

1 DESIGN OF SMALL LOW HEAD AND HIGH HEAD PLANTS UNDER THE ASPECT OF USING LOCAL SOURCES

The civil works of hydroelectric plants are a complex and specialized topic. In the following pages, we try to present a précis of the main typologies, focusing mainly on the options, together with their related advantages and disadvantages, suitable for micro and small schemes in the Asian continent.

A very important remark: the hydroelectric schemes implementation needs an important engineering work on the field, much more than that necessary to implement other energy production plants, renewable or not. Actually each hydroelectric plant is “tailor made”, to save money and to get the optimum performances, in terms of energy production and operating costs. As a consequence, the following notes are addressed mainly to the designers, who are the only ones suitable to find out the best solutions for each specific scheme.

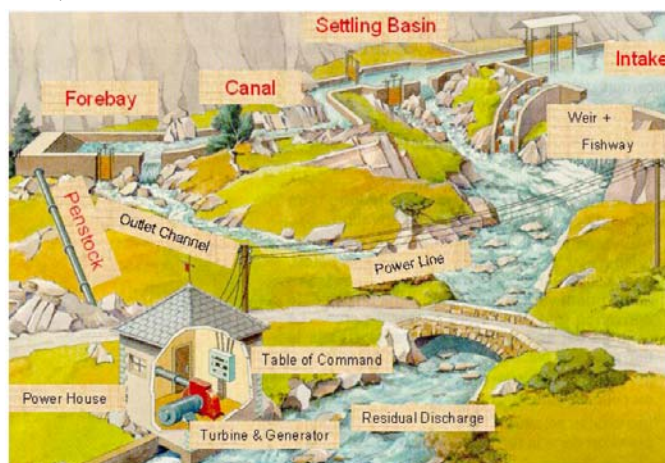
The civil works of hydroelectric plants belong to the category of the *hydraulic works* (for the water diversion and conveyance): moreover *other civil works* are needed to supply the infrastructures (buildings, roads, and so on) necessary to the plant operations. The *hydraulic works* have two basic division, related to their function.

Diversion structures

1. Dam (or weir)
2. Spillways
3. Energy dissipations arrangements
4. Fish leader
5. Residual flow arrangements

Water conveyance systems

1. Intake
2. Canals (or pipelines)
3. Tunnels
4. Penstocks



The *other civil works* can be quite different, depending on each peculiar situation of the schemes, but generally they belong to the following categories.

1. Powerhouse
2. Electric substation
3. Electric line facilities
4. Roads
5. Environmental restoration

An important chance to use local sources is in the civil works erection, which represents, approximately and in common situations, the 40% of total costs of high head plants and the 60% of low head plants.

Then they are a *relevant item from the economic point of view*, the most weighty one!

But they are important not only for their economic relevance; they are also a *crucial technological component* of the plant, as they strongly contribute to the success of the process which transforms the potential energy of the natural source in the most easy-to-use form of energy, such as the electric one. A supply canal or tail race in low head schemes, as well as a penstock in high head ones, undoubtedly aren't simple foundations or shelters for some electromechanically equipment, like, for example, in thermal, wind or solar plants, but they take active part to the process and dramatically affect the final performances of the plants.

As a consequence, we state the first key point: *the design and the implementation of the civil works must be carried out by real experts in the hydroelectric field*. A house designer, even if excellent, cannot switch onto an hydro plant project without any specific study and field experience.

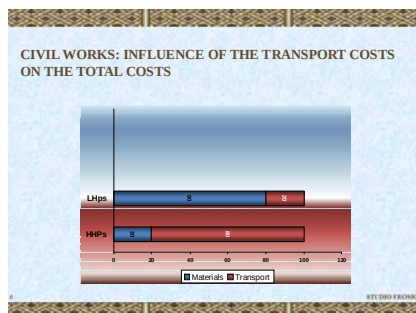
Actually the hydro plants involve large surfaces, from the intake structures to the restitution section can be many kilometres long, so the designer must face a great variety of ground (and underground!) situations. A common experience is that the main problems of HP come from geomorphologic aspects.

