

A Combined Cycle Co-generation Plant

Technical Field

The present invention relates to a combined cycle
5 co-generation power plant for producing power and steam.

Background

A combined cycle co-generation plant generally
refers to a power and steam generation plant, which
10 operates using more than one thermodynamic cycle. During
the operation of the combined cycle co-generation plant,
the objectives of power supply, heat recovery and steam
production are simultaneously achieved.

A combined cycle co-generation plant typically
15 consists of three main sections: a Gas Turbine (GT)
section, a Heat Recovery Steam Generator (HRSG) section
and a Steam Turbine (ST) section. Conventionally, fuel
and air are mixed in a burner and the resultant gaseous
products are used to drive electrical generators
20 connected to the gas and steam turbine(s). Thereafter,
through heat exchange, the exhaust heat from the GT
section is used to generate steam of varying pressures in
the HRSG section. Subsequently, the highly pressurized
steam is then routed to the steam turbine section,
25 wherein more power (measured in terms of megawatts, MW)
is generated. One advantage of combined cycle co-
generation plants lies in their high utilization of heat
integration as compared to conventional power plants,
thereby avoiding the unnecessary utilisation of furnaces
30 or auxiliary boilers, which can in turn lead to
substantial savings in power and steam generation.

Co-generation plants are typically required to
fulfill two main obligations in their day-to-day
operations. First, co-generation power plants need to be

able to reliably and consistently supply a predetermined and contractually agreed amount of electrical power to a primary consumer/load. In most situations, the primary consumer is a plant load of about at least 1
5 megawatt (MW). Alternatively, the primary consumer is a central power collector and distributor, (hereinafter also known as the "power grid"). In this regard, there exists an obligation on the part of the operator of the combined cycle power plant (hereinafter the "Gen-Co") to
10 maintain and deliver a reliable and constant power supply to the power grid. In many jurisdictions, a contravention of the agreed power supply may result in detrimental economical liabilities and pose legal ramifications to the Gen-Co.

15 Secondly, the Gen-Co may also be obligated to supply a predetermined and a contractually agreed amount of steam to one or more primary steam consumers. The steam is typically extracted from the HRSG section or steam turbine(s) and transported to a distribution system
20 wherein it is subsequently supplied to the consumers. In some cases, the primary steam consumers may be downstream units or steam consuming units of other non-power related industries, such as a petroleum refinery.

A common problem arises wherein a fault occurs
25 during the course of plant operation, which causes either the steam turbine or the gas turbine to operate at a reduced capacity. Such faults can manifest in a variety of scenarios, such as for example fail-close valve designs, electrical trips, boiler overheat, disruptions
30 in fuel service or even scheduled offline maintenance. In such a situation, the Gen-Co often has to make a decision to either sacrifice steam production at the expense of power generation or power generation at the expense of steam generation. In conventional cogeneration plant

design, power supply is often sacrificed for the sake of increasing/maintaining steam production. As mentioned previously, this can have potentially adverse economical and legal ramifications for the Gen-Co.

5 Yet another problem is that known combined cycle co-generation plant designs are unable to achieve high levels of thermal efficiency without sacrificing its net exportable electrical output. A typical combined cycle co-generation plant achieves thermal efficiencies of
10 about 50% to about 60% thermal efficiency. A higher thermal efficiency is generally desired as it represents superior fuel economy and consequently translates to significant cost savings and an overall improved performance of the co-generation plant. A high
15 electrical output is generally desired especially if electricity is exported to a grid-based and/or merit order dispatch system which rewards on the volume and efficiency of the electricity dispatched/exported. However, in co-generation plants, improving the thermal
20 efficiency by increasing the steam output tends to reduce the electrical output (MW) and the net electrical efficiency of the co-generation plant.

A known co-generation power plant design deals with problems associated with varying demand loads from the
25 power grid by installing supplementary burners in combination with a complementary gas turbine. However, such a design does not make provisions for maintaining a constant level of steam production when a need arises to increase power generation beyond the normal capacity.
30 The known design also does not provide a design for improved thermal efficiency.

Duct firing is another commonly employed method in co-generation plants to provide for increased steam production in times of need. Duct firing typically

involves supplementary burners installed in the HRSG section, which can be used to boil up feed water to produce additional steam as desired or required for the particular HRSG in which they are installed. However, duct firing is an inefficient combustion process and they are known to reduce the thermal efficiency of the co-generation plant. Furthermore, duct firing only addresses the problem of increasing steam supply, but they do not provide solutions to maintaining electrical power supply in times of disruptions in plant operation.

Therefore, there exists a need for a combined cycle co-generation plant that is able to balance power and steam production, in such a way such that supply shortfalls (steam or power) of any kind are avoided, by way of ingenious design. There also exists a need to provide a combined cycle co-generation plant, which can achieve higher thermal efficiencies as compared to existing combined cycle power plants.

Summary

In a first aspect, there is provided a combined cycle power system for producing power and steam, the system comprising:

- at least two fuel turbines capable of combusting fuel to produce power and exhaust gas from said combusted fuel;

- at least two heat recovery steam generators for producing steam from said exhaust gas;

- at least two steam turbines for producing power from steam produced by said heat recovery steam generators;

- at least one steam supply stream for receiving steam produced by said heat recovery steam generators; and

- a heat source thermally coupled to each of the said heat recovery steam generators and being

configured to intermittently and independently supplement heat to one of said heat recovery steam generators to meet a required steam duty of said steam supply stream and at least one of said steam turbines, and wherein the heat source is configured to heat one of the at least two heat recovery steam generators if the other heat recovery steam generator is unable to meet the required steam duty, without a substantial loss of the steam duty of the said steam supply stream and at least one of said steam turbines.

