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火力抽水－蓄能发电

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摘　要: 提出一种具有更高经济性能的电力生产方式－火力抽水－蓄能发电。火力抽水－蓄能发电是由汽轮机直接带动水泵抽水蓄能, 减少了两次能量转换环节, 发电效率可提高 11%以上。锅炉、汽轮机、水泵都可以按额定容量满负荷运行, 得到最高的效率。火力抽水－蓄能发电系统还具有更高的安全性, 深度的调峰能力, 可以节约冷凝器循环水, 建设投资小等优点。

关　键　词: 火力抽水蓄能发电; 抽水蓄能发电; 调峰; 电力经济

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1　前言

随着"九五"期间电力建设的高速发展, 一大批高参数大容量的发电机组相继投产, 我国的电力生产能力迅速增长。个别省区已经出现了电力生产能力大于用电需求, 设备利用小时数下降到 4 500 以下的局面。而且, 由于用电结构发生了变化, 非均衡性用电负荷的增长高于均衡性用电负荷的增长, 电网负荷的峰谷差越来越大, 使得调峰越来越困难。特别是以火力发电为主的电网, 不得不动用 300 ~ 600 MW 的大容量亚临界发电机组参加调峰。一些原来按基荷发电定压运行设计的机组被迫改造成变压运行的有调峰能力的机组, 日平均负荷率仅 60% ~70%。

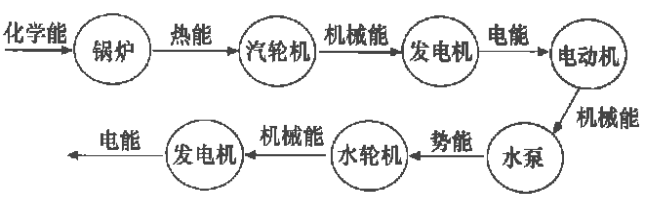
现代大容量亚临界凝汽式中间再热汽轮发电机组按额定容量满负荷运行的发电效率可达 41%, 计及厂用电的供电效率约 38%。如果机组能够一直满负荷运行, 就有比较高的热效率和经济性。而机组在较低的负荷下运行, 锅炉效率、汽轮机效率和循环效率都明显下降。发电机组在负荷率 70%时的供电效率约为 35%。当负荷率下降到额定负荷的 50%时, 供电效率仅 29%左右。火力发电厂的热效率下降, 发电煤耗率上升, 电网的经济性能下降。

2　抽水蓄能发电

抽水蓄能发电是解决电网的调峰填谷问题的有效方案。抽水蓄能电站在夜间电网的低谷负荷时间利用剩余的电能从低水库向高水库抽水, 把电能转化成水的势能储存起来。在电网的高峰时间用储存的水力发电, 满足高峰负荷的需要, 明显地改善了以火电为主的电网的调峰性能, 避免了火电厂的低谷调停。

抽水蓄能电站实际上是和电网中的火力发电厂联合运行的。由于抽水蓄能电站是把电能转化成其它能量保存起来, 以后再重新转化为电能, 火力发电厂与抽水蓄能电站联合运行就经历了多达 7 次的能量转换, 每次能量形式的转换都伴随着能量的损失:

抽水蓄能电站在将电能转换成势能再重新转换



成电能的过程中损失了 1/4 的能量, 效率 η_w 约为 70% ~ 78%。其中, 水泵的效率约 78% ~ 83%, 水轮发电机组的效率约 90% ~ 94%。火力发电厂与抽水蓄能电站联合运行的总发电效率

$$\eta_{CO} = \eta_f \cdot \eta_t \cdot \eta_w$$

式中, η_f 是火力发电厂的计及厂用电的供电效率, η_t 是输电效率, η_w 是抽水蓄能电站的效率。

由于抽水蓄能电站吸收了一部分低谷负荷, 使得火力发电机组的日平均负荷率略有增大。假设火力发电机组的 η_f 约为 35%。输电效率主要考虑的是向水泵提供电能的输电线路的线损和变压器损耗, η_t 约为 99%。若抽水蓄能电站的效率(计及厂用

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电) η_w 为 74%。则

$$\eta_{CO} = \eta_f \cdot \eta_t \cdot \eta_w = 35\% \cdot 99\% \cdot 74\% = 25.6\%$$