If we well know the problems in the design phase, we can face them in the most appropriate way, for example, adjusting the plant lay-out or finding out the most suitable techniques to solve them. In any case, we can set in the budget the related costs. If some geological problem occurs during the erection phase, the costs increase, the time schedule is tight and, frequently, the best solution can't be implemented anymore; the budget is not enough and the times shift away. If it happens when the plant is already working, you must add the lost energy value too, and the addition becomes awful.

Second key point: *accurate geomorphologic survey*.

NB: geomorphology means: *geo*, geological and geotechnical data acquisition; *morphology*, accurate topographic survey.

It is well known that the *low head schemes are more expensive than the high head schemes*, at the same rated power.



Going deeper in the structure of civil costs, we find quite a different influence of the *transport* cost versus the *materials* cost in the high head plants (briefly HHPs) and in the low head plants (briefly LHPs). Of course, we are speaking about average values in common situations; referring to peculiar cases, the costs structure can be quite different.

Transport represents a critical problem which must be faced in the design phase, because it dramatically affects the construction costs as well the maintenance ones, mostly in the plants located in remote areas.

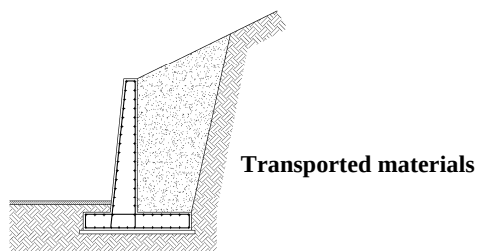
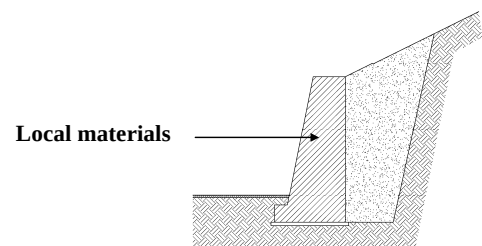
The access to every part of the plant must be as easy as possible, even adjusting the general lay-out of the scheme to get this goal. Generally speaking, it would be better to have a lower efficiency in energy production but better access facilities to save money during the construction phase and for the maintenance works.

Another cost effective approach to civil works of the HHPs is to use as much as possible *local materials* with appropriate techniques. This concept is quite obvious and it is traditionally used in existing HHPs.

Otherwise, if something must be transported, it's better to use small amounts of *high quality materials* with sophisticated techniques in design and construction. This approach is more innovative as it is on the opposite side of the traditional one.

In the pictures a typical civil structure is represented, a retaining wall.

In the first picture it is built using local and poor materials, without relevant performances from the structural point of view. Basically only the *gravity* property of local stones is exploited. Many example of such walls can be found in the existing HHPs.



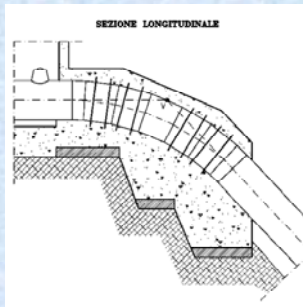
In the second picture the same wall is represented designed using *transported materials*. The material amount is quite(a bit) smaller as we exploit also the structural attitude of an high quality reinforced concrete.

A good chance to use local materials or, if impossible, small amounts of transported materials of high performances is represented by the civil works associated to the penstocks, that have only structural function, to sustain and to anchor the pipeline to the ground, avoiding any displacement which can damage the pipes.

Referring to the *anchoring blocks*, which are the most relevant structures connected to penstocks, the general rule shown above is certainly valid. That means big gravity blocks using *local materials*, where available, or smaller ones, but reinforced with steel anchoring bars or micro-piles, using *high performance transported materials*.

In the first case they are *covered type*, including the penstock in their body.

HPPs: PENSTOCKS

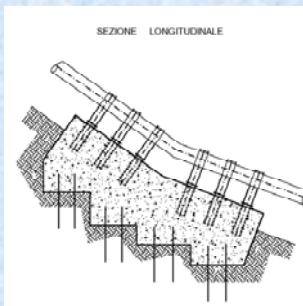


8

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In the second case they may be *uncovered*, with steel structures anchoring pipes to blocks.

