Using Variable Frequency Drives (VFD) To Save Energy and Reduce Emissions in New Building and Existing Ships

ABB

Using Variable Frequency Drives (VFD) To Save Energy and Reduce Emissions in New Building and Existing Ships

Energy Efficiency plays the most important role in CO_2 emission reductions, accounting for up to 53% of total CO_2 emission reductions. In pump and fan applications onboard vessels, using Variable Frequency Drives (VFD) can cut the energy consumption for these applications by as much as 60%.

Author: Jan-Erik Räsänen, jan-erik.rasanen@fi.abb.com – Eric W Schreiber, eric.w.schreiber@us.abb.com, ABB Marine & Cranes Service, 2012/04/24

ENERGY EFFICIENCY AS A PART OF DESIGN CRITERIA. Until recently, energy efficiency in auxiliary systems was not taken into account during the design process or construction of marine vessels. Due to this reason, the systems on existing ships are not energy efficient and have not been fully optimized for minimizing overall fuel consumption. Many of the ships currently in production continue to be built with little emphasis on energy efficient solutions. More so, shipyards typically do not focus on long term cost of vessel's ownership. Unless owners define the technologies to be included in the specifications, the ship's energy efficiencies capabilities will be limited, even though the additional equipment pays back in savings well within one year. To date, most marine installations adjust for changes in environmental conditions by inefficient methods, such as 'Throttling' and 'By-Pass loops'.

The onboard ship systems most suitable for improving energy efficiency are systems with large pumps and fans, which are not required to run continuously and at full capacity. When applicable, electric motors could be fitted with VFD to operate pumps and fans more efficiently in partial loads during slower sailing speeds or with reduced ventilation requirements. The electric power consumption of a pump is related to the pump volumetric flow according to affinity laws. The reduction of pump speed will affect the system pressure, Head, to the power of two and the electric power consumption to the power of three. As an example, a reduction of the pump speed with 10% will save 27% of the consumed power.

A reduction of the pump speed with 10% will save 27% of the consumed power

$$\text{Flow } Q_1/Q_2 = n_1/n_2$$
$$\text{Head } H_1/H_2 = (n_1/n_2)^2$$
$$\text{Power } P_1/P_2 = (n_1/n_2)^3$$

Table 1, Affinity laws – Proportion of speed (n), flow (Q), head (H) and power (P)

EMISSION REDUCTION. COP15 conference held in Copenhagen at the end of 2009 aimed to get a global agreement of reducing the amount of Green House Gases (GHG) worldwide. The goals at the conference were not achieved. The parties could not agree, and the countries had only recommendations for the reduction of GHG. All parties were in fact aware that something needs to be done.

There is now a tangible effort within the MARPOL Annex VI regulations that has recently been voted favorably last 15 July 2011 by the 62nd session of the Marine Environmental Protection Committee

(MEPC). It is coming into effect January 2013 and it affects new and existing fleets. For new ships the Energy Efficiency Design Index (EEDI) will define the efficiency of the ship's design. Ships built between 2015 and 2019 will have to be 10% more efficient, ships built between 2020-2024 need to be 20% more efficient, and ships build after 2024 need to be 30% more efficient. Meanwhile, for the existing tonnage the Ship Energy Efficiency Management Plan (SEEMP) will require that ship operators develop a plan to improve efficiency. Ships will need to keep specific energy use and a plan to manage it. This piece of legislation is significant because it is the first industry sector to introduce global mandatory GHG reduction measures. The rules were passed in a vote of 48 to 5, reflecting the intense interest in these measures.

CO_2 is the most common GHG and shipping industry today stands for 3-4% of total GHG emissions. It is estimated that this figure will grow rapidly if the shipping industry does not do anything to make the vessels more energy efficient. In "business as usual scenarios" IPCC estimates an increase by 150-250% to 2,5 – 3,5 billion ton of CO_2 emissions from shipping towards 2050 [1].