In one embodiment, there is provided a combined cycle power system for producing power and steam, the system comprising: at least two fuel turbines capable of combusting fuel to produce power and exhaust gas from said combusted fuel; at least two heat recovery steam generators for respectively producing steam from said exhaust gas; at least one steam turbine for producing power from steam produced by said heat recovery steam generators; a steam supply stream for receiving steam produced by said heat recovery steam generators; and a heat source thermally coupled to said heat recovery steam generators and being configured to intermittently and independently supplement heat to one of said heat recovery steam generators to meet a required steam duty

of at least one of said steam supply stream and said steam turbine and wherein the heat source is configured to heat one of the at least two heat recovery steam generators if the other heat recovery steam generator is
5 unable to meet the required steam duty, without a substantial loss of the steam duty of the said steam supply stream and said steam turbine.

Advantageously, the HRSG units in the combined cycle power system are able to recover waste heat derived from
10 the combustion of the fuel turbine. The recovered heat energy can be utilized in a plurality of ways, one of which is to generate steam through a HRSG or a waste heat reboiler.

In one embodiment, the heat source coupled with the
15 HRSG is a duct burner. Advantageously, the duct burner of one HRSG unit can be supplementary fired to increase the steam production of a single HRSG unit.

In a second aspect, there is provided a system for continuously producing power and steam comprising: at
20 least two combined cycle power modules, each module comprising: a fuel turbine capable of combusting fuel to produce power and exhaust gas from said combusted fuel; heat recovery steam generators for respectively producing steam from said exhaust gas; a steam turbine for
25 producing power from steam produced by said heat recovery steam generators; and a heat source thermally coupled to said heat recovery steam generator for supplementing heat thereto; a steam supply stream for receiving steam produced from said modules; and a controller configured
30 to activate the heat source of one combined cycle power module if the other combined cycle power module is unable to meet a required steam duty of at least one of its steam supply stream and said steam turbine, thereby continuously producing power and steam.

In one embodiment, each combined cycle power modules can work in tandem and in combination to meet both required steam and power duties of the system. Alternatively, each combined cycle block is capable of
5 independent operation, wherein one combined cycle block is able to continue operation when the other combined cycle block is partially or completely offline while the steam and power duties of the system are being met.

Advantageously, one HRSG unit is able to compensate
10 for the steam or power supply shortage of the other HRSG unit. Should one HRSG unit fail to deliver the required steam supply to meet the steam duties of both the process steam and the steam turbine, the other HRSG unit can fire its coupled duct burner to make up for the shortfall in
15 steam generated by the HRSG, thereby allowing the system to meet its overall power and steam duty requirement. The arrangement of the combined cycle blocks therefore allows the power system to reliably supply a predetermined steam and power duty without interruption.

20 In one embodiment, the controller is a feedback controller. The controller is able to monitor and analyze the steam flow rates of the extracted steam streams. The controller is further electronically coupled with a respective duct burner and is capable of activating or
25 terminating the combustion process of the duct burner. Accordingly, when a steam shortage is detected by the controller, an activating signal will be transmitted to the duct burner to initiate the duct firing process and vice versa. Advantageously, this allows the controller
30 to be able to control the steam flow rates at a predetermined set point and reduce flow rate fluctuations in the extracted steam flow rates.

In one embodiment, there is provided a method for continuously producing power and steam in a system comprising the steps of:

- a) combusting fuel in at least two fuel turbines to produce power and exhaust gas;
- b) generating steam by passing the exhaust gas produced by said fuel turbines into a respective at least two heat recovery steam generators;
- c) generating power by passing some of the steam produced by said heat recovery steam generators into a respective at least two steam turbines, the amount of steam being for a predetermined steam duty to meet a predetermined power output;
- d) removing steam produced by said heat recovery steam generators, the amount of steam being for a predetermined steam duty; and
- e) selectively heating the exhaust gas passing into one of the at least two steam generators to increase the amount of steam when the other steam generator is unable to meet the required steam duty for at least one of said steam turbine and said removed steam, without a substantial loss of the steam duty of the said steam supply stream and said steam turbine.

In a third aspect, there is provided a method for continuously producing power and steam in a system having at least two combined cycle power modules, each module comprising: a fuel turbine capable of combusting fuel to produce power and exhaust gas from said combusted fuel; a heat recovery steam generators for respectively producing

steam from said exhaust gas; a steam turbine for producing power from steam produced by said heat recovery steam generators; and a steam supply stream for receiving steam produced from said modules, the method comprising the steps of:

- a) monitoring the steam output from each of said modules;
- b) providing a supplemental heat source to one of the heat recovery steam generators when said monitored steam output of a module falls below a predefined steam duty.

In a fourth aspect, there is provided a method of continuously producing power and steam comprising the steps of:

- a) combusting fuel in at least two fuel turbines to produce power and exhaust gas;
- b) passing the exhaust gas from the two fuel turbines to respective at least two heat recovery steam generators to produce steam;
- c) passing some of the steam produced by the at least two steam generators to respective at least two steam turbines to produce power; and
- d) removing a selected amount of the steam produced by the at least two steam generators, wherein the selected amount of steam is at a steam-to-power ratio of at least 2.5.

In one embodiment, the selected amount of removed steam is at a steam-to-power ratio of at least 3 t/h.MW or at least 3.5. Advantageously, the selected amount of removed steam being at a steam-to-power ratio of at least 2.5 increases the thermal efficiency of steam and power generation.

In one embodiment, there are two distinct steam extraction points in the system. These two steam extraction points have been chosen for optimal heat

integration (ie thermal efficiency). Advantageously, by choosing the extractions points as such, the combined cycle system is able to achieve a superior thermal efficiency of more than 60%, preferably more than 70%
5 preferably more than 75%.

In another embodiment, the system is able to achieve thermal efficiency of about 77% whilst maintaining a steam to power ratio of 7.16. Advantageously, the power plant with such high thermal efficiencies enjoys the
10 benefits of fuel economy and lower operating costs.

Definitions

The following words and terms used herein shall have the meaning indicated:

15 The word "substantially" does not exclude "completely" e.g. a composition which is "substantially free" from Y may be completely free from Y. Where necessary, the word "substantially" may be omitted from the definition of the invention.

