Development of small scale concentrated solar power plant using organic Rankine cycle for isolated region in Indonesia


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Abstract

Electrification ratio in Indonesia by the end of 2011 was about 74%. This means that 26% of the population does not have electricity. Indonesian Institute of Sciences (LIPI) is developing small scale concentrated solar power plant using Organic Rankine Cycle (ORC) that can be operated in remote, isolated areas or small islands. Some constraints of electrification in these areas are the cost of integrated grid construction is relatively high, the limitation of energy resources and the population of the area is relatively small. Research in concentrated solar power (parabolic trough) has been carried out by LIPI since 2010. A stand-alone power unit (“off grid”) by utilizing local energy resources, especially renewable energy, will be constructed by LIPI. A hybrid system of solar thermal and biomass energy can be a suitable choice to solve the electricity problem in the area. This option is based on the relatively good potential intensity of solar energy in some areas of Indonesia which is daily average intensity is about 4.8 kWh/m²/day. This paper presents a series of activities in developing a concentrated solar power plant which includes the conceptual design of the small-scale system with the capacity of 10kW.

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Keywords: Concentrated solar power plant; hybrid system; organic rankine cycle; remote and isolated areas.

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1. Introduction

Solar energy is a source of energy that is never depleted, hence, it is worth to be developed. In the next future, solar energy can play a fundamental role to replace fossil fuel plants, and to move from a carbon technology to a green technology [1]. One of many ways to utilize solar energy as an energy source is developing a Concentrated Solar Power (CSP) system. CSP is a system that use direct solar radiation concentrated to generate heat onto a small area for producing electricity [2]. This system has been developed in several countries such as Algeria, Egypt, Greece, India, Italy, Mexico, Morocco, Spain, and America [3].

Meanwhile, electrification ratio in Indonesia by the end of 2011 was about 74% [4]. This means that 26% of Indonesia's population does not have electricity. Most Indonesian who does not have access to electricity lives in remote, isolated areas or small islands. Most of Eastern Indonesia region even have an electrification ratio below of 30% [5]. Some constraints of electrification for these areas involve: cost of power plant construction and integrated grid are expensive, fossil energy sources are limited or even nonexistent, and population in these areas is relatively small. Solar energy as energy sources can be one alternatives to reduce dependence on fossil fuels.

CSP plant offers some benefits. It provides conversion easiness compared to other kinds of power plants. While others employ different source of energy to produce steam or gas to propel motor or turbine, CSP plant uses concentrated solar heat. Besides, fuel is not needed for CSP plant. Moreover, assembled in hybrid with other sources of energy, CSP can run at nights.

CSP technologies mainly use parabolic troughs, solar towers, dish/engine systems, and linear Fresnel reflectors. Parabolic trough and linear Fresnel are systems that use line focusing to capture solar radiation, while solar tower and dish engine system uses point focusing [6].

The solar parabolic trough collector (SPTC) is the easiest yet the most used among other concentrating technologies [8]. This system is the most mature application than other system [1] [9]. SPTC has been installed in 29 plants around 1220 MWe power, corresponding to 96.3% of the total operational concentrating solar power as of the beginning 2011, while solar tower only 3%, dish engine 0,1% and linear Fresnel 0,7% [2].

Despite the fact that Indonesia is crossed by the equator, granting abundant amount of energy source with considerably high intensity (up to 4.8 kWh/ m²/ day) [7], the development of CSP has not yet initiated. Considering the intensity, Indonesia is suitable for the development of CSP. The eastern part of Indonesia is the most potential site for developing this system. Fig.1 shows intensity of solar radiation in Indonesia. However, considering the high humidity level, the most suitable CSP is parabolic trough with low focal length.

SPTC operate at low temperature, so that needed electrical generating system by vaporization method at low temperatures. Organic Rankine Cycle (ORC) can be used in the system, because it can operate at low temperatures [10] [11]. This paper discusses the design and construction activities of the solar collector system that has been carried out by LIPI since 2010. The discussion includes the design and manufacture solar collector system and plan ahead where the system is expected to be installed in the UPT BPPTK Gunung Kidul, Yogyakarta by the end of 2012.

