ODRŽAVANJE NAZIVNIH PERFORMANSI PLINSKE TURBINE PRI POVIŠENIM TEMPERATURAMA OKOLIŠA

MAINTAINING DECLARED PERFORMANCE IN GAS TURBINES DURING INCREASED AMBIENT TEMPERATURES

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Klasični proces plinske turbine karakterizira kompresija zraka iz okoline, koji se u komorama izgaranja zagrijava izgaranjem goriva te tako stvoreni dimni plinovi ekspandiraju u turbini i proizvode mehanički rad. Performanse plinske turbine ovise o svemu što mijenja gustoću i/ili maseni protok zraka na usisu kompresora. Najočitije promjene u performansama plinske turbine su smanjenje snage i povećanje specifične potrošnje goriva s porastom temperature okoliša, pri čemu nastaju značajna odstupanja od vrijednosti garantiranih (i postignutih) pri ISO uvjetima. Hlađenjem zraka na usisu kompresora pri povišenim temperaturama okoliša postiže se povećanje masenog protoka i kompresijskog omjera, te se sprječava smanjenje snage i povećanje specifične potrošnje goriva. Primjenom plinskih turbina u kombikogeneracijskim postrojenjima za proizvodnju električne i toplinske energije, povećanje masenog protoka kroz plinsku turbinu dovodi do povećanja energije koju dimni plinovi odvode na ispuhu turbine, a koja se kod kombi postrojenja u kotlu utilizatoru predaje ciklusu parne turbine. Time je kod kombi postrojenja efekt smanjenja specifične potrošnje goriva još značajniji. U radu je na primjeru turbine GE-PG6101FA prikazana ovisnost o okolišnim klimatskim uvjetima, te način na koji se ta ovisnost može smanjiti ili otkloniti.

The classical gas turbine process is characterised by air compression from its surroundings, heating fuel in the combustion chambers, hence causing the created flue gases to expand in the turbine and thus induce mechanical action. The performance of gas turbine depends on anything that affects the airflow density and/or mass at the compressor inlet. The most obvious changes in gas turbine performance is a reduction in power and an increase in specific fuel consumption following an increase in the ambient temperature, resulting in significant deviations of the guaranteed (and achieved) values at ISO conditions. In cooling air at the compressor inlet at increased ambient temperatures, an increase in the mass flow and compression ratio is achieved, thus preventing a reduction in power and an increase in specific fuel consumption. When using gas turbines in combined cycle cogeneration power plants for the production of electrical and thermal power, increasing mass flow through gas turbines leads to an increase in power transferred by the flue gases to the turbine exhaust, and which in the waste heat recovery boiler at the combined cycle plant transfers to the steam turbine cycle. Consequently, the effect at the combined cycle plant is a more significant reduction in specific fuel consumption. The work has used the example of the GE-PG610FA turbine to show the dependency on surrounding climatic conditions, and the manner in which this dependency can be reduced or removed.

Ključne riječi: hlađenje zraka na usisu plinske turbine; izlazna snaga; plinska turbina; specifična potrošnja goriva

Key words: cooling air at the gas turbine inlet, output power, gas turbine, specific fuel consumption

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1 UVOD

Plinske turbine su vrlo pouzdani, raspoloživi i učinkoviti strojevi, čija je uloga pogonskog stroja našla široku primjenu u postrojenjima za proizvodnju električne i toplinske energije, te u industriji. Rasprostranjenost u primjeni potiče njihov razvoj u smjeru postizanja maksimalne efikasnosti i minimiziranja pogonskih troškova. Razvoj plinskih turbina radi poboljšanja efikasnosti provodi se u dva osnovna područja:

— konstrukcijska unaprjeđenja plinskih turbina kojima se omogućuje rad sa sve višim temperaturama na ulazu u prvi stupanj turbine, višestupanjske kompresije s međuhlađenjem, te višestupanjske ekspanzije s međuzagrijavanjem i regeneracijom topline dimnih plinova koji se primjenjuju u razvoju i unaprjeđenju novih modela turbina, a odnose se prvenstveno na poboljšanje osnovnog toplinskog procesa koji se odvija u turbini, i
— smanjenje utjecaja uvjeta eksploatacije na rad turbine, pri čemu se nastoji poboljšati efikasnost i smanjiti degradacija snage prouzročena utjecajem okolišne temperature, vlage, čistoće zraka na ulazu kompresora, starosti postrojenja i sličnog.

Po svojoj konstrukciji plinske turbine su strojevi konstantnog radnog volumena, a njihova je izlazna snaga proporcionalna masenom protoku radnog medija, tj. zraka kojeg iz okoliša dobavlja kompresor. Pri povišenim temperaturama okolišnog zraka, plinske turbine gube snagu zbog konstantnog volumnog ali smanjenog masenog protoka zraka, koji je povećanjem temperature sve rjeđi i čiji se specifični volumen u tom slučaju povećava.
Premda su plinske turbine vrlo pouzdani i široko primijenjeni strojevi u proizvodnji električne energije, njihova slaba točka je ovisnost o svemu što mijenja gustoću i/ili maseni protok zraka na usisu kompresora, tj. ovisnost o realnim atmosferskim uvjetima u kojima se nalaze tijekom eksploatacije.

Smanjenjem masenog protoka zraka ne samo da se smanjuje izlazna snaga plinske turbine, nego se smanjuje i količina dimnih plinova čija se energija u kotlu utilizatoru predaje ciklusu parne turbine. Smanjenjem energije predane u utilizatoru, smanjuje se i učinkovitost ciklusa parnoturbinskog postrojenja, bez obzira da li je ono u kondenzacijskom, toplifikacijskom ili mješovitom toplifikacijsko-kondenzacijskom režimu rada. Prema tome, degradacija snage plinske turbine uzrokuje degradaciju snage ostalih vezanih jedinica.

Iako efekt smanjenog masenog protoka zraka prati i smanjena potrošnja goriva u njenom apsolutnom

1 INTRODUCTION

Gas turbines are very reliable, fairly available and efficient machines, whose role as a drive machine has found wide application in plants used for the production of electrical and thermal power, and in the industry in general. Its extensive use has encouraged development leading to the achievement of optimal efficiency and minimising operational costs. Development of gas turbines for improving efficiency is carried out in two basic fields:

— construction improvements of gas turbines allowing operation at higher temperatures upon entering the first stage of the turbine, multi-stage compression with inter-cooling, and multi-stage expansion with inter-heating and thermal regeneration of flue gas used in the development and advancement of new turbine models, relating primarily to improvements in the basic thermal process that occurs in the turbine, and
— reducing the impact of exploitation conditions on the turbine operation, while endeavouring to improve efficiency and reduce power losses caused by the effects of ambient temperature, humidity, air purity at the compressor entry, age of the plant and so on.

Based on its construction, gas turbines are machines with constant operational volume, and their output power is proportional to the mass flow of the operating medium, i.e. air from the surroundings supplied by the compressor. At higher ambient air temperatures, gas turbines lose power due to the constant volume but reduced air mass flow, which, due to an increase in temperature, is all the more sparser and the specific volume of which increases in such cases. Although gas turbines are very reliable and widely applicable machines in the production of electrical power, their weakness is a dependency on anything that changes air flow density and/or mass at the compressor inlet, i.e. dependency on actual atmospheric conditions in which they are found during exploitation.

Reducing airflow mass does not only reduce the output power of the gas turbine, but also reduces the amount of flue gases the energy of which in the waste heat recovery boiler is transferred to the steam turbine cycle. Reducing the energy transferred to the recovery boiler reduces the efficiency of the steam turbine power plant cycle, regardless of whether it is in the condensation, thermal or mixed thermal-condensation operating mode. Hence, a power reduction in a gas turbine causes a power reduction in the other related units.