火力发电厂与抽水蓄能电站联合运行的平均供电煤耗率约480 g/(kW·h)。

3 火力抽水－蓄能发电

本文作者提出一种改善电网调峰性能，提高电网经济性的新思路——火力抽水－蓄能发电。这种新的电力生产系统不是用火力发电厂输出的电力去抽水蓄能发电，而是由汽轮机直接带动水泵抽水，将热能而不是电能转化成水的势能蓄能发电，减少了能量转换次数。火力抽水－蓄能发电的运行方式是锅炉－汽轮机－水泵系统全天抽水，水轮发电机组只在上午、下午和晚上电网出现高峰负荷的若干小时中发电。由于锅炉、汽轮机和水泵都可以在额定容量下满负荷工作，效率是最高的。假设，包括锅炉和汽轮机在内的热力系统的效率(计及厂用电) η_R 约为39%，水泵的效率 η_{PU} 约82%，水轮发电机组的效率 η_{WE}(计及厂用电) 约为91%。则火力抽水－蓄能发电的总效率

$$\eta_{HWE} = \eta_R \cdot \eta_{PU} \cdot \eta_{WE} = 29.1\%$$

火力抽水－蓄能发电的供电煤耗率约422 g/(kW·h)。

火力抽水－蓄能发电的总效率明显高于火力发电厂与抽水蓄能电站联合运行的效率。这一方面是因为火力抽水－蓄能发电比火力发电厂与抽水蓄能电站联合运行所经历的能量转化过程的次数从7次减少到5次，减少了一次机械能转化为电能和电能再转化为机械能的过程。另一方面是因为火力抽水－蓄能发电的锅炉、汽轮机、水泵、水轮机和发电机都工作在效率最高的满负荷状态。

火力发电的一个重要问题是污染。火力发电的污染包括：排放二氧化硫对大气的污染，烟尘和灰渣固体排放物污染，锅炉排污水的污染等。火力抽水－蓄能发电系统实质上相当于在水库旁边建火电厂，因此，环保问题(包括循环水产生的热污染) 必须妥善解决。火力发电需要消耗大量的水，为了循环水的供应和排放的方便，有一些火电厂就建在江河湖海旁边。例如，青岛、威海、厦门嵩屿等电厂建在海边。福建樟平、邵武、永安等电厂建在江河边。这些电厂在水体的环境保护方面应该有可供借鉴的经验。

4 火力抽水－蓄能发电的其它优点

火力抽水－蓄能发电系统不仅有比传统的抽水蓄能发电更高的效率，而且还有另外的一些优点。

4.1 节约冷凝器循环水

火电厂循环水的消耗量十分巨大。火力抽水蓄能发电系统可以利用水泵抽水的水流作为汽轮机凝汽器的冷却循环水。例如，300 MW 汽轮机的冷凝器循环水流量约6～14 m^3/s。而300 MW 水泵的抽水流量约100～300 m^3/s(与扬程有关)，水泵抽水的流量完全可以满足冷却循环用水量的需要，无须像火电厂那样使用专门的循环水，减少了水资源的消耗。

此外，火力抽水－蓄能发电系统有可能完全不用循环泵，直接用水泵抽水的进口水流对冷凝器进行冷却。考虑到进口水流的压力比较低，需重新设计冷凝器的结构，增大散热面积，以满足冷却要求。由于循环泵耗电占发电厂用电的相当大的比例，取消循环泵将会十分明显地降低厂用电率和供电煤耗率。

4.2 深度的调峰能力

火力抽水－蓄能发电系统的组成是非对称的。例如，专门用于调峰运行的火力抽水－蓄能发电系统，与额定容量300 MW 的锅炉－汽轮机－水泵配合的水轮发电机的容量可以是600～900 MW。由于水轮发电机组升降负荷的速率比汽轮发电机组高，启停过程短，火力抽水－蓄能发电系统具有良好的调频和调峰性能。

传统的抽水蓄能电站的设备利用率很低。由于抽水蓄能电站是利用夜间用电低谷时间抽水的，装机容量600 MW 的抽水蓄能电站的水泵每天只有约9～10个小时的时间抽水，相当于一个24小时连续工作的250 MW 水泵，只能维持600 MW 的水轮发电机组工作7～8小时。而容量为300 MW 的火力抽水系统连续24小时抽水，可以供600 WM 的水轮发电机组发电10个小时，设备利用率明显提高。火力抽水－蓄能发电系统的调峰电量比传统的抽水蓄能电站多25%。

