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REVIEW ARTICLE

SOLAR THERMAL: TECHNICAL CHALLENGES AND SOLUTIONS FOR POWER GENERATION

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ABSTRACT

As the largest source of energy to the earth, solar is the promising source to meet the increasing demand of clean energy. The objective of the current paper is to briefly highlight the obstacles and challenges facing the utilization of solar energy in the energy transition initiative. The transition from fossil-based power to renewable based power is found to have not just technical problems as there are social, financial and investor concerns. The paper focuses on the technical problems and the possible solutions that has been achieved or under investigation to overcome the challenges in the solar technologies by the author and his research team in the solar thermal advanced research centre in Universiti Teknologi PETRONAS. Those achievements are part of the commitments of this solar research team for going heavily towards solar energization in the globe.

KEYWORDS

solar, power generation, energy, fossil-based power

1. INTRODUCTION

As a matter of truth, the 21st century prodigious economy development would not be possible to achieve without power resources at each activity in the human and industrial lifecycle. But when the power history starts? In their blog, Super Green Solutions posted that "one of the most famous entrepreneurs of all time, Thomas Edison, said that necessity is the mother of invention: For your entrepreneurial solutions to succeed, they must address a real problem that many people face, [1].

1.1 Historical remarks on power generation

In almost all the scholars, starting of power history is related to electricity generation. Faraday method is the igniter for the power history, started from 1820 and early 1830. In 1870, commercial electricity production started with the coupling of the dynamo to the hydraulic turbine. The first central power generation started in 1882 in US when coal fired Pearl Street Station was implemented to produce DC current for lighting Pearl Street in New York. Sooner after that, the electric power generation was used for lighting of buildings and powering public transports like trams and trains [2].

The steam turbine and improved steam-generating equipment made possible the larger plants that were needed to make electricity economical. The polyphase AC system gave electricity the reach and flexibility essential to wide-scale application [3].

In 1896, about a decade after Charles Parsons developed his steam turbine generator, he offered an invention of a different turbine to the General Electric Co. (GE). By 1901, GE had successfully developed a 500-kW Curtis turbine generator, and by 1903, it delivered the world's first 5-MW steam turbine to the Commonwealth Edison Co. of Chicago. Innovations in aircraft and manufacturing technology advancements during both World Wars boosted gas power technology to new elevations. Development of jet engines permitted its know-how to develop gas turbines for industrial application. In 1948, GE installed its first commercial gas turbine for power generation, a 3.5-MW heavy-duty unit at the Belle Isle Station owned by Oklahoma Gas & Electric in July 1949 [4].

In addition to these key developments, which might be called the foundations on which today's electrical systems are built, the past 125 years have seen many other advances. They include the invention and application of new prime movers; first is the diesel and then the gas turbine, followed by what is now the ubiquitous combined cycle power plant [3]. Some professionals consider that because that GE 3.5-MW unit at the Belle Isle Station used exhaust heat for feed water heating of a steam turbine unit, it was essentially also the world's first combined cycle power plant [4].

1.2 Current Scenario of Energy resource

Over the time, power covered the addition of each new power-generating source; from water and coal to oil and gas to the atom and, more recently, the wind and solar. While new power sources were added, improvements in old technologies continued to be made, targeting cleaner-burning coal, safer nuclear plants and performance enhancement. Until now, about 40% of electric power is generated by thermal power plants using coal, 25% of it is generated by combusting natural gas or oil petroleum. Nuclear are producing around 13-14% of electricity and hydro power is 16%. Other resources like wind, solar PV, solar thermal and geothermal are producing 4%, while biomass contributes by 2% for electric power generation. However, the natural gas power sector, which today takes the lion's share of both installed capacity and generation, was slower to replace the existing coal and oil fuel based power generation.

On the renewable energy resources, solar seems the main focus as a clean source for the 2050 energy demand and above. The coming 30 years are representing the research challenge to overcome the lacks and challenges in solar technologies, including PV, bio-solar and thermal conversions. This paper presents some of the humble efforts paid by the researchers in the Solar Thermal Advanced Research Centre to resolve some of the technical challenges in solar technologies.

2. OPPORTUNITIES OF SOLAR POWER

In 2014, the total word energy demand is around 16 TW. This figure is estimated to increase to around 21 TW in year 2020 and goes up to 25-30 TW and 40-50 TW in years 2050 and 2100, respectively. Earth receives 120,000 to 125,000 TW at its surface, every year. Rough estimation tells that this energy is around 5000 times the required total energy of the world in year 2020. In 2012, the total world energy consumption is around 559.8 EJ which is several times larger than the total world need. [5].

Radiation from sun can be utilized in different types of energy forms and applications such as electric power generation, water and/or air heating for industrial process, space heating, greenhouse plantation and day lighting. Generation of electricity from harvested solar can be achieved by two methods of energy conversion. First is; solar radiation-to-electricity through solar-to-chemical conversion as in various types of photovoltaic solar cells (PV). Second is; solar radiation-to-electricity through solar-to-thermal conversions as in various types of solar absorbers and concentrators. The solar thermal technologies may be categorized according to the grade of temperature in the solar conversion system. In high temperature solar power generation, higher than 100 oC, there are four main types of technologies, which are all using concentrated solar power (CSP) technology. In the low temperature solar power generation, less than 100 oC, there are two types which are based on artificial air stream creation using updraft solar power (USP) technology. The classification of solar thermal technologies for power generation is summarized in figure 1.