Even though the effect of reduced airflow mass is followed by a reduction in fuel consumption in its iznosu, specifična potrošnja goriva (specifična potrošnja topline) se povećava proporcionalno porastu temperature zraka na ulazu u kompresor. Kod primjene plinskih turbina u kombikogeneracijskim postrojenjma za proizvodnju električne i toplinske energije povećanjem specifične potrošnje goriva negativna posljedica povećanja temperature zraka uzrokuje smanjenje iskoristivosti i ekonomičnosti rada cijelog kombikogeneracijskog bloka.

absolute value, specific fuel consumption (specific gas consumption) increases proportionally with a rise in air temperature at the compressor inlet. When using gas turbines in combined cycle cogeneration power plants for the production of electrical and thermal power, by increasing the specific fuel consumption, the resulting negative effect of an increase in air temperatures causes a reduction in utilizable and economically viable operation of the whole combined cycle cogeneration unit.

2 ODSTUPANJE KARAKTERISTIKA PLINSKIH TURBINA OD STANDARDNIH VRIJEDNOSTI

Termodinamički kružni proces po kojem plinovi proizvode rad u plinskoj turbini naziva se Braytonov ciklus, a u osnovi je to teorijski Jouleov proces otvorenog tipa. Sastoji se od dvije izobare i dvije izentrope te je prikazan na slici 1 u p-V i T-s dijagramu. Proces započinje usisom zraka iz okoliša (točka 1, slika 1). Nastavlja se komprimiranjem zraka do točke 2. Od točke 2 do točke 3 komprimiranom zraku se predaje toplina izgaranjem goriva pri konstantnom tlaku:

2 DEVIATION OF GAS TURBINE CHARACTERISTICS FROM STANDARD VALUES

The thermodynamic cyclic process whereby gases produce operation in the gas turbines is called the Brayton Cycle, and is fundamentally the theoretical open-type Joule process. It comprises of two isobars and two isentropes and is shown in Figure 1 in the u p-V and T-s diagram. The process begins with air suction from the surroundings (point 1, Figure 1). It continues with compressed air up to point 2. From point 2 to point 3, heat is transferred to compressed air by fuel combustion at a constant pressure:

$$Q_{\mathrm{dov}} = Q_{23} = mc_{\mathrm{p}}\left(T_3 - T_2\right), \quad \mathrm{J/ciklusu} \quad , \tag{1}$$

gdje je:

Q_{dov} – dovedena toplina,
m – masa zraka,
c_p – specifična toplina zraka pri stalnom tlaku.

Proces se nastavlja izentropskom ekspanzijom od točke 3 do točke 4, te se pri tome dobiva mehanički rad od kojeg se jedan dio koristi za pogon kompresora, dok je ostalo korisni rad za pogon gonjenog stroja. Od točke 4 do 1 toplina se odvodi, što predstavlja ispuh i izlazak dimnih plinova iz turbine:

where:

Q_{dov} – incoming heat,
m – mass,
c_p – specific heat at constant pressure.

The process continues through isentropic expansion from point 3 to point 4, thus producing mechanical action part of which is used for compressor operation, while the remaining part is used for operation of the driven machine. Heat travels from point 4 to 1, representing the exhaust and exiting of flue gases from the turbine:

$$Q_{\mathrm{odv}} = Q_{41} = mc_{\mathrm{p}}\left(T_4 - T_1\right), \quad \mathrm{J/ciklusu} \quad , \tag{2}$$

gdje je:

Q_{dov} – odvedena toplina.

Odvođenje topline ili ispuh dimnih plinova mogu biti u atmosferu, ili u slučaju kombikogeneracijskog postrojenja dimni plinovi ulaze u kotao utili-

where:

Q_{dov} – outgoing heat.

Removal of heat or outflow of flue gases may occur into the atmosphere, or, in case of a combined cycle cogeneration power plant, the flue gases en-

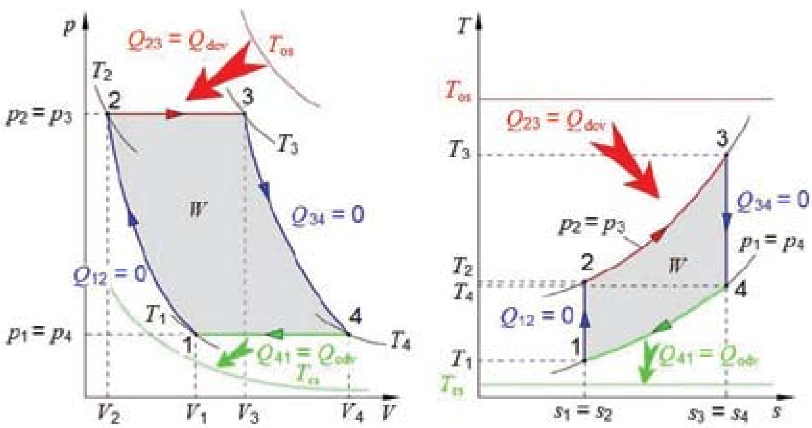
zator u kojem se toplina ispuha plinske turbine koristi za proizvodnju pare.
Dobiveni rad W po ciklusu je jednak:

ter the waste heat recovery boiler where heat from the gas turbine exhaust is used for production of steam.
Gained work W per cycle equals:

$$W = Q_{dov} - Q_{odv} \quad , \quad \text{J/ciklusu} \quad . \tag{3}$$

Kako atmosferski uvjeti okoliša u kojem započinje kružni proces plinske turbine (točka 1, slika 1) variraju ovisno o dobu dana, godišnjem dobu, lokaciji na kojoj je plinska turbina instalirana, nametnula se potreba određivanja standardnih uvjeta na kojima se temelje jamstvene karakteristike, a u odnosu na koje se rade i sve ostale usporedbe karakteristika postignutih izvan standardnih uvjeta. U industriji plinskih turbina standardni uvjeti zraka na ulazu u kompresor su: temperatura 15 °C, relativna vlažnost 60 %, te tlak od 1 013 mbar. Nominirani su od International Standards Organization (ISO uvjeti).

Since the surrounding atmospheric conditions in which the gas turbine cyclic process (point 1, Figure 1) begins varies depending on the time of day, season of the year, location where the gas turbine is installed, there need has arisen for determining the standard conditions upon which the guaranteed characteristics are founded, and in relation to which all other comparisons of characteristics achieved outside of the standard conditions are made. In the gas turbine industry, standard air conditions at the compressor inlet are: temperature 15 °C, relative humidity 60 %, and a pressure of 1 013 mbar. These comply with the International Standards Organisation (ISO conditions).



Slika 1 — Termodinamički teoretski proces plinske turbine prikazan u p-v i T-s dijagramu [1]
Figure 1 — Thermodynamic theoretical process for gas turbines shown in the p-v and T-s diagram [1]

U radu se za analizu koriste podaci plinske turbine General Electric tip PG 6101 FA. Performanse plinske turbine GE - PG 6101 FA temeljene na ISO standardu razlikuju se s obzirom na vrstu goriva koju turbina koristi.

Prema ISO uvjetima zraka na ulazu u kompresor i pogon na dizelsko gorivo, odnosno prirodni plin, definirane su jamstvene karakteristike na baznom opterećenju (tablica 1).

Analysis during operation uses data from the General Electric PG 6101 FA type gas turbine. Performance of the GE – PG 6101 FA gas turbine based on ISO standards differs with respect to the type of fuel used by the turbine.

