Parallel pumping

IPC technology in parallel pump control

Li Jinguo

The desire to get more for less is pursued by almost everybody, from economists and production managers to householders paying their bills. Usually, marginal improvements require heavy investments. Major breakthroughs with short pay-back times remain a pipe dream.

Variable-speed drives, however, are a refreshing exception. Energy consumption and overall life-cycle costs of equipment are reduced significantly, permitting operators to run the same production with much less energy. This becomes all the more topical in view of high energy prices and the unacceptability of the energy-related emissions on the one hand, and the industrial requirements of fast-growing economies such as China on the other.

ABB's intelligent pump control (IPC) goes even further than harnessing the strengths of the individual drive. It links and coordinates drives in pumping applications permitting these to be operated to the highest levels of overall efficiency, achieving savings of up to 20 percent beyond that of "normal" drive applications. The high levels of redundancy obtained also assure the highest levels of availability.

Generally speaking, AC drives are the most energy-efficient method for the control of pumps. ABB provides an optional software package for water-pump control in conjunction with its ACS800 industrial drive: intelligent pump control (IPC). In this application, every water pump is controlled by one drive. The power range of the drives can be between 0.55 kW and 5,600 kW (depending on the application). An example with three drives controlling three parallel water pumps is shown in 1. The adoption of communications between the drives (using fiber-optical cables) eliminates the need for an external PLC[1], thus permitting energy savings, shortening repair times, and preventing blocking of the rotation of the water pump and jam (blocking of the flow).

The operation of a multi-pump system at efficient speed therefore offers potential for significant savings.

Energy-saving principles

Pump control using general-purpose drives is mainly implemented through the control of flow rate. As in many other variable-speed drive applications, this enables notable energy savings.

2 depicts the head of a pump in function of its flow rate. The curve 2a traces the head-flow characteristic at pump-rotation speed n_1. 2b shows the same at a reduced rotation speed n_2. 2c shows the characteristic of the pipe resistance and 2d the characteristic with an increased pipe resistance (achieved with a valve constricting the flow).

With the pump running at the rotation speed n_1, and the pipe resistance set to its lowest value 2c, the working point of the pump is at A (intersection of 2a and 2c). The output flow rate Q_1 is maximal and the power P_1 applied to the shaft is proportional to the area Q_1H_1.

If the flow rate must be reduced from Q_1 to Q_2, the traditional method is to change a valve setting, increasing the resistance of the pipe from 2c to 2d. The working point hence changes to *B*. This increases the pump lift from H_1 to H_2. The power P_2 now applied to the shaft is proportional to the area Q_2H_2.

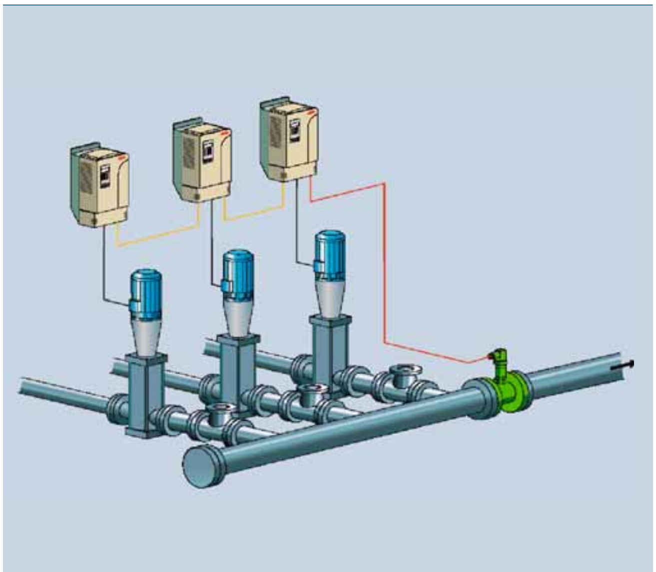
If instead of a valve, a drive-control mode is used, the pipe resistance remains at 2c but pump rotation speed is decreased from n_1 to n_2. The new head-flow curve is thus 2b and the working point moves to *C*. The pump head is decreased substantially to H_3. The power P_3 applied to the shaft is directly proportional to the area Q_2H_3. This represents a reduction (compared to P_2) proportional to the area $Q_2(H2\text{-}H_3)$. The energy savings achieved will be similary impressive.

Pump control using general-purpose drives is mainly implemented through the control of flow rate. As in many other variable-speed drive applications, this enables notable energy savings.

