1. Introduction

Here in Japan, the issue of securing a supply of electric power oriented toward stable power supply has grown in importance given the domestic situation since the Great East Japan Earthquake of March 11, 2011, and supply and demand conditions for power since that event. Abroad, the demand for thermal power generation is increasing, particularly in the markets of newly developing countries demonstrating prominent economic growth. In these circumstances, demand for combined-cycle power generation is expanding, likely due to reduced emissions of carbon dioxide (CO2) in comparison with conventional thermal power generation and its excellent thermal efficiency.

In January 2013, Toshiba signed a memorandum of understanding with General Electric Company (GE) to form a global strategic alliance, under which the two companies will jointly develop combined-cycle power generation systems, in January 2013. We have embarked on this collaborative relationship to expand the global share of combined-cycle power generation by focusing on a high-efficiency combined-cycle power generation system integrating both GE’s most advanced gas turbine technologies and Toshiba’s latest high-efficiency steam turbine generators. As our first implementation of technical collaboration, we are developing power generating facilities for the Nishi-Nagoya Thermal Power Station Group No. 7 of Chubu Electric Power Co., Inc., which will achieve the world’s top-level gross efficiency of 62% (lower heat value basis) utilizing GE’s latest 7HA series (hereinafter abbreviated as 7HA) gas turbine.

2. Latest in high-efficiency combined-cycle power generation system technology

2.1 Air-cooled gas turbines 7HA and 9HA

The 7HA (60 Hz) and the similarly-designed 9HA series (50 Hz, hereinafter abbreviated as 9HA) currently under development at GE are designed around the 7F.05 compressor utilized in the newest F-class devices in current production. All other components are supplied from the evolution of proven extant technology, producing a highly reliable product (Figure 1).

This 14-stage high-efficiency compressor, utilizing advanced three-dimensional aerodynamically-designed vanes having a pressure ratio of approximately 20:1, contributes to the functional improvement of the latest high-efficiency F-class gas turbine In order to further improve maintainability, all 14 stages employ a rotor vane root structure that can be exchanged on-site, similarly to an aviation engine.

The combustor is an existing DLN 2.6+ model used almost as-is. In the 7HA turbine, an axial fuel staged...
(AFS) fuel channel is used as the combustor liner. As such, under a typical operating load, nitrogen oxide (NOX) emissions are reduced and the minimum load under which low-NOX operation is possible has been successfully brought as low as 30%.

The turbine has a 4-stage structure. The load division among the stages has been optimized by increasing capacity, and further improvements in efficiency have been achieved by using the latest in seal technology. The turbine casing employs the same double structure as the 7H and 9H models, designed to achieve an optimal heat gradient.

The rotor vanes of one turbine stage use the same monocrystalline alloy as previous F model devices. All other rotor and stator vanes use uni-directional solidifying materials, polycrystalline materials, and so on, as found in conventional devices. Other merits include making the stator vanes in stages one to three variable, in addition to having a variable inlet guide vane, thus providing variable stator vanes in a total of four stages. Also, a hybrid radial diffuser is used in the channel leading from the compressor exit toward the combustor in order to reduce pressure loss and recover static pressure.

2.2 Compatibility with fuel diversification

The 7HA and 9HA gas turbines are 1 600°C machines, and are also compatible with liquid fuels, like conventional devices. These turbines are also adaptable for light fuels. As such, the 7HA turbine is rated ±15% and the 9HA turbine is rated ±10% on the modified Wobbe index (MWI)(*) for fuel gas.

2.3 Steam cycle plan

The steam cycle is designed for main steam pressure of 15 MPa and main steam temperature in excess of 580°C, and is configured for maximum utilization of exhaust energy heat from the gas turbine, thus enabling high-efficiency performance. Furthermore, high-efficiency performance is achieved by using a feed-water heater, taking extraction steam from the low-pressure turbine as a heat source to heat the feed-water to the heat recovery steam generator (HRSG), and by optimizing the gas turbine fuel heating system.

2.4 Steam turbine

The steam turbine utilizes the highly reliable, high-performance product from Toshiba group member Sigma Power Ariake Co., Ltd., in operation at the Mikawa Power Plant since 2008 and established as production-demonstrated experimental steam equipment serving to raise the level of performance strategy (Figure 2). Optimized reaction stages are used in the advanced steam path to improve stage efficiency. Also, a drum structure rotor is used in the high-pressure section to realize improved axial stability while also remaining adaptable for multi-stage operation. The last-stage buckets are from the largest series in the world, and thus minimize exhaust loss thanks to exhaust flow speed reduction.

