Design and Manufacturing of Parabolic Trough Solar Collector System for a Developing Country Pakistan

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Abstract: Pakistan's thirst for electric power has been constantly rising over the years because of population growth, increase in industrial activity and failure of other resources for producing enough energy to meet its growing energy demand, particularly in the remote areas where energy is most needed. Pakistan is basically an energy deficient society and now going towards extreme energy crisis. Moreover, with current demand growth at 8 % annually, Pakistan will have to add 4000 MW to its existing capacity by the year 2018. Pakistan is rich in renewable energy resources; particularly solar energy has a special relevance in Pakistan due to high availability of Sun radiations at an average rate of 4.5-6 kwh / m^2 / day. The purpose of this research is to reduce the cost of conventional power plant by focusing on simplifying the design of collector structure to achieve a high reflecting quality and tracking precision, using available cost effective components, minimizing field construction requirements, and by utilizing the advantages of design engineering and equipment specifications as per environmental impact at feasible locations in most remote and energy starved areas of Pakistan. Most of the area of Pakistan lies in sunny belt of the earth with the sun shine of 6 – 8.5 hours daily having the greatest amount of radiant energy more than 90% of solar radiation, which comes as direct radiation because of the limited cloud coverage and clear sunny weather is experienced 250 to 300 days a year. Different concentrating technologies have been developed or are currently under development for various applications. The Parabolic Trough Solar Collectors system will undoubtedly provide within next decade a significant contribution to efficient, economical, sustainable renewable and clean energy supply to developing countries with positive effect on environmental activities. The collector materials will be used considering conversion efficiency, abundance of the material, low cost structures, ease of application, expected lifetime, and the availability of space at the collection site. Available sites in Pakistan desert can theoretically cover the whole electricity demand of the country. A small configuration system like 25KW can lead to 100MW by scale up as sub unit of larger power plants. This will be the first step to fulfill the energy demand of Pakistan, which has become essential for our economic revival.

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1. Introduction

Renewable energy sources have also been important for humans since the beginning of civilization. Pakistan is facing severe energy challenges – indigenous oil and gas reserves are running out, energy demand is rapidly increasing, gap between demand and supply is growing, concerns about secure supply of energy are increasing and fuel cost is rising at an unprecedented rate. Pakistan has 84% dependence on oil and gas to meet its primary energy demands. It has an electrical power generation system with more than 19,404 MW of installed power, with 63.97% being generated by thermal resources. The emissions from power plants cause smog in cities and various undesired health complications for our children and us. Rapid progress in solar energy technology around the world went unnoticed in Pakistan for several years due to frequent shuffling of decision makers as well as absence of solar resource analysis. Several countries have planned solar energy participation in the active energy matrix. Because of the threats associated with dependence on use of oil and gas for generating power, now it is the time to evaluate commercial aspects of this technology in Pakistan and venture into this field by taking lead. It costs us nothing to get it--just free sunny days all over this country. There are almost no on-going costs; just build the plant and let it produce free power for well more than over 20 years because most of the area of Pakistan lies in sunny belt of the earth with the sun shine of 6 – 8.5 hours daily Fig 1.

Energy produced by sun is being used to produce heat and electricity and all essential requirements in a house like water heating, home heating, lighting, cooking and cooling in many parts of the world but not in Pakistan. Pakistan is presently in the process of developing various energy technologies. Solar option with its merits and demerits is also a promising technology of tomorrow and must be given its adequate place today so that we remain current with this technology once it is fully matured. The Solar system and the associated power with the sun cannot be effectively covered in few words. Currently, research in the field of solar power generation is very limited in Pakistan.