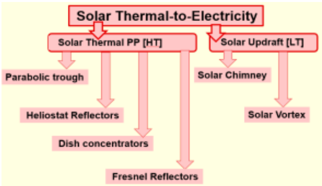

Figure 1: Classification of solar thermal power technologies.

Opportunities for solar to be a major source of future energy is raising day by day due to the facts that it is renewable, clean and available in large areas around the earth. Solar is going to be a major contribute to sustainable development and job creation where it is going to be installed. In addition, solar technologies, summarized in figure 1, are generally simple and can be implemented in large scale for centralized power generation, and in rural areas, for standalone and localized power generation.

Solar energy has opportunity not only from the point of technical view, but also from economical point of view. Countries that are going towards solar utilization will reduce the dependency on imported fuels. By that, the government can save wealth for local development. In addition, solar industry will open great opportunities for job creation through production industry, research & development and employment of local staff for solar projects management and maintenance.

3. TECHNICAL PROBLEMS AND SUGGESTED SOLUTIONS

In fact, there are three major technical setbacks in the solar-to-power approach. First; the main setback is the low conversion efficiency of the solar-to-power. Second; is that the harvesting of solar energy is requiring large size land to become feasible. And the third issue is the interruption during the night and cloudy days. In addition, there are some other problems in each particular solar technology which are pushing towards research and development by the solar research centres, universities and the related industries. Below are some ideas to partly or fully resolving the main three issues.

3.1 Low conversion efficiency

So far, all the technologies on solar-to-power conversion are still relatively low. Mean efficiency of PV is around 15% to 20%. Mean efficiency of solar updraft is still very low, at around 2% at its best, with large scale plants. Demonstrated annual solar efficiency of CSP are varies as 8%-10% for solar power tower, around 16-18% for the solar dish, around 10-15% for the parabolic trough and 9%-11% for Fresnel reflectors. Table 1 presents comparison of the efficiencies of CSP technologies.

Table 1: Comparison of efficiencies of CSP technologies (extracted from [6])

Type of CSP	Solar Power tower	Parabolic trough	Fresnel reflectors	Solar dish system
Standard plant size (MW)	10-150	10-200	10-200	0.01-1.5
Max efficiency ,%	22	24	20	30
Specific power, W/m^2	300	300	300	200
Demonstrated annual solar efficiency (%)	8-10	10-15	9-11	16-18

3.1.1 Enhancement by nano-paint coating

Among the attempts carried out in STARC is the testing of black nano-paint to enhance the optical properties of the solar absorbing surfaces in solar air collector. Tests of different types of nanoadditives to enamel black commercial paint have demonstrated good enhancement in solar-to-thermal process. Using 5%wt Aluminium additive to the enamel paint to coat Aluminum absorber resulted in improvement of solar conversion efficiency, where air temperature rise increased by 33% and the collector efficiency was improved by 28.5%, compared not painted absorber.

3.1.2 Enhancement by artificial roughening

Another enhancement in the solar conversion efficiency was achieved by artificially roughening the absorber surface. Literature present many techniques for artificial roughening to enhance the convection heat transfer including installation of ribs, fins and many other types of turbulators. The idea is to break the laminar sublayer near the absorber surface and enhance the heat transfer coefficient. In STARC, new protrusions having shape of pins, were tested in solar air heater. Many sizes and arrangements have been tested. The solar conversion efficiency has been increased by up to 26.5% for absorber plate with 16 mm pin pitch and 4 mm height, as compared to flat smooth plate. [7]

3.2 Land for solar harvesting

Solar power has a low density per unit area. It is around 0.1 kW/m2 to 1.0 kW/ m2 depends on the location on the earth and time of the day, month and year. Solar harvesting requires a large ground area by the collectors to harness feasible and sufficient amount of solar energy. The collectors can be concentrating type or non-concentrating type.

3.2.1 Land for non-concentrated solar and PV

Non- concentrated solar technologies may be the PV or solar updraft. A solar chimney power plant with 6000 m of collector diameter and with1000 m of SC height is designed to deliver a maximum electric power of 200 MW, for solar irradiation of 2.30 MWh/m2, on a summer noon.

There are fast growing societies with limited land availability for solar concepts like Singapore, South Korea, Japan…etc. Also, many coastal resorts and tourist areas located in isolated areas from centralized power production plans. The transport of power may not economically feasible due to the tough geographical nature. Sample of that is existing in west part of Malaysia, the Caribbean countries, Indonesia…etc. Floating solar is representing great opportunity to resolve the land problem. STARC researchers are working in collaboration with HelioRec –France to tackle the problem by floating solar. The proposal of a research under planning is to recycle the waste plastic, mainly the used water bottles, to produce floating decks. The decks have a novel design structure which permit solid floating base to install solar PV for power generation. Some proposals have been reported in terms of Intellectual Property rights on floating USP. In 2015, [8] presented a novel solution, through US Patents, US9049752 B2, for extracting work for the production of electricity by a heat engine powered by the solar heat put on the surface of the oceans.

