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Modeling of a solar power plant in Iran

M.R. Shahnazari*, H.R. Lari

Department of Mechanical Engineering, K. N. Toosi University of Technology, Tehran, Iran

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ABSTRACT

Parabolic Trough Concentrating Solar-thermal Power (CSP) technology represents one of the most promising options among available CSP systems for generating renewable electricity at utility scale. Within geographical boundaries of the Islamic Republic of Iran, there are a large number of potential sites with solar insolation levels around 1800kwh/m^2.yr. The power plant complex in Yazd (a city in middle of Iran) is selected as a study site. Two computational codes are used for modeling of different configurations of solar power plants. These are the Pilksolar's performance model and Fichtner's cycle process calculation software. In this article two plant configurations are considered. They are the standalone solar electricity generating system (SEGS). And, integrating a solar field into a combined cycle plant, the Integrating Solar combined cycle System (ISCCS). Performance calculations for these configurations are carried out and a comparison between the methods is made. It shows that integrating solar plants into the Iranian grid may be considered as an action to counter production losses from the gas turbines due to high summer ambient temperatures.

1. Introduction

Compared to other renewable energy technologies, the solar thermal power industry is a relatively new industry with a limited operational experience. The rapid growth over the past few years has led to a fast development in Concentrated Solar Power (CSP) technology and to an increase in the scale and complexity of projects and associated risks. From an International Energy Agency study, it is estimated that by 2050 CSP could provide 11.3% of global electricity comprised of 9.6% from solar power, and 1.7% from backup fuels (fossil fuels or biomass). In the sunniest countries, CSP can be expected to become a competitive source of bulk power in peak and intermediate loads by 2020 and of base-load power by 2025–2030 [1].

During the last decade the overwhelming majority of new electric generating capacity in the I.R. IRAN has been in the form of natural gas-based technologies. Over 90% of the approximately 78,000 MW of nameplate capacity that was added to the generating portfolio from 1995 to 2015 use natural gas as the primary fuel. Further, a significant amount of this capacity was built came in the form of 2-on-1 combined cycle power plants equipped with supplemental duct-firing capacity in the HRSG to provide low-cost peaking capacity. The steam turbines in these plants are sized to accommodate the additional steam resulting from duct firing.

Islamic Republic of Iran is keenly interested in large-scale exploitation of its abundant solar resources, specifically by means of Concentrated Solar Power technology. The principal rationale of this interest is the Iranian Government's strategic goal of diversification of its power production basis and even more efficient energy consumption and prolongation of the country's oil and natural gas reserves.

Starting in the early 1990's, several pre-feasibility studies discussed the application of solar thermal electric power in Iran [2–4]. The objective of this paper is to evaluate the best configuration to integrated solar energy into the existing thermal power plant complex, specifically using commercially-proven parabolic trough solar technology. This paper is the results of Feasibility Study of the First Solar Power Plant in Iran that had been done according to a contract with Fichtner Solar GmbH, Pilkington Solar International GmbH [4].

2. Solar power plant technology overview

Upon introduction of Parabolic Trough Collector Technology Between 1984 and 1991 which is the most matured solar thermal concept among other CSPs' like Solar Tower(ST), Fresnel Reflectors(FR), and Solar Dish(SD) for utility size electric power generation, nine solar thermal power stations of the parabolic trough

* Corresponding author.
E-mail address: Shahnazari@kntu.ac.ir (M.R. Shahnazari).

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collector type, with unit capacities ranging from 14 to 80 MWe, have been built in the Californian Mojave Desert. LUZ International was the project developer, designer, constructor and operator of these largest solar power stations ever built, called SEGS (Solar Electric Generating Systems).

The SEGS I facility consists of 82,960 m^2 of collector aperture area used to heat a mineral-oil-based heat transfer fluid (HTF), which in turn passes through a steam generator to generate steam at 35.3 bar for a conventional steam-turbine power cycle. In this system the solar field energy is used to preheat feed water and generate steam, and a natural-gas-fired independent super heater raises the steam temperature to 415 °C. Two large hot and cold storage tanks (with a capacity of about 3220 m^3 each) provide enough storage to produce nearly 3 h of full-load turbine operation. The solar field was constructed entirely of LUZ LS-1 collector technology. SEGS I went on line in December 1984. Fig. 1 shows a schematic flow diagram of the SEGS I plant.

