GRIMSTAD RENEWABLE ENERGY PARK

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1. PROJECT GOALS AND TECHNICAL OBJECTIVES

1.1 Norwegian National Centre for renewable energy

On May 23, 1997, Agder University College (HiA), Aust-Agder Kraftverk (AAK), and Vest-Agder Energiverk (VAE) signed an agreement to cooperatively develop renewable energy and energy efficient technologies. Kristiansand Energiverk joined the partnership in 1998. In 2001, the three energy companies joined to form one company, called Agder Energi (AE), and became one of the major energy companies in Norway. The intention of the partnership agreement was to improve the competence of the partners in renewable energy technologies other than hydro-electricity, which has been their main focus up to now. Four areas were defined as important:

- International contacts
- Ph.D. program
- Energy studies
- Energy Park

The success of the international hydrogen conference, HYPOTHESIS II, held in Grimstad in August 1997, provided the basis for an international network. The previous year, the Norsk Hydrogen Forum (NHF), a forum for Norwegian institutions and companies interested in hydrogen technologies, was established. The college, HiA, is hosting the secretariat for NHF.

The Ph.D. program began in 1999. It is financed by two companies, AE and ELKEM, a major Norwegian company that produces silicon, and the Norwegian Research Council (NFR). Five Ph.D. students are now working in the program. A new Ph.D. student, financed by the Minister of Education and Research, will soon join the programme. The areas studied are hydrogen, solar grade silicon materials, wind energy, and economics related to renewable energy. Two engineering courses related to renewable energy have been established, one in technical economics, with a focus on renewable energy and one in electrical engineering, with focus on renewable energy.

Efforts regarding the last item, the Energy Park, are the focus of this paper.

1.2 The Energy Park

The Energy Park is located at Dømmesmoen in Grimstad, Norway. King Harald of Norway officially opened the centre in June 2000. It is a tool for research and education in renewable energy and is open to the public. The goal of the Energy Park is to provide information to the public by demonstrating different aspects of renewable energy and hydrogen technology. The park is designed for studying integrated energy systems. The installations in the centre include thermal solar collectors and photovoltaic cells. Three heat pumps collect heat from four 150-m deep boreholes, which are also connected to the solar collectors. An electrolyser, which produces hydrogen, and hydrogen storage tanks are also installed at the site. Recently, a 2.5-kW alkaline fuel cell stack has been obtained for the centre. All subsystems, such as the electrolyte circulation system, CO_2 removal system, fans, etc. are implemented. However, there is still work to be done on the control system. The total fuel cell system will be started and tested in December 2002.

Recently, energy crops, i.e., Reed Canary Grass, Elephant Grass, and Short rotation coppice of willow, have been planted at the Energy Park. The aim is to study the energy content of these plants under Norwegian conditions.

Figure 1: An overview over the Energy Park at Dømmesmoen, Grimstad

2. GENERAL DESCRIPTION

The Energy Park is financed by the Norwegian Water Resources and Energy Directorate, the Energy Efficiency Centres of Agder, Agder Energy, Norsk Hydro Electrolysers, and HiA. It is located in Grimstad (in Southern Norway) at Dømmesmoen, a former horticultural school, which is now part of HiA. An overhead photograph and a schematic drawing of the Energy Park are shown in Figures 1 and 2, respectively. As can be seen, the park has two lines, one thermal line and one electric line.

The thermal line consists of 85 m^2 solar collectors, heat exchangers, three heat pumps, and water heat storage tanks. Four 150-m deep boreholes can be used for heat collection as well as for heat storage. The heat pumps and solar collectors can be combined for optimum operation. The thermal energy is used to heat a nearby building.