与传统的抽水蓄能电站相比，火力抽水－蓄能发电系统可以有更加灵活的运行方式，抽水时间不受电网状况的限制；发电时间和功率也可任意改变，既可作为调峰厂，也可参加基荷发电，或者作为事故备用。

4.3　系统的安全性提高

火力发电厂的锅炉、汽轮机和发电机是一个串联的系统, 其中任何一个环节发生故障都可能使整个系统突然停止工作, 发电机解列。发电厂突然停止输出电能将严重影响整个地区电网的稳定和安全, 影响供电的可靠性。而"火力抽水－蓄能发电系统"中的锅炉－汽轮机－水泵系统是与水轮发电机系统并行工作的。锅炉－汽轮机－水泵系统的故障可能造成水泵抽水中断, 影响高水库的水位, 可能影响若干小时以后的发电量, 而不会立即影响发电机发电。通常, 锅炉和汽轮机系统的故障概率高于发电机的故障概率。在"火力抽水－蓄能发电系统"中, 能直接影响电网的是水轮发电机组的故障, 所以, 总的故障概率明显低于火力发电厂。此外, 水轮发电机系统通常是包含两台以上的水轮发电机组。单台水轮发电机组的容量通常比单台亚临界凝汽式中间再热汽轮发电机组的容量小得多, 单台水轮发电机组的故障对整个电网的影响也相应地小得多。因此, 火力抽水－蓄能发电系统的可靠性和安全性比普通的火力发电厂高, 而整个电网的可靠性和安全性也相应得到提高。

4.4　减少投资

建设火力抽水－蓄能发电厂的投资比分别建设一个同容量的火电厂和抽水蓄能电站投资少(见表 1)。

表 1　以 300 MW 系统为例, 两者的主要设备

	锅炉	汽轮机	水泵	发电机	升压变压器	降压变压器	电动机	水轮发电机组
火力抽水－蓄能发电厂	1 000 t	300 MW	300 MW	－	－	－	－	600 MW
火电厂＋抽水蓄能电站	1 000 t	300 MW	600 MW	300 MW	300 MW	600 MW	600 MW	600 MW

与"火电厂＋抽水蓄能电站"相比, 火力抽水－蓄能发电厂的主要设备少了; 发电机, 升压变压器, 降压变压器, 电动机各一台; 水泵的容量也小一半。这些设备及其辅机的减少可节省约一亿元人民币的投资, 大约相当于一座 300 MW 火电厂投资的 6%。

以调峰为主的火力抽水－蓄能发电厂不需要很大的库容, 水工建设投资也比较小。建设火力抽水－蓄能发电系统不一定要全套新建, 可以将火力抽水系统建在现有的水电站旁边, 组成水力发电－火力抽水－蓄能发电复合系统。这样的系统在平水期和枯水期都能有比较大的发电量, 即可以作为有深度调峰能力的基荷发电厂, 又可以提高水轮发电机组的设备利用小时, 还可以减轻以水电为主的省区电网的电力生产受季节影响的程度。

5　结束语

我国是一个发展中国家, 电力的生产和消费水平远远低于发达国家。随着经济发展对电力需求的增长, 很多地区有新建大型火力发电厂的需要。同时, 由于调峰困难, 抽水－蓄能电站的建设也已经纳入以火电为主的地区电网建设规划。对于既需新建火电厂又需新建抽水－蓄能电站的地区来说, 如果把一部分规划建设的火电厂与抽水－蓄能电站改为建设火力抽水－蓄能发电厂, 则不仅可以从长远解决电网的调峰问题, 同时又提高了整个系统的发电效率和安全性, 降低发电成本, 经济效益十分明显。

(渠　源　编辑)

IGCC 在炼油厂大有用武之地

据《Gas Turbine World》2000 年 9—10 月号报道, 意大利 Saras 炼油厂 550 MW 整体煤气化联合循环(IGCC)装置原来自 3 月起以馏出油运行的三台联合循环装置已于今年夏天转变到合成气运行。

