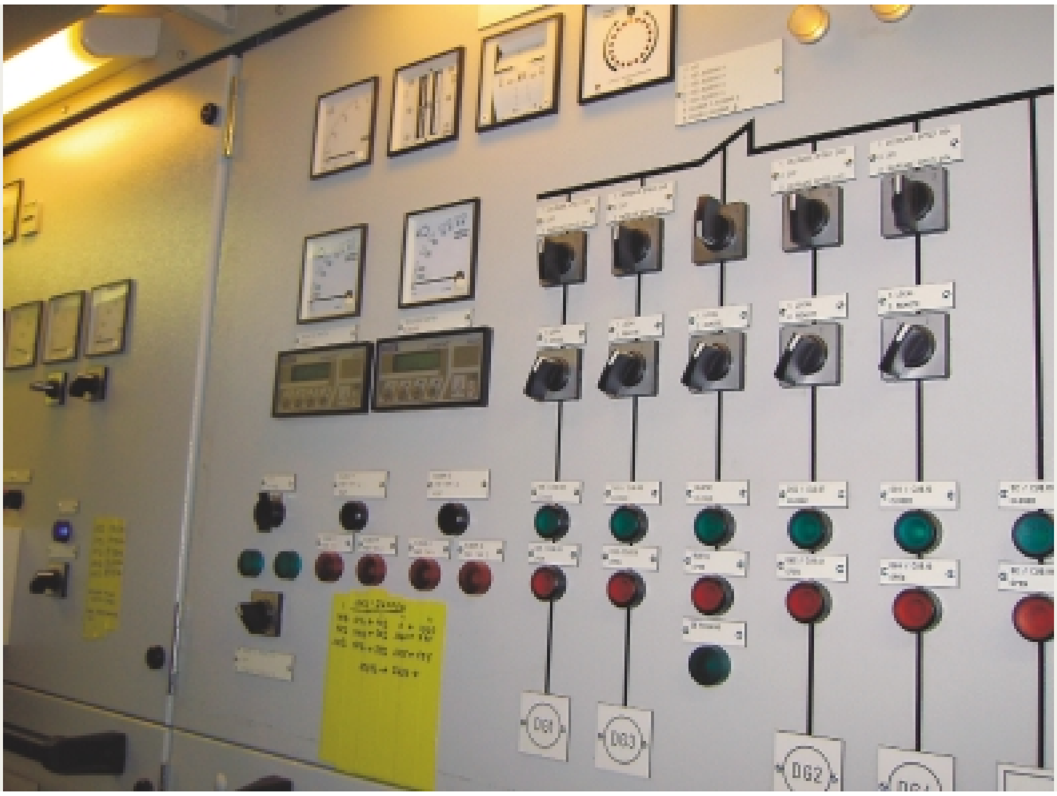

Fig. 6 – Back-up control at the main switchboard in case of PMS failure.

Smooth load variations must be achieved whenever possible and therefore the following values must be measured:

- Network frequency
- Number of connected generator sets
- Active power of each individual generator.

Power management system (PMS)

The main task of an electrical power management system is to control the generation plant and to ensure availability of the electrical power as well as to avoid blackouts. Depending on the type and size of electrical network (auxiliary power or ME power network), the PMS may be a stand-alone system or integrated in the ship's automation system. The PMS has different control possibilities: full automatic control, remote control and local control.

A sophisticated ship power management system usually provides the following main functions:

- Diesel generator (DG) start, stop control
- DG safety system
- Auto-synchronizing of generators and breaker control
- Load depend start, stop
- Load sharing, if droop control
- Load increase control
- Blackout monitoring
- Power reservation of heavy consumers
- Preference trip (load shedding)
- Frequency control
- Ship operation mode selection and start sequence program
- Shaft generator (SG) load transfer.

Brief description of the PMS control functions

DG start/ stop

The diesel start/stop function can be carried out manually or automatically. The automatic start/stop of the DG includes the following functions (DG must be in standby mode):

- Alarm start
- Load-dependent start
- Blackout start
- Ship operation mode selection start
- Faulty engine stop (change over)
- Shutdown of engine
- Load-depend stop.

Auto-synchronizing

Automatic synchronizing is performed using synchronizing units to acknowledge generators running at the same voltage, speed and phase (synchronous speed). The PMS is able to connect a generator breaker in the switchboard. Normally, if synchronizing exceeds 45 seconds after the engine is running, a synchronizing time-out alarm is given.