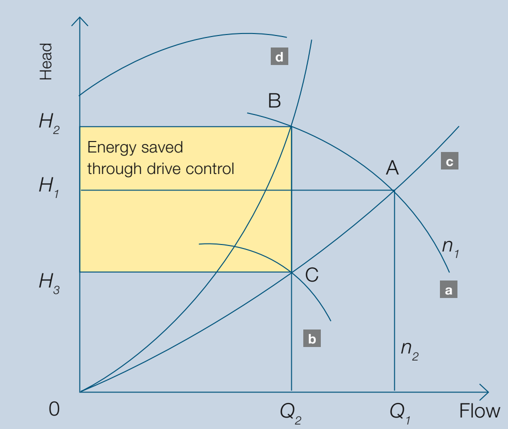
Efficiency of pump, motor and drive

The overall efficiency of a constant-pressure water supply depends on various factors. Normally, the larger the output power of the pump, motor or drive, the higher the efficiency of the system. When the same system is operated at a low speed, the overall efficiency of the system also drops. For a water pump designed to be operated in the 35 to 50 Hz range, the efficiency of the drive and motor system is about 90 percent at the rated operating point. This drops to 83 percent at 35 Hz. The efficiency of the water pump itself varies between 50 and 85 percent. Generally speaking, the efficiency of pump is affected by its speed and system curve.

1 Variable-frequency water-pump configuration: Optical fiber connections are used between the drives.



2 Power applied to the shaft is reduced significantly when drives rather than valves are used to control speed.



a and b are lift-flow curves of the pump at different rotation speeds n_1 and n_2. c and d are characteristics of the pipe for different resistances. Reducing flow by reducing speed is much more energy efficient than reducing it by increasing the pipe resistance using valves.

Energy savings with IPC technology

As an example, reducing the operating rotational speed of the water pump discussed above from 50 Hz to 45 Hz reduces flow rate by about 10 percent (see the formulae in the Factbox), therefore the time required to effect the same work is 11 percent greater. The power required, however, is 73 percent of the original power. As a result, electrical energy saved is about 19 percent (1-[0.73*(1+0.11)]). Although the overall efficiency remains similar, the energy consumption is reduced by a much larger margin.

If a product competes in the market only by relying on its sale price, its operating costs can be high.

When a water pump operates at efficient speed (in this case, 45 Hz), it delivers energy savings of about 19 percent. Energy savings of more than 10 percent can be achieved in long-term operations with IPCs.

In practice, most systems use parallel pumps. If the traditional pump and fan control method (PFC) is adopted (one drive is used to power multiple water pumps), it cannot achieve the energy savings results of IPC technology.

As illustrated by 4, the relationship between the efficiency, power, rotation speed, flow rate and lift of a system can easily be determined. In moving from working point A to B (upper diagram), the flow-rate is reduced by about 40 percent, on the other hand, power is reduced by about 60 percent (lower diagram). The operation of a multi-pump system at efficient speed therefore offers potential for significant savings.

The initial investment cost makes up a small portion of the total lifetime cost compared to the cost of electricity consumed in day-to-day operations.

Life-cycle costs

If a product competes in the market only by relying on its sale price, its operating costs can be high. If life-cycle costs (LCC) are considered on the other hand, the customer can reap tremendous economic benefits. For a water pump, motor and drive, these costs can be divided into three parts: initial cost, electricity costs and maintenance costs. 3 shows that the initial investment cost makes up a small portion of the total lifetime cost compared to the cost of electricity consumed in day-to-day operations. Cost savings focusing on this area can therefore return the greatest benefits.

Multi-pump control modes

Two distinctive types of control mode used for IPC are multi-pump control and water-level control. The multi-pump control modes can be further subdivided into:

- Master-regulated mode
- Multi-pump synchronization control
- Multi-pump reference synchronization control

Master-regulated mode

In master-regulated mode, one drive is designated the master drive. The pumps attached to the other drives are either run at full speed or are off. Only the master drive's output frequency is varied to match load changes 5. Once the master has reached full speed, the next drive is started and takes over as master.

Multi-pump synchronization control

When pumps are operated with the multi-pump synchronization control method, all drives follow the reference of the master drive 6. Starts and changes are synchronized.

Factbox A background to pumps

The following explanation is mainly focused on centrifugal pumps, the most common type in water-pumping applications in industry.