PUMPS AND FANS ARE VITAL PARTS OF THE PROCESS ONBOARD A VESSEL. Pumps and Fans onboard vessels are often a vital application. If these are not working the vessel is not sailing.
Onboard vessels there are a lot of different pump applications. Sea water cooling pumps, boiler feed pumps, HVAC pumps, bilge water pumps, lubrications pumps, fire pumps, waste water pumps and many other kinds. It is common for pump applications to be over-dimensioned. This is simply because the design criterion is set to meet the extreme conditions the vessel may operate. For example, the sea water temperature is generally dimensioned for above normal operating conditions.
Although it is required for a ship to be able to operate in extreme cases and environments, every-day operations rarely come close to such conditions. While maximum allowed engine load is typically 75… 90% of maximum, heat is always recovered from the system and seawater temperature very seldom reaches design value.

A lot of energy is easily saved by letting pumps and fans be controlled by a VFD, either standalone or with a pressure or temperature sensor loop control. Using a VFD to adjust the power demand to the operational conditions is the most effective method to optimize the shipboard systems.

Displacement pumps and Centrifugal pumps are the two most common pump types used on ships, around 80% of all pumps onboard ships are centrifugal pumps. This kind of pump has the same duty characteristics as a fan. Fans are used for ventilation in engine room, on car deck, cargo spaces and other places where forced ventilation is needed.

When operating a centrifugal pump or a fan you can get a fairly big reduction in energy consumption by even a small reduction in rpm of the pump.

Cavitations are another important issue when talking about pumps and dimensioning of pumps. If the pump is too large, the suction capability is very poor and the risk of cavitations is very high.
Cavitations appear as a result of evaporation of the fluid, when the static pressure drops below the actual steam pressure inside the pump. Cavitations inside a pump results in severe damage to the

---

[1] DNV presentation 26.1.2010. Fuel management, Ship Performance and Energy Efficiency – London, Lloyd's Maritime Academy

material, especially the impeller is often badly damaged. The damage to the impeller can in some cases cause the pump to fail within couple of months.

When using a VFD to decrease the pump speed you reduce the chance of cavitations, and the risk of damage to the pump.

By far the most commonly used flow control in pump applications is throttle control and by-pass loops to control the temperature. As a consequence pumps are running at 100% loads continuously, even though the requirement would be actually about 40% in average. Using these antiquated control methods is as ineffective as controlling a car's speed with the brakes while going at full throttle. In other words, we not only waste energy but also exasperate the equipment wear.

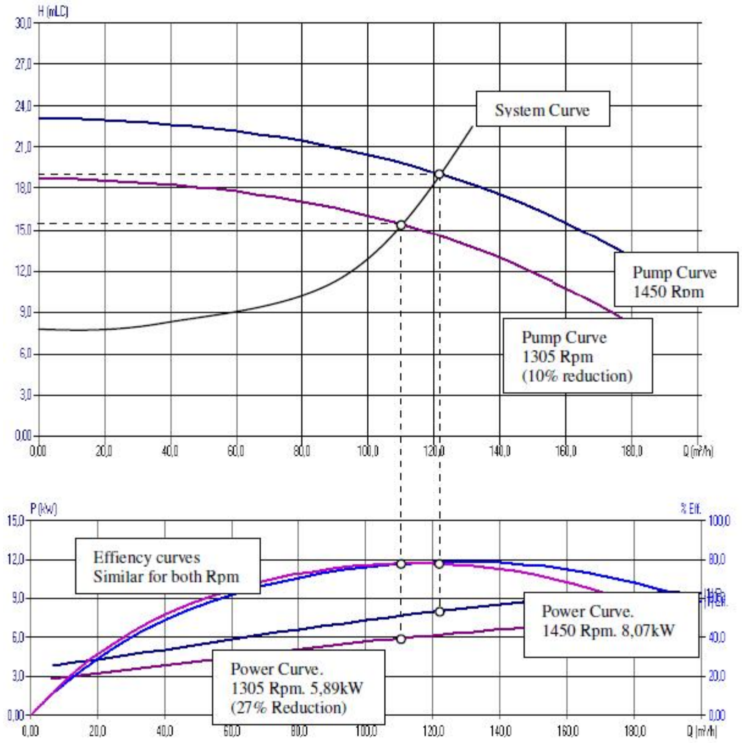
There are few large capacity pumps and fans required to run continuously at 100% that will not benefit from VFD in the respect of energy efficiency.

