SPECIAL DESIGN ASPECTS OF CO-GENERATION UNITS

J.P. Ninan and B. Khan
Water and Electricity Department, Abu Dhabi, UAE

Keywords : MSF, HER, HP, MP, MSL, MVA, MCR, Steam Generators

Contents

Summary

The thermo-mechanical exergy of hot combustion gases must be utilized in a heat cycle for the production of power. In Middle Eastern circumstances the balance of advantage between efficiency, continuity of operation, plant size and output, spares procurement and maintenance frequency can result in the selection of the single superheat regenerative steam cycle.

The steam cycle is easily adapted to supply steam to multi-stage flash evaporators, available in large unit sizes, and moreover provide a larger water to electricity ration than a more advanced heat cycle. The evaporator may be regarded as a heat cycle producing power in the form of purified water, where 1 m^3 of pure water from Gulf seawater requires around 20-25 kWh of thermo-mechanical exergy, in the form of low pressure, slightly superheated steam. The ideal consumption is around 1 kWh^{-1} m^{-3} for Gulf seawater.

Earlier plants needed a heat cycle for electricity production, and separate steam generators for fresh water production, a relatively inefficient arrangement, with however, the advantage that any ratio of water to electricity production can be provided.

The steam cycle and multistage flash evaporator in combination, adopt well to an operational regime in which water demand is substantially constant, but electricity demand has strong daily and seasonal variations.

Early in the plant design, a decision has to be made; to have a turbine exhaust suitable for electricity production without water production; or to have a reduced exhaust, on the assumption that water production will always be there.

With that decision made, the upset conditions of the plant can be defined and provision for the them made in the overall plant control system. The low pressure extraction steam to be piped to the distiller must be slightly superheated, requiring an extraction control valve to divert steam from the low pressure stages of the turbine and a throttle valve in the extraction line for refined control of steam dryness/superheat. Two cylinder construction of the turbine is convenient when there is an extraction valve at the cross-over.

At minimum electricity production the extraction control valve is near to closure, albeit mechanically prevented from total closure. However, an extraction valve bypass valve allows a flow of steam from upstream of the extraction valve to partway down the low pressure cylinder, to keep the low pressure stages from overheating.

For zero electricity production (turbine outage), and maximum water production, the turbine is bypassed by a reducing station.

At start up, the distiller is slow to equilibrate at full output, and the overall control system for the combined plant must cater for both turbine and distillate characteristics. The resulting plant design, its energy balances, its control system and its safety features are described in detail, against a background of operating experience.

1. Introduction

Exergy/energy input for a multi-stage flash (MSF) desalination plant, in a co-generation configuration, comes in the form of low pressure (LP) steam. Typically, this is made available from either:

- The exhaust of a back pressure steam turbine; or
- A low pressure steam extraction port of a controlled extraction condensing steam turbine; or
- A medium pressure exhaust heat recovery steam generator (ehr boiler) attached to a gas turbine; or
- High pressure to low pressure reducing station taking live steam from hp or lp boilers.

The MSF process normally requires large quantities of slightly overheated (dry) steam at 2.5 bar (absolute) pressure.

The need for constant heat supply to the desalination plant, in order to maintain constant water production, irrespective of the load on the generators and also to maintain power production at times when there is no demand for process steam calls for certain unique characteristics in the design and operational capability of the plant.

The extraction condensing process, both with or without reheat, is distinguished by great flexibility in design and operation and it allows the individual requirements of power generation and heat extraction for a desalination plant to be met. In extreme case it can also be operated as a pure back pressure process with the low pressure stages idling, and with zero extraction as a pure condensing turbine.

The co-generation processes discussed hereunder is a topping cycle when the prime mover is (steam turbine) used to generate electric power and the waste or the byproduct steam from it is used for plant processes (multi-stage flash evaporators).

When compared to the system that generates electric power and electrical energy for the processes separately, the topping cycle is more fuel efficient, hence more commonly used.

This paper discusses some of these unique features of equipment design and control systems which lend operational flexibility to the extraction condensing process.

2. Steam Turbine

2.1. HP-LP Cylinder Features for Large Steam Extraction

The two figures shown below depict two typical arrangements to supply low pressure heating steam to desalination plant.

In Figure 1 the extraction heating steam is taken from a bleed of a single cycle turbine exhausting to a condenser. A pressure control valve (6) installed on the extraction line maintains a constant pressure of LP steam supply to desalination plant from when the bleed pressure reaches to a pre-determined value corresponding to electrical load.