A pump presents a square-torque load. In such a setup, the flow rate Q is proportional to the rotation speed n, the lift H to the square thereof and the shaft power P to the cube of the rotation speed.

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \qquad \frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2 \qquad \frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

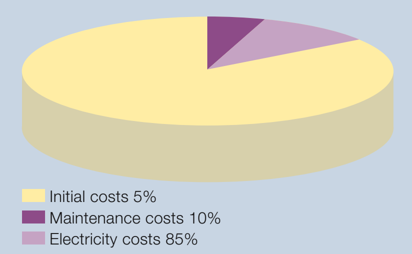
When a motor drives a pump, the shaft power of the motor can be calculated according to the following expression:

$$P = \frac{\rho * Q * H}{\eta_C * \eta_P} * 10^{-2}$$

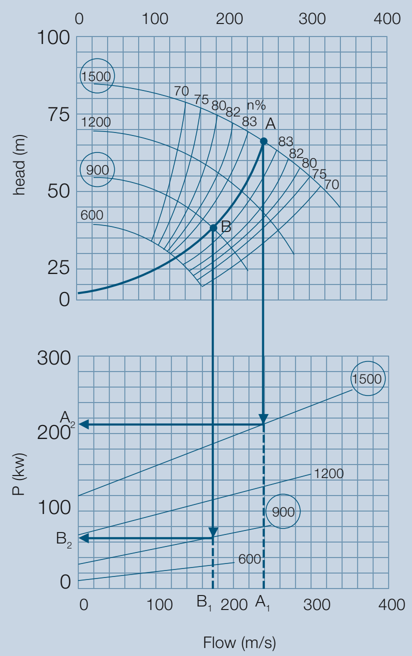
where,

P power (kW)
Q flow rate (m³/S)
H full lift (m)
ρ fluid density (kg/m³)
η_C transmission efficiency
η_P pump efficiency

3 Energy costs constitute the largest part of a pump's lifetime costs.



4 Flow-power and flow-lift diagrams for a pump at different rotation speeds



Productivity

Multi-pump reference synchronization control

When pumps are operated with the multi-pump reference synchronization control method, all drives follow the reference of the master drive, but their starting times can be pre-set 7.

Water-level control mode

Water-level control is often used to control water tank filling or discharge. One feature, designed to prevent sediment from attaching to the inner walls of the water tank, involves changing the water-level according to a pattern set by the user. This creates a washing effect that keep pipes clean while operating pumps at suitable points on the efficiency curve. Water-pump control can not only be applied to a single pump but also to in two or three parallel pumps.

The control method is shown in 8. The critical issue is permitting the pumps to operate at an efficient speed (for example, 45 Hz) to as large a degree as possible. If the water level changes, demanding a much larger flow rate, additional pumps must be switched on to permit the individual pumps to continue operating under efficient conditions. The example presented in 8 features three sets of pumps. The initial water level and efficient speed settings are adjustable in the control system, making it suitable for different demands and situations.

Using this method and according to calculations, energy savings of 10 to 20 percent are possible.

The redundant setup of a multi-pump application makes it ideal for use in pump stations.

Further advantages

Multi-pump redundancy

In traditional PFC mode (one drive controlling multiple water pumps), the failure of that one drive can cripple the system. As IPC technology features multi-pump redundancy, a single failed drive may affect the overall performance of the system but does not cause an overall system breakdown. Such a failed drive can be taken out of operation within 500ms, with the rest of the system continuing to operate.

Not just the drives themselves are redundant. Redundant connections, for example, reduce the impact of lost sensor signals. This ensures high availability and a low-risk operation of the system.

Anti-jam function

The anti-jam function allows a drive to perform preventative maintenance of water pumps, and clean them when they are blocked 9. It can be triggered in three ways:

- Reverse rotation started when current exceeds preset limit.
- Time-triggered reverse rotation.
- Reverse rotation started by digital signal.

Water-pump priority control

The priority-based control function of the pumps helps optimize their operating times to permit more efficient maintenance schedules.

Flow-rate calculation

Flow-rate calculation can be used in single-pump operation. In this situation, the drive acts as a flowmeter, enabling a sensor-free flow-rate measurement. This permits a dedicated flowmeter to be eliminated from applications in which flow-rate data is not required for billing purposes. Safety parameters can be defined for pressure control.