SYSTEM CURVE AND PUMP CURVE. A fluid flow system can in general be characterized with a system curve. This curve visualizes the system head, a combination of the elevation (static head) and the friction of pipe bends and valves within the system. It is very difficult to change the characteristics of the system curve in an efficient way. The system curve is totally independent of the pump. The pump curve on the other hand is a graphical description of the flow and the pressure (Head) relation for one specific pump.

The duty point of a pump in a system will always be at the intersection between the pump curve and the system curve.

On a vessel there are several ways to change the duty point of the pump. Blinds, semi closed valves and By-passes have been used for many years but these are all very inefficient. A more efficient solution is to reduce the diameter of the impeller in the pump. This solution will enhance the risk of cavitations in the pump, and there is no possibility to increase the flow or head if this should become necessary.

VFD mounted on pump is by far the most efficient way to change the duty point of a pump system, and reduce the power consumption. VFD gives a much more flexible pump control and reduces the risk of cavitations. See graph 1 for details.



Graph 1, Relation between the system curve, pump curve and needed electrical power.

REDUCING EMISSIONS DOESN'T MEAN RE-ENGINEERING YOUR EXISTING VESSEL. Retrofitting existing vessels with VFD is a systems engineering task that needs process knowledge as well as deep understanding of VFDs, motors and pumps/fans. Sometimes it is necessary to replace the existing motor with a new motor designed for VFD use. This highly depends on the voltage level and power demand of the pump. As a rule of thumb one could say that ABB Random Wound motors with a voltage level not exceeding 500V is good for VFD use as such, whilst other motors should be checked case by case for suitability. In addition, ABB provides expert insight on the cost / benefit trade-off of replacing motors. The proliferation of energy efficiency motors has significantly increased the demand for these motors consequently expanding the market. Market expansion of energy efficient motors has in effect brought the price down of these special motors.

Control method of the VFD depends on the existing Automation system. In some cases it may even be beneficial to install an independent control system for the modified processes.

ABB Marine Service has excellent knowledge on complete retrofit energy efficiency design packages, including ABB products together with project service and all site activities, to suit the customer requirements.

In vessels built between years 1988 to 2008 and still operating, approximate 2% of the main sea water cooling systems have VFD control. By modifying these systems, which is a fairly simple thing to do for expert systems engineers, there is a substantial amount of reduced emissions and costs to achieve. Small changes in the system have a big impact on emission reduction.

All ship types can make use of VFD technology and all typically have a return on the investment of less than one year. One particular case study highlights the significant attractive financial proposition. A Chemical Tanker with three seawater pumps, four engine room ventilation fans in the system adopted ABB's proposition to fit VFDs to drive two of the pumps and all engine room fans. The installation was successfully commissioned with an evident payback of six month. Once the engineering and equipment specification was secured in a proof of concept, the financial benefits of retrofitting the motors with VFD on sister ships was within month.

ENERGY EFFICIENCY IN NEW BUILDINGS. The recommendation for new buildings is to install the VFD with a common DC bus to reduce the amount of cabling and space needed, so-called Multidrive. It offers all of the benefits of a single VFD, but unlike single VFD (which have to have their own rectifier, DC link and inverter), the Multidrive system generates the required DC voltage in a "central" unit and feeds it onto a common DC bus to which the single, independently operated inverters are connected. In a Multidrive system all the desirable features of a single VFD are still retained. In addition, the individual inverters do not all have to have the same power rating. On the contrary, a Multidrive package can consist of drives of very different sizes. See Figure 1 with a typical setup of a MultiDrive system.

The Multidrive cooling method can be either with air or liquid.

Some of the benefits of a Multidrive system include:

- Reduced cabling due to the single power entry for multiple drives.
- Cost effective reduction of harmonics using an active front end supply unit or at least a 12-pulse line supply.
- Common DC bus bar
- Shared energy and motor-to-motor braking without braking chopper or regenerative supply unit
- Reduced line current
- Energy savings
- Does not require use of separate MCC
- Higher power factor for VFD controlled applications, results in better efficiency on the main generators
- Centralized engineering at the ship yard, since all the consumers are controlled from a single point.