HPPs: PENSTOCKS

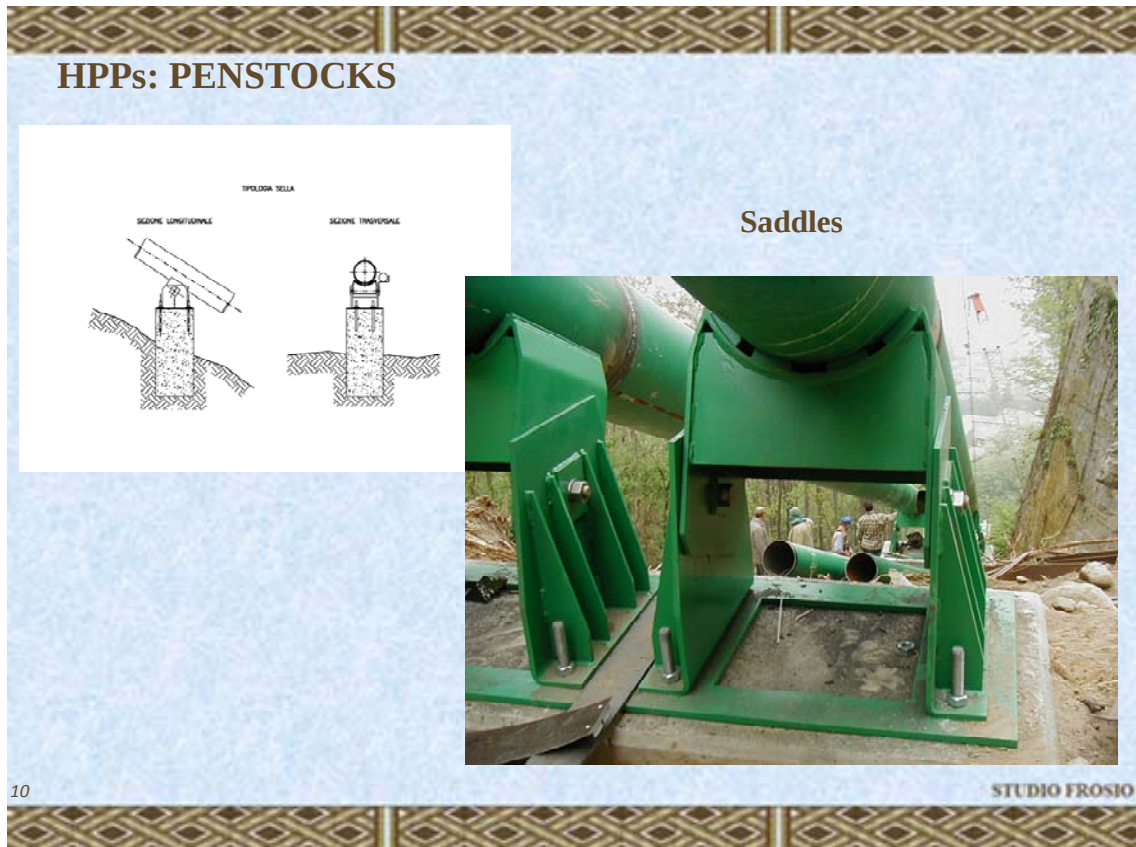


9

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The uncovered blocks can lay completely underground, without any visual impact.

Some simplification can be introduced in the saddles design of the small schemes, for example the pillars can be in local material and only the top, more complex to erect, by means of steel structures, as shown in the picture.



In small hydro plants, very often we have the alternative to design the penstock with *expansion joints* or not: in the first case, the main loads on the civil works come from the *pressure*, in the second option they arrive from the *thermal variations*.

The expansion joints add some extra costs and, mainly, they require routine maintenance to avoid water leakages, very dangerous for the civil works foundations.

A penstock without joints must tolerate the thermal loads and it is more difficult to erect, mainly with large diameters (more than 1.000 mm).

In our experience on the field, in the small schemes the maintenance costs can be critical, so the penstocks without joints are the best solution with diameter smaller than 1.000 mm and in situations of difficult access to the pipeline.