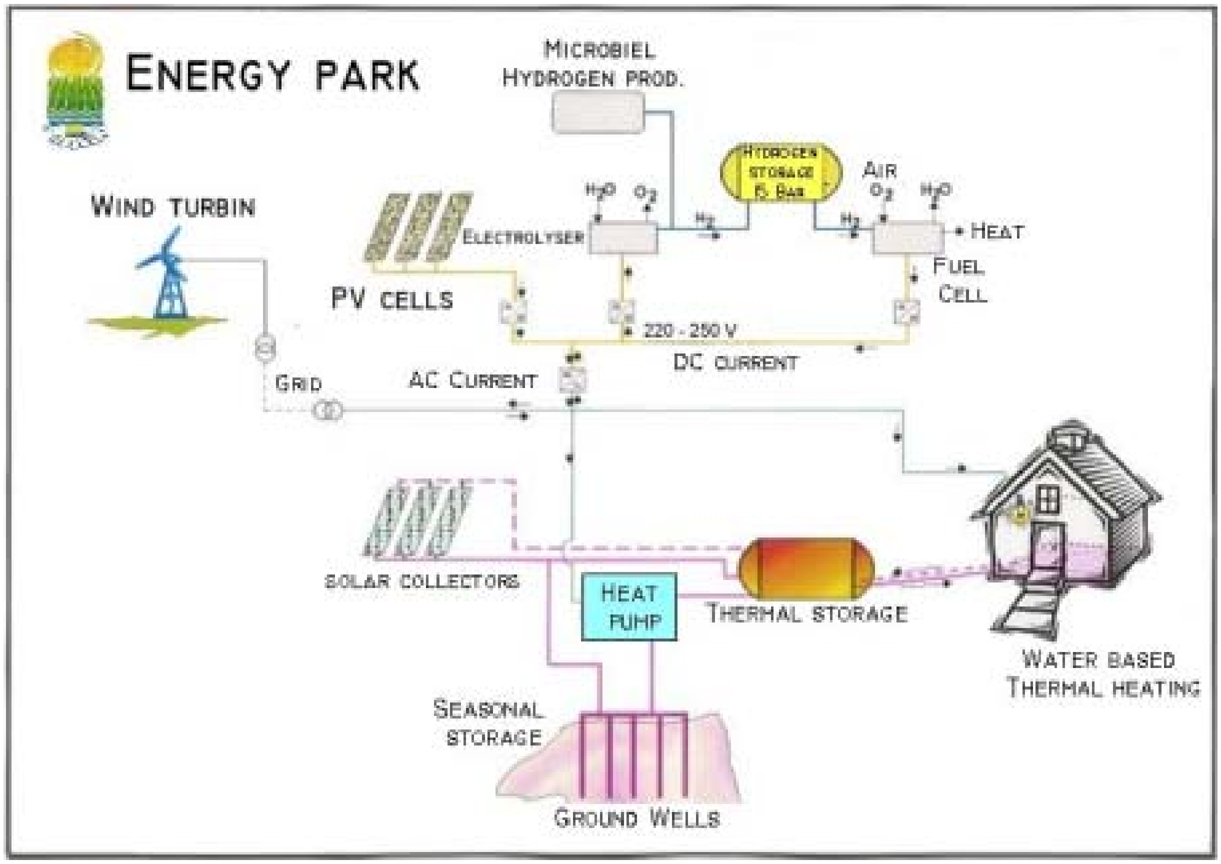

Figure 2: A schematic drawing of the Energy Park

The electric line, which consists of 220 m^2 PV cells and inverters, produces 400 V_{AC} (50 Hz). The electricity can be fed into the main grid or used to power a 50-kW high-pressure electrolyser to produce hydrogen. The hydrogen is stored in two storage tanks until it is used to power fuel cells and other hydrogen-fueled equipment, such as small gas turbines. The instrumentation and equipment are housed in three separate locations, mainly for safety reasons.

Because the wind in the Grimstad area is quite calm, there are no wind turbines in the energy park. However, AE is owner of a windmill park at Lindesnes, the most southern part of Norway. A direct data transfer line between the windmill park and the energy park will be established in order to enable wind energy studies at Dømmesmoen.

3. DESCRIPTION OF THE COMPONENTS

3.1 The thermal system

The solar collector systems are standing free on the ground (see Figure 1). Four types of solar collectors are installed:

- 22.5 m^2 of Viessmann w 2.5 solar collectors are divided into 3 groups, connected in parallel
- 25 m^2 of Arcon HT collectors are divided into 2 groups, connected in series
- 28 m^2 of Solsam LGB1 collectors are divided into 2 groups, connected in parallel.