The biggest benefit designing the new building in a more energy efficient way – is the potential of reducing size of the power plant.

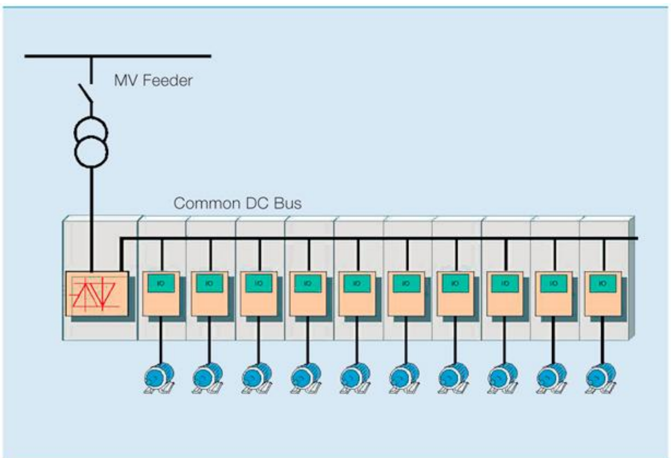


Figure 1. A typical single line diagram for a MultiDrive system consist of one common supply unit together with the inverter units supplied from the common DC-bar.

Figure 2. Air cooled Drive cabinet and Module

MARINE TYPE APPROVED DRIVE. The ACS800-01/04 product is type tested and approved for marine drive applications. The type approval test is required for essential applications onboard. Essential applications are those related to navigation, propulsion, safety of the ship and passenger, cargo and crew. Examples of essential applications are ballast pumps, bilge pumps, circulating and cooling water pumps.

The ACS800-01 product is type tested and approved by:

- DNV (Det Norske Veritas)
- LR (Lloyd's Register of Shipping)
- ABS (American Bureau of Shipping)
- RINA (Registro Italiano Navale)
- BV (Bureau Veritas)
- GL (Germanischer Lloyd)

To further more extend the energy saving potential in pump and fan applications, ABB have introduced an Intelligent Pump Control solution

INTELLIGENT PUMP CONTROL TO FURTHER ENHANCE THE ENERGY SAVINGS. Intelligent Pump Control (IPC) is an optional SW package for ACS800 drives. Incorporating all the most common functions required by pump or fan users, it eliminates the need of an external PLC and other additional components. A pump system with fewer electrical components is always more reliable, especially in a harsh environment typical in marine applications. IPC can help save energy, reduce downtime and prevent pump jamming and pipeline blocking.

All of the IPC features presented in this paper are new innovations. The development of a new software package was based on a long-established experience with pump and fan control software for ABB Drives. The new features were partly developed and tested in co-operation with ABB's global pump customers.

CONTROL LOGIC OF LEVEL CONTROL MODE. Control logic of the level control mode is described in graph 2. The key issue is to run pumps with efficiency speed as far as possible. If the temperature demand in the cooling circuit varies so that more cooling water is needed, more pumps are switched on and run with efficiency speed. In a situation where all pumps are running with efficiency speed and cooling demand reaches the maximum, all pumps start to run at a high speed.