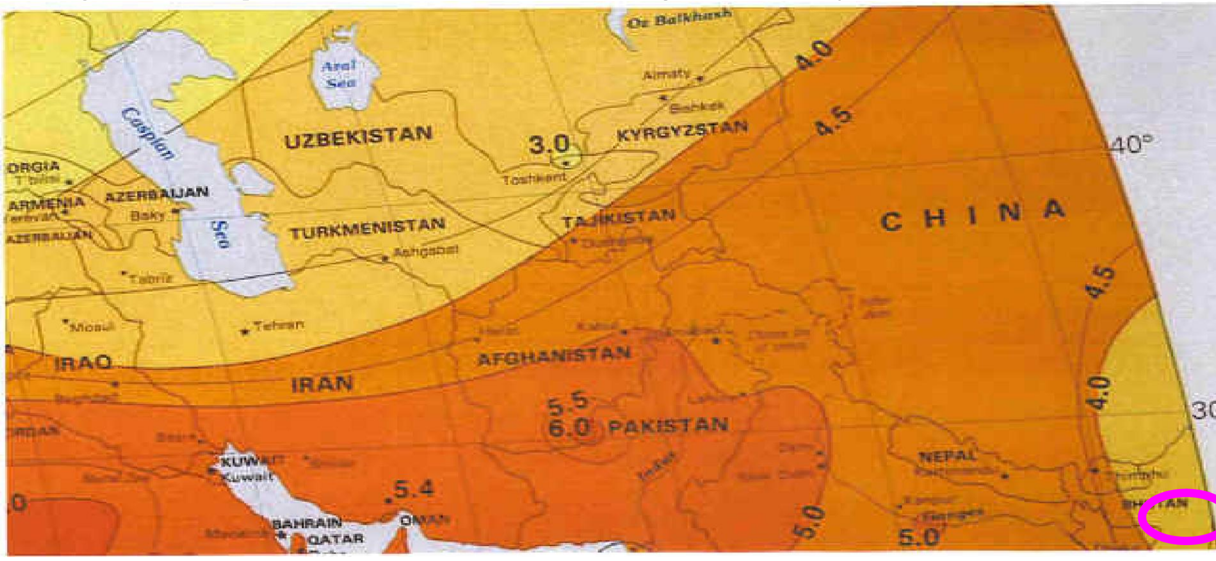

Fig.1. Solar insulation map of Pakistan (Courtesy of the Advanced Energy Group, http://www.solar4power.com)

2. Solar Thermal Power Technology

The idea of using mirrors to concentrate sunlight is not a new idea. It is said that, in 212 BC, Archimedes used polished bronze shields to focus sunlight, trying to set fire to wooden ships from the Roman Empire which were besieging Syracuse. Although we don't know whether this worked, the Greek navy recreated the experiment in 1973 and successfully set fire to a wooden boat at a distance of 50 meters. Leonardo da Vinci proposed the use of concave mirrors to heat water on an industrial scale. Parabolic trough solar technology is the most proven and lowest cost large-scale solar power technology available today, primarily of the nine large commercial-scale solar power plants that are operating in the California Mojave Desert. These plants developed by Luz International Limited and referred to as Solar Electric Generating Systems (SEGS), range in size from 14 - 80 MW and represent 354 MW of installed electric generating capacity. More than 2,000,000 m^2 of parabolic trough collector technology has been operating daily for so many years. The Luz collector technology has demonstrated its ability to operate in a commercial power plant environment like no other solar technology in the world. A number of new parabolic trough projects are currently in varying stages of project development around the world, some of these will include thermal energy storage. Energy Information Administration, Renewable Energy Annual (1996), Charles Smith Technology Review, (July 1995), Pilkington Solar International: (1996)

The three most promising solar thermal technologies are the parabolic trough, the central receiver or solar tower, and the parabolic dish. But in this paper only parabolic trough collector will be focused as being the proven and reliable technology. It has been successfully demonstrated in the Californian desert for two decades using commercial parabolic trough technology and steam turbines, achieving an annual field availability of 99 %. Pilkington Solar International: (1996)

2.1 Parabolic Troughs

A parabolic trough solar collector is designed to concentrate sun rays via parabolic curved solar reflectors onto a heat absorber element – a “receiver” – located in the optical focal line of the collector. Solar collectors track the sun continuously. The key components of a parabolic trough power plant fig.2 are mirrors, receivers and turbine technology.

The receiver consists of a specially coated absorber tube, which is embedded in an evacuated glass envelope. The absorbed solar radiation warms up the heat transfer fluid flowing through the absorber tube to almost 400°C. This is conducted along a heat exchanger in which steam is produced, which then generates power in the turbines.