In the event of any load beyond the control range of the extraction control valves (6) the heating steam is maintained by a high pressure reducing station (7). It is obvious that in this configuration extraction steam pressure becomes a function of electrical load.

The extraction pressure control valve (6) installed on the bleed line throttles the steam pressure at the bleed point to the desired pressure of the brine heater thereby the mass of the steam extracted is not allowed to expand through further stages. This, is in addition to the throttle losses, adversely affect, the efficiency of the plant.

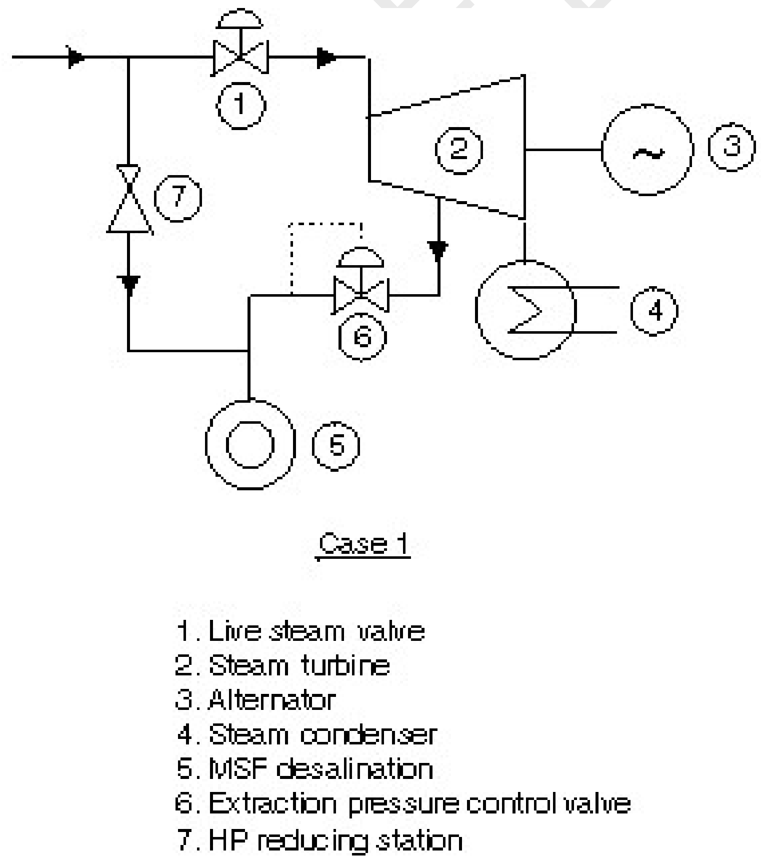

Figure 1. Case 1 HP-LP cylinder features for large steam extraction.

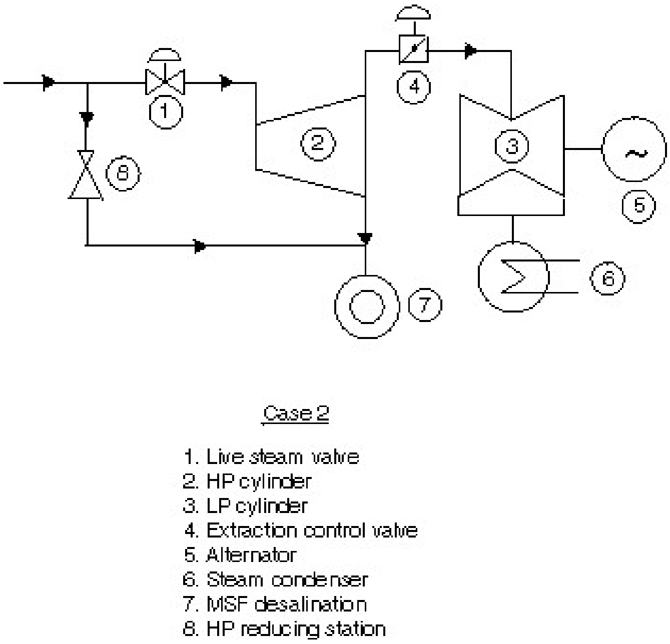

Figure 2. Case 2. HP-LP cylinder features for large steam extraction.