20 The term "substantial loss of the steam duty" means that no more than 10% steam is lost from a required steam duty, preferably no more than 5% steam is lost from the required steam duty, more preferably less than 2% steam is lost from the required steam duty.

25 The term "substantial loss of the power (MW) output/duty" means that no more than 10% of the electrical power is lost from a required power output/duty, preferably no more than 5% power is lost from the required power output/duty, more preferably less
30 than 2% power is lost from the required power output/duty.

The term "removed steam" unless stated otherwise, in the context of this specification refers to an amount of steam generated by the HRSG which has been extracted from

the power and steam co-generation system as process steam and which has not been expanded through the steam turbine.

The term "steam-to-power ratio" in the context of this specification, is a dimensionless ratio which refers to the tons per unit time of steam that has not expanded through the steam turbine but is extracted from the system to the power loss (in Megawatts) of the turbine as a result of said steam being extracted. For example, assuming 100% of all steam produced in the system reports to the steam turbine, then the steam-to-power ratio will be zero. If for example, in the same system, 150 t/h of steam is removed from the system and this results in a loss in power (MW) of the steam turbine of 41.9 MW (i.e. loss relative to 100% steam input to the steam turbine), then the steam-to-power ratio is $150 \text{ t/h} / 41.9 \text{ MW} = 3.58$.

The term "thermal efficiency as used herein refers to the total amount of steam and power energy produced by the system or process, expressed as a percentage of the energy provided as fuel in the system or process (for example, the amount of gas consumed where the fuel turbine is a gas turbine). The energy provided by the fuel may also include the fuel energy consumed in the HRSG section and not simply in the gas turbine itself.

The term "high pressure" and abbreviation "HP" are to be used interchangeably to refer to fluid at a pressure of above 60 Bar (6000 kPa) to about 150 bar (15,000 kPa). In one embodiment, the high pressure steam is about 12,000 kPa to about 13,000 kPa. The term "intermediate pressure" and abbreviation "IP" are to be used interchangeably to refer to fluid at a pressure of between 15 bar (1500 kPa) to 60 bar (6000 kPa). In one embodiment, the intermediate pressure steam is about 25

Bar (2,500 kPa) to about 27 Bar (2,700 kPa). The term "low pressure" and abbreviation "LP" are to be used interchangeably to refer to fluid at a pressure of between above atmospheric pressure to about 15 bar. In one embodiment, the low pressure steam is about 4 Bar (400 kPa) to about 6 Bar (600 kPa).

Unless specified otherwise, the terms "comprising" and "comprise", and grammatical variants thereof, are intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, unrecited elements.

As used herein, the term "about", in the context of concentrations of components of the formulations, typically means +/- 5% of the stated value, more typically +/- 4% of the stated value, more typically +/- 3% of the stated value, more typically, +/- 2% of the stated value, even more typically +/- 1% of the stated value, and even more typically +/- 0.5% of the stated value.

Throughout this disclosure, certain embodiments may be disclosed in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the disclosed ranges. Accordingly, the description of a range should be considered to have specifically disclosed all the possible sub-ranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

Disclosure of Optional Embodiments

Exemplary, non-limiting embodiments of a combined cycle power system will now be disclosed.

5 The fuel turbine may be any type of turbine that comprises a combustion chamber, a compressor and a turbine.

 The heat source thermally coupled with the HRSG may be any type of means for producing heat. In one
10 embodiment, the means for producing heat is selected from the group consisting of: duct burners, auxiliary boilers, auxiliary heat exchangers and furnaces.

 Each HRSG may be thermally coupled to at least one duct burner. The duct burner may be installed prior to or
15 in each of the pressure sections of the HRSG, such as the HP section, the IP section and the LP section.

 The combined cycle power system may be comprised of two modules of a combined cycle block, each block comprising a gas turbine, a HRSG having at least one duct
20 burner therein and a steam turbine. Optionally, the combined cycle system may comprise more than two modules of combined cycle block. Typically, in each combined cycle block, the gas turbine combusts gas to produce power and heated exhaust gas. The heated exhaust gas
25 passes to a HRSG and is intermittently heated further by the duct burner to thereby produce more steam. Some of the steam passes to a steam turbine for producing power and some of the steam is extracted from the combined cycle power system as one or more of HP, IP and LP steam.
30 In one embodiment, the system may comprise of three or four combined cycle blocks, each capable of producing steam and power in tandem or independently of each other in that the mass flow of exhaust gas for the respective HRSG and subsequently steam of the HRSG and steam turbine

are in parallel flow to the other combined cycle power blocks.

The controller of the combined cycle power system may be a feedback controller. Optionally, the controller
5 may be a feedforward controller, a PID controller, a PI controller, a PD controller or any combination of the above.

The high pressure steam generated by the HRSG may be from about 12000 kPa to about 13000 kPa. In alternative
10 embodiments, the pressure of the HP steam may be from about 12000 kPa to about 12800 kPa, from about 12000 kPa to about 12600 kPa, from about 12000 kPa to about 12400 kPa and from about 12000 kPa to about 12200 kPa.

In one embodiment, each HRSG unit is capable of
15 generating up to 300 tons/hr of steam for expansion through its respective steam turbine or for extraction as process steam. In one embodiment, the HP steam produced by one HRSG unit may be extracted as process steam or expanded through a fluidly communicated steam turbine. In
20 another embodiment, the HP steam produced by one HRSG unit may be routed to a second combined cycle block for expansion through a second steam turbine installed therein.

The combined cycle power system is able to remove
25 process steam for distribution or use in downstream units at the expense of power generated by the steam turbine. In general, the amount of steam (in tons/hr) removed by the system that results in one megawatt of power loss from the steam turbine is termed as the steam-to-power
30 ratio. The steam-to-power ratio may be at least 5. In one embodiment, the steam-to-power ratio may be from about 2.5 to about 7.5 or about 5 to about 7.5. In one embodiment, the steam-to-power ratio may be from about 2.5 to about 4.0, from about 5.5 to about 7.5 and from

about 3.0 to about 5.5. Advantageously, the high steam-to-power ratio is also characterized by an improved thermal efficiency in the power system. A high steam-to-power ratio is advantageous in that minimal power supply loss results from the reduction in steam input to the steam turbine due to the process steam being removed by the system. Accordingly, the total energy output by the system remains high relative to the total energy input in terms of fuel combusted, thereby resulting in high thermal efficiencies of the system.