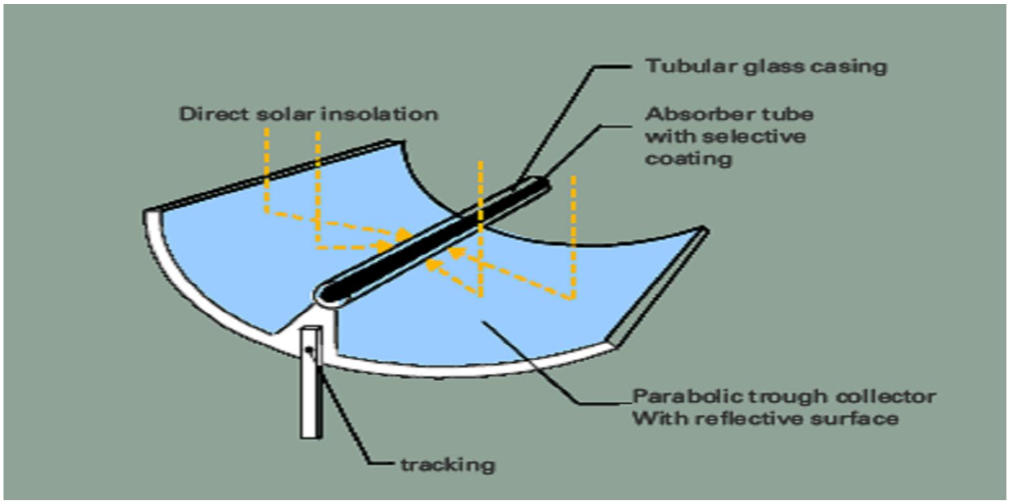

Fig.2: Parabolic Trough Concept

2.2 Tracking the Sun
Tracking is particularly important in solar energy collection systems that work under concentrated light. The parabolic concentrators always require the orientation towards the sun. By tracking the sun from sunrise to sunset, the parabolic collectors concentrate the sun's radiation with their parabolic mirror facets on the absorber tubes along their focal line to collect the heat. The mirrored troughs face the sky and direct sunlight to a large metal and glass receiver in the middle of trough that holds circulating oil. The thermal efficiency of a parabolic trough solar collector depends on the accuracy with which the collector follows sun. Tracking system consists of 0.25kw, 685 rev/min, 8-pole AC motor with electromechanical brake and a 463:1 high – reduction helical gearbox. Stephenlas Vegas, Nevada, Renewable EnergyAccess.com, Naidoo, P., Nelson Mandela Metropolitan University, (2005)

2.3 Land
Parabolic trough plants require a significant amount of land that typically cannot be used concurrently for other uses. Parabolic troughs require the land to be graded level. Pakistan has a range of desert in remote area where such small configuration power units are needed. In general, a parabolic trough solar power plant in a good resource reigns requires approximately 5 acres (20,000 m^2) per MW of plant capacity. Kearney,D., and C. Miller, (January 15, 1988). A study for the state of Texas shows that land use requirements for parabolic trough plants are less than that those of the most of other renewable technologies (wind, biomass, hydro) and also less than those of fossil when mining and drilling requirements are included. Contract No. 500-89-001, San Diego, CA :(December 2, 1991), (July, 1995), ISBN 0-9645526-0-4

2.4 Wind
The performance and structural design of solar field are impacted by high winds. The solar field is not designed to operate at winds of more than15.64 meter/sec; consequently, high-wind sites limit the performance potential of the solar plant. Moreover, wind forces dictate the collector structural design. Since the structure constitutes about 40% of solar field costs, it is important to optimize this component. Price, H.; and Kearney, D. (1999)

2.5 Mirrors
The glass mirrors are one of the most reliable components in the parabolic trough solar collectors. The mirrors concentrate the sunlight more than 80 times on a metal absorber pipe in the line of focus. San Diego Regional Renewable Energy Study Group, (August 2005). Mirror mounting ceramic pad is given special emphasis to cater for the problem caused by differential thermal expansion between the mirror and the pad. Mirror breakage due to high winds has been observed near the edges of the solar field where wind forces are high. These mirrors are manufactured in Pakistan with the size limitations of manufacturing plants. Each mirror fig 3 is supported on the structure at four points on its backside.

Design of Collector Structure
Factors considered in the construction of the parabolic trough solar collector include stability and accuracy of the parabolic profile, optical error tolerance, and method of fabrication, cost, material availability and strength constraints. H.