2 WATER STORAGE ON SMALL SCALE AND CONSTRUCTION OF SIMPLE SMALL DAMS

When the SHPs have store facilities, they normally are small dams, not suitable for seasonal transfer of the water. Definitely, the storage capacity depend on the storage finalities(, that would be different for the plants connected with a large grid than for the ones supplying small stand alone grids. Of course, as the energy storage is by gravitational potential, it is cheaper for high head plants

If on-grid, the storage allows to get better tariffs, concentrating the energy production when the energy prices are higher. Regarding the storage volume, if the tariff defines the peak hours, the approach is deterministic and normally a 8 hours storage, at the maximum generation capacity, could be enough. If the production enters in a stoking exchange of energy, the approach could be statistic, and the capacity need could rise up to 12 hours.

As for the off-grid schemes, the storage has to cover the maximum power required during the daily peak hours, that normally means 4 hours of storage capacity, whereas weekly, that means 24-48 hours of storage volume.

Additional benefits may come from the storages and their amount depends on the specific characteristic of the schemes.

- a) Prevent the units from working at very low flow rate, that means very low efficiency of the electromechanical equipments.
- b) Easy routine maintenance without energy losses.
- c) Increasing a bit the Q_{mean} with respect to Q_{max} .
- d) Complete de-sanding of the water before entering the conveyance works.

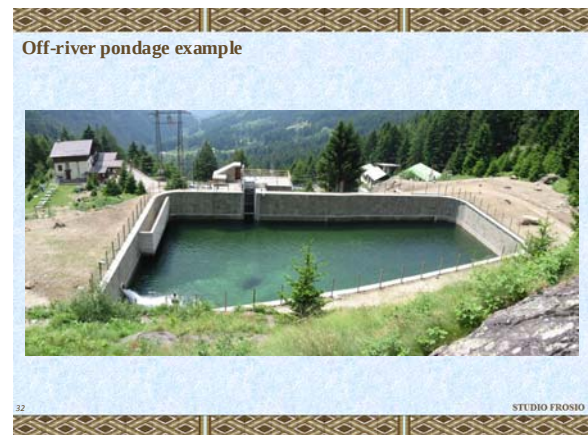
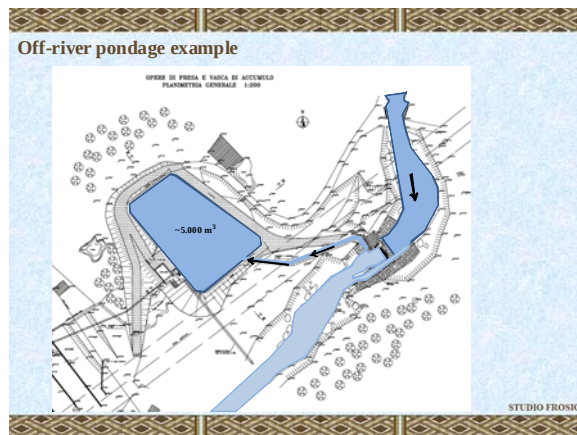
Taking into consideration the small capacity normally needed, as shown above, in the small hydro schemes an interesting alternative to the traditional dams in the river are the pondages off-river, that are beside the river.

Actually a well known problem of the traditional on-line reservoirs is the interment, because of the solid transport interruption by the dams' structures. In the small reservoir this problem becomes particularly critical, as the storage capacity is small then it can be quickly reduced by the interment.