The generated steam from the HRSG may be extracted from the system at a variety of operating temperatures and pressures. The HP stream that is removed may have temperatures ranging from 450 °C to 550°C or higher. The HP steam removed may also have pressures ranging from 12000 kPa to 12300 kPa. The extracted IP steam may have pressures ranging from 2500 kPa to about 2700 kPa. The LP steam extracted may have pressures ranging from about 400 kPa to 600 kPa. In one embodiment, the process steam is extracted at about 500°C and 12000kPa (absolute) and also at about 250 °C and 2600 kPa.

Brief Description Of Drawings

Figure 1 shows a simplified schematic diagram of a combined cycle co-generation plant with two combined cycle block modules.

Figure 2 shows a simplified schematic diagram of a heat recovery steam generator with triple pressure reheat design.

Figure 3 shows a graph relating steam loads (tons/hr) and power output (MW) with the thermal efficiency of a power plant with a 90% CC configuration.

Figure 4 shows a graph relating steam loads (tons/hr) and power output (MW) with the steam-to-power ratio of a power plant with a 90% CC configuration (hereinafter the phrase "CC configuration" means a combined cycle plant operating at the quoted percent capacity. That is the phrase "90% CC configuration" means a combined cycle plant operating at 90% capacity).

Figure 5 shows a graph relating various steam loads (tons/hr) with the steam-to-power ratio of a power plant with a 90% CC configuration.

Figure 6 shows a graph relating various steam loads (tons/hr) to the steam-to-power ratios in a power plant with a 90% CC configuration with duct firing.

Figure 7 shows a graph relating steam loads (tons/hr) and power output (MW) with the thermal efficiency of a power plant with a 90% CC configuration with duct firing.

Figure 8 shows a graph relating steam loads (tons/hr) and power output (MW) with the steam-to-power ratio of a power plant with a 90% CC configuration with duct firing.

Figure 9 shows a graph relating steam loads (tons/hr) and power output (MW) with the thermal efficiency of a power plant with a 100% CC configuration with duct firing.

Figure 10 shows a graph relating steam loads (tons/hr) and power output (MW) with the steam-to-power ratio of a power plant with a 100% CC configuration with duct firing.

Figure 11 shows a schematic diagram of the control system for steam production in the combined cycle power plant.

Figure 12 shows a basic algorithm for the feedback control loop of the steam flow control system.

Detailed Description of Drawings

5 Referring now to Fig. 1, there is provided a combined cycle co-generation power system 10, comprising a pair of combined cycle power blocks (11,11a), which are in parallel mass flow to each other. The combined cycle power blocks comprise turbines in the form of a pair of
10 gas turbines (12,12a), heat recovery steam generators in the form of HRSG pair (14,14a) and steam turbines in the form of steam turbine pair (20,20'). The gas turbines (12,12a) and the HRSG (14,14a) and the steam turbines (20,20') and electrical generators (16,16a) are each
15 respectively organized in a single shaft configuration, wherein the rotating means of the gas turbines (12,12a) is mechanically coupled to the steam turbines (20,20') via a connecting shaft (13,13a). The combined cycle power blocks (11,11a) are in parallel mass flow and are
20 able to generate power and supply steam independently and/or in tandem.

The gas turbines (12,12a) are SGT5-4000F gas turbines, supplied from Siemens Power Generation Inc of Siemens AG Wittelsbacherplatz 2 D-80333 Munich, Federal
25 Republic of Germany with a rated power output of 287 MW and 39.5% simple cycle efficiency. The turbines feature an annular combustion chamber with ceramic combustion tiles.

During normal plant operation, a feed stream
30 (21,21a), comprising a mixture of natural gas (as fuel) and ambient air is fed to the gas turbines (12,12a) for combustion. The pressurized combustion exhaust from the gas turbine subsequently drives a generator (16,16a),

thereby producing electrical power. Typically, the gas turbines (12,12a) are responsible for generating the majority of the power load required of the system 10. The generated power is then routed to a power grid (not shown). Distillate fuel oil (not shown) is used as an emergency back-up fuel source should the supply of natural gas trips. Furthermore, provisions are made to the design to ensure that online fuel switchovers between natural gas and fuel oil are feasible during plant operation with minimal down time. The distillate fuel can be any suitable petroleum derived fraction, for example, diesel fuel.

Heated exhaust gas (24,24a) produced from the gas turbine (12,12a) is typically at a temperature range of 400°C to 600 °C. The exhaust gas (24,24a) is then fed to a horizontal flow HRSG (14,14a) for heat recovery and steam production.

The HRSG (14,14a) is typically of a triple-pressure-reheat design, capable of generating process steam at three different pressures, namely high pressure (HP) steam (28,28a), intermediate pressure (IP) steam (31,31a) and low pressure (LP) steam (33,33a). The HRSG (14,14a) are thermally coupled to a heat source in the form of a respective duct burner (18,18a) that is capable of independent and intermittent combustion. The heat energy that is derived from the independent and intermittent combustion of fuel in the duct burner (18,18a) is used to boost the generation of steam in the HRSG (14,14a).

The duct burner pair 18,18a are operable by a controller as will be described further below and can be used to supplement the heat duty supplied by the exhaust gas from the gas turbines. The pressure of the HP steam is in the range of about 12000 kPa to about 12300 kPa,

the pressure of the IP steam is in the range of about 2500 kPa to about 2700 kPa and the pressure of the LP steam is in the range of about 400 kPa to about 600 kPa.