Guven,Technical Brief in Journal of Solar Energy Engineering, Vol. 116, No. 3, pp. 164-166, (1994) proposed a Parabolic Trough Solar Collector (PTSC) design approach that differentiates between developed and developing nations, where design objectives are not limited to maximizing thermal efficiency but must also favor cheaper, labor-intensive design and production techniques. Elements of this approach, which partitions the PTSC design problem into a macro-level stage dealing with the reflector, receiver and tracking system and a micro-level stage in which the subsystems are integrated, were employed in this research. Deviations included pre-selecting the rim angle based on parabolic-rib material constraints and selection of the receiver glass envelope diameter based on availability of glass tubing.

This research work produced a 4 m long parabolic trough solar collector assembly Fig.4. The three of these assemblies are placed in one row to be operated with just one drive mechanism. This meant that 12m long collectors per drive could be constructed which would meet the high optical requirements, at all stages of operation, when sunlight falling onto the 5.07 m wide aperture has to be concentrated onto an absorber diameter. The horizontal wind loads and the low degree of permissible distortion are relevant to the design of a suitable steel-glass structure. The frame structure of parabolic trough collector is made up of four steel ribs. The cross-section is reinforced using diagonal struts and end frames, providing the support points for the mirror of thickness of 5mm.

Fig. 4 Frame structure of parabolic trough collector design and developed by researchers

Consequently, a 12 m long collector assembly in one row consists of a reinforced of 3 parabolic reflectors. Fig 4 shows at every 4m, a support for the pivotal mounting of the collector elements is located and fixed to a drive pylon, which bears the dead weight of the collectors and the horizontal wind load. The drive pylons are fitted with hydraulic drives which enable the total 12 m long collectors to track the current position of the sun, satisfying the high degree of precision being (0.04 degrees) required. Renewable Energy Annual (1996), US Department of Energy, Washington, DC 20585, USA; April (1997) The entire steel structure of 4m long for the loop of 24m lengths is manufactured at site in Pakistan. This saves the transportation expenses of huge assembly of steel structure to the power plant site. As the collectors are optical devices, and a high degree of geometric precision is required – which, as a welded construction, is only achieved at great effort and cost – the individual components are manufactured using the degree of precision typical to the steel construction industry and the final collector geometry was then achieved when accurately assembling in special jigs on site fig 6. This enables geometric precision to be achieved, almost to the nearest millimeter, necessary for optical performance. Energy Information Administration, Renewable Energy Annual (1996).Reflector mirrors of 924.38×1333.33mm in total 18 mirrors per collector assembly each with a length of 4 m and width of approx 5.07 m are installed on a surface area.. Each 4m long elements of collector are joined together to an approximately 24m long collector unit, tracking the sun by using hydraulic drives. The one loop is made up of three of these collectors which are arranged in the field in a north-south direction. Therefore, the collector field reflective surface area of approximately 240 m².

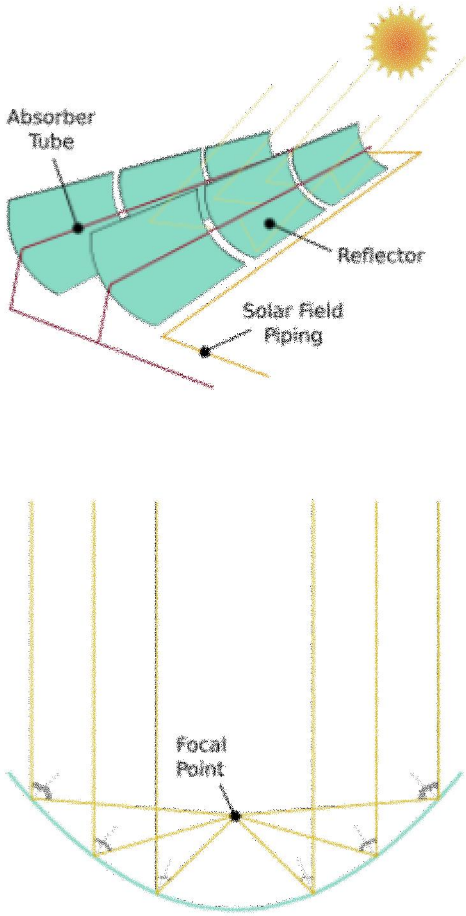

Fig.5. A diagram of a parabolic trough solar farm (top), and an end view of how a parabolic collector focuses sunlight onto its focal point.