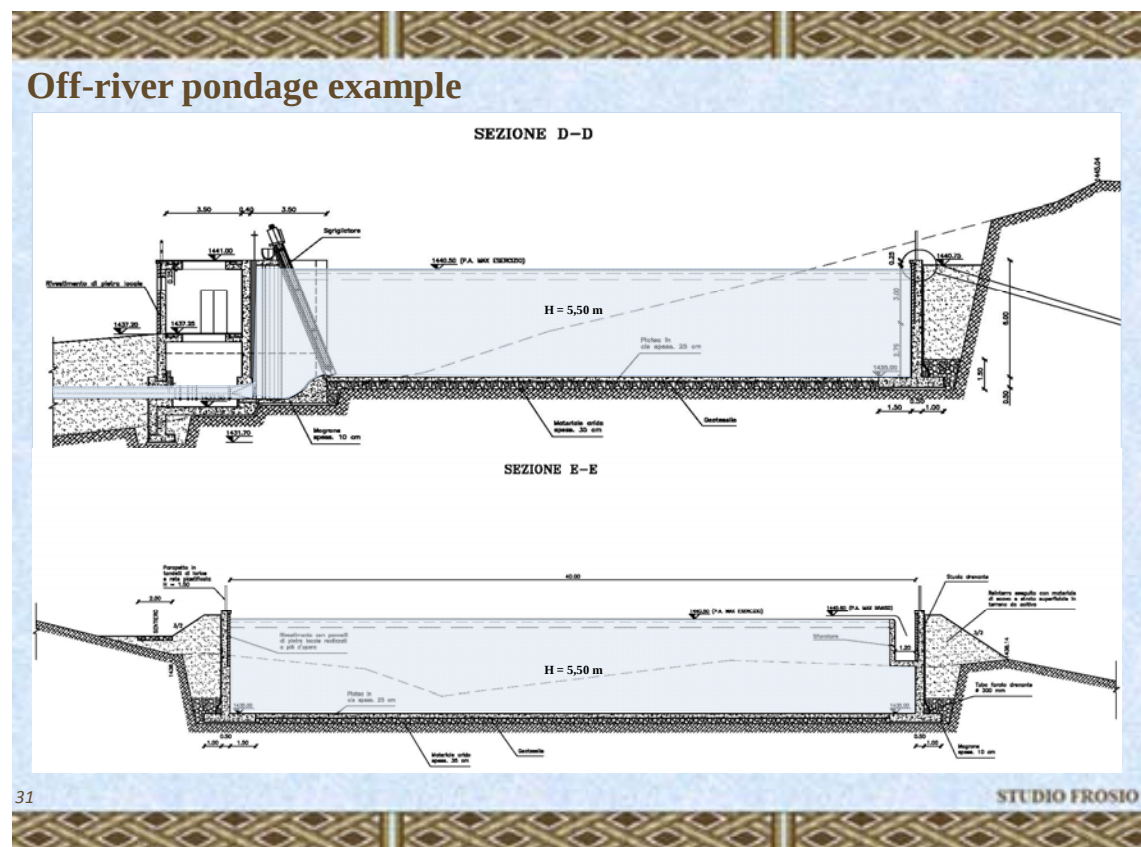


The most significant advantages of such solution are related with:

1. Structures safety: the maximum flow rate in the pondages is only the design flow of the plant, which is many times less than the flood flow affecting the on-line reservoirs.
2. Managing costs: the amount of sand deposition is very little, then the costs to maintain the original capacity are negligible.
3. Environment: the only interruption to the river continuum comes from the intake structures that simple fish ladders are usually enough to save. There are no significant interruptions in the solid transport.



Concerning the construction costs, usually the off-line pondages are more expensive but depending on specific site geo-morphology.



Hereby a significant example of a project of a high head schemes connected to a stand-alone grid in Tanzania, equipped with a small pondage of 5.000 m^3 very similar to the one shown in the pictures above.

Hydrodynamic input of the scheme

- Average net head = 440 m
- Min flow rate (dry season) = 195 l/s
- Max flow rate of the plant (rain season) = 500 l/s
- Max flow rate in the river (flood) = $100 \text{ m}^3/\text{s}$ = 100.000 l/s

Data input of the grid

- Users: ~40.000 villagers in remote areas
- Daily empty hours = 12 h
- Daily full load hours = 8 h
- Daily peak hours = 4 h
- Min capacity needed in the empty hours = 300 kW
- Max capacity needed in the peak hours = 2.000 kW
- Capacity available in the full load hours ($Q = 195 \text{ l/s}$) = 715 kW

Designing input for the water storage

- Flow rate needed in the empty hours = 82 l/s
- Flow rate needed in the peak hours = 545 l/s
- **Storage capacity needed** = $(545 - 195) \times 4 \times 3,6$ = **5.042 m^3**
- Flow rate available for filling the storage = $(195 - 82) = 113 \text{ l/s}$
- Time needed to fill the storage ~ 12 h

3 AUTOMATION AND MANAGEMENT OF HYDROPOWER PLANTS

Plant *automation* and *management* are strictly related, since they both belong to the information technology field, which doesn't imply using computers (as it's commonly thought of) but managing information.