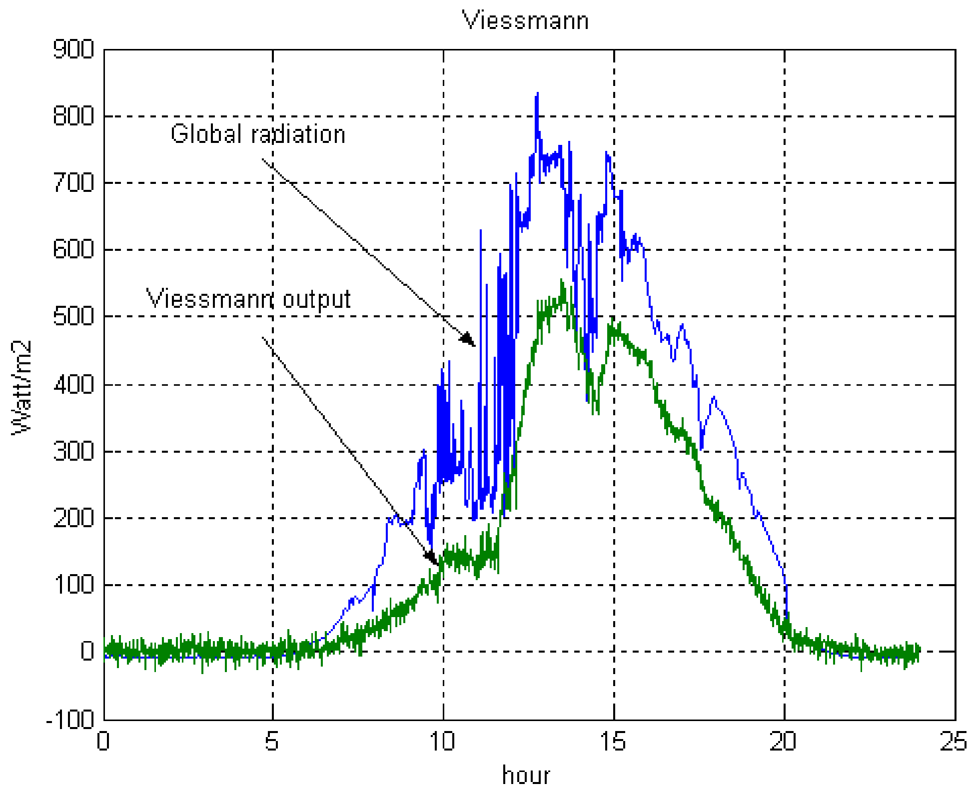

Figure 3: Heat production from Viessman solar collectors

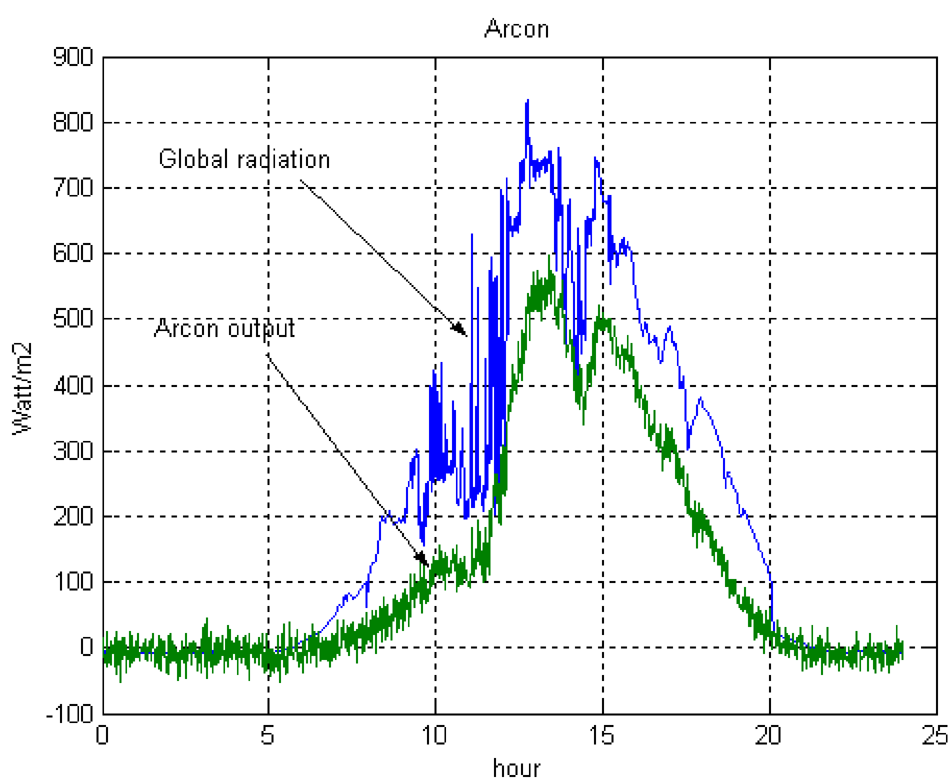

Figure 4: Heat production from Arcon solar collectors

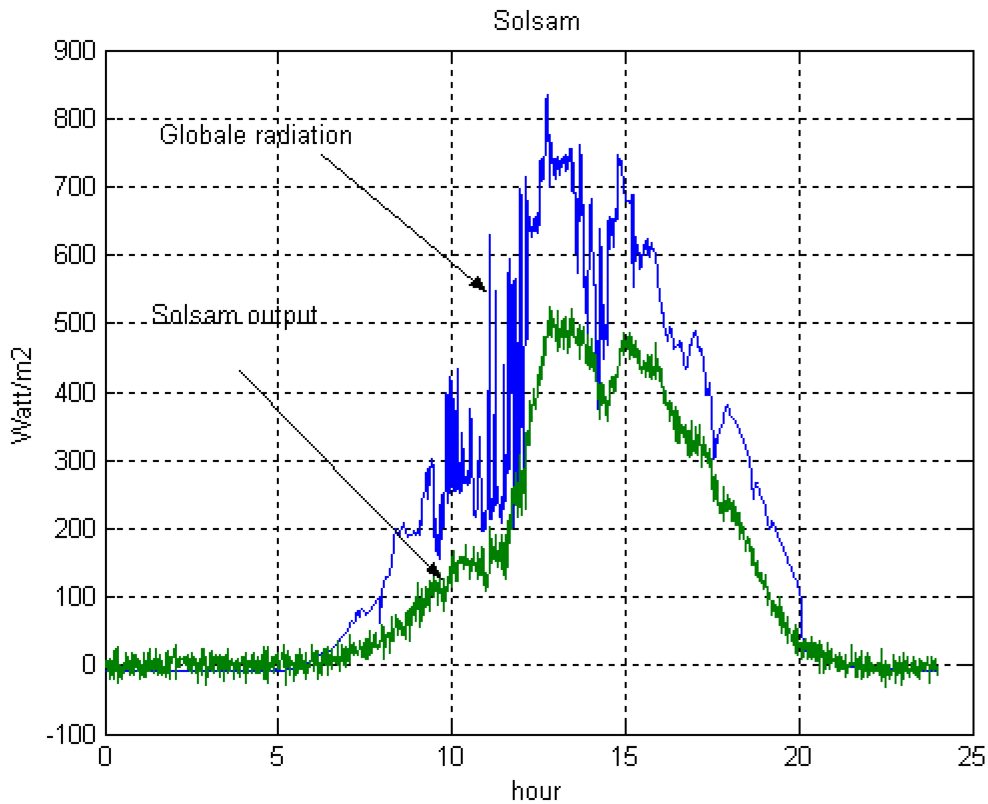

Figure 5: Heat production from Solsam solar collectors

The thermal energy produced by each of the systems is shown in Figures 3-5. The measurements were made on August 8, 2002. The heat production was calculated by measuring the temperature difference between the output and input temperature on the collector and the temperature of the fluid flowing through the collectors, using the heat capacity of the solution.

The global radiation is also presented in Figures 3-5. As the figures show, the heat production from the solar collectors closely follows the global radiation curve. Viessman and Solsam have both a maximum production close to 500 W/m^2, while Arcon has a maximum close to 600 W/m^2.

Plate heat exchangers are used to transfer the heat between the collectors and the heat storage systems (primary and secondary systems). The heating fluid flowing through the solar collectors is a glycol-water mixture and water is used for the storage tank. Figure 6 shows the piping and the storage tanks inside the thermal cottage.