气化器试运转和利用合成气的点火已在 7 月中旬举行。

IGCC 设计使用 Texaco 夹带床气化过程, 以便气化来自 Saras 炼油厂的石油精炼残渣, 生产供炼油厂运行用的电力、蒸汽和氢气。

电力也销售给意大利国家电力管理局 ENEL, 并通过撒丁岛的电网给市政配电。

动力岛包含三个单轴 S109E 联合循环组件。每个组件包括一台 MS9001E 燃气轮机、一台冷凝式汽轮机、一台双端发电机和一台余热锅炉。

该装置成功的运行充分表明, 利用炼油厂残渣作为燃料的 IGCC 装置在热电联产中是大有可为的。

(思娟　供稿)

simulation, power plant system

铸铁锅炉爆破压力的热态试验和理论分析＝**Hot-state Explosion Pressure Test of a Cast-iron Boiler and Its Theoretical Analysis** [刊, 汉] / LIU Wen-tie, HE Yu-rong, LI Zhi-hong (Energy Engineering College under the Harbin Institute of Technology, Harbin, China, Post Code: 150001), BAI Wu-yin (Shijiazhuang Baoshi Electronics Group Co., Shijiazhuang, Hebei Province, China, Post Code: 050061) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(4). —434 ~ 436

On the basis of the test results of a full-scale hot-state explosion test a calculation and analysis was conducted of the explosion pressure of the following: square-box test parts, nodular cast-iron boiler, grey cast-iron boiler and grey cast-iron boiler plates. As a result, obtained were the relevant safety factors recommended for selection. The tests and analysis indicate that the safe and reliable operation of cast-iron boilers can be assured. **Key words**: hot-state explosion test, cast-iron boiler, explosion pressure, safety factor

流化床中焚烧有机废液的热力特性分析＝**Thermodynamic Analysis of the Burning of Organic Waste Liquid in a Fluidized Bed Incinerator** [刊, 汉] / BIE Ru-shan, LI Bing-xi, LIU Wen-tie, LU Hui-lin, YANG Li-dan, ZHOU Ding (Energy Engineering College under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(4). —437 ~ 440

With coal serving as an auxiliary fuel heat balance equations were established for the burning of organic waste liquid in the dense-phase zone and rare-phase zone of a fluidized-bed incinerator. By solving for these equations determined were the following: 1.The ratio of waste liquid being incinerated in the dense-phase zone as calculated against the total incinerated quantity; 2. Characteristics curves showing the effect of the incineration temperature in the dense-phase zone, excess air factor at the furnace outlet and the preheating air temperature on the consumption of the auxiliary fuel and the furnace outlet temperature. The results of calculation indicate that with the ratio of the waste liquid incinerated in the dense-phase zone being kept at 70% of the total incinerated quantity the temperature in the dense-phase zone can be roughly maintained at the same level as that at the furnace outlet. Moreover, it is highly desirable to control the dense-phase zone temperature at 850 - 900 ℃ in order to reduce the consumption of auxiliary fuel and to limit the excess air factor at less than 1.7 in order to maximize the preheating air temperature. The above findings can serve as a theoretical basis for the design and operation of fluidized bed-based waste liquid incinerators. **Key words**: organic waste liquid, fluidized bed, incinerator, auxiliary fuel consumption

WDR 系列 0.35 ~ 1.4MW 电热锅炉及其设计＝**WDR Series 0.35 - 1.4 MW Electric Heating Boilers and Their Design** [刊, 汉] / CAO Xi-gong (Technology Center of Zhengzhou Boiler Works, Zhengzhou, Henan Province, China, Post Code: 450052) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(4). —441 ~ 443

Electric heating boilers enjoy the following merits: no noise, no pollution, advanced technology, simple fabrication, compact construction, safe and high-efficiency operation, etc. A detailed account is given of the structural design and specific features of the WDR series 0.35 - 1.4 MW pressure-bearing electric heating hot-water boilers. **Key words**: electric heating, pressure-bearing hot water boiler, cylindrical body, heating surface, specific features

活性炭联合脱硫脱硝工艺＝**Activated Carbon-based Combined Desulfuration and Denitration Technology** [刊, 汉] / LUO Yong-gang, LI Da-ji, YANG Ya-ping (Research Institute of Thermal Energy Engineering under the Southeastern University, Nanjing, China, Post Code: 210096) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(4). —444 ~ 446