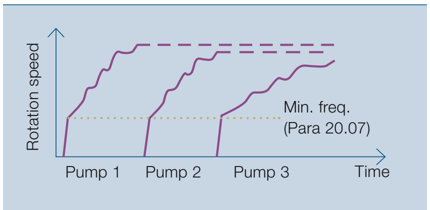
Application examples in pumping

Two applications are presented here, a multi-pump application and a water-level control application.

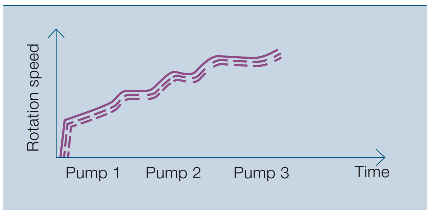
Multi-pump application

The redundant setup of a multi-pump application makes it ideal for use in pump stations. Communications among drives can be implemented via NDBU-95 DDCS 10.

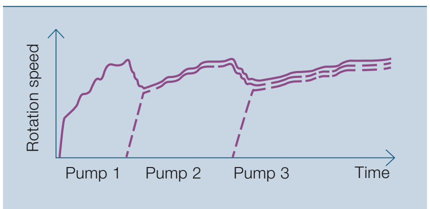
5 Multi-pump master/slave control



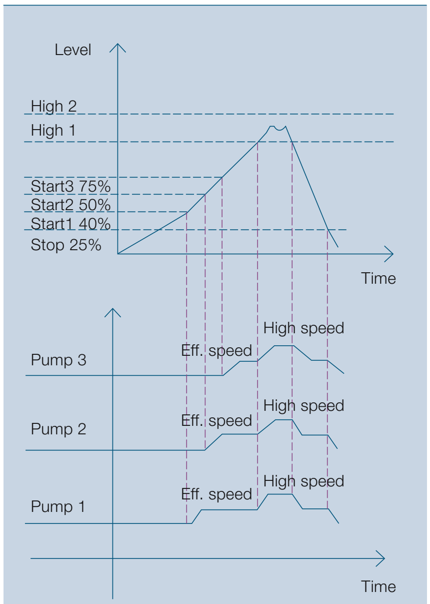
6 Multi-pump synchronization control



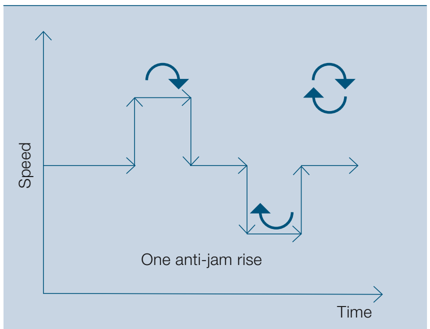
7 Multi-pump reference synchronization control