In addition to the three systems mentioned above, a small system, designed for use in small houses, provides heat for one of the cottages. This system consists of two groups of Solsam vacuum solar collectors mounted on the roof of the thermal cottage (see Figure 7). The system has a total area of 6.6 m^2. It can be connected either in series or in parallel. The temperature is controlled by a standard residential thermostat.

Figure 6: A view of the storage tank and the piping inside the thermal cottage

In addition to the solar collectors, four boreholes are drilled in the ground. They are 150-m deep with a diameter of 15 cm. In two of the wells, the ground water is flowing freely. The other two are nearly dry. This gives us an opportunity to extract heat from the ground water and to store heat in the two dry wells. The heat is extracted by means of heat pumps. Three heat pumps are available:

- House pack 9Z - nominal output heat 30 kW
- BVNor BV-60vv - nominal output heat 7 kW
- Mec 6TB - nominal output heat 6 kW

A pipeline is used to transfer heat from this location to the nearby buildings, over a distance of 230 m.

Figure 7: Solar collectors on the roof

3.2 The electric system

Two types of photovoltaic cells are installed:

- Unisolar US64, triple junction amorphous cells - total area 150 m^2. They are divided into five different circuits. Each circuit has four groups connected in parallel and each group consists of eight panels connected in series. The nominal power is 64 W/m^2.
- Neste NP100G, polycrystalline cells - total area 72 m^2. The cells are divided into four different circuits. Each circuit has two groups connected in parallel. Each group has 12 panels connected in series. The nominal power is 119 W/m^2.

The total nominal power is 20 kW_{DC}. Because AC is often needed, four 2-kW Sunny Boy SWR 2000 inverters are installed. They convert DC power to 400 V_{AC}/50 Hz.

The flexible design of the system makes it possible to perform several different experiments and also allows power to be fed to the main grid.

3.3 Hydrogen related components

3.3.1 Electrolyser

A 50-kW high-pressure electrolyser (Norsk Hydro Electrolysers HPE 10) is installed in the park (see Figure 8). It is an alkaline electrolyser producing hydrogen at 15 bars. The maximum hydrogen production rate is 10 Nm^3 per hour with a purity of 99.9%. The hydrogen is stored at a pressure of 15 bars in one of two hydrogen storage tanks. Each hydrogen storage tank has a volume of 4 m^3. Currently the oxygen produced is vented to the air.

Figure 8: The 50 kW high-pressure alkaline electrolyser

3.3.2 Fuel cells

A 2.5-kW alkaline fuel cell stack has been obtained from Ze-Tek Power. It will be installed in the park in the near future. In addition to the stack, subsystems required for fuel cell operation include systems for electrolyte circulation, CO_2 removal, cooling, air fans, and control. All of the subsystems, except the control system, are now finished. When the control system is ready, the fuel cell will be tested. Figure 9 shows the fuel cell stack installed with the subsystems.

We hope to install other types of fuel cells in the future. We are especially interested in PEM cells, because they are most likely to be used for residential power generation.

Figure 9: The ZeTek Power fuel cell with electrolyte circulation system, CO_2 removal, etc.

4. DATA ACQUISITION

Because the Energy Park's main objective is education and research in renewable energy, flexibility is important. In order to follow the different processes, 100 sensors are distributed all around the park, measuring temperature, gas and liquid flow, hydrogen concentration, water purity, current and voltage, all with Field Point I/O units. In addition, valves, switches and pumps can be externally controlled. The pumps are frequency controlled, whereby the flow rates through solar collectors and through the ground wells, etc. can be continuously controlled.

Communication with the net of sensors and the controllers is made through Ethernet TCP/IP, as shown in Figure 10. The system has unlimited possibilities for implementing new functions.