The thermal heat transfer medium synthetic oil is pumped through the individual loops of 12 Solar Collector Assemblies (SCAs) Fig.5 that are arranged in two parallel rows of 6 SCAs each and is heated by about 100°K as it flows through a loop, by means of the concentrated solar radiation. The heat transfer medium thus heated to a temperature of about 400°C is then pumped to the steam generator. Energy Information Administration, Renewable Energy Annual (1996).

Fig.6 Structure of parabolic trough collector showing four steel ribs and Pylon

The Heat Collecting Element (HCE) fig 7 is a steel absorber tube of 7cm in diameter, which is coated with black chrome .The absorber tube, is surrounded by a glass envelope. The space between the steel tube and the glass is evacuated to limit heat losses from the absorber tube to the surrounding environment.

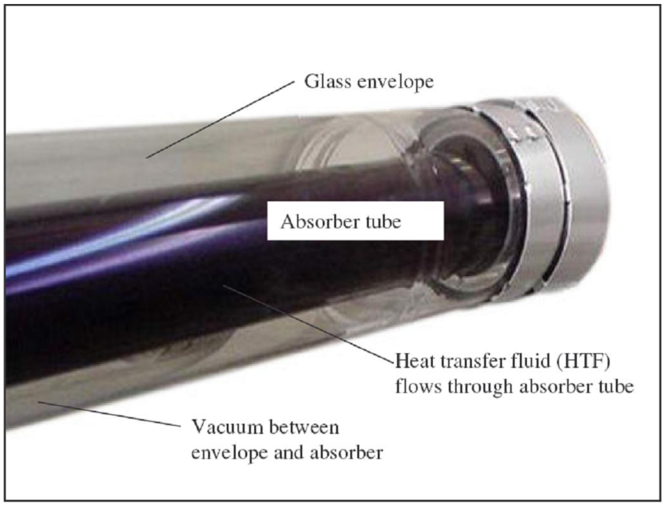

Fig.7 Heat Collecting Element (source : Solel UVAC, 2004)

The focused radiant energy from the sun is absorbed through the HCE and transferred to a heat transfer fluid (HTF), which is synthetic oil such as a mixture of biphenyl and diphenyl oxide (Therminol VP-1) that is pumped through each HCE tube. The heated HTF is pumped back to the power plant, where it becomes the thermal resource for steam generation in the power cycle. Cologne, Germany: (June 1994).

3.1 Technical Requirements of Parabolic Trough Solar Collector

Longitude	**Between 62 and 75 degrees East**
Latitude	Between 24 and 37 degrees North
Structure	Steel frame with mirrors supported arms
Aperture Width	5007milli meter
Focal length	1001millimers
Length per collector	4000millimeters
Length of Solar Collector Assembly	24000millimeters(two rows of 12000mm)
Wind load	39m/s
Rim angle	90°
Drive	Hydraulic
Heat Collecting Element	Evacuated tube
Interconnect	Rotating joints
Receiver technology	Parabolic trough solar field
Receiver absorptivity	0.96
Receiver emittance	0.20
Mirror reflectivity	0.93%
Mirror size	1333.33*924.38mm
Selective surface	Black chrome
Piping heat loss	$10w/m^2$
Net out put	22kw
Errection method	On site simple assembly
Heat collecting element (HCE) pipe diameter	0.70mm
HCE length	4000mm
Concentration ratio	16.7

3.2 Power Plant Size

Increasing plant size is one of the easiest ways to reduce the cost of solar electricity from parabolic trough power plants. Studies have shown that doubling the size reduces the capital cost by approximately 12-14%.Pilkington Solar International: (1996) Status Report on Solar Thermal Power Plants. Report ISBN 3-9804901-0-6. The increased manufacturing volume of collectors for larger plants drives the cost per square meter down. Secondly, a power plant that is twice the size will not cost twice as much to build. Thirdly, the O&M costs for larger plants will typically be less on a per kilowatt basis. For example, it takes about the same number of operators to operate a 10 MW plant as it does for a 400 MW plant. Naidoo, P., Nelson Mandela Metropolitan University,(2005).