Management of a plant consists in a set of actions decided as a consequence of information coming from the various parts of the plant itself.

Automation means that this management is done by means of algorithms, of higher or lower complexity, implemented on electric or electromechanical devices, that perform unique actions based on the information coming from the plant.

A typical instance is the PID electronic regulation of a turbine according to the water level in the forebay, or the activation of a penstock protection valve by an exclusively mechanical process.

This overview already shows the key points necessary for a correct plant management, that are:

- *information* coming from the plant;
- *rules* for managing the plant;
- *drives (actuators)* to modify the state of the various plant devices.

3.1 INFORMATION

Plant *information* can be obtained in different ways.

In a manned (attended) plant, the most immediate way is direct view (e.g. water level in a reservoir) or indirect view through measuring device reading (thermometers, pressure gauges, wattmeters...). Other senses can as well be used in particular situations:

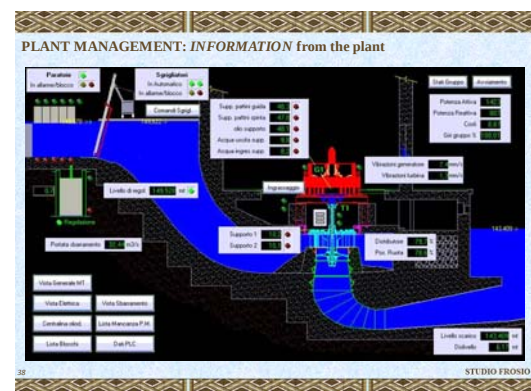
- olfaction → burning smell,
- hearing → abnormal noise,
- touch → excessive vibrations or temperatures.

For automatic management (remote control) each information must be converted into an electric signal (Ampere, Volt, Hz) by means of *sensors*, capable of measuring the physical quantity of interest, and *transducers*, converting it into a modulated electric signal. It's also possible to have visual control by closed circuit cameras (CCTV).

The essential classification of plant information is based on the fact that it is punctual (on/off) or continuous.

- Signals, alarms and commands: on/off
- Measures: continuous, by current (4÷20 mA), voltage or frequency measure.

On/off information is easier (and cheaper) to get, while continuous the one requires more complex acquisition and digitalization in order to be smoothly processed, transmitted and stored.



The designer must identify which information must be acquired from the plant, choosing the position and type of sensor, and how to transmit the information from the sensor to the control room or to the automation PLC (copper wiring, optical fibre, radio signal...). Moreover the information coming from the plant must be shown to the operators in a proper way, like in synoptic pages.

Typical signals are:

- maximum and minimum level (level switch)
- maximum and minimum pressure (pressure switch)
- maximum and minimum flow (flow switch)
- maximum and minimum temperature
- maximum opening or closure of gates, valves (stroke end)

Typical measures are:

- water level
- fluid pressure
- flow rate
- temperature
- position of the devices on the field (linear for distributor, flat gate or valve, angular position for flap gate ...)

There are also less common signals and measures, such as the sand or gravel level in settling basins, the number of fishes passes through fish-ladders, etc.

3.2 RULES

Some rules are of general validity, while others (at least 20%) depend on the specific plant and can range from the simplest to the most complex types.

The always present ones are:

- measures and events recording (SCADA)
- alarms, usually of two levels:
 - 1st level: *alert* (personnel warning only)
 - 2nd level: *alarm* (implying an action - more or less “drastic” - on the plant)
- start-up sequences and parallel with the grid
- simple (slow) halt sequences
- electric disconnection (fast) halt sequences
- unit trip for serious mechanical anomalies
- PID level regulation
- groups voltage/velocity regulation (for stand-alone plants)

Here an example of the rules to start an unit.

PLANT MANAGEMENT: *RULES* for managing the devices

Auxiliaries start ...