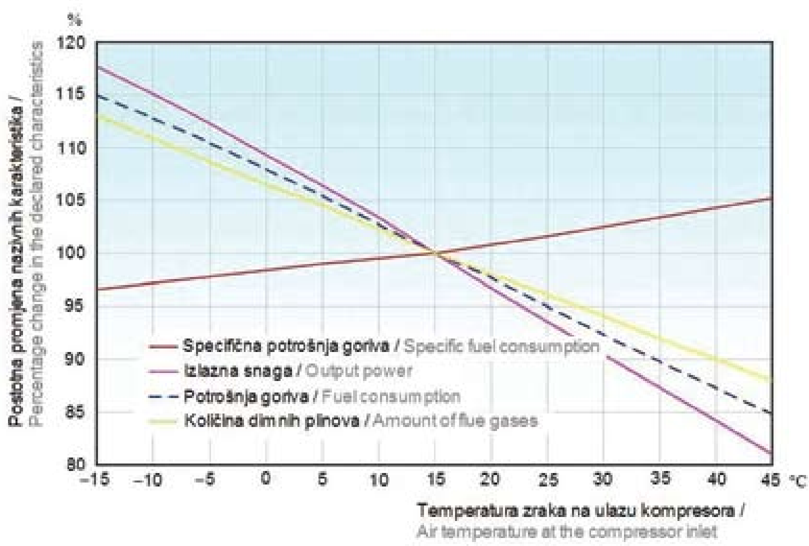
According to ISO conditions relating to air at the compressor intake and the engine running on diesel fuel or on natural gas, guaranteed characteristics are defined for base loads (Table 1).

Tablica 1 – Jamstvene karakteristike za plinsku turbinu GE - PG 6101 FA prema ISO uvjetima [2]
Table 1 – Guaranteed characteristics for the GE - PG 6101 FA gas turbine according to ISO conditions [2]

Karakteristike turbine / Turbine Characteristics	Jedinica / Measurement unit	Gorivo / Fuel	
		Dizelsko gorivo / Diesel fuel	Prirodni plin / Natural gas
Snaga na generatoru / Power at the generator	kW	74 270	69 450
Specifična potrošnja topline / Specific thermal consumption	kJ/kWh	11 152	10 593
Maseni protok dimnih plinova / Mass flow of flue gases	kg/h	761 100	731 600
Izlazna temperatura dimnih plinova / Output flue gases temperature	°C	584	596,7

Sve karakteristike plinske turbine značajno se mijenjaju promjenom atmosferskih uvjeta ulaznog zraka. Te promjene mogu biti i na dnevnoj osnovi vrlo velike, mada je njihova promjena najočitija usporedbom zimskog i ljetnog režima rada. Na slici 2 prikazana je relativna (postotna) promjena izlazne snage, specifične potrošnje goriva, potrošnje goriva i količine dimnih plinova ovisno o temperaturi zraka na usisu kompresora. Rast temperature zraka iznad ISO uvjeta degradira performanse turbine, smanjenjem izlazne snage i povećanjem specifične potrošnje goriva.

All gas turbine characteristics significantly change under various atmospheric conditions for incoming air. Such variations occurring on a daily basis may be great, although these variations are most evident when comparing winter and summer operation. Figure 2 shows the relative (percentile) variation in output power, specific fuel consumption, fuel consumption and the amount of flue gases dependent on air temperature at the compressor inlet. An increase in air temperature above the ISO norms degrades the performance of the turbine, reducing its output power and increasing the specific fuel consumption.



Slika 2 — Ovisnost karakteristika plinske turbine GE - PG 6101 FA o temperaturi zraka na usisu kompresora [2]
Figure 2 — Correlation between the GE - PG 6101 FA gas turbine characteristics and the air temperature at the compressor inlet [2].

Do degradacije performansi dolazi zbog toga što je gustoća zraka obrnuto proporcionalna temperaturi izmjerenoj mokrim termometrom, što znači da porastom temperature okolišnog zraka opada maseni protok zraka na usisu kompresora plinske turbine. Izlazna snaga plinske turbine direktno ovisi o masenom, a ne o volumnom

Degradation in performance occurs because the air density is inversely proportional to the temperature measured by a wet-bulb thermometer, meaning that with an increase in the ambient air temperature the airflow mass falls at the compressor inlet on the gas turbine. The output power of the gas turbine directly depends on the mass and not the airflow protoku zraka (volumni protok je konstantan, određen konstrukcijom plinske turbine). Na slici 2 prikazano je kako se promjena gustoće zraka ovisno o temperaturi očituje na performanse plinske turbine, pri čemu je vidljiv značajan utjecaj na:

— specifičnu potrošnju goriva,
— izlaznu snagu,
— protok dimnih plinova,
— potrošnju goriva.

Iz slike 2 je vidljivo da kao što povećanje temperature zraka degradira performanse, smanjenje temperature poboljšava performanse.

U praksi je uobičajena korekcija izlazne snage dijeljenjem nominalne snage pri ISO uvjetima s korekcijskim faktorom α koji uključuje ovisnost snage o vanjskoj temperaturi i relativnoj vlažnosti (formula 4) [2]. Korekcijski faktor α za turbinu GE - PG 6101 FA, kojeg je odredio proizvođač, prikazan je dijagramom na slici 3. Ovisnost izlazne snage o relativnoj vlažnosti je zanemariva, što je vidljivo iz dijagrama na slici 3. Pri temperaturama okoliša manjim od 10 °C relativna vlažnost nema utjecaja na izlaznu snagu plinske turbine, dok je pri temperaturama višim od 10 °C taj utjecaj zanemarivo malen (poklapanje vrijednosti faktora α pri različitoj relativnoj vlažnosti je u granici ± 1%). Jednako je zanemariv utjecaj relativne vlažnosti na ostale performanse plinske turbine te se u ovom radu ne promatra.

Korigirana izlazna snaga:

volume (volume flow is constant, and determined by the gas turbine construction). Figure 2 shows that a variation in air density dependant on temperature is evident in the performance of the gas turbine, with a clearly visible affect on:

— specific fuel consumption,
— output power,
— flue gas flow,
— fuel consumption.

Figure 2 clearly shows that as the increase in air temperature degrades performance, a reduction in temperature improves performance.

A correction of the output power by dividing the nominal power during ISO conditions with a corrective factor α that includes power dependent on the external temperature and relative humidity (formula 4) is standard procedure [2]. The correction factor α for the GE - PG 6101 FA turbine, defined by the manufacturer, is shown in the diagram in Figure 3. Dependency of the output temperature on relative humidity is negligible, as is evident from the diagram in Figure 3. At ambient temperatures less than 10 °C, relative humidity has no influence on the output power of the gas turbine, while at temperatures exceeding 10 °C this effect is negligibly small (correlation of the α factor value at different values for relative humidity is within the limits ± 1%). What is also negligible is the impact of relative humidity on the other performances of the gas turbine and therefore it is not taken into account in this work.

Corrected output power:

$$P_{\mathrm{N}}^{\mathrm{kor}} = \frac{P_{\mathrm{N}}(15\ ^{\mathrm{o}}\mathrm{C})}{\alpha} \quad , \qquad (4)$$

gdje je:

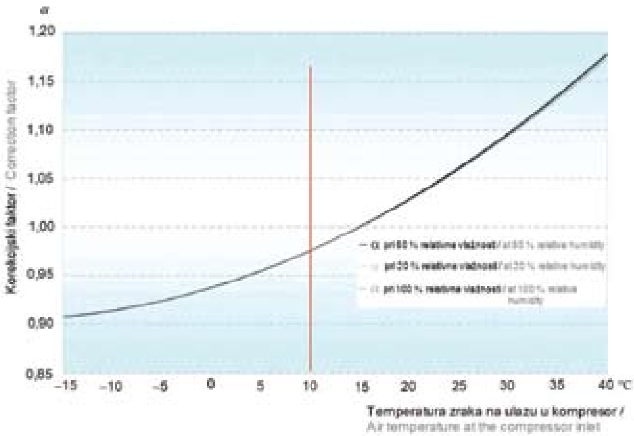
$P_{\mathrm{N}}^{\mathrm{kor}}$ – korigirana nominalna snaga,
P_{N} – nominalna snaga pri ISO uvjetima,
α – korekcijski faktor.