2. Design and manufacture

The main components of the solar collector system are concentrator, absorber and thermal storage. Concentrator is a system that uses mirrors surface or lenses to capturing and concentrate a large area of sunlight, or solar thermal energy, onto a small area. The solar radiation will be reflected to the absorber located at the focus point of the linear parabolic. The heat is then absorbed and will heat the thermal fluid
inside the absorber which in turn will flow into the thermal storage for use as an organic fluid heater located inside the evaporator. Organic fluid in the evaporator and then heated/evaporated by thermal fluid from the absorber, and the evaporated organic fluid is expanded in the turbine to drive a generator that produces electricity. Thermal storage in the system serves to homogenize the temperature of the fluid before it is piped into the evaporator, thus the heat of the fluid supplied to the evaporators will be evenly distributed. Thermal storage is also useful as a tool to store heat from the fluid, therefore the stored fluid may be used at night or when there is no sun (cloudy) and the system can remain operational at all times. The use of thermal storage can improve performance of the system [12]. Fuel burner for heating assistance is made when the heat captured by the PTSC cannot meet the requirements because of cloudy weather or at night. Schematic diagram of the solar power generation system is shown in Fig. 1.

![Fig. 1. Concentrated solar power system](image)

Initial specification was determined to perform design and manufacturing. As a basis we assume that the initial design of some design parameters on the test results from the previous project by "Archimede" as shown in Fig. 2. Fig. 2 shows the Archimede project of 313.1GWh solar energy which was capable of generating electricity by 55.9 GWh or 17.8%. Therefore, by referring to the basic design of solar electric generating system in Fig. 3, LIPI was performed the initial design with the desired electrical power of 10 kW. The design begins with system design ORC as electric production system. Organic Rankine Cycle (ORC) is a Rankine cycle that can generate electricity from low temperature heat sources by using organic fluids as the working medium. ORC system efficiency is low, because the system is working at low temperatures.

Therefore, the selection of working fluids with good physical properties is essential to improve efficiency. Properties of a good ORC fluid are: isentropic saturation vapor curve, low freezing point, high stability temperature, high heat of vaporization and density, high efficiency, low specific volumes, moderate pressures in the heat exchangers, good availability and low cost, safety, low environmental impact and acceptable pressure [10] [14]. ORC consists of turbine, condenser, feeder pump and evaporator. The working principle of the ORC is the same with conventional Rankine cycle, but the ORC system works using a fluid other than water, which is the organic fluid. ORC was designed with the evaporation pressure of 10.18 bar (112°C, saturated vapor), and the condensing temperature of 40°C.
(1.545 bar pressure, saturated liquid). Organic fluid shown on the design is isentropic fluid vapor saturation curve type. This type is parallel to the line of the isentropic expansion and fits very well the cycle. Some of organic fluid candidates with the type mentioned can be seen in Table 1.

Thermal storage is a storage tank that serves to store heat energy, so the system will still be able to serve the load despite the use of solar thermal energy supply is not there. Thermal energy storage is key components in solar thermal energy system. Thermal storage must have thermal energy losses as small as possible and have a high efficiency in the process of extraction of heat energy it contains. Thermal storage is also very important due to this system being able to adjust the mismatch between supplies of solar thermal energy with the load demand. The thermal storage was designed by using sensible type with a single tank.

The solar collector system was designed with modular system where one module of solar collector has an aperture width of 3.5 meter, focal length of 1 meter and absorber pipe diameter of 1 in. Absorber was designed to obtain maximum heat absorption where the temperature could be reached.

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**Table 1. Organic fluid candidate [10] [15]**

<table>
<thead>
<tr>
<th>Organic fluid</th>
<th>Physical data</th>
<th>Safety data</th>
<th>Environmental data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Molecular mass (kg/kmol)</td>
<td>Boiling point at 1.013 bar</td>
<td>Critical point</td>
</tr>
<tr>
<td>R134a</td>
<td>102</td>
<td>-26.1°C</td>
<td>40.6 bar, 101.1°C</td>
</tr>
<tr>
<td>R123</td>
<td>152.9</td>
<td>27.6°C</td>
<td>36.6 bar, 183.7°C</td>
</tr>
<tr>
<td>R245fa</td>
<td>134</td>
<td>14.6°C</td>
<td>36.4 bar, 154°C</td>
</tr>
<tr>
<td>R141b</td>
<td>116.95</td>
<td>32.2°C</td>
<td>42.5 bar, 204.4°C</td>
</tr>
</tbody>
</table>
3. Result and discussion

3.1. Solar intensity measurement

Measurement of solar intensity in some areas in Indonesia has been done in 2009. Measurement is done from 8 AM to 4 PM in Bandung, Bali, Jember, Nusa Tenggara Timur and Yogyakarta. Result of measurement shown in Fig. 3.