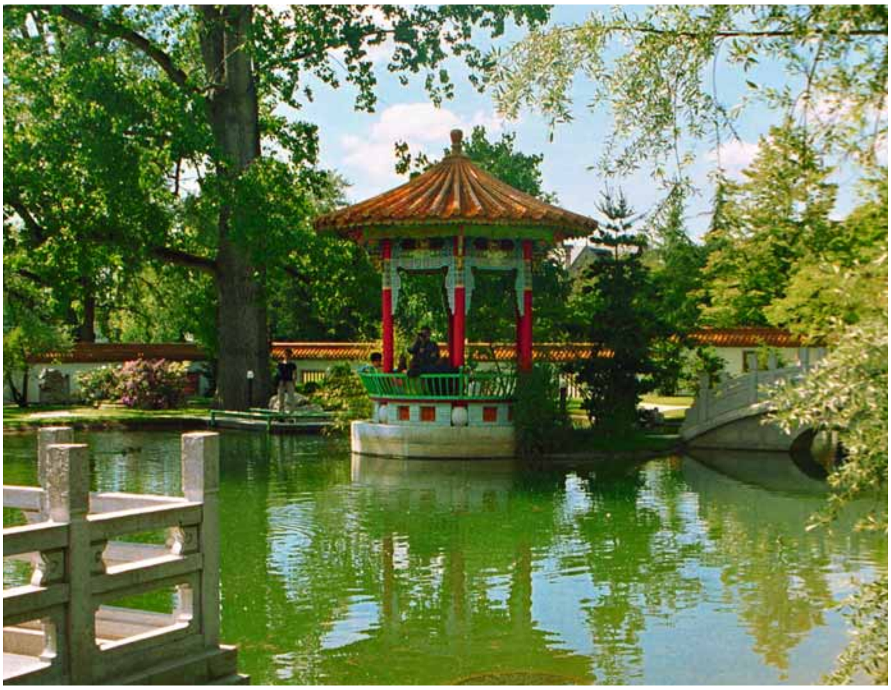


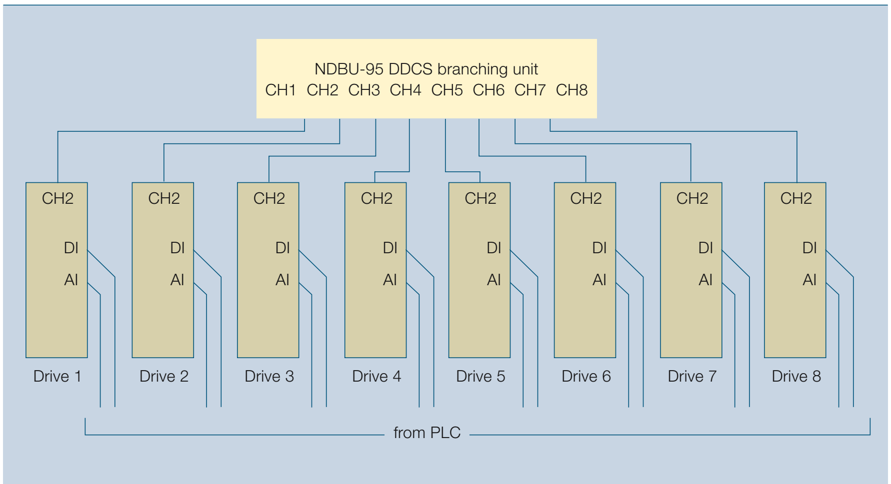
8 Control strategy of water-level control mode



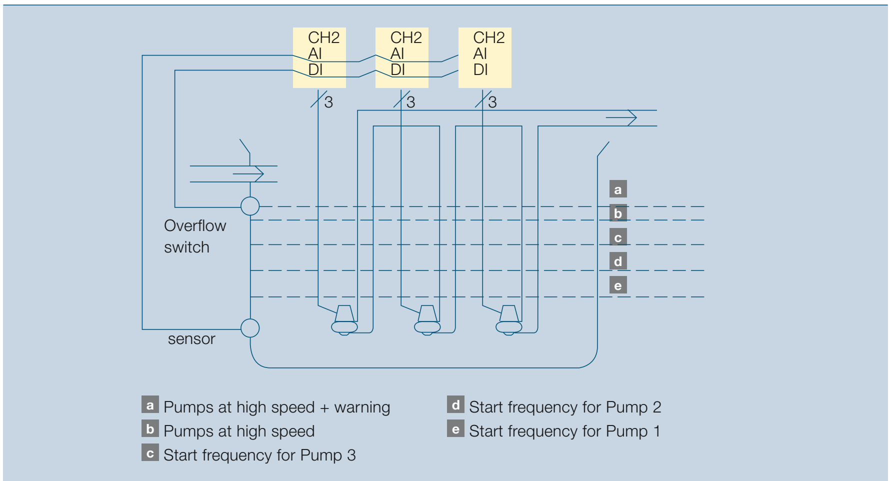
9 Anti-jam actions of a pump







10 Multi-pump macro control diagram



11 Water level control diagram

Water-level control application

In a water-level control application, up to eight water pumps can be coordinated in the filling or emptying a water tank as shown in 11. The overflow switch and water level sensor are connected to the digital/analog interface (DI/AI). Any of these drives can be set as master and the start/stop water level in the master/slave setup can be customized.

A successful solution

IPC has boosted energy efficiency and practicability in pumping applications. Compared to a rated speed of 50 Hz, at an efficient speed of 45 Hz, it can save about 19 percent of energy: Water pumps can achieve savings of about 16 percent over the equipment life-cycle.

Two significant benefits are the system's 100 percent redundancy and the IPC's software with its anti-jam function and pump priority control that greatly reduce the risk of malfunctions in the water pump.

ABB's IPC technology in parallel pumping applications (particularly for high-power parallel pumps) meets the growing need for measures to save energy and reduce emissions.

Li Jinguo
ABB Drives System Co.
Beijing, China
lude-jinguo.li@cn.abb.com

Further reading:
Anrong, H. (Chief editor), General-purpose Drives and Their Applications (2nd Edition)/Han, Beijing: China Machine Press, 2000.
ACS800 Firmware Manual – Pump Control Application Programs Version 7.1 (+N687) (Version B). ABB Drives Co. 2004.