Utjecaj atmosferskog tlaka na performanse plinske turbine također se ne razmatra, jer je atmosfersko obilježje lokacije na kojoj je turbina instalirana.

where:

$P_{\mathrm{N}}^{\mathrm{kor}}$ – corrected nominal power,
P_{N} – nominal power,
α – corrective factor.

Impact of atmospheric pressure on the gas turbine performance is also not taken into account, since it is the atmospheric property of the location where the turbine is installed.



Slika 3 — Korekcijski faktor α koji ovisi o relativnoj vlazi i vanjskoj temperaturi zraka [2]
Figure 3 — Correction factor α which depends on relative humidity and external air temperature [2]

3 VRSTE I PRINCIP RADA SUSTAVA ZA HLAĐENJE ZRAKA NA USISU KOMPRESORA PLINSKE TURBINE

Mogućnost održavanja i poboljšanja nazivnih performansi smanjenjem temperature zraka na ulazu kompresora pokrenula je istraživanja i praktična ispitivanja tog područja. Do danas je razvijen veliki broj tehnika za hlađenje zraka na ulazu kompresora plinske turbine, a većina njih je primijenjena i u komercijalnoj uporabi. Te tehnike se prema funkciji i načinu rada dijele u sljedeće osnovne grupe [3] i [4] :

— evaporativno hlađenje:
  · strujanjem zraka kroz vlažni medij,
  · ušpricavanjem vode u obliku maglice,
  · ušpricavanjem vode u obliku maglice iznad zasićenja,
— klasični rashladni sustavi:
  · klasični rashladni sustav – direktni,
  · klasični rashladni sustav – indirektni,
  · klasični rashladni sustav sa spremnikom leda,
  · klasični rashladni sustav sa spremnikom smjese vode i leda,
— apsorpcijski rashladni sustavi:
  · apsorpcijski jednostupanjski rashladni sustav,
  · apsorpcijski dvostupanjski rashladni sustav,
— hlađenje uplinjavanjem LNG-a,
— hibridni rashladni sustavi.

Svaka od tih tehnika ima svoje dobre i loše osobine, koje se očituju kroz troškove investicije, troškove rada i održavanja, efikasnost, ali i kroz mogućnost primjene u ovisnosti o klimatskim uvjetima lokacije na kojoj je postrojenje izgrađeno.

3 TYPES AND PRINCIPLES OF OPERATION OF THE AIR COOLING SYSTEM AT THE GAS TURBINE COMPRESSOR INLET

The possibility of maintaining and improving declared performance by reduction in air temperature at the compressor inlet has initiated research and practical testing in this area. Up until today, a large number of techniques have been developed for cooling air at the compressor inlet in gas turbines, with most of them applied in commercial use. Such techniques are divided according to the function and manner of operation into the following basic groups [3] and [4]:

— evaporative cooling using:
  · air flow through a humid medium,
  · spraying water in the form of drops,
  · spraying water in the form of drops above saturation levels,
— classical cooling systems:
  · classical cooling system – direct,
  · classical cooling system – indirect,
  · classical cooling system with ice storage,
  · classical cooling system with a reservoir for water and ice mixture,
— absorption cooling system:
  · single-stage absorption cooling system,
  · two-stage absorption cooling system,
— cooling by gasification of LNG,
— hybrid cooling systems.

Each of these techniques has its positive and negative qualities, revealed thorough investment, operational and maintenance costs, efficiency, and through the possibilities of application depending on the climatic condition of the location where the plant has been assembled.

3.1 Evaporativno (tzv. mokro) hlađenje zraka

3.1.1 Strujanje zraka kroz vlažni medij

Strujanje zraka kroz vlažni medij je jedna od mokrih tehnika kojima se hlađenje postiže evaporacijom (hlapljenjem) vode koja se dodaje struji zraka na usisu kompresora. Povijesno gledano, to je prva komercijalno korištena tehnika hlađenja zraka na usisu kompresora. Tom tehnikom struja zraka se izlaže vodenom filmu koji prolazi nekom od mnogih primijenjenih vrsta vlažnih medija. U nekim slučajevima voda koja se koristi da ovlaži medij mora biti kemijski tretirana (pripremljena), ovisno o kemijskom sastavu sirove vode te o zahtjevima i specifikacijama proizvođača medija. Strujanjem kroz vlažni medij zrak se može ohladiti za oko 85 % do 95 % razlike između temperature mokrog i temperature suhog termometra okolišnog zraka.

Kod ovog načina hlađenja investicijski trošak, te troškovi rada i održavanja najniži su, ali njegov osnovni nedostatak je to što je dubina hlađenja ograničena temperaturom mokrog termometra, tj. učin je ovisan o atmosferskim uvjetima. Pored toga, u radu je potrebno stalno praćenje kemijskih karakteristika recirkulirajuće vode koja prolaskom kroz vlažni medij apsorbira nečistoće, te praćenje degradacije materijala ispune vlažnog medija.

Hlađenje zraka strujanjem kroz vlažni medij najefikasnije je u toplim i suhim klimatskim uvjetima, a efikasnost mu izrazito opada pri visokoj vlazi u zraku. Također, ovaj način u radu troši velike količine vode. Pored svih nedostataka, hlađenje strujanjem kroz vlažni medij je najrasprostranjenija i najviše korištena tehnika hlađenja zraka na usisu kompresora plinske turbine.

3.1.2 Ušpricavanje vode u obliku maglice

Ušpricavanje vode u obliku maglice sljedeća je mokra tehnika hlađenja koja se bazira na dodavanju sapnicama fino raspršene vode u struju zraka. Ušpricavanjem vode u obliku maglice zrak je moguće ohladiti za 95 % do 98 % razlike između temperature mokrog i temperature suhog termometra okolišnog zraka, pa je taj način samo malo efikasniji od strujanja vlažnim medijem. Sustavi za ušpricavanje uglavnom koriste kemijski pripremljenu (demineraliziranu) vodu, a mogu biti projektirani za različite veličine kapljica ovisno o željenom vremenu evaporacije (hlapljenja) te klimatskim uvjetima lokacije. Veličina kapljica je uglavnom manja od 40 μm, dok je u većini slučajeva približno 20 μm.

Troškovi ovog načina hlađenja vrlo su slični troškovima pri hlađenju strujanjem zraka kroz vlažni medij, a također su slična i ograničenja i nedostaci. Ušpricavanje vodene maglice u struju zraka na drugom je mjestu po zastupljenosti u instali-

3.1 Evaporative (Wet) Air Cooling

3.1.1 Air Circulation Through a Moist Medium

Circulation of air through a moist medium is one of the wet techniques whereby cooling is achieved by evaporation of water which is added to the circulating air at the compressor inlet. Viewed historically, this was the first commercially used technique for cooling air at the compressor inlet. This air circulation technique is exposed to film of water passing through some of the many applicable types of moist mediums. In some cases, water used in order to moisten the medium must be chemically treated (prepared), depending on the chemical composition of the raw water and the requirements and specifications by the medium manufacturer. Circulation through the moist medium allows air to be cooled by around 85 % to 95 % of the difference between the moist and dry ambient air temperature.