4. Latest Trends in Renewable Solar Energy Field

Chinese government supports the development of concentrating solar power (CSP) technology strongly, to change the energy-intensive and environment-burdensome economical development way, through renewable energy for sustainable electricity generation. Qu Hanga,_, Zhao Juna, Yu Xiaob, Cui Junkui, Renewable and Sustainable Energy Reviews 12 (2008) 2505–2514 . Recently solar thermal absorption cooling has again aroused researchers' interest in the development of high temperature solar receivers, double effect chillers, and advanced control The Center for Building Performance and Diagnostics (CBPD) at Carnegie Mellon University has carried out research on solar thermal absorption cooling and heating to assess the feasibility of this technology through installation, testing, modeling, and evaluation of a new system with an advanced system configuration using recently available parabolic solar receivers. Ming Qu a,*, Hongxi Yin b, 1, David H. Archer c, 2 Solar Energy 84 (2010) 166–182. Solar adsorption cooling machine, where the reactor is heated by a parabolic trough collector (PTC) and is coupled with a heat pipe (HP). This reactor contains a porous medium constituted of activated carbon, reacting by adsorption with ammonia. A. El Fadar a, A. Mimet a,*, A. Azzabakh a, M. Pérez-García b, J. Castaing, Applied Thermal Engineering 29 (2009) 1267–1270 . An experiment platform of a parabolic trough solar collector system (PTCS) was developed for thermal power generation, and the performance of the PTCS was experimentally investigated with synthetic oil as the circulate heat transfer fluid (HTF). The solar collector's efficiency with the variation of the solar flux and the flow rate of the HTF was identified. The collector efficiency of the PTCS can be in the range of 40%–60%. It was also found that there existed a specified delay for the temperature of the HTF to response to the solar flux, which played a significant role in designing the PTCS. LIU QiBin1, WANG YaLong1,2, GAO ZhiChao1,2, SUI Jun1*, JIN HongGuang1 & LI HePing3Sci , China Tech Sci, 2010, 53: 52−56, doi: 10.1007/s11431-010-0021-8. The major direct use solar thermal market is China, which leads the world by a long margin, followed by the United States, Germany and Turkey. Although the installed capacity of CSP, solar power generation is still small it has started to take off in the last two years, notably in Spain and the United States. Reportlinker PRWire 2009 - By Robert Miller (18.12.2009) 12:44:16. An optimal design procedure for internally insulated, carbon steel, molten salt thermal storage tanks for parabolic trough solar power plants. The exact size of the vessel and insulation layers and the shape of the roof are optimized by minimizing the total investment cost of the storage system under three technical constraints: remaining within the maximum allowable values of both temperature and stress in the steel structure, and avoiding excessive cooling and consequent solidification of the molten salt during long periods of no solar input. R. Gabbrielli, C. Zamparelli. J Sol. Energy Eng. (November 2009) Volume 131, Issue 4, 041001 . Intel Corporation (Intel) has reported that new contracts are in place to incorporate around 2.5 MW worth of new solar power projects at eight US locations in Arizona, California, New Mexico and Oregon. In addition, Intel announced it has renewed and increased by 10% its purchase commitments for renewable energy credits (REC) to more than 1.43 billion kW hours, more than 51% of its estimated 2010 US electricity use. Global Data's Power Research Views Announced Date: (Jan 25, 2010).

5. Conclusions

The cost, performance, and risk of parabolic trough technology are fairly well established by the experience of the existing operating parabolic trough plants. As the government cannot afford the cost of supplying electricity to the far-flung remote area of Pakistan, those could be provided power on the cheapest production cost by developing Solar Energy System. Solar energy technologies have great potential to benefit our nation. They can diversify our energy supply, reduce our dependence on imported fuels, and improve the quality of the air we breathe and stimulate our economy by creating jobs in the manufacturing and installation of Solar Energy Systems. In order to effectively mold the trend of society towards the use of solar energy product, it is imperative that indigenously produced solar products are of high quality with better engineering design, having high efficiencies and cost-effectiveness for average users.

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