In addition, improvements in sealing technology, the utilization of low-loss direct lube pad bearing, and so on also contribute to improved efficiency of the steam turbine by providing technology to reduce loss of all types.

2.5 System configuration

To meet client needs, we have proposed a generally economical system configuration that is suitable for the required output scale, on-site conditions, operating conditions, and so on. The system configuration is described below, divided into single-shaft and multi-shaft models.

(1) Single-shaft

This powertrain configuration enables start and stop selection for each shaft, and makes the number of shafts currently in operation selectable. This model is typically flexible and highly operable. When installed for multiple shafts, the system provides highly efficient operation for the plant from...
low-load to full-load conditions. The use of an axial flow exhaust steam turbine makes low floors possible for the turbine building. Also, given that synchro-self-shifting (SSS) clutches are used, the steam turbine is never subjected to forced rotation between the start of the gas turbine and the fulfilling of steam turbine start conditions. This eliminates the need for auxiliary steam to cool the vicinity of the last stage buckets.

(2) Multi-shaft

The amount of steam flowing into the steam turbine goes up in proportion to the number of connected gas turbines. This makes higher temperature and pressure possible for the steam conditions, as not only improves the efficiency of the steam cycle but also enables the loss of all types to be reduced through economies of scale in the steam turbine. This configuration is optimized for base load operation with a focus on better performance. This steam turbine is large in comparison to the single-shaft model. However, improvements to the precision of thermal stress prediction for rotors and advancements in finite element method (FEM) analysis technology have served to bring the startup performance in line with the single-shaft model until a full plant load is reached.

2.6 Operating performance improvements and optimal steam turbine startup

2.6.1 Smart startup

In consideration of the NOx density emitted by thermal power plants, combined-cycle power generation is required to be more efficient. That is, there is a trade-off with increasing gas turbine combustion temperatures. With smart startup, the gas turbine combustor is brought up to the NOx emission compliance load (i.e., the smart load), until conditions for passing to the steam turbine are in place. Achieving this has served to optimize the capacity of a heat recovery steam generator (HRSG) desuperheater and the cascade bypass system connecting the high-pressure steam system with the low-temperature steam reheating system. Also, the HRSG incorporates thermal stress reduction mechanisms in thicker portions, being designed to be compatible with such smart startup conditions. Utilizing this smart startup enables the environmental load to be reduced during startup of the gas turbine, and also achieves faster plant startup.

2.6.2 Steam turbine-optimized startup (2)

Conventional steam turbine startup control involves selecting a startup schedule in several patterns corresponding to the difference between the first stage steam temperature in the high-pressure turbine and rotor surface metal temperature (i.e., the mismatch temperature) at steam turbine startup. This startup method (termed mismatch chart startup) leads to selecting a schedule with a sufficient margin in terms of thermal stress and differential expansion during the turbine startup process. As such, the startup could take up to four hours to go from roll-off to the rated load, particularly during cold startup. Steam turbine-optimized startup uses thermal stress predictions to correct the startup schedule in real time. This speeds up the expected control time and enables large-scale reductions in startup time (Figure 3).

In November 2011, this technology was awarded the Minister of Education, Culture, Sports, Science, and Technology Incentive Award and the Electrical Science and Engineering Promotion Awards from the Promotion Foundation for Electrical Science and Engineering.

2.7 Fieldbus introduction

The electrical valve circuit is conventionally connected to a distributed control system (DCS) via a switch-gear (SWGR) from on-site electrical valves with hard cable.

In this case, an intelligent electrical valve actuator is used, which has an on-board CPU capable of device data transmission and correction. The actuator is configured to make a direct connection between the TOS-MAP™-LX in the DCS and multiple electrical valves using PROFIBUS as a fieldbus communication. Up to 20 devices can be connected with a single communication loop, thus reducing the amount of field cables. We are applying PROFIBUS communication to this electrical valve circuit as a standard.

2.8 Automated operation

Conventionally, operators were usually assigned to a central operating room to perform plant operation control and react to any abnormal events. However, the provided system can be operated automatically and is...
not dependent on any operators. Specifically, once the schedule calculation has been set up, the plant runs completely automatically from startup until a target load is reached. Also, if an abnormal event occurs, operations performed by conventional operators are automatically interlocked. The system thus provides savings in staffing without impeding the operability of power plant equipment.