Load-dependent start/stop

The PMS calculates the bus-bar nominal power and measures load on each generator. The total generator load is compared against the load-dependent automatic start/stop limits. The objective is to ensure the best possible energy efficiency and fuel economy.

Load-dependent start:

- If available power is less than the start limit
- If the average load on the connected generators exceeds a certain limit (%) and time
- If the current of the connected generators is more than a certain, adjustable limit (%)
- If load reduction is detected to one of the running generators.

Load-dependent stop:

- If available power is more than the load-dependent stop limit
- If average load, calculated from the running generators, minus the one in line to stop, remains below a certain limit (%) and time.

Load sharing and frequency control
See diesel engine speed control.

Load increase control
During a normal start, when the engine is preheated, the load increase curve (Fig. 5) given by the engine maker must not be exceeded.

A problem can occur in droop when the PMS follows the pre-programmed load ramp while at the same time a big load increase arises in the ship network. The network load change affects the ramp-up engine simultaneously with the loading programme. This usually results in an 'overloaded' engine. In isochronous control, this unwanted situation is avoided because the ramp-up engine is not affected by the network load before the engine is loaded properly.

During a blackout, the first available generator must be able to take the base load after connecting in the main bus-bar. This has to be considered when designing the electrical network system.

Blackout monitoring
All available DG(s) will be automatically started and connected to the bus-bar when a blackout is detected. The breaker of the first running engine will be connected to a 'dead' net using the direct breaker in command (without synchronizing) while the other generators are synchronized and connected one by one.

Power reservation of heavy consumers
The power reservation function checks if the available network power is sufficient for the heavy consumers. If necessary the PMS starts and connects the standby generator and gives start permission to the heavy consumer when there is enough generator power connected to the network.

Preference trip
In order to protect the generator against sustained overload and ensure required power in the network, a suitable preference trip (load shedding) should be arranged. Typical consumers (breakers), which may be tripped are:

- Galley
- AC compressors
- Accommodation ventilation.

The trip function can also be applied in two or three steps.

Ship operation mode selection
Different operation modes will be programmed in the PMS to ensure proper electrical power availability in the network. These modes are:

- Harbour mode. For example, one or more generators are connected when power demand is low and load-dependent start/stop is functioning.
- Manoeuvring mode. For example, two or more generators are connected and load-dependent stop is prohibited.
- Sea mode. For example, two or more generators are connected and load-dependent start/stop is functioning.

Shaft Generator (SG) load transfer
The PMS ensures the following controls when the SG is running:

- Assures that the constant speed is selected (contact to electronic speed governor).
- Synchronizes the MSB and SG and closes the SG bus-tie breakers.
- Transfers load to the SG by unloading the DG(s).
- Opens the DG breaker(s).
- Stops the DG(s).

Ship machinery automation

Ship automation technology today is based on digital systems with microprocessor controllers. Technologies are based on supplier-specific software and hardware. Integrated ship automation architectures are based on modular concepts, which allow standardized hardware, spares and easy maintenance.

Today's automation systems have a wide range of features for performing basic functions and generating reports, as well as an extensive capability to handle large amounts of data. The systems consist of integrated automatic control, monitoring and alarm functions for main machineries, the Power Management System (PMS), standby pump controls, remote valve controls, tank level measurement, cargo control, engines start/stop and safety system, automatic bilge system, ballast and heeling control, etc.

A lot of other sub-processes are nowadays integrated into a ship's automation system in addition to these. As the amount of alarm and data handling capacity is increasing all the time, an important feature for operating personnel is a user-friendly human machine interface (HMI) and a sufficient number of quality software mimics.

Redundancy is one important requirement in ship automation. When talking about technical redundancy, it is equally important that installations onboard also follow redundancy requirements. System components must be arranged and powered in such a way that power failure, fire or flooding are minimized. Dual-bus communications should be routed on both sides of the ship, and essential system controls should have manual back-up controls.

Future aspects

What will development focus on in the near future?

There are many sides to this question and in fact not all the available features of modern automation systems are fully or efficiently utilized today. Development will most likely focus on at least the following aspects:

- Monitoring of system efficiency to assist the crew by monitoring the processes onboard and giving advice as to how the efficiency can be optimized.
- System control for ship safety. The system can help to prevent accidents and most importantly, if an accident does occur, it should guide the officer in making the right decisions.
- Troubleshooting (system tuning) via satellite communication. Diagnostics from the manufacturer's technical support department.
- Intelligent field devices.
- Wireless data transfer.
- Optical data transfer.
- Communication and field buses with standardized protocols and open architecture.