Described is a kind of new technology featuring combined desulfuration and denitration. With the use of this technology it is possible to remove such a variety of items as SO_X, NO_X and poisonous matter in flue gas like mercury, dioxin, etc. The merits, demerits and the development trend of the above-cited technology have also been presented. The information provided may serve as major reference data for the treatment of air pollution in China. **Key words**: desulfuration, denitration, activated carbon

火力抽水—蓄能发电＝**Thermal Power and Pumped Storage-based Electric Power Generation** [刊, 汉] / SHENG Jian-lun (Computer Department, Qingdao Architectural Engineering Institute, Qingdao, Shangdong Province, China,

Post Code: 266033) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(4). —447 ~ 449

Presented is a highly cost-effective mode of electric power generation, the so-called thermal power and pumped storage-based electric power generation. Under the above-mentioned power generation mode a steam turbine directly drives a water pump for pumped storage power generation, thereby reducing the secondary energy conversion link and making it possible to enhance power generation efficiency by 11%. The boiler, steam turbine and pumps all can operate at a full rated load, thus attaining the maximum efficiency. Moreover, the thermal power and pumped storage-based power generation system enjoys a higher operational safety, a better peak load shaving capability and greater savings in condenser circulating water. Furthermore, it also entails a moderate investment outlay. **Key words**: thermal power and pumped storage-based power generation, peak load shaving, electrical power economy

逆向 FTF 方法在船用燃气轮机故障分析中的应用= **The Application of Reverse FTF Method in the Fault Analysis of Marine Gas Turbines** [刊, 汉] / LIU Yong-bao (Naval Engineering University, Wuhan, China, Post Code: 430015), HAN Feng-ke (Harbin Turbine Works, Harbin, China, Post Code: 150046) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(4). —450 ~ 452

Discussed are the specific features of FTA (failure tree analysis) and FMECA (failure mode effect criticality analysis) as well as the interrelationship between the two methods of analysis. On this basis the authors have come up with a reverse FTF (FTA + FMECA = comprehensive analysis method) method to analyze system reliability. With the help of the above-cited method a quantitative analysis was conducted of the start-up failure of a marine gas turbine with vulnerable links in the turbine system being identified and practical countermeasures suggested. **Key words**: failure analysis, fault tree analysis, gas turbine

燃用褐煤锅炉改烧烟煤时干燥剂的计算及选取= **The Calculation and Selection of Drying Agents in Connection with the Change of Fuel for a Boiler from Brown Coal to Bituminous One** [刊, 汉] / SHU Ji-wei, MENG Fan-bing (Energy Engineering College under the Harbin Institute of technology, Harbin, China, Post Code: 150006), HUANG Qi-long (Heilongjiang Provincial Electric Power Research Academy, Harbin, China, Post Code: 150030) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(4). —453 ~ 456

Contrast tests were conducted concerning a 200 MW brown coal-fired boiler prior to and after its modification to firing bituminous coal of Heilongjiang Province. During the tests it has been found that after a change of coal to the bituminous one the boiler enjoyed a stable combustion and basically attained the same design efficiency as that of the brown coal-fired boiler. No severe slag-formation has been detected. However, regarding the pulverized coal preparation system there was an excessively high temperature and oxygen content of flue gas at the coal mill outlet. Through a renewed thermodynamic calculation and selection of the drying agent it was decided to adopt a more rational drying mode involving the use of "high-temperature boiler flue gas + hot air + pressurized cooling air". The latter can also meet the explosion-proof requirements of the pulverized coal preparation system. **Key words**: brown coal, bituminous coal, pulverized coal preparation system, drying agent

邻炉高温风加热技术的应用= **An Exploratory Study on the Technique of Using High-temperature Air from a Neighboring Boiler** [刊, 汉] / MENG Xiang-jun (Changjiakou Xiahuayuan Power Plant in Hebei Province, Changjiakou, Hebei Province, China, Post Code: 075300) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(4). —457 ~ 458

Prior to conducting the start-up of a peak load-shaving boiler it is essential to enhance the metal temperature of its various components. This plays a very unique role in attaining the rapid and stable ignition and burning of the pulverized coal at the early period of the boiler start-up. In view of the above one should pay due attention to improving the high-temperature air heating system of a neighboring boiler so that the high-temperature air can be made available during the whole process of a boiler start-up. The addition of a recirculation pipe for the neighboring boiler high-temperature air may improve the above-mentioned heating system and render its design more rational. **Key words**: boiler, high-temperature air, heating system