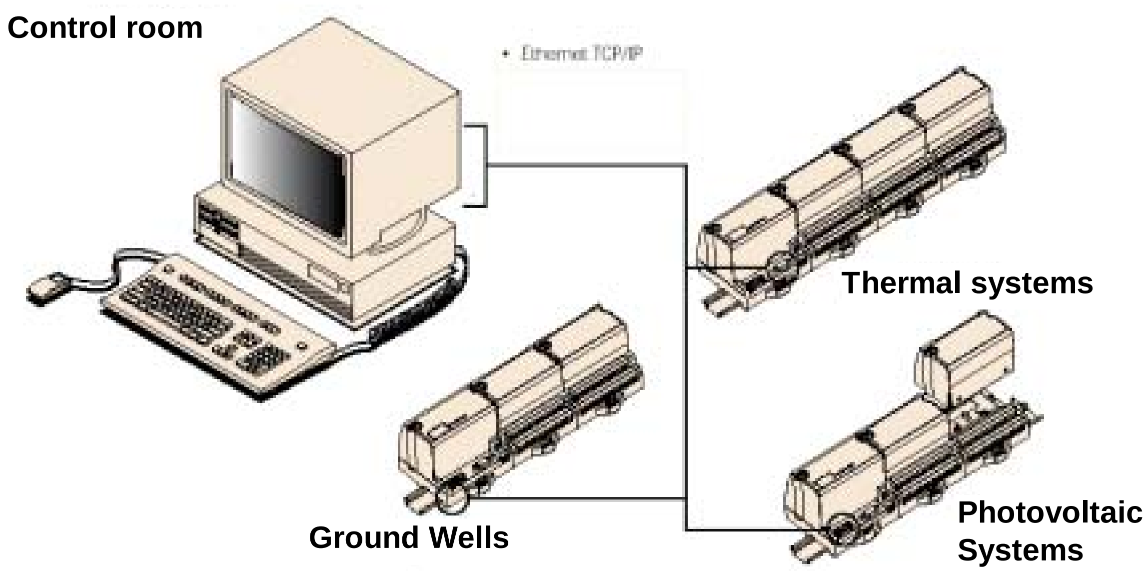

Figure 10: Communication between the sensors/controllers and the control room

In the control room, all data are treated using Bridge VIEW software program (National Instruments), thus providing an opportunity to have virtual instruments on the screen. A screen picture of the virtual instruments connected to the PV-cell system is shown in Figure 11.Data collection and system control are managed from the control room. Figures 3-5 are examples of data that have been obtained with the data acquisition system.

The data acquisition system will be connected to Internet, enabling the real-time data from the Energy Park to be monitored by researchers all over the world. However, the project is not finished yet, mostly due to data security problems. For such a complex system it is important to prevent misuse.

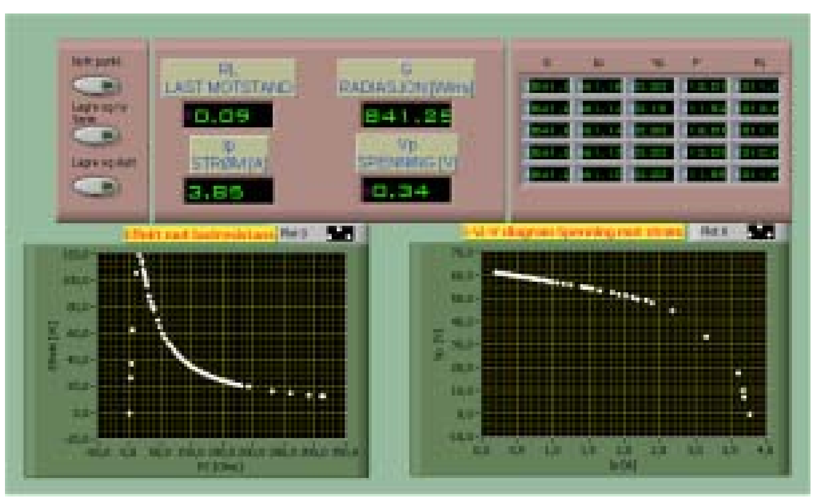

Figure 11: Virtual instruments connected to the PV cell system

5. OPERATIONAL EXPERIENCE

Due to the complexity of the system, a large effort has been required to test the system and get it in operation. The PV cells and the solar collectors are now working well. An example of data that can be obtained from the system is shown below:

One-third of the PV system, i.e., 36 m^2 of the crystalline cells and 37.2 m^2 of the amorphous cells, has been connected to the main grid via the four “Sunny Boy” SWR 2000 converters. These converters are maximum power point trackers, which convert the DC current to 50 Hz AC current. The total converter system produces a maximum of 8 kW of power, with 2 kW from each converter.