![Solar Intensity Measurement](image)

Fig. 3. Solar intensity on some regions

3.2. Electric production system

ORC system design is using R123 as organic fluid. R123 was chosen because it has properties in accordance with the terms of ORC fluid selection. The result of the SPTC system using the ORC system for 10 kW electric production systems is shown in Table 2. As we seen in Table 2, ORC thermal efficiency is 10.63%. This happens because the system works at low temperatures, so that the difference between the heat (evaporation) and cold (condensation) temperature is small.

The result of power estimation for solar parabolic trough collector power plant based on Fig. 2 shows in Fig. 5. Fig. 5 shows a series of estimated power from each system of concentrated solar power. The electric power output of 10 kW would be generated from 214 kW of solar collector. In addition, the fluid inside the absorber is expected to reach temperatures of 200°C. The resulting efficiency is lower than the Archimede models, because of the low heat source temperature. Some local content of material and technology have been used in this work. Simple and cheap black-Zn coating was deposited onto some absorber pipes. Palm oil was used as heat transfer fluid other than thermal oil. The palm oil was selected because they have similar physical properties with heat transfer fluid as well as cheaper in cost.

Table 2. The ORC system design with 10 kW electrical output

<table>
<thead>
<tr>
<th>Flow rate</th>
<th>Heat input</th>
<th>Heat output</th>
<th>ORC Thermal efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.45 kg/s</td>
<td>91.05 kW</td>
<td>81.37 kW</td>
<td>10.63%</td>
</tr>
</tbody>
</table>
3.3. Storage system

Thermal storage was designed by using sensible type with a single tank to obtain power output of 107 kW as shown in Fig. 4. Table 3 shows that to produce 107 kW output power it will required thermal storage with total volume of 24103 liter. The smaller capacity of 2170 liter thermal storage have been manufacturing in workshop thus eleven thermal storage will be required to produce 107 kW output power.

![Diagram](image)

**Table 3. Result of thermal storage design**

<table>
<thead>
<tr>
<th>Thermal storage capacity</th>
<th>Operation time</th>
<th>Palm oil inlet temperature</th>
<th>Palm oil outlet temperature</th>
<th>Caloric heat input</th>
<th>Thermal storage volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>107 kW</td>
<td>6 hours</td>
<td>200°C</td>
<td>150°C</td>
<td>2311200 kJ</td>
<td>24103 liter</td>
</tr>
</tbody>
</table>

3.4. Solar collector system

Fig. 5 shows that to produce 214 kW of heat from solar collector system with an average solar intensity of 327 W/m² (which is measured in Yogyakarta), it will required 187 meter of linear parabolic length. SPTC which are installed in Yogyakarta is 18 m. Solar collector with the additional length of 18 m will be installed again in Yogyakarta, so the total length parabola existing is 36 m. Absorber was designed to obtain maximum heat absorption where the temperature could be reached. Table 4 shows the result of absorber design.

**Table 4. Specification of absorber/receiver**

<table>
<thead>
<tr>
<th>Glass tube material</th>
<th>Thermal exp. coefficient</th>
<th>Length</th>
<th>Diameter Pipe material</th>
<th>Pipe diameter</th>
<th>Absorption coating material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borosilicate</td>
<td>32.5 x 10⁻⁷ °C</td>
<td>1500 mm</td>
<td>80 mm (OD); 76 mm (ID)</td>
<td>1 inch</td>
<td>Black Zn</td>
</tr>
</tbody>
</table>

4. Conclusion

Conclusion of this paper is Indonesia has a potential application of concentrated solar power with a type of parabolic trough and the selected linear parabolic solar collector has a low focal distance considered the high humidity on some areas. The total heat of 214 kW from solar collector is required to generate 10 kW power output from organic turbine. These results could be obtained from a 3.5 meter aperture width and total 187 meter length of linear parabolic. The Organic Rankine Cycle (ORC) turbine system was selected to couple a generator for electric power generation. This system was chosen because the technology developed using an ORC (Organic Rankine Cycle) could be operated in low temperature heat source.
References