For this type of cooling, the investment, operational and maintenance costs are lower, but its main deficiency is that the depth of cooling is limited by the temperature of the wet-bulb thermometer, i.e. the result depends on the atmospheric conditions. Furthermore, during operation, continual monitoring is necessary of the chemical characteristics of the re-circulated water which, passing through the moist medium, absorbs impurities, and the monitoring of the degradation of materials filling the moist medium.

Cooling air by circulating it through a moist medium is optimally effective in hot and dry climatic conditions, whereas its efficiency deteriorates exceptionally at very high air humidity. Moreover, this manner of operation uses large quantities of water. Besides these inadequacies, cooling by circulation in a moist medium is the most common and widely used technique for cooling air at the compressor inlet on gas turbines.

3.1.2 Spraying Water in Drop Forms

Spraying water in drop forms is the next wet cooling technique, which is based on adding finely dispersed water in the circulating air by nozzles. By spraying water in drop forms, air is cooled by 95 % to 98 % of the difference between the dry and wet temperature of an ambient air thermometer, hence this method is only somewhat more efficient than circulating air in a moist medium. Spraying systems mainly use chemically prepared (demineralised) water, and can be designed for various drops sizes depending on the desired evaporation time and climatic conditions at the location. The size of the drops is mainly less than 40 μm while in the majority of cases they are approximately 20 μm.

The costs of this type of cooling are very similar to the costs associated with cooling by circulating air ranim sustavima hlađenja, iako pojedini proizvođači i korisnici plinskih turbina ne dozvoljavaju njegovu primjenu zbog moguće degradacije karakteristika i mogućih kvarova kompresora, koji se pripisuju ušpricavanju.

3.1.3 Ušpricavanje vode u obliku maglice iznad zasićenja

Ušpricavanje vode u obliku maglice iznad zasićenja treća je mokra tehnika hlađenja u kojoj se ušpricava više vodene maglice u struju zraka nego što je moguće da ishlapi pri okolišnim uvjetima. Struja zraka, u tom slučaju zasićena do 100 % relativne vlage, višak ušpricane vode u obliku maglice unosi u kompresor, gdje ona pri promjeni tlaka i temperature zraka dodatno hlapi i hladi komprimirani zrak, stvarajući tako dodatni maseni protok koji povećava izlaznu snagu plinske turbine u većoj mjeri nego je to moguće klasičnim evaporativnim sustavima hlađenja. Ova tehnika zahtijeva vodu visoke kvalitete, jer bi u protivnom troškovi održavanja nastali zbog vode loše kvalitete mogli biti veći nego ekonomski efekt poboljšanja karakteristika hlađenjem zraka.

3.2 Klasični rashladni sustavi

Klasičnim rashladnim sustavima moguće je rashladiti ulaznu struju zraka do temperatura mnogo nižih nego su to u stanju evaporativni sustavi hlađenja, te je bez obzira na vlagu u zraku i temperaturu mokrog termometra moguće postići i održavati temperaturu zraka na bilo kojoj vrijednosti do minimalnih 5 °C. Rashladni sustavi mogu biti pogonjeni električnim motorima, ili parnim turbinama. Hlađenje se u tom slučaju odvija strujanjem zraka preko cijevnog snopa izmjenjivača topline postavljenog iza usisnih filtara zraka, kroz koji struji rashladni medij ili ohlađena voda i hladi zrak na željenu temperaturu.

Opće prednosti klasičnog rashladnog sustava su da se njime može postići i održati željena temperatura zraka neovisno o atmosferskim i klimatskim uvjetima. Nedostaci ovog načina hlađenja su veći troškovi investicije, rada i održavanja. Klasični rashladni sustavi pogonjeni elektromotorima povećavaju vlastitu potrošnju proizvodne jedinice, jer za svoj pogon troše dio proizvedene električne energije. Za razliku od evaporativnih sustava, da bi proizveli rashladni učin malim dijelom smanjuju predanu snagu proizvodne jedinice, ali takva usporedba s mokrim sustavima nije vjerodostojna, jer je njihova primjena uglavnom na lokacijama na kojima zbog atmosferskih i klimatskih uvjeta evaporativni sustavi nemaju značajnog efekta, tj. na lokacijama gdje je relativna vlaga u zraku visoka.

through a moist medium, and the limitations and inadequacies are also similar. Spraying water drops into the circulating air is the second most common method in installed cooling systems, although certain gas turbine manufacturers and users do not allow such use due to possible degradation of characteristics and compressor breakdowns associated with spraying.

3.1.3 Spraying Water into Drop Forms Above Saturation Levels

Spraying water in the drop forms above the saturation level is the third most popular cooling technique whereby more water drops are sprayed into the circulating air than can evaporate at ambient conditions. The circulating air, in this case saturated at 100 % relative air humidity, excess sprayed water in the form of drops enters the compressor, creating therefore additional mass flow which increases the output power of the gas turbine to a greater extent than possible when using classical evaporative cooling systems. This technique requires high-quality water, since, in the opposite case, maintenance costs occurring due to poor water quality might be greater than the economic effect of improving air-cooling characteristics.

3.2 Classical Cooling Systems

Classical cooling systems can cool incoming circulating air up to a temperature much lower than is possible by evaporative cooling systems, and regardless of the air humidity and temperature of the wet thermometer, these can achieve and maintain air temperatures at any value up to a minimum of 5 °C. Electrical motors or steam turbines can drive cooling systems. Cooling in this case is conducted by circulating air through a series of tubes in a heat exchanger placed behind the inlet air filters, through which the cooling medium or cooled water and cooled air circulate at the desired temperature.

The general advantages of the classical cooling system are that it can achieve and maintain desired air temperatures regardless of the atmospheric and climatic conditions. The disadvantages of this manner of cooling are higher investment, operational and maintenance costs. Classical cooling systems driven by electrical motors increase consumption at the production unit since part of the produced electrical power is used for operation.

In order to produce a cooling effect, compared to evaporative systems, classical cooling systems reduce power supplied from the production unit to a lesser extent. But such comparisons with wet systems are not reliable, because their use occurs mainly at locations where, due to atmospheric and climatic conditions, evaporative systems do not have a significant effect, i.e. at locations with relatively high air humidity.

Razlikuju se:

- direktni klasični rashladni sustav – sustav kod kojeg rashladni medij (uglavnom amonijak) neposredno iz rashladnog uređaja prolazi kroz cijevi hladnjaka zraka na ulazu kompresora,
- indirektni klasični rashladni sustav – za razliku od direktnog uvodi još jedan cirkulacijski krug vode, koja se hladi rashladnim medijem (uglavnom amonijak) iz rashladnog uređaja, te tako ohlađena prolazi kroz cijevi hladnjaka zraka na ulazu kompresora,
- klasični rashladni sustav sa spremnikom leda – kao i klasični rashladni sustav sa spremnikom smjese vode i leda koristi akumulaciju leda ili hladne smjese vode i leda. Ovakav način se koristi kod postrojenja kojima u tarifnim sustavima cijene isporučene energije bitno odstupaju između vršnih i normalnih sati. Akumulacijom je omogućen kontinuirani rad rashladnog uređaja s manjim opterećenjem, jer se izvan vršnih sati hladi spremnik, iz kojeg se u vršnim satima tarifnog sustava povlači rashladna tekućina te se dobiva mnogo veći rashladni kapacitet nego je kapacitet rashladnog sustava. Parazitska potrošnja električne energije rashladnog sustava i time nastalo povećanje vlastite potrošnje proizvodne jedinice na taj način se pomiče u vrijeme izvan vršnih sati.