The energy delivered to the grid has been recorded continuously from November 2001. Figure 12 shows the cumulative energy production on a sunny day in November.

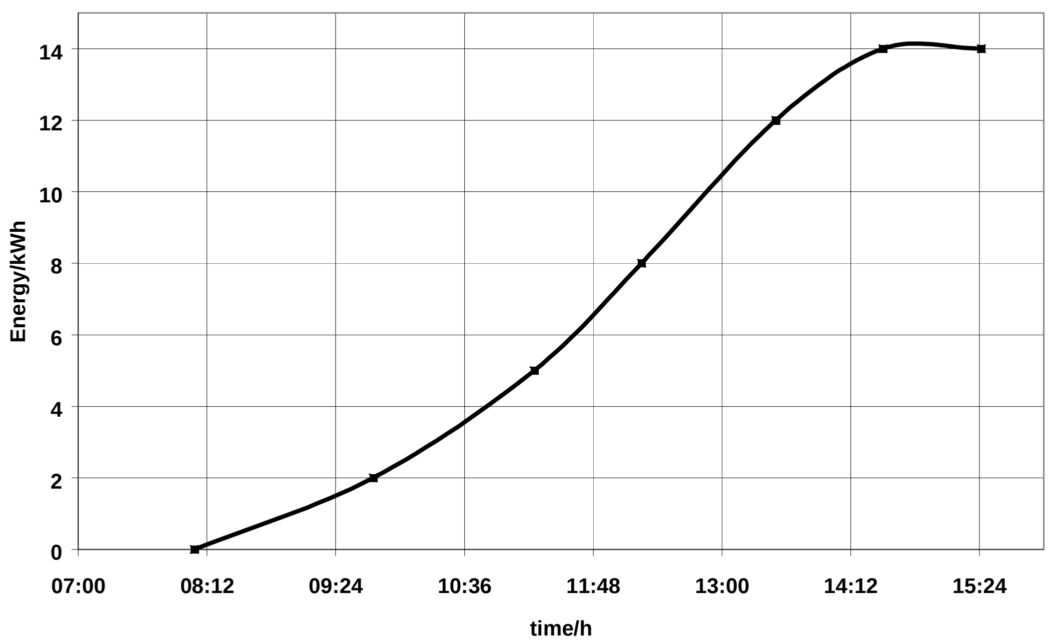

Figure 12: Cumulative electrical energy delivered to the grid on a sunny day in November 2001

As the figure shows, energy production begins at approximately 9.30 in the morning. After 14.00 in the afternoon there is virtually no production. The total electricity production on that day was 14 kWh, or 190 Wh/m^2.

Figure 13 shows the total electricity production in November 2001. Approximately 200 kWh were produced to the grid in that month. The total area of the PV cells connected to the grid is 73.2 m^2, for an output of 2.7 kWh/m^2. The slope of the curve decreases gradually, showing how the energy production decreases towards the end of the month.