Figure 2 shows another arrangement with two separate cylinders i.e. one high pressure (HP) cylinder and one low pressure (LP) cylinder. The arrangement is basically identical to the first except for separation of the turbine cylinder into a HP and LP part and the extraction pressure control valve placed on the cross over connection between HP and LP cylinders. The extraction bleed point is usually at the exhaust of the HP cylinder.

The above arrangement combines functional flexibility of a back pressure turbine as well as a pass-out turbine. Here a certain amount of steam is continuously being extracted for desalination heating, the remainder passing through the extraction pressure control valve (4) to the LP part of the turbine. Regardless of the variations in the power and heating loads the turbine speed as well as the pressure of the extraction steam is always kept sensibly constant. However when the electrical load drops below a certain preselected value the process steam pressure control for desalination is possible only with the help of the HP reducing station (8).

2.1.1 HP-LP Cylinder Design

The selection of the arrangement for the cylinders and the capacity of a controlled extraction turbine in a co-generation configuration is mainly dictated by the required power to water ratio, flexibility of operation and economics. As mentioned in the earlier paragraph a controlled extraction turbine is a combination of a back-pressure cylinder which provide the heating steam and LP pressure cylinder which exhausts to a condenser participating only in the extra power production requirements. At partial load (electrical) and low load operation of the turbine most of the work done is by the HP cylinder with little or no contribution from the LP cylinder. During such operations when the LP cylinder is not participating in electrical output the overall efficiency drops. At very low loads the cooling steam going to the LP cylinder is almost completely wasted.

Low pressure cylinders are sized to take the full flow of steam in case of zero extraction or for just enough steam to produce the rated amount of power with full-extraction flow. In the former situation if the turbine is designed to develop its maximum output when running as a pure condensing machine, the LP stage will be too large for most other operating conditions. This will result in appreciable amount of loss of power, unless some form of nozzle-control governing is employed at the LP end. This is in addition to the extra expense in installation and maintenance of matching auxiliaries and ancillaries. For this reason the specified power output for no extraction should be kept as low as possible. Whereas in the latter situation the LP cylinder is too small to handle the extra steam production capacity in case of zero extraction. This will result in (electrical) load rejection whenever the desalination heating steam requirement is reduced. Therefore, in order to make the power production totally independent of heating steam, a LP cylinder designed for the full flow may be required, depending upon the power systems configuration.

When a controlled extraction turbine is run at low electrical loads, with extraction flow to desalination, for prolonged periods theoretically the exhaust control valve is closed. But in practice a small amount of steam is allowed to flow through the LP stages in order that the heat generated in those stages by disc-friction and blade windage may be continuously removed. Additional water injection nozzles to cool the steam leaving the last LP stages is provided. Exhaust steam temperatures are preferably kept below 120°C.

Controlled extraction steam turbine used in co-generation applications usually have very large LP steam exhaust ports. A relatively low specific volume of low pressure steam and the velocity limitation of process steam to desalination plant ($V < 45\ m\ s^{-1}$) will result in large diameter pipes from the turbine exhaust extraction to brine heater. Often such an unusually large size of pipe for the LP steam makes it difficult to find quick closing valves and extraction control valves of standard product line size. To overcome such situations, the brine extraction port on the turbine casing can be bifurcated, to allow use of smaller standard sizes of valves.

In order to save the steam turbine from any adverse effect from the quick closure of the brine heater inlet valve, the LP steam line is equipped with fast pneumatic or hydraulic operated non-return valves. The physical location of these valves are also very important in controlled extraction turbine where there is a low pressure cylinder or section. The valves must be kept as close as possible to the turbine extraction points in order to minimize entrapment of steam in the large sections of the pipes between the valves and extraction ports thereby minimizing the expansion of untrapped steam through the LP cylinder suction, tendency to overspeed the turbine.

Safety valves of adequate capacity are installed before the extraction control valve to protect the turbine against over-pressure due to possible accidental sudden closure of the control valve. Additionally a total trip of the turbine is also provided as a safety protection for the above situation.

2.2. Steam Condensers

Condenser design used in co-generation plant are generally of the surface type operating under vacuum. The design of the condenser is to attain conditions which will ensure that only the unusable heat in the steam at the exhaust of the turbine is rejected.

The condensing plant is an integral part of the co-generation cycle which provides the lowest economic heat rejection temperature for the steam cycle. In design of the turbine condenser, care should be taken to ensure that only the unusable heat in the steam at the turbine exhaust is rejected to convert the steam to water for re-use in the cycle.

The condenser vacuum has to be selected bearing in mind the limits to the vacuum which can be economically employed due to the fact that the specific volume of the steam, leaving the LP cylinder rapidly increases with decrease in pressure thereby causing losses due to kinetic energy in the exhaust steam. In the co-generation configuration, if the turbine is designed to develop its maximum rating when running in pure condensing mode, the condenser has to be designed to condense the entire amount of steam passing through the turbine.

In co-generation plants with large extractions, a heating load rejection will result in live steam being dumped into the condenser via by-pass stations. The design of the condenser must take into account sudden steam flows via by-pass reducing stations.

Alternatively if the condensers are designed to handle only the balance of the steam after the extraction for desalination, steam losses during all the above described transient conditions are unavoidable.

Distinct from power only cycles, the condenser sizing in the co-generation cycles is not only for the relative small amount of heat cycle drains associated with power plant. The make up water fed into the condenser to compensate for the losses in the heat cycle drains of desalination plant is substantial. Due to poor quality the return condensate from the vacuum system of the distiller plant is rejected on a continuous basis. Start-up of a desalination plant is a relatively lengthy process, and often acceptable quality of return condensate to the power cycle does not happen until a steady-state operating condition of the desalination plant is achieved.

Hot well sizing in terms of maximum residence time or the storage capacity to cover the continuous and transient operating conditions as well as the adverse conditions due to failure of components of steam/condensate system has to take into account the large amount of steam flow to the desalination plants.

In co-generation configuration, it is not economically sound to design the condenser for full flow of steam when operating in a pure pass out mode as this mode of operation is not a continuous one. However when the unit is operating in a pure pass out mode, departures from the design operating parameters of the condensers like differential temperature of cooling water, condenser vacuum, condensate temperature etc., are tolerated.

2.3. Circulating Water System

Co-generation plants with multi-stage flash evaporation units are generally located near coastal regions. The condenser circulating water (sea water) is used once then discharged. In view of the large quantities of water required the condition of the water and the site condition must be given careful consideration.

The circulating water pump capacity is selected to meet the required amount of circulating water when the turbine is operating as a pure condensing unit and operating at minimum sea water suction level. In computing the net available suction head in addition to the allowance for the low water level, all the pressure drops due to the water screening and strainers system are considered. The resulting capacity is usually much more than the actual requirements of the turbine condenser when the plant is operating in a co-generation mode. The pumps are also designed to supply circulating water to both units in case of reduced circulating water requirements (low loads) or load operation with desalination plant in operation with extraction steam. Although the NPSH/capacity/head/motor torque characteristics are designed for maximum possible flow rate (highest seawater level, clean equipment etc.) at the same time the pumps are capable of delivering the required flow with lowest sea water level, fouled equipments etc. However it is foreseen that for most of the operating time the pumps are expected to run with average sea water level, hence, best efficiency point of the pump is fixed at this rated point.

-
-
-

Bibliography and Suggestions for further study

Babcock and Wilson, Steam its generation and use (1978) LC. No. Babcock 77-90791/1978.

Barclay F J (1988). Co-generation in arid and cool climates: a new unified perspective using energy analysis. *Institute of Mechanical Engineering.*

C. Sommariva, V.S.N. Syambabu, (2001), *Increase in water production in UAE*, Desalination 138, Elsevier, pp. 173-179.

Kearton W J (1973) Steam turbine theory and practices 7th edn. ISBN 0273 430610.

Li W M (1 985) Power plant system design TK 119 L5. John Wiley and Sons Inc.

M.A. Darwish, (2001), *On electric power and desalted water production in Kuwait*, Desalination 138, pp. 183-190.

M.A. Darwish, (2004), *Cogeneration steam power desalting plants using steam turbines*, Int. J. Exergy, Vol. 1, No. 4, pp. 495-515

M.A. Darwish, Najem Al Najem, (2004), *Co-generation power desalting plants: new Outlook with gas* *turbines*, Desalination 161, Elsevier, pp. 1-12.

Modern power station practices (1971) Central Electricity Generating Board. Pergamon Press, Oxford.

Osman A. Hamed, (2005), *Overview of hybrid desalination systems – current status and future prospects*, Desalination 186, Elsevier, pp. 207-214.

The Parsons Centenary a Hundred Years of Steam Turbines (1984) Institute of Mechanical Engineering, vol. 198, no. 53.