3.3 Apsorpcijski rashladni uređaji

Apsorpcijski rashladni uređaji funkcionalno su slični klasičnim rashladnim uređajima, s bitnom razlikom da umjesto mehaničkog rada elektromotora ili parne turbine za proizvodnju rashladnog učina koriste vanjski izvor toplinske energije, koja im se dovodi vrućom vodom ili vodenom parom. Njihov konzum električne energije daleko je manji, jer je potreban samo za pumpe cirkulacije rashladne vode. Apsorpcijski rashladni uređaji mogu ohladiti zrak do temperature od oko 10 °C, a mogu se poput klasičnih rashladnih sustava koncipirati sa ili bez akumulacijskih spremnika leda ili smjese leda i vode. Razlikuje se:

- jednostupanjski apsorpcijski rashladni uređaji kao vanjski izvor toplinske energije koriste vruću vodu ili pregrijanu paru tlaka približno 2 bar,
- dvostupanjski apsorpcijski rashladni uređaji koji za isti učin troše osjetno manje količine pare, ali je potrebna para viših parametara, oko 9 bar.

Prednost ovih sustava je da ne opterećuju vlastitu potrošnju proizvodne jedinice, tj. opterećuju je vrlo malo u odnosu na klasične rashladne

The following are distingushed:

- direct classical cooling systems – a system whereby the cooling medium (most often ammonia) passes directly from the cooling system through the piping of the air cooler at the compressor inlet,
- indirect classical cooling system – introduces, in comparison to the direct system, still another water circulation cycle, cooled using a cooling medium (most often ammonia) from the cooling device, and therefore once cooled passes through the piping of the air cooler at the compressor inlet,
- the classical cooling system with an ice reservoir – as in the classic cooling systems with a reservoir containing a mixture of water and ice, this system uses an accumulation of ice or a cold mixture of water and ice. This technique is used for plants where the tariff price system for delivered power deviates greatly from the peak or normal hours. Accumulation allows continual operation of the cooling device and less loading, since, outside of the peak hours, the reservoir is cooled, and during the tariff system peak hours, from the reservoir the cooling liquid is used and a much larger cooling capacity is gained than is the capacity in a cooling system. Parasitic consumption of electrical power in the cooling system and therefore the increase in proprietary consumption by the production unit is transferred to the time periods outside of the peak hours.

3.3 Absorption Cooling Devices

Absorption cooling devices are functionally similar to classical cooling devices, with the main difference being that instead of mechanical operation of the electrical motor or steam turbine for the production of the cooling effect, an external source of thermal energy is used sourced from hot water or water steam. Their consumption of electrical power is far less, since such power is necessary only for the cooling water circulation pumps. The absorption cooling devices can cool air up to a temperature of around 10 °C, and just like the classical cooling systems, these can be designed with or without accumulation reservoirs for ice or ice-water mixtures. The following differences exist:

- single-stage absorption cooling devices as the external source of thermal energy use hot water or heated steam at a pressure of approximately 2 bar,
- two-stage absorption cooling devices for the same effect use considerably lesser amounts of steam, but steam at higher parameters of around 9 bar is necessary.

The advantages of these systems is that they do not exert proprietary consumption from the production sustave pogonjene elektromotorom, no investicijski troškovi su značajno veći nego kod klasičnih rashladnih sustava. Apsorpcijski sustavi se prvenstveno primjenjuju u termoenergetskim objektima gdje postoji jeftina toplinska energija čijom je pretvorbom u rashladni učin moguće proizvesti dodatnu skupu električnu energiju.

3.4 Hlađenje zraka uplinjavanjem LNG-a

Hlađenje uplinjavanjem tekućeg prirodnog plina (LNG) primjenjuje se kod postrojenja smještenih u blizini terminala za uplinjavanje tekućeg prirodnog plina. Proces uplinjavanja LNG-a zahtjeva izvor topline, te se primjenom cirkulacijskog kruga vode između hladnjaka zraka na usisu kompresora i isparivača tekućeg plina ta toplina dovodi iz struje zraka koja ulazi u kompresor plinske turbine. Kod ovakvog načina hlađenja zraka investicijski troškovi i troškovi održavanja sustava su jedini, jer se njegovim radom supstituira jedan dio ionako potrebnog izvora toplinske energije za isparivač tekućeg plina.

3.5 Hibridni rashladni sustavi

Hibridni rashladni sustavi kombiniraju pojedine od spomenutih tehnika, npr. klasični i apsorpcijski rashladni sustav. Takvi sustavi se projektiraju i optimiraju prema posebnim zahtjevima na pojedine elektrane ovisno o traženim količinama isporučene električne energije i njenim cijenama, te raspoloživosti toplinske energije.

Na slici 4 prikazan je hladnjak zraka ugrađen u filtarsku jedinicu usisnog kanala kroz koji kompresor usisava zrak iz okoline. Hladnjak se ugrađuje iza filtra zraka, a njegovim smještajem u struji zraka omogućeno je njeno hlađenje, tj. odvođenje topline rashladnim medjem. Hladnjaci se ugrađuju kod klasičnih, apsorpcijskih ili hibridnih rashladnih sustava. Kod evaporativnih sustava na istom mjestu potrebno je ugraditi postolja sa sapnicama za ubrizgavanje vode, ili nosače važnog medija, ovisno o vrsti mokrog sustava hlađenja. Rekonstrukcija i proširenje filtarske jedinice hladnjakom ujedno je i jedini zahvat na plinskoturbinskom agregatu. Ostali dijelovi sustava hlađenja su periferni, pomoćni sustav koji ne mijenja i ne zadire u konstrukciju plinske turbine.

4 ODRŽAVANJE PERFORMANSI PLINSKE TURBINE HLAĐENJEM ZRAKA NA ULAZU U KOMPRESOR

Ovisnost osnovnih performansi plinske turbine (specifične potrošnje goriva, izlazne snage, pro-

units, i.e. such loading is very small with respect to classical cooling systems driven by electrical motors, but the investment costs are considerably greater than with classical cooling systems. The absorption systems are primarily used in thermal power plants where there exists cheap thermal energy whose transformation into a cooling effect produces additionally expensive electrical power.

3.4 Air-Cooling By Gasification of LNG

Cooling using gasification of liquefied natural gas (LNG) is used in plants located close to terminals for gasification of liquefied natural gas. The process of gasification of LNG requires a thermal source, and in using the water circulation cycle between the air coolers at the compressor inlet and the liquefied gas evaporator, this heat is brought from the airflow entering the gas turbine compressor. This manner of cooling air exerts only investment and maintenance costs for the system, since its operation replaces part of the already necessary source of thermal energy for the liquefied gas evaporator.

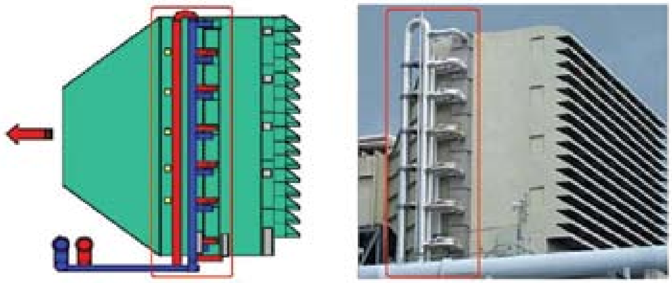
3.5 Hybrid Cooling System

Hybrid cooling systems combine various parts of the stated techniques, for instance, the classical and absorption cooling system. Such systems are designed and optimised according to particular requirements for certain power stations and depending on the required amounts of delivered electrical power and prices, as well as the availability of thermal energy.