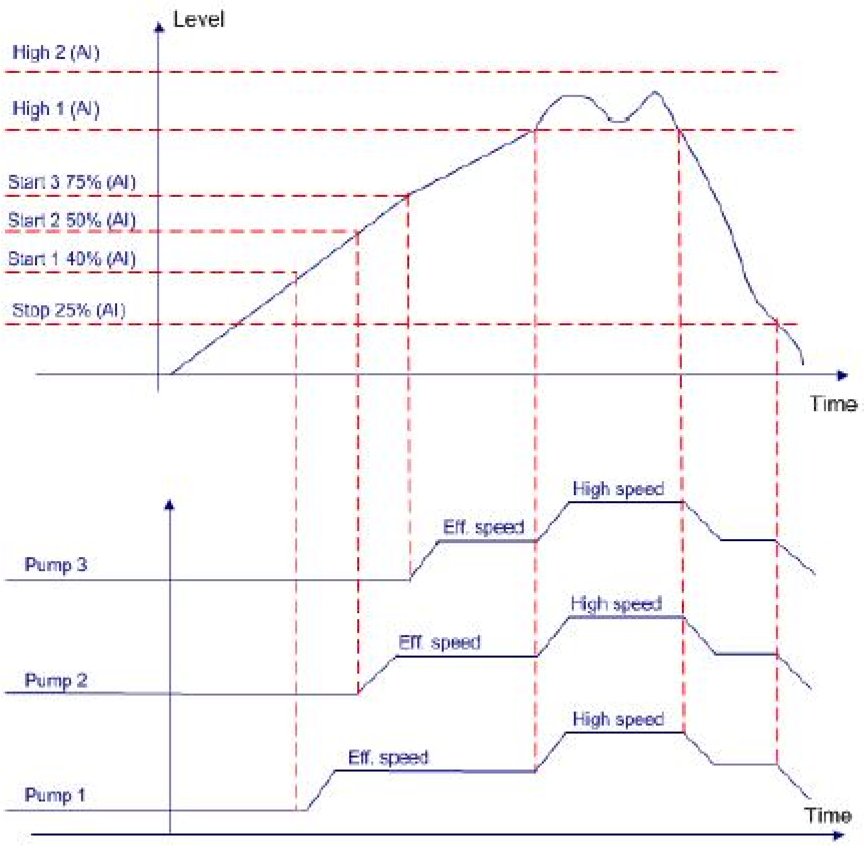
With this approach, according to the theory presented earlier, it is possible to achieve almost 20...30% more energy savings, and still have flexible control method when the cooling demand of the process vary a lot.

OTHER BENEFITS WITH INTELLIGENT PUMP CONTROL. Dimensioning a cooling system with parallel pumps enables creating a redundant system. With the cooling demand control of the IPC, the redundancy of the system is 100%. If one of the pumps/motors/drives goes off, the system will continue uninterrupted. Even of the master of the parallel drives fails, it takes only 500 ms to have a new master drive. This is possible through a fast fiber optic connection between each drive. A 100% redundancy of the system guarantees high usability and risk-free operation of the pump system even in fault situations.

The Anti-Jam function enables the drive to perform preventive maintenance on the pump. When the function is trigged, the pump is run at high speed and then either reversed or stopped in a number of user-defined cleaning cycles. This helps to prevent congestion through build-up of particles. The trigger parameters are set by the user - high current, run-on-time, external input and every start.

When operating with liquids containing particles there is always a risk that pipelines get stuck – especially when running with smooth control and/or slow speeds. With Level Control fast mode fast ramp in starting creates a flush effect which keeps the pipelines clear. If the pumps are running, they are always running close to the nominal point where the risk of pipeline problems is lower due to higher flow.

Pump Priority Control balances the operating time of all the pumps in the system over a long term. This facilitates maintenance planning and can boost energy efficiency by operating pumps closer to their best efficiency point. In a system where the consumption rate is higher during the day, for example, the drive can be programmed to operate higher capacity pumps during the sea voyage and smaller units at harbor time.



Graph 2. Control logic of Intelligent Pump Control

Major benefits from installing a VFD:

- Soft starting – no big starting currents causing disturbance on the network
- No process disturbance due to voltage drops; no trips of other electrical devices connected to same bus
- No excessive thermal mechanical stress on the motor; longer lifetime of the motor
- Immediate start-up without warming-up delays (e.g. steam turbines)
- Controlled and smooth start-up
- Accurate process control – flow based on production need.
- Mechanical weariness of piping is minimum
- Risk of cavitations in the pump is minimum
- Passenger comfort (in air conditioning application)
- Energy efficiency
- Reliability/technical improvement
- Environmental compliancy
- Size of Energy bill

Pump and Fan applications onboard suitable for VFD

- Sea Water Pumps
- High and Low Temperature Cooling Water Pumps
- Boiler feed pumps
- Bilge water pumps
- Waste water pumps
- Engine Room Ventilation Fans
- Cargo Area Fans
- Air Handling Units, such as Air Conditioning Systems onboard cruise ships and passenger vessels
- Hotel Auxiliary System Pumps and Fans (mainly in passenger vessels)