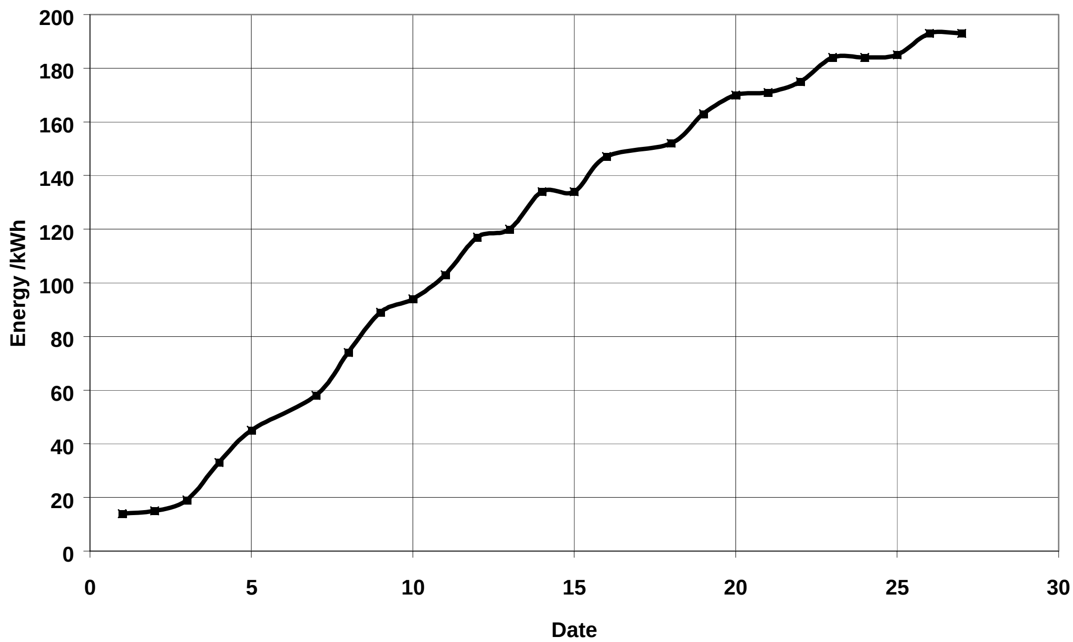

Figure 13: Cumulative electrical energy delivered to the grid in November 2001

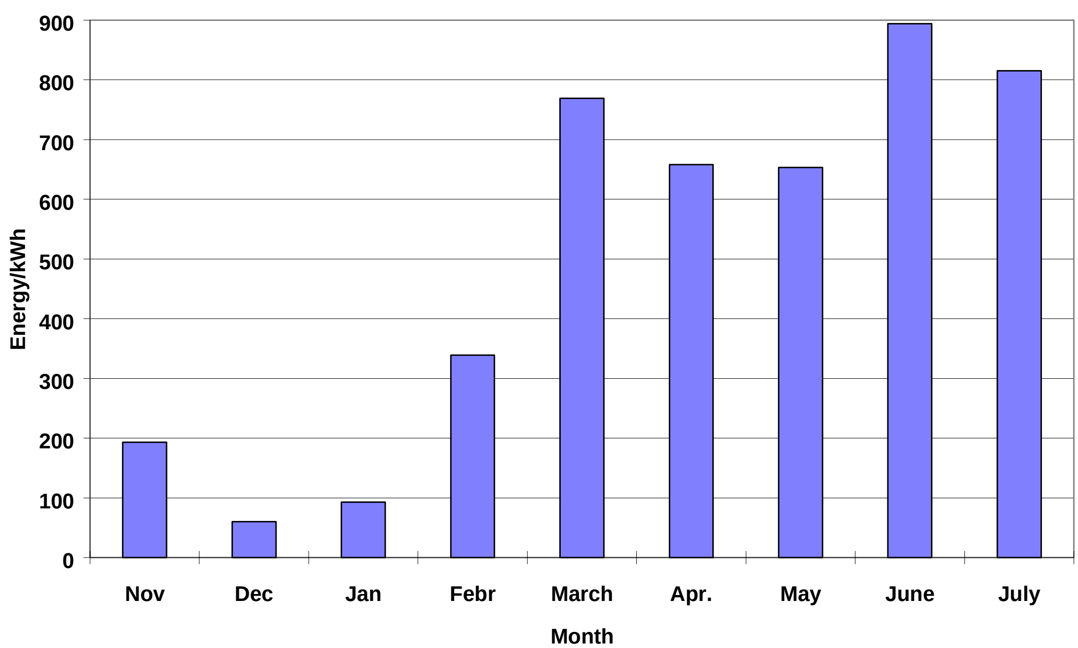

Figure 14: The electrical energy delivered to the grid from November 2001 to July 2002

Figure 14 shows the electrical energy produced to the grid from November 2001 to July 2002. As expected, very little was produced in December, while in June a maximum of approximately 900 kWh was produced. March had an unexpectedly high production (770 kWh), due to snow and clear skies on some days in that month.

Assuming an average of 5 hours production time in June, a fairly high production rate, 82 W/m^2, is calculated. The expected rate is 91 W/m^2, based on the nominal production rates of 119 W/m^2 for the crystalline cells and 64 W/m^2 for the amorphous cells.

The thermal energy production has also been measured. One of the heat storage tanks was used as a calorimeter. It contained 3,000 liters water. On the same sunny day in November 2001, 75 m^2 of thermal solar collectors were used to heat the water in the tank from 13°C to 45°C.

In Figure 15 the cumulative thermal energy production during one day is shