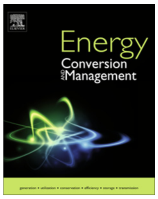
Energy Conversion and Management 85 (2014) 7–12

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman



Study on power plants arrangements for integration

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ARTICLE INFO

Article history:
Received 25 February 2014
Accepted 7 May 2014

Keywords:
Combined
Exergy
Irreversibility
Organic
Triple
Heat

ABSTRACT

The three power cycles viz. gas cycle (Brayton cycle), steam cycle (Rankine cycle) and organic Rankine cycle (ORC) are arranged in two possible methods to form a triple cycle and to increase its power generating performance. In one approach, all the three cycles are arranged in series, the heat rejection of gas cycle is supplied to steam power plant having back pressure turbine and the heat rejection of steam plant is supplied to ORC plant similar to a cascading. In second option, the two bottoming cycles i.e. steam plant and ORC plant are arranged in parallel to gas turbine exhaust. In this connection, steam cycle works with high temperature heat recovery and ORC plant with low temperature heat recovery. Thermal efficiency and specific work of two triple cycles are compared with combined cycle (CC) power plant to draw the relative merits of two choices with a focus on compressor pressure ratio and gas turbine inlet temperature (GTIT). The results showed that the parallel arrangement in triple cycle offers greater benefit over the series arrangement. Therefore the wok is focused on parallel configuration triple cycle results.

1. Introduction

The power demand is increasing continuously due increase in living standards, per capita energy consumption and population. But the energy sources are limited and decreasing for power generation. So, there is a need to improve the available power generation systems with maximum energy conversion. Currently combined cycle (CC) power plants are gaining more interest due to its higher thermal efficiency. Organic Rankine cycle (ORC), Kalina cycle system (KCS) or similar can be integrated to a CC power plant to extract more heat recovery from the gas turbine exhaust. In current work, two possible options of integrations in a triple cycle are studied to select the best one.

Researches are proposed many ideas and concepts to enhance the performance of CC power generation. In a steam power plant a multi pressure heat recovery results complicated design and also increases the cost of heat recovery equipment [1]. A triple cycle solves this problem by increasing the heat recovery without any complexity in design and minimizing the cost of heat recovery. Hung [2] developed the conceptual arrangements in heat recovery in multiple cycles. Kribus [3] also addressed the technological feasibility of the solar triple cycle. The power and cooling cycles are also can be integrated either in series or parallel operation for cooling cogeneration [4]. Hasan and Goswami [5] employed thermodynamics to analyze a binary ammonia-water mixture cycle that produces power and refrigeration. The rate of steam injection in combustion also increases the gas turbine power and was studied by Marrero [6]. Kalina [7] patented a new thermodynamic cycle with modification in Rankine cycle with NH_3–H_2O as the working substance. Singh and Kaushik [8,9] proved the performance and cost benefit of triple cycle (gas cycle, steam cycle and Kalina cycle) over the CC at Indian atmospheric conditions. Peng et al. [10] developed the energy utilization diagrams for a triple cycle plant having gas, steam and Kalina cycle. In the design of triple cycle, steam power plant's sink plays an important role in integration. The literature review shows that not much focus is given on comparison of triple cycle's arrangement with key operational variants.

The current work is aimed to identify an efficient configuration for triple cycle arrangement. An attempt has been made to maximize the triple cycle benefit by properly selecting the source and sink temperatures for bottoming cycles.

2. Methodology

Figs. 1 and 2 shows the schematic plant arrangement and temperature–entropy diagram for triple cycle series (TCS) power plant. A simple Brayton cycle for gas power plant, reheat-regenerative steam Rankine cycle for steam power plant and simple Rankine cycle for ORC have been selected for thermodynamic evaluation. The material flow lines are shown for gas plant (1–10g),

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http://dx.doi.org/10.1016/j.enconman.2014.05.057
0196-8904/

Nomenclature

HHV	higher heating value (kJ/kg)
m	mass, kg/s
W	work (kW)
η	efficiency

Subscripts

ORC	organic Rankine cycle
th	thermal
TC	triple cycle

Acronyms and abbreviations

CC	combined cycle
GTIT	gas turbine inlet temperature
HRSG	heat recovery steam generator
HRVG	heat recovery vapor generator
KCS	Kalina cycle system
ORC	organic Rankine cycle
TCP	triple cycle parallel
TCS	triple cycle series
TIT	turbine inlet temperature
TTD	terminal temperature difference

steam plant (1–12s) and ORC plant (1–6v). The components in the gas power plant in the order are air compressor, gas turbine combustion chamber, gas turbine, supplementary firing and heat recovery steam generator (HRSG). The components in the considered steam power plant are high pressure steam turbine (HPST), low pressure steam turbine (LPST), deaerator, heat recovery vapor generator (HRVG), pumps and HRSG. In the steam power plant, HRVG performs the condenser duty. The components in ORC plant are vapor turbine, condenser, pump and HRVG. The HRVG performs the duty of heat source to ORC system. The HRSG acts as a connector between gas plant with steam plant. Similarly, HRVG plays a connecting role between steam plant and ORC plant. For ORC, R134a is considered as working fluid. The three cycles are linked serially with heat recovery similar to cascading. The heat rejection of gas power plant is supplied to steam power plant and heat rejection of steam plant is supplied to ORC plant. Since the steam plant heat sink is connected to ORC plant, the steam power plant sink should be maintained above standard reference temperature. Therefore a back pressure steam turbine is used in this category.

The triple cycle parallel (TCP) power plant is shown in Fig. 3 and its temperature–entropy diagram is depicted in Fig. 4. The material flow lines are shown for gas plant (1–13g), steam plant (1–12s) and ORC plant (1–6v). In this arrangement, there is no alternation for heat recovery for steam generation. The two heat recoveries for steam generation and ORC vapor generation are connected to gas turbine exhaust. This arrangement facilitates to recover more heat from turbine exhaust. Since the sensible heat of gas is less than the latent heat of steam, the available heat recovery for the ORC cycle will reduce. There is a need for comparative analysis because the latent heat supply for ORC in TCS plant and sensible heat supply for ORC in TCP plant.

The following assumptions have been made during the analysis of triple cycle power plant. Atmospheric condition is taken as 25 °C and 1.01325 bar. Gas cycle pressure ratio and maximum temperature is fixed at 15 and 1200 °C. The inlet condition for high-pressure steam turbine is taken as 120 bar and 550 °C. The steam condenser pressure is assumed as 0.085 bar. Steam reheat pressure is taken as 25% of HRSG pressure. Steam reheat temperature is equal to superheated temperature. Deaerator bled steam temperature is in middle of HRSG evaporator temperature and condensate temperature. In parallel type, ORC condensate temperature is equal to steam condensate temperature. The saturated vapor temperature in HRVG is 90 °C. Degree of superheat in ORC cycle is 5 K. The minimum temperature difference between condensate steam and condensate vapor with circulating cooling water is 8 K. Isentropic efficiency of gas turbine is taken as 90%. Isentropic

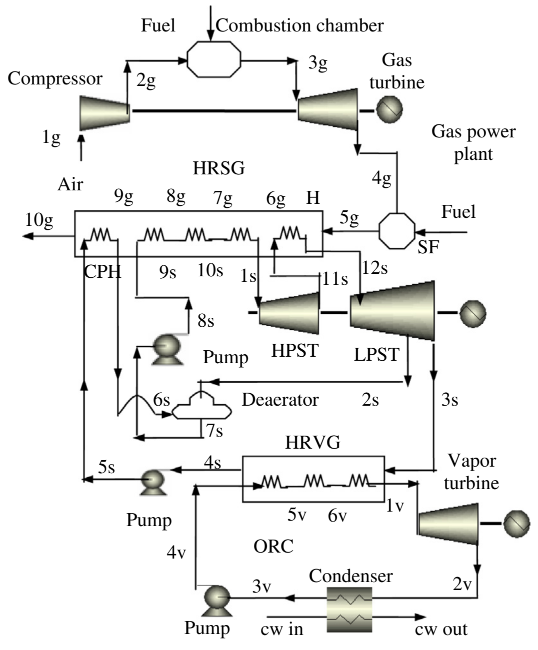

Fig. 1. Schematic material flow diagram of triple plant series type.

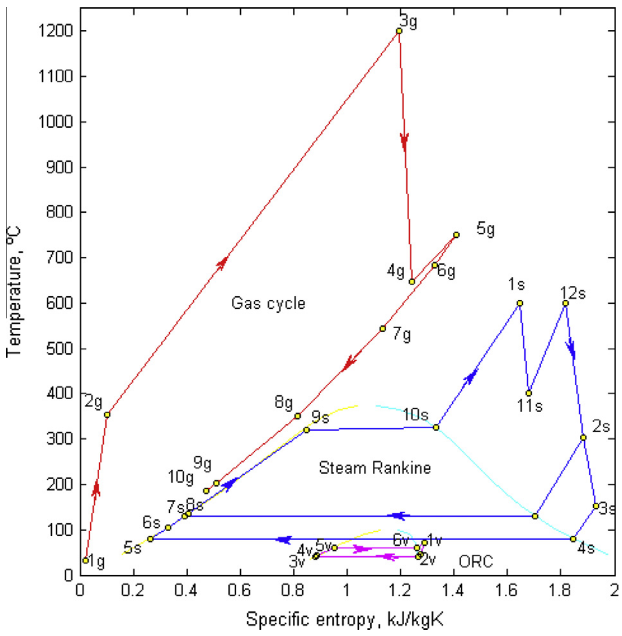

Fig. 2. Temperature–entropy diagram for triple plant series type.