Figure 4 shows the air cooler installed into the filter unit of the inlet canal through which the compressor sucks air from the surroundings. The cooler is fitted behind the air filter, while its position in the airflow allows it to be cooled, i.e. removal of the heat from the cooling medium. The coolers are installed in classical, absorption or hybrid cooling systems. For evaporative systems located at the same position, it is necessary to install a base with nozzles for accelerating water, or carriers for the moist medium, depending on the type of wet cooling system. Reconstruction and expansion of the filter units using the cooler is actually the only intervention on the gas turbine generator. The other parts of the cooling system are peripheral, auxiliary systems that do not alter or affect the gas turbine construction.

4 MAINTAINING PERFORMANCE OF THE GAS TURBINE BY COOLING AIR AT THE COMPRESSOR INLET

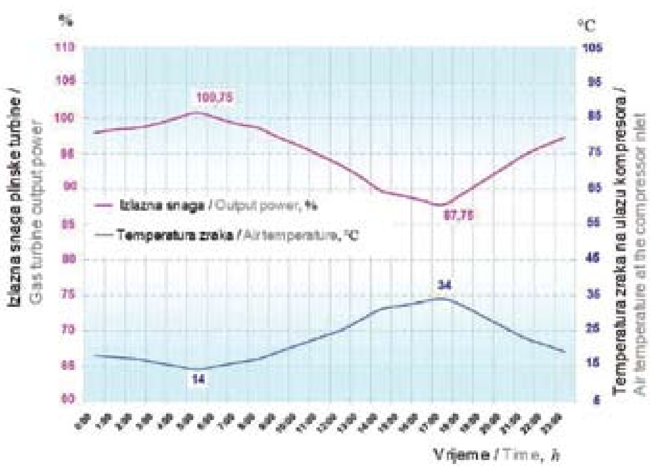
Dependency of the gas turbine's fundamental performance (specific fuel consumption, output power,



Slika 4 — Hladnjak zraka smješten u filtarskoj jedinici usisnog kanala zraka
Figure 4 — Air cooler located in the filter unit of the air inlet canal

toka dimnih plinova i potrošnje goriva) o temperaturi na ulazu u kompresor prikazana je na slici 2. Na slici 5 prikazan je dijagram promjene izlazne snage plinske turbine u tipičnom ljetnom danu, u odnosu na doba dana i temperaturu okoliša.

flue gas flow and fuel consumption) on the temperature at the compressor inlet is shown in Figure 2. Figure 5 shows the diagram for gas turbine output power variation in a typical summer day with respect to the time of day and ambient temperature.



Slika 5 — Ovisnost izlazne snage plinske turbine o temperaturi zraka na usisu kompresora u tipičnom ljetnom danu
Figure 5 — Dependency of gas turbine output power on the air temperature at the compressor inlet during a typical summer day

Apscisa dijagrama na slici 5 je vrijeme, te je kao vremenski okvir odabrano 00:00 do 24:00 sata. Skala na lijevoj ordinati prikazuje postotni iznos nominalne snage plinske turbine pri ISO uvjetima, gdje je 100 % nazivne snage vezano uz temperaturu od 15 °C. Desna ordinata prikazuje temperaturu okoliša, koja je ujedno i temperatura zraka na ulazu kompresora.

Donja krivulja pokazuje promjenu temperature zraka kroz dan, a gornja krivulja promjenu izlazne snage ovisno o temperaturi okoliša prema dijagramu na slici 2. Indikativan je značajni pad izlazne snage plinske turbine od 12,25 % pri temperaturi od 34 °C, koja se na dijagramu pojavljuje između 17:00 i 18:00 sati, što je kod turbine GE - PG 6101 FA gotovo 8,5 MW.

The x-axis on the diagram in Figure 5 is time, and the time period chosen covers 00:00 to 24:00 hours. The scale on the left ordinates shows the percentage value of the gas turbine's nominal power at ISO conditions, where 100 % of the nominal power relates to a temperature of 15 °C. The right ordinate shows the ambient temperature, which is also the air temperature at the compressor inlet.

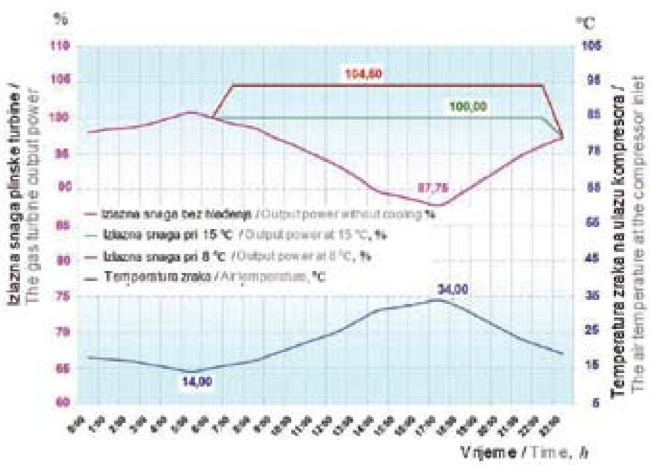
The lower curve shows the air temperature variation during the day, while the upper curve shows the variation in output power with respect to the ambient temperature as shown in the diagram in Figure 2. What is indicative is the significant reduction of 12,25 % in output power of the gas turbine at temperatures of 34 °C occurring on the diagram between 17:00 and 18:00 hours, which for the GE – PG 6101 FA turbine is almost 8,5 MW.

Ovdje je istaknuta maksimalna degradacija snage, ali je iz dijagrama uočljivo da je degradacija snage prisutna cijelo vrijeme u kojem je temperatura viša od 15 °C. Da bi se ta degradacija spriječila, okolišni zrak se na ulazu u kompresor hladi. Efekt hlađenja zraka, tj. utjecaj na izlaznu snagu prikazan je dijagramom na slici 6, u istom vremenskom okviru i istim ordinatama.

Ključni trenuci prikazani dijagramom na slici 6 su start rashladnog sustava hlađenja zraka, koji se po dijagramu potrošnje električne energije događa između 06:00 i 07:00 sati ujutro. Zelena i crvena krivulja predstavljaju izlaznu snagu plinske turbine u periodu rada rashladnog sustava. Mogući načini rada su održavanje ulazne temperature zraka na 15 °C, što je prikazano zelenom krivuljom, te eliminiranje degradacije izlazne snage plinske turbine s porastom temperature. Na taj način turbinu održavamo na njenim nominalnim parametrima pri ISO uvjetima.

Here the maximum degradation in power is emphasised, but is can be concluded from the diagram that the degradation in power is present during the whole time in which the temperature is greater than 15 °C. In order to prevent this degradation, the surrounding air at the compressor inlet is cooled. The effect of cooling the air, i.e. the effect on the output power is shown by the diagram in Figure 5, in the same time period and same axis.

The key moments shown in the diagram in Figure 6 are the starting of the cooling system for cooling the air, which according to the diagram for electrical power consumption occurs between 06:00 and 07:00 hours in the morning. The green and red curves represent the gas turbine's output power in the period of operation of the cooling system. The possible modes of operation are maintaining the output air temperature at 15 °C, shown by the green curve, and an elimination of the degradation of the gas turbine's output power at temperature increases. In this way, the turbine is maintained at its nominal parameters at ISO conditions.