In addition to the land saving for housing, plantation, urban development, floating solar has many advantage in terms of technicality, compared to the installation on land. Floating solar is more compact and simpler to be managed with lower cost for constructions in the land. If the floating solar is performed in a lake surface, it has the advantage of saving water evaporation and also may use the lake water for PV cooling. In addition, there is a big advantage of utilising platform tracking, which is really contribute to enhance the harvesting of solar radiation, which is very complicated in the land and requires sophisticated mechanisms to orient the collectors or the PV towards the high incident solar beam.

3.2.2 Land for concentrated

An approximate land surface of 115 ha is required for each 50 MWe plant (Concentrating Solar Power Projects, 2016). This area per 50 MWe is sufficiently large to prevent the shadowing effect caused by shade cast between solar collectors on a mounting area during full sunny hours, which can reduce the efficiency of the system. It can also provide the space required for the conventional thermal components of a plant [39]. Table 2 presents approximation of the required land for each CSP technology and the estimated capital of each technique.

Table 2: Comparison of the required land and the experienced capital for CSP technologies (extracted from [6])

Type of CSP	Solar Power tower	Parabolic trough	Fresnel reflectors	Solar dish system
Land use (m²/MW ha)	8-12	6-8	4-6	8-12
Cooling water (L/MW h)	1,500 or dry	3,000 or dry	3,000 or dry	None
Capital cost ($/W)	2.4-3.62	2.9-3.22	2.8-3.0	2.65-2.9

3.3 Demand/Production mismatch

Solar as energy resource has the setback of interrupted supply or input to the energy generation system. The solar time during the day is differing according to the location. Generally speaking, solar input is available around 8 hours a day, mostly from 7.00-8.00AM to 5.00-6.00PM. PV may start producing electricity earlier than the solar thermal plants. The possible solutions to this dispatch are: a. connection with the national grid, b. integration with energy storage and c. integration with other resources.

3.3.1 Connection with the national grid

By connecting the solar power system to the national grid, then the produced power is fed to the national grid. Many research works have been published and many projects have been implemented on the PV and CSP that are connected to the national grid and supply what produced power during the day to the network. In some applications, the solar power system is utilized to balance the over-demand and the heavy loading of the national grids.

3.3.2 Integration with energy storage

The problem is existing with the standalone solar system. Possible solutions are the integration with other types of resources or integration with energy storage(s). Integrated energy storage provides the ability to shift electricity generation to meet the demand, as presented schematically in figure 2.

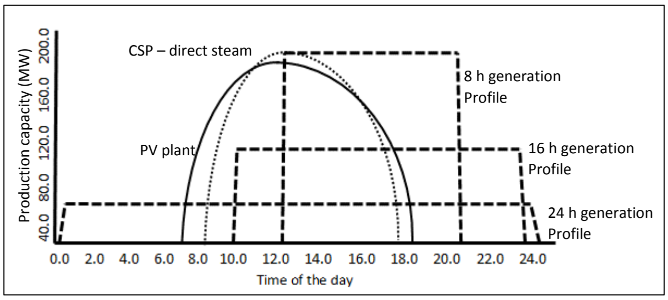

Figure 2: Production scenario of integrated solar plants with energy storage

3.3.3 Integration with other resources.

Among the solutions for the production mismatch during the absence of the solar irradiance are integration with energy storage and/or integration with another source of energy. Large numbers of research works and applications have been presented in the literature on the battery storage and TES storage. In STARC, a new TES nanocomposite has been developed and patented under MyiPO PI 2013001609 [9]. Integration with another source of energy is suggested by [10] where a model of solar chimney integrated with flue gas is evaluated and demonstrated 24/7 functioning of the SCPP for power generation. The integration arrangement of the proposed solar hybrid system is shown in figure 3.

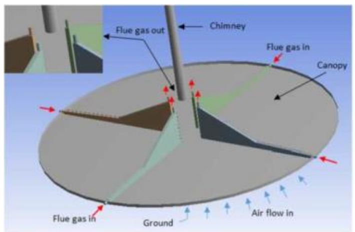

Figure 3: Layout of the proposed HSC model showing the added TECs

4. CONCLUSIONS

The paper presents a brief on the setbacks of solar technologies which are requiring considerable attention by the R&D bodies to bring the solar to the top of renewable and clean energy resources for the future, with low GHG emission. The need of energy by human to sustain civilization development is estimated to increase to around 21 TW in year 2020 and goes up to 25-30 TW and 40-50 TW in years 2050 and 2100, respectively. Solar, as the largest energy resource to the earth, is providing around 120,000 to 125,000 TW every year. Comparing the figures of energy supply and demand gives the hope for solar to cover the major need of the human for energy. But, technical problems are obstacle the hope to be reality and breakthrough in the solar energy conversion is certainly required to make reality for the solar to be the lion of energy resources.

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