Work commenced on SEGS II in early 1985. This plant was a 30 MWe facility with a solar field comprised of both LS-1 and the next generation LS-2 collectors (see Table 1). The SEGS II plant introduced a major and very important design concept to the SEGS plants. A natural gas boiler was added to the plant configuration in parallel with the solar field. That is, turbine steam can be supplied either by the solar field or by the natural gas-fired boiler. The concept of an alternate fossil-fired source of energy was incorporated in all subsequent SEGS plants. Once the concept of a hybrid plants able to operate on solar or natural gas was conceived, its benefits became apparent. Such a plant has the capability to operate under any conditions of low insolation (e.g., inclement weather or night) and provides a reliable capacity for any special needs that the utility might have. By federal law, the energy supplied by natural gas is limited to 25% of the total effective annual thermal plant energy input (specifically, by regulations of the U.S. Federal Energy Regulatory Commission). LUZ continued developing 30 MWe SEGS plants on a yearly basis. Table 2 summarizes the characteristics of all the SEGS installations. Several factors contributed to advances in collector and plant performance as SEGS III through SEGS VII were developed. Improvements in the collector technology led to higher temperatures, which in turn allowed higher steam-turbine cycle efficiencies.

Plant capacities were at first restricted to 30 MWe net by federal regulations for PURPA power plants. In 1989 this regulation was suspended, permitting further economies-of-scale in the development of 80 MWe plants. Further economies were realized by planning a “power park” of five 80 MWe plants at a single site in which common facilities could be utilized for interconnection to the grid, raw water supply and treatment, fire protection, control building and administration. While the technology know-how and experience grew, costs were reduced through the larger units, through better performance and efficient sourcing of components. Fig. 2 shows the investment costs, the annual full load hours (capacity factor) based on performance in the year 1993, and the calculated LEC. Since the inception of SEGS I, advancements in the mechanical structure and operating parameters of the LUZ solar collector technology resulted in a steady increase in the outlet temperature of the SEGS solar field, from 307 °C in the first generation LS-1 collector design to 349 °C in the second generation LS-2 used in SEGS III-V. Further advances, notably the introduction of a

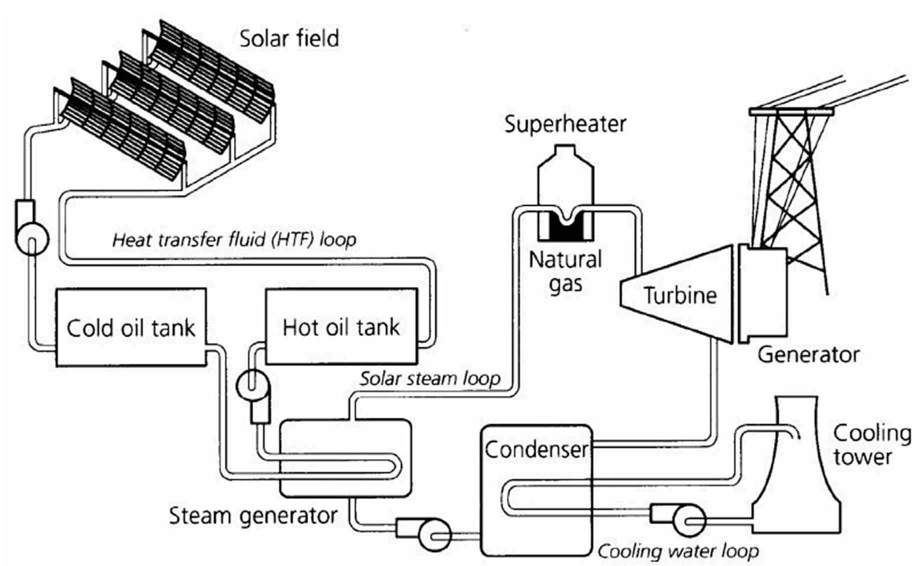

Fig. 1. Schematic diagram of SEGS I plant.

Table 1
Basic characteristics of SEGS I-IX.

Plant	1st Year 1985Operation	MWe net	SF Temp. (°C)	SF Area (m2)	Turbine Effic.(%) Solar	Turbine Effic.(%) Nat.Gas	Annual Output (MWh)
I	1985	13.8	307	82,960	31.5	–	30,100
II	1986	30	316	190,338	29.4	37.3	80,500
III/IV	1987	30	349	230,300	30.6	37.4	92,780
V	1988	30	349	250,560	30.6	37.4	91,820
VI	1989	30	399	188,000	37.5	39.5	90,850
VII	1989	30	399	194,280	37.5	39.5	92,646
VIII	1990	80	399	464,340	37.6	37.6	252,750
IX	1991	80	399	483,960	37.6	37.6	256,125