2.9 Hydrazine removal initiative
Hydrazine used in feedwater systems has been identified as having mutagenic properties and designated as a chemical substance with effects on health. Therefore, regulations have recently been strengthened. Hydrazine has also been identified as possibly contributing to flow-accelerated corrosion (FAC) in pipes. In many Western countries, all-volatile treatment (oxidizing) (AVT(O)) hydrazine-free feedwater systems have been introduced. We have recently proposed using this standard in our combined-cycle power generation system. Furthermore, through independent validation testing, control by ammonia injection has been proposed for HRSG wet preservation, without using hydrazine.

Avoiding the use of hydrazine provides power generation having better consideration for health. Also, using ammonia enables an appropriate pH (hydrogen ion density) to be maintained, which in turn enables the device reliability to be kept equivalent or to surpass conventional devices. Also, this makes the pollutant release and transfer register (PRTR) system and harmful substance management as directed by the Ministry of Health, Labor, and Welfare no longer necessary.

2.10 Construction period reduction through transition to large modules and commissioning optimization
HRSG systems are installed in factory as two broadly-divided modules, and shipped with all pipes, valves, and other equipment included. Also, transition to large modules expands the application range of pipe racks and reduces the work period required for on-site installation. Furthermore, a reduction of 2.5 months in time to HRSG setup start has been achieved, in comparison to our conventional models, by optimizing on-site commissioning.

3. Overview of Nishi-Nagoya Thermal Power Station Group No. 7 system equipment
The Nishi-Nagoya Thermal Power Station run by Chubu Electric Power Co., Inc. was constructed in 1970 with steam-powered power generation equipment, and uses oil as a fuel to produce a total 1 190 MW. Since that time, the plant has largely satisfied its role in providing stable power to the city of Nagoya and surrounding communities over the long term. In June 2012, we accepted an order from Chubu Electric Power Co., Inc. for a set of combined-cycle power generation equipment, to be installed once the current equipment has been disposed of. The newly-built cutting-edge equipment will operate at 1 600°C and uses liquefied natural gas (LNG) as fuel. This plant will be equipped with the latest multi-shaft combined-cycle power generation equipment, and have two power blocks each having a rated output of 1 158 MW. Operation is expected to start in March 2018.

3.1 Plant specifications
In order to achieve high efficiency during base load operation, the plant employs a 3-on-1 multi-shaft system made up of three gas turbines and three HRSGs, and of one steam turbine. As such, this environmentally friendly combined-cycle power generation plant uses cutting-edge technology to achieve characteristic high efficiency, high output, and low NOx emissions (Figure 4). The plant maintains high durability while transitioning to high performance, and is expected to achieve a world-leading 62% efficiency.

The number of gas turbines, characteristic of multi-shaft combined-cycle power generation, can be changed quickly through a request made at the load dispatching center. Also, changes can be performed without decreasing the load on the operating unit, which improves operability.

Figure 4. Nishi-Nagoya Thermal Power Station Group No. 7 system.
This plant is in harmony with the environment, having taken scenery into consideration as part of system optimization.

3.2 Plant layout
The layout of the plant takes both scenery and system optimization into consideration. The power generation plant treats each 3-on-1 multi-shaft module as one block, and is configured with a mirrored layout having one block on each side. The mirrored layout that lines up the six gas turbines into lateral rows realizes improvements in productivity during regular inspections.
4. Conclusion
The introduction of cutting-edge combined-cycle power generation equipment enables further reductions of CO₂ emissions and produces longer-term power generation facilities.

We are sure that the enhanced speed of technological development resulting from a global strategic alliance with GE will accelerate further, and that we will contribute to society and to the region by securing stable power with high reliability and providing clean energy systems that are environmentally friendly.

References

HATTORI Yuta
Specialist. Plant Engineering Department, Thermal & Hydro Power Systems & Services Division, Power Systems Company. He is engaged in thermal power plant systems engineering.

HYOMORI Katsuhiro
Specialist. Thermal Power Plant Project Engineering Department, Thermal & Hydro Power Systems & Services Division, Power Systems Company. He is engaged in combined-cycle power generation plant estimation.

Note:
This is basically a full English translation of TOSHIBA REVIEW Vol. 68, No. 11, 2013, published by Toshiba Corporation. Only the names of gas turbines have been updated.