Slika 6 — Utjecaj hlađenja zraka na izlaznu snagu plinske turbine tijekom tipičnog ljetnog dana

Figure 6 — The impact of cooled air on the gas turbine's output power during a typical summer day

Dodatna pogodnost dobro kapacitiranog rashladnog sustava je hlađenje zraka na temperaturu nižu od 15 °C prema kojoj je ISO uvjetima određena nominalna snaga, te porast izlazne snage zbog toga. Taj način rada prikazan je crvenom krivuljom, gdje je kao ciljana temperatura ohlađenog zraka odabrano 8 °C, a čime se dobiva porast izlazne snage plinske turbine od 4,5 % u odnosu na nominalnu. Usporedbom krivulja snage bez hlađenja zraka, te krivulje hlađenja na 8 °C pri okolišnoj temperaturi zraka od 34 °C, dobivena je razlika od 16,75 % nominalne snage, ili za turbinu GE - PG 6101 FA gotovo 11,5 MW.

Pored prikazanog utjecaja temperature zraka na izlaznu snagu, po istoj logici je napravljen dija-

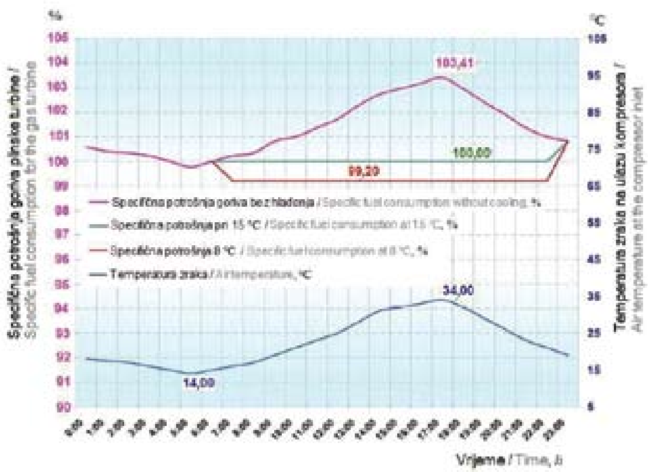
Additional benefits of a well-capacitated cooling system is cooling air at a temperature lower than 15 °C based upon which ISO conditions determine the nominal power, and the resulting increase in output power. This manner of operation is shown by the red curve, where the desired temperature of the cooled air is chosen as 8 °C, and where a 4,5 % increase in the gas turbine power output of 4,5 % is achieved compared to the nominal power output. A comparison of power curves without air cooled, and the cooling curve 8 °C at an ambient temperature of 34 °C, achieves a difference of 16,75 % in nominal power or almost 11,5 MW for the GE – PG 6101FA turbine.

Besides the shown impact of air temperature on output power, the same logic applies to the diagram utjecaja temperature okoliša na specifičnu potrošnju goriva, prikazan na slici 7.

Promatrajući iste uvjete kao i kod ovisnosti izlazne snage plinske turbine, iz dijagrama na slici 7 vidljivo je povećanje specifične potrošnje goriva pri povećanju temperature okoliša, tj. zraka koji ulazi u kompresor plinske turbine. Održanjem temperature na ISO uvjetima, specifična potrošnja goriva ostaje na svojoj nominalnoj vrijednosti, ili se hlađenjem zraka na 8 °C ona smanjuje. Pri tome se ne smanjuje apsolutna potrošnja goriva, koja je proporcionalna izlaznoj snazi, već se postiže ekonomičniji rad turbine, tj. potrebna količina goriva za proizvedenu električnu energiju je manja. Sukladno tome, i emisije dimnih plinova po proizvedenom kilovatsatu električne energije su manje.

gram showing the impact of the surrounding temperature on the specific fuel consumption, as shown in Figure 7.

Taking into consideration the same conditions as for output power dependency of the gas turbine, the diagram in Figure 7 clearly shows the increase in specific fuel consumption during increased ambient temperatures, i.e. air entering the gas turbine compressor. By maintaining the temperature at ISO conditions, the specific fuel consumption remains at its nominal value, or by cooling air to 8 °C, it falls. Consequently, the absolute fuel consumption which is proportional to the output power does not fall, but higher efficiency of turbine operation is achieved, i.e. the necessary amount of fuel for the produced electrical power is less. Therefore, the emission of flue gases for every produced kilowatt-hour of electrical power is lesser.



Slika 7 — Ovisnost specifične potrošnje goriva plinske turbine o temperaturi zraka na usisu kompresora u tipičnom ljetnom danu (s hlađenjem zraka, i bez hlađenja)

Figure 7 — Dependency of specific fuel consumption for gas turbines and the air temperature at the compressor inlet during a typical summer day (with and without air cooling)

5 ZAKLJUČAK

Hlađenje zraka na ulazu u kompresor plinske turbine danas je razvijena i poznata tehnika, višestruko potvrđena u eksploataciji. Osnovni razlog njene primjene je taj što pri povišenim temperaturama okolišnog zraka plinske turbine gube snagu zbog konstantnog volumnog, ali smanjenog masenog protoka zraka, koji je povećanjem temperature sve rjeđi i čiji se specifični volumen u tom slučaju povećava. Ovisno o klimatskim uvjetima lokacije na kojoj je postrojenje sagrađeno, taj efekt je više ili manje značajan, te je za svaku pojedinu lokaciju potrebno provjeriti ekonomičnost investicije u rashladni sustav. Ekonomičnost investicije ovisi prvenstveno o atmosferskim uvjetima, ali bitni parametri su i vrsta postrojenja, stanje elektroenergetskog su-

5 CONCLUSION

Today, cooling air at the compressor inlet of the gas turbine is a well-developed and common technique, confirmed many times through exploitation. The fundamental reason for its use is that during increased ambient air temperatures, gas turbines loose their power due to constant volume, but reduced air mass flow, which with increasing temperature is less dense and the specific volume of which increases in such cases. Depending on the climatic conditions of the location where the plant has been assembled, this effect is more or less important, and for each particular location, it is necessary to verify the economic viability of investing in a cooling system. Economic viability primarily depends on the atmospheric conditions, but also other important parameters include the type of plant, the state of stava na koji je vezan, te tarifni sustav naplate isporučene električne energije.

Na lokacijama na kojima se potvrdi opravdanost ugradnje rashladnog sustava, efekti ugradnje očituju se kroz eksploataciju maksimalnog učina postojećeg postrojenja, tj. eliminira se potreba izgradnje dodatnog vršnog izvora električne energije koji je elektroenergetskom sustavu potreban kada se superponira ljetna vršna potrošnja električne energije i efekt degradacije snage turbine pri visokim dnevnim temperaturama. U tom slučaju nema potrebe za ishođenjem dozvola i suglasnosti za izgradnju dodatnog izvora, oprema rashladnog sustava zauzima manje prostora nego novi izvor, a i troškovi pogona i održavanja rashladnog sustava su manji u odnosu na troškove pogona i održavanja dodatnog izvora.

Ekološki efekt se očituje kroz smanjenu specifičnu potrošnju goriva, tj. direktno smanjenje emisija u okoliš po proizvedenom kilovatsatu električne energije.

the electrical power system to which it is connected, and the tariff payment system for the supplied electrical power.

At locations where the constructing a cooling system is justified and confirmed, the effects of installing the system are evident in the exploitation of the maximum effect in the existing plant, i.e. elimination of the need to construct an additional peak source of electrical power necessary for the electrical power system when the summer peak consumption of electrical power and the effect of a degradation of the turbine's power is superimposed during high daily temperatures. In this instance, there is no need for obtaining a permit and consent for construction of an additional source; the cooling system equipment consumes less space than the new source, and the costs of the plant and maintenance of the cooling system are lesser compared to the costs associated with the plant and maintenance of the additional source.

The environmental effects are evident in reduced specific fuel consumption, i.e. a direct reduction in emissions into the environment for each produced kilowatt-hour of electrical power.

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