5 The HP steam stream (28,28a) is passed from the respective outlets of the HRSG (14,14a) to respective downstream steam turbines (20,20'). Each steam turbine (20,20') is comprised of three main sections, a HP section (20a,20a'), an IP section (20b,20b') and an LP section (20c,20c'). The IP steam (31,31a) generated from
10 the HRSG (14,14a) is routed to the IP section (20b,20b') of the steam turbine, while the LP steam (33,33a) is routed to the LP section (20c,20c') of the steam turbine respectively. A portion of the HP steam (28,28a) is first expanded through the HP section (20a,20a') of the
15 steam turbine to generate electrical power. The depressurized and expanded steam is subsequently expanded through the IP and LP sections sequentially to achieve an appreciable pressure drop across the three sections of the steam turbine. Finally, the let down steam (26,26a),
20 which has been fully expanded through steam turbine (20,20'), is finally routed from the LP section (20c,20c') and condensed in a heat exchanger (22,22a) to become condensate.

However, not all of the steam produced by the HRSG
25 pair (14,14a) is used to respectively drive the steam turbines (20,20'). Some of the steam is extracted as HP steam from the system 10 via HP steam header 32, while some of the steam is extracted as IP steam via IP steam header 34, where the steam is subsequently being consumed
30 or sold. Accordingly, the system 10 produces both steam and power.

For process steam extraction, the steam will be extracted at two different pressure points. Particularly,

the process steam is extracted from both the HP steam (28,28a) and the IP steam (31,31a). A first extraction point (40,40a) is situated downstream to the HRSG's high pressure superheater and a second extraction point
5 (42,42a) is situated at the cold reheat section, between the steam turbine (20,20') and the HRSG (14,14a). In one embodiment, the HP steam (28,28a) is extracted at a temperature of 500°C and a pressure of 12000 kPa (absolute) while the IP steam (31,31a) is extracted at a
10 pressure of 2600 kPa and 250°C. However, it should be realized that this is just one possible embodiment and in reality, more than two extraction points may be provided. It may also be desirable to extract LP steam (33,33a) from the system 10. The let down steam (26,26a), having a
15 sub-atmospheric pressure of 100kPa absolute or lower and a temperature of 98°C or lower, is passed through a heat exchanger (22,22a) for recycle back into the HRSG

The extracted HP steam stream (29,29a) are then routed to a common HP steam header 32 and distributed as
20 HP steam 36, while extracted IP steam streams (30,30a) are subsequently routed to common LP steam header 34 and distributed as LP steam 38.

The levels of steam production are constantly monitored and controlled by a series of transmitters and
25 controllers. As the extracted HP steam (29,29a) flows past controllers (50,50a) respectively, the controllers (50,50a) will be able to analyze the mass flow rate of the steam stream and react to any disturbance or changes in the steam supply. In one embodiment, the controllers
30 (50,50a) are electronically coupled with the duct burners (18,18a). When one of the controllers detect a change in steam flow rates, it will reactively send an "activating" or a "terminating" electrical signal to its respective

duct burner (18,18a). In this manner, when one of the HRSGs (14,14a) does not supply sufficient steam to meet the steam duty as required, the corresponding duct burner (18,18a) will receive an electrical signal from the controller to either activate firing or terminate firing, thereby controlling the steam production in a feedback loop. This is a simplified description of one possible method of control instrumentation in the system. Other possible embodiments of process control such as proportional, integrative, derivative or feedforward control can be used singularly or in conjunction with an exemplary feedback system as described above.

Now referring to figure 2, there is shown a simplified schematic of the triple pressure reheat design HRSG 14. The hot exhaust gas 24 from the gas turbine passes through the HRSG 14 where the high temperature exhaust gas 24 heats up the boiler feed water 50 through a series of evaporators, namely the LP evaporator 44, IP evaporator 46 and the HP evaporator 48. The cooled exhaust stream 24 is then passed to an exhaust stack 60. The duct burner 18 is installed in front of the HP evaporator 48. To control the main steam temperature, the main HP steam 28 and the hot reheat line 58 are equipped with a de-superheat spray system (not shown). Steam heated in the HP evaporator 44 flows through the main piping for admission into the steam turbine. Steam produced from the IP evaporator 46 flows through an IP pre-heater 46a before joining up with the cold reheat steam line 56. An IP steam stream 54 is extracted at one point prior to the mixing of the IP steam from the IP evaporator 46 and the cold reheat line 56. The mixed stream 64 then enters the HRSG 14 reheater section 62 and is then admitted to the steam turbine as a stream of IP steam 58. Steam from the LP evaporator 44 passes through

a LP preheater 44a before being admitted into the steam turbine as LP steam 52.

Referring now to figure 11, there is shown a simplified schematic diagram of the control system 69 responsible for monitoring the flow rate of steam, comprising of the flow rate analyzer 50, a main control system 66, an actuator 68, duct burner 18, and the HP steam header 32. As the extracted steam from both HRSGs are routed to common steam header 32 via header 32, each respective HP steam stream's flow rate will be detected by an analyzer 50 which will subsequently transmit an electrical signal 70 to a main control system 66. In one embodiment, the main control system is a distributed control system (DCS). Upon receiving the electronic signal from the analyzer 50, the main control system 66 will react to the disturbances in the steam flow rates by transmitting a relay signal 72 to an actuator 68. The relay signal 72 can be an electronic or a pneumatic signal. In one embodiment, the relay signal 72 results in the actuator 68 closing/opening the fuel valve leading to the duct burner 18, thereby activating or terminating the combustion process in the duct burner.

Referring now to figure 12, there is shown a feedback control algorithm for the above disclosed control system. The steam control system 69 is perturbed by a drop in steam flow rate with respect to a predetermined set point. The analyzer responds by transmitting an electronic signal to the main control system which in turn transforms the electronic signal and relays an "activating" signal to the duct burners (18,18a). Combustion in the duct burners (18,18a) are subsequently initiated and steam production is increased comparatively. As the steam production continues, steam

flow rates will increase to a point that is above the predetermined set point. Thereafter, the reverse happens except that now the controller relays a "terminating" signal to the duct burners (18,18a), thereby stopping additional steam production. The "terminating" signal can take the form of either a pneumatic or electronic signal, and has the effect of terminating the combustion process in the duct burner. This can be done in a plurality of ways such as shutting down fuel service valves or by disabling the firing mechanism in the duct burner.