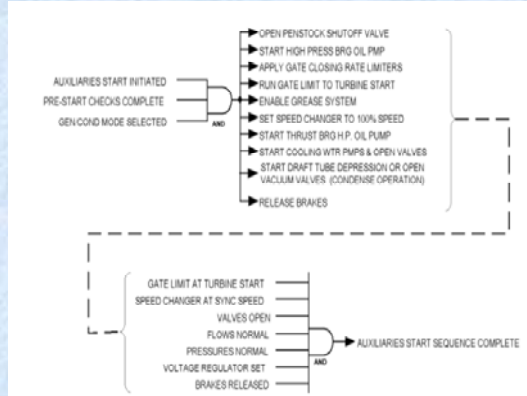


Figure 23—Logic representation of auxiliaries start—generate/condense mode

... unit run

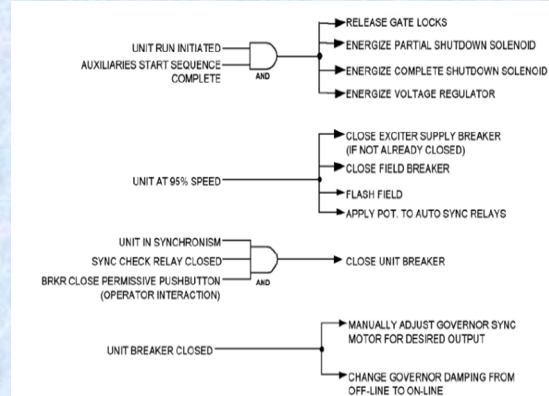


Figure 24—Logic representation of unit run sequence—generate/condense

43

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3.3 DRIVES (ACTUATORS)

They're the final link of the chain and they're used to change the operating conditions of the adjustable devices installed in a plant, such as turbines, gates, valves, etc.

The most common types are:

- manual (manpower)
- oil hydraulic (by means of single or double action cylinders)
- electrical (engines, pumps, solenoid valves)
- mechanical (by gravity)

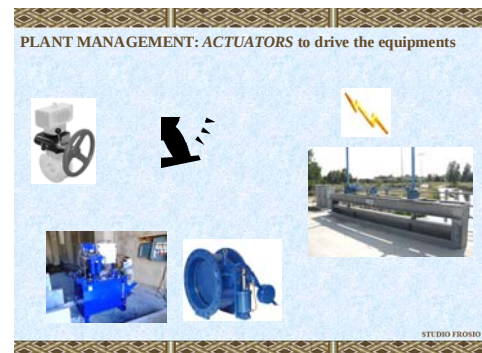
Less common are the pneumatic ones, which are frequently used in other industrial sectors.

An important aspect to take into account is that actuators require a certain energy to work, which can be supplied by external sources (electrical engines, oil hydraulic systems) or by the system itself (water pressure, counterweights).

For emergency operation, that is for plant safety measures, the second ones (internal energy supply, or “intrinsic safety”) are preferable; for instance flap gates or counterweight closing/opening valves.

3.4 AUTOMATION

In the automation field it's important to divide the information and action level, which can be at:



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1. specific devices level (mainly power units, but also valves or gates)
2. plant level.

A typical example of first level automation is the one that assists the generator unit. The group PLC receives all the information on the unit, coming from all the sensors: pressure switches, flow switches, thermometers in the oil hydraulic and cooling circuits, position of the manoeuvre devices, valves and gate, measure and state of electronic devices.

Based on that, a *software* implemented on the group PLC is able to automatically manage the single unit. The basic sequences (normally performed according to an external command) are:

1. Start-up sequences and parallel with grid
2. Stop (halt)
3. Fast stop
4. Increase
5. Decrease

Moreover the system provides the required information for the unit management, that is:

- Available /not available
- Running/stop (on/off)
- Starting
- Active and reactive power
- Voltage
- Frequency
- Current intensity
- Alarms
- Trips

Each group in a plant has its own automation; the different group automations don't communicate with each other.



The plant level has the task to collect all the information coming from the different groups and from the other parts of the plant (water level, needed power, optimization of performance) and to manage all the groups in order to assure the maximum efficiency of the plant.

In a manned plant this level is given to the skilled personnel.

In a unmanned plant a PLC is assigned to manage this superior level. On the PLC is implemented a *software* which can give direct commands (open; close; to valves and gates) or indirect command (start; stop; block; increase; decrease; to the PLC that manage the different groups) according to the information coming from the plant.



In an unmanned plant, opportune redundancy must be provided on the main control devices, and so called *watch-dog* systems must be implemented in order to make the system able to manage (even in a simplified way) emergency operations also in total black-out situations.

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