Examples

Non-limiting examples of the invention will be further described in greater detail by reference to specific Examples, which should not be construed as in any way limiting the scope of the invention.

Example 1

In-silico modeling of a singular combined cycle co-generation power plant is carried out using engineering simulation software program KRAWAL™ from Siemens AG, Germany. The configuration employed in this simulation was a 90% Combined Cycle (CC) without the use of Duct firing (DF). The results below are for a combined cycle module comprising of a single HRSG unit. The parameters that were simulated in the modeling exercise included power generation (MW), Heat rate (kJ/kWh), Electrical efficiency (%), thermal efficiency (%) and Steam extraction rates (tons/hour). The modeling results are tabulated below:

Simulation Run	Steam (as extracted)			Steam (as delivered)		
	SU	SM	Total	SU	SM	Total
	t/h	t/h	t/h	t/h	t/h	t/h
C2	0	0	0	0	0	0
C6	63	0	63	65	0	65
C11	63	44	107	65	50	115
C16	91	49	140	95	55	150
C16B	63	75	138	65	85	150

Table 1.

Simulation Run	Power	Heat Rate	Electrical Efficiency	Thermal Efficiency	Power decrease	Steam-to-Power Ratio
	MW	kJ/kWh	%	%	MW	Ratio
C2	334	6,427	56.0%	56.0%	-	-
C6	310	6,969	51.7%	61.4%	23.7	2.74
C11	299	7,263	49.6%	65.6%	34.9	3.30
C16	289	7,529	47.8%	68.6%	44.9	3.34
C16B	292	7,467	48.2%	68.4%	41.9	3.58

Table 2.

As seen in Table 1, simulation run C2 is a control run with no steam extraction at all. The power generation for Run C2 (control Run) was about 334 MW (electric). Runs C6 to C16B show that the power generation is slightly reduced when increasing amounts of steam is being extracted from the power plant.

Fig. 3 shows the decrease in power generation from 334MW to 292MW as steam production increased from 0 to 150 tonnes/hour. This is a logical result from having less steam available to drive the steam turbine. However, the loss in power generation is also accompanied by an increase in thermal efficiency to a value as high as about 68%. The extraction of the ultra high pressure steam (SU) and the medium pressure steam (SM) results in less steam available for expansion in the steam turbine for power generation. Consequently, a slight drop in power generation is thereby experienced. It is proposed that the high thermal efficiencies of nearly 68% are a result of the choice of the steam extraction points. The choice of the steam extraction points are derived from the optimization of the heat balance of the combined cycle system. In this example, the steam is extracted at 500°C and 120 bar (absolute). Accordingly, these are the

optimal conditions for steam extraction in order to achieve high thermal efficiencies.

Figures 4 and 5 show that the steam-to-power ratio for this particular configuration can vary from about 2.7 to about 3.6. In particular, Run C16B shows a normal operating mode, with no duct firing, having a steam output of about 150 tons/hour, with an ideal steam-to-power ratio of about 3.58. The steam-to-power ratios is advantageous in that nearly 4 tons of steam can be removed for sale and distribution at the expense of one MW drop in the power generated by the steam turbine. In conventional combined cycle co-generation plants, the primary concern is usually steam production and therefore existing co-generation designs usually have a less ideal steam-to-power ratio of about 2.0 to 2.5.

Example 2

In-silico modeling was carried out for the same power plant configuration as in Example 1, except this time with the firing of the duct burners. The modeling software and methods used are the same as in Example 1. The tabulated results are as follows:

Simulation Run	Steam (as extracted)			Steam (as delivered)			Configuration
	SU	SM	Total	SU	SM	Total	
	T/h	t/h	t/h	t/h	t/h	t/h	
C2	0	0	0	0	0	0	90% CC
C7	125	0	125	130	0	130	90% CC with DF
C12	124	91	215	130	100	230	90% CC with DF
C17	178	100	278	190	110	300	90% CC with DF
C17B1	124	146	270	130	160	290	90% CC with DF
C17B	124	155	279	130	170	300	90% CC with DF

Table 3.

Simulation Run	Power	Heat Rate	Electrical Efficiency	Thermal Efficiency	Power decrease	Steam-to-Power Ratio
	MW	kJ/kWh	%	%	MW	
C2	334	6,427	56.0%	56.0%		0.00
C7	310	7,519	47.9%	65.8%	23.7	5.49
C12	299	8,141	44.2%	72.6%	34.9	6.59

C17	289	8,800	40.9%	76.3%	44.9	6.68
C17B1	292	8,536	42.2%	76.3%	41.9	6.92
C17B	292	8,573	42.0%	77.1%	41.9	7.16

Table 4.

As seen in Tables 3 and 4, Run C2 is a control run with a 90% CC configuration with no duct firing and no steam production. Run C17B shows a situation wherein there exists a need to increase steam production, e.g. to make up for steam shortfall arising from another combined cycle block module. Duct firing is employed to increase the steam production to about 300 tons/hr. It is notable that there is no significant drop in power supply (292 MW) despite the increased steam production. The steam to power ratio of Run C17B is surprisingly high at 7.16. The above results also suggest a relationship between the ratio of SU steam to SM steam extracted and the steam-to-power ratio. Run C17 similarly depicts a steam production rate of 300 tons/hour, however, with a larger proportion of high pressure steam being extracted as compared to Run C17B. This is observed to be less thermally efficient than Run C17B.

Figure 7 shows the relationship between steam production, power generation and thermal efficiency of the power plant. As shown, the maximum steam duty achievable with duct firing can go up to 300 tons/hr for a single HRSG unit. At the highest steam production rate of 300 tons/hr, the power generated is about 292 MW and the thermal efficiency is about 77.1%.

Figure 8 shows the relationship between the steam-to-power ratios at various steam duties. It can be seen that the steam-to-power ratio increased with increasing steam loads up to a value of 7.16. This is a very advantageous result as the implication is that about 7 tons of steam are extracted/delivered at the expense of each MW drop in power generated as a result of less steam

driving the steam turbine. Generally speaking, the higher the steam-to-power ratio, the more efficient the combined cycle process is considered to be.

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Example 3

In silico modeling of a power plant with a 100% combined cycle configuration with duct firing was carried out using the methods and software as disclosed in Examples 1 and 2. The simulations are results are presented below in table form:

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Simulation Run	Steam (as extracted)			Steam (as delivered)			Configuration
	SU	SM	Total	SU	SM	Total	
	t/h	t/h	t/h	t/h	t/h	t/h	
C1	0	0	0	0	0	0	100% CC
C4	124	0	124	130	0	130	100% CC with DF
C9	124	91	215	130	100	230	100% CC with DF
C13	90	49	139	95	55	150	100% GT
C13B	63	76	139	65	85	150	100% GT
C14	178	98	276	190	110	300	100% GT with DF
C14B	124	153	277	130	170	300	100% GT with DF
C15	178	99	278	190	110	300	100% GT with max DF
C15B	124	155	279	130	170	300	100% GT with max DF

Table 5.

Simulation Run	Power	Heat Rate	Electrical Efficiency	Thermal Efficiency	Total Gas Consumption	Power decrease	Steam-to-Power Ratio
	MW	kJ/kWh	%	%	MJ/h	MW	
C1	371	6,348	56.7%	56.7%	2,352,569	0	0.00
C4	344	7,354	49.0%	65.4%	2,531,247	26.4	4.92
C9	332	7,865	45.8%	72.2%	2,609,607	38.8	5.93
C13	321	7,335	49.1%	68.3%	2,352,335	49.9	3.01
C13B	324	7,259	49.6%	68.3%	2,352,642	46.5	3.23
C14	293	8,514	42.3%	78.3%	2,490,345	78.1	3.84
C14B	296	8,327	43.2%	78.8%	2,463,127	74.8	4.01
C15	309	8,455	42.6%	76.9%	2,615,977	61.2	4.90
C15B	316	8,264	43.6%	77.2%	2,607,292	55.1	5.44

Table 6.

Run C1 is a control run, wherein no steam was produced or extracted and no duct firing was activated. Thermal efficiency of Run C1 was relatively low at 56.7% as compared to other runs with steam production with duct firing. Run 13B was carried out with a 100% Gas Turbine

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configuration, it can be seen that steam production was capped at 150 tons/hr and the thermal efficiency of such a configuration is slightly better than Run C1 at about 68.3%. Run C14B shows a typical situation wherein there is a need to increase steam production to compensate for the shortfall of another combined cycle module. In this simulation run, duct firing is used to approximately double the steam production to about 300 tons/hr. It is notable that the power production is maintained at approximately 300MW and there is no drastic power loss due to increased steam production. The thermal efficiency of Run C14B was also surprisingly high at 78.8%.

Figure 9 shows the relationship between the steam load and power output and thermal efficiency. It can be seen that with increasing steam production, the power supply is slightly reduced. Thermal efficiency displayed an increasing trend along with increased steam production. It is proposed that the presently optimized steam extraction points allows for such superior thermal efficiencies over conventional combined cycle systems.

Figure 10 depicts the relationship between the steam to power ratios to increasing steam loads. It can be seen that the maximum steam-to-power ratio was at 5.93 when the steam loading was at about 230 tons/hr.

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Applications

The disclosed combined cycle co-generation power system comprises of a pair of combined cycle blocks, each combined cycle block comprising a gas turbine, a heat recovery steam generator and a steam turbine. The pair of combined cycle blocks are arranged and coupled to be able to produce steam and power in tandem and independently of one another. Advantageously, when one combined cycle block experiences a process fault and, the other combined

cycle block is not affected and is able to continue power and steam production independently. Even more advantageously, such a configuration allows the disclosed system to be able to supply steam and power reliably to
5 meet the predetermined steam and power duties.

The disclosed gas turbine is also able to combust both gaseous and liquid fuel. Advantageously, the combined cycle power system is able to use distillate petroleum fuel as an alternative source of fuel, thereby
10 minimizing process stoppages due to fuel service disruptions.

The disclosed duct burner is thermally coupled to at least one HRSG. The duct burner can be fired with natural gas or distillate fuel to increase steam
15 production in the HRSG of the combined cycle block. Advantageously, when the steam producing capacity of the power generating capacity of one combined cycle block is compromised, the duct burner of the other combined cycle block can be fired to compensate for the steam or power
20 shortfall in the system.

The disclosed combined cycle power system is able to extract steam from its system for distribution to downstream units at the expense of a drop in power generated by the steam turbine. Through the optimization
25 of the heat balance of the system, two specific steam removal points are carefully determined to provide the greatest thermal efficiency to the system. Advantageously, by choosing the extraction points as disclosed above, the system is able to achieve superior
30 thermal efficiencies of about 60% to about 80%. The range of steam-to-power ratios thus achieved is about 2.5 to about 7.5. Such high steam-to-power ratios indicate that a minimal loss of power generated by the steam turbine is experienced due to the large amount of steam

removed from the system. Advantageously, the combined cycle plant enjoys high thermal efficiency as a result of the superior steam-to-power ratios.

It will be apparent that various other modifications
5 and adaptations of the invention will be apparent to the person skilled in the art after reading the foregoing disclosure without departing from the spirit and scope of the invention and it is intended that all such
modifications and adaptations come within the scope of
10 the appended claims.

Claims

1. A combined cycle power system for producing power and steam, the system comprising:

5 at least two fuel turbines capable of
combusting fuel to produce power and exhaust gas
from said combusted fuel;

 at least two heat recovery steam generators for
producing steam from said exhaust gas;

10 at least two steam turbines for producing power
from steam produced by said heat recovery steam
generators;

 at least one steam supply stream for receiving
steam produced by said heat recovery steam
generators; and

15 a heat source thermally coupled to each of the
said heat recovery steam generators and being
configured to intermittently and independently
supplement heat to one of said heat recovery steam
generators to meet a required steam duty of said
20 steam supply stream and at least one of said steam
turbines, and wherein the heat source is
configured to heat one of the at least two heat
recovery steam generators if the other heat
recovery steam generator is unable to meet the
25 required steam duty, without a substantial loss of
the steam duty of the said steam supply stream and
at least one of said steam turbines.

30 2. A system as claimed in claim 1, wherein said heat
source is configured to directly heat said heat
recovery steam generators.

35 3. A system as claimed in claim 2, wherein said heat
source comprises firing means for combusting fuel in

the path of the exhaust chamber passing through said heat recovery steam generators.

5 4. A system as claimed in claim 1, wherein said at least two fuel turbines are respectively in exhaust gas fluid communication with said heat recovery steam generators.

10 5. A system as claimed in claim 1, wherein said at least two fuel turbines are gas turbines.

15 6. A system as claimed in claim 1, wherein said at least two steam turbines are respectively in exhaust gas fluid communication with said heat recovery steam generators.

20 7. A system as claimed in claim 3, wherein said heat source comprises within each heat recovery steam generators, at least one duct burner.

25 8. A system as claimed in claim 7, comprising two modules for generating power and steam independently of each other, each of said unitized modules comprising one of the gas turbine pairs, one of the two heat recovery steam generators having the at least one duct burner therein and one of the steam turbine pairs.

30 9. A system as claimed in claim 8, wherein the system further comprises a controller to intermittently and independently fire a duct burner of a heat recovery steam generator in one module should the other module not deliver a required steam duty to the

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steam supply stream or steam turbine of that other module.

5 10. A system as claimed in claim 1, wherein the steam supply stream comprises a plurality of headers at respective plural pressures.

10 11. A system as claimed in claim 10, wherein the steam supply stream comprises a high pressure steam between 6000 kPa to 15000 kPa, an intermediate pressure steam between 1500 kPa to 6000 kPa, and a low pressure steam between 100 kPa to 1500 kPa.

15 12. A system as claimed in claim 11, wherein the steam supply stream comprises a high pressure steam between 12000 kPa to 12300 kPa, an intermediate pressure steam between 2600 kPa to 2700 kPa, and a low pressure steam between 400 kPa to 600 kPa.

20 13. A system for continuously producing power and steam comprising:

25 at least two combined cycle power modules, each module comprising: a fuel turbine capable of combusting fuel to produce power and exhaust gas from said combusted fuel; a heat recovery steam generators for respectively producing steam from said exhaust gas; a steam turbine for producing power from steam produced by said heat recovery steam generators; and a heat source thermally coupled to said heat recovery steam generator for supplementing heat thereto;

30 a steam supply stream for receiving steam produced from said modules; and

5 a controller configured to activate the heat
 source of one combined cycle power module if the
 other combined cycle power module is unable to
 meet a required steam duty of at least one of its
 steam supply stream and said steam turbine,
 thereby continuously producing power and steam.

10 14. A method for continuously producing power and
 steam in a system having at least two combined cycle
 power modules, each module comprising: a fuel
 turbine capable of combusting fuel to produce power
 and exhaust gas from said combusted fuel; a heat
 recovery steam generator for respectively producing
 steam from said exhaust gas; a steam turbine for
15 producing power from steam produced by said heat
 recovery steam generators; and a steam supply stream
 for receiving steam produced from said modules, the
 method comprising the steps of:

20 a) monitoring the steam output from each of
 said modules;
 b) providing a supplemental heat source to one
 of the heat recovery steam generators when
 said monitored steam output of a module
 falls below a predefined steam duty.

25 15. A method as claimed in claim 14, wherein when
 one of the modules falls below the predefined steam
 duty, the supplemental heat source is applied to the
 heat recovery steam generator of the other module.

30 16. A method as claimed in claim 14, wherein said
 steam to power ratio is about 2.5 to about 7.5.

17. A method as claimed in claim 14, wherein said steam to power ratio is 3.6 to 7.5.
18. A method as claimed in claim 14, further comprising the step of removing the steam from the system at a plurality of pressures.
19. A method as claimed in claim 14, wherein the steam supply stream comprises a high pressure steam between 6000 kPa to 15000 kPa, an intermediate pressure steam between 1500 kPa to 6000 kPa, and a low pressure steam between 100 kPa to 1500 kPa.
20. A method as claimed in claim 19, wherein the removal of the stream is undertaken at a high pressure of 12000 kPa to 12300 kPa, an intermediate pressure steam between 2600 kPa to 2700 kPa, and a low pressure steam between 400 kPa to 600 kPa.
21. A method of continuously producing power and steam comprising the steps of:
- a) combusting fuel in at least two fuel turbines to produce power and exhaust gas;
 - b) passing the exhaust gas from the two fuel turbines to respective at least two heat recovery steam generators to produce steam;
 - c) passing some of the steam produced by the at least two steam generators to respective at least two steam turbines to produce power; and
 - d) removing a selected amount of the steam produced by the at least two steam generators, wherein the selected amount of

steam is at a steam-to-power ratio of at least 2.5.

22. A method as claimed in claim 21, wherein said
5 steam-to-power ratio of at least 5.

23. A method as claimed in claim 21, wherein said steam-to-power ratio of at least 6.

10 24. A method as claimed in claim 21, further comprising the step of:
e)selectively heating the exhaust gas passing into one of said at least two steam generators to increase the amount of steam.

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25. A method as claimed in claim 21, further comprising the step of:

f)selectively heating the exhaust gas passing into one of said at least two steam generators to
20 increase the amount of steam when the other steam generator is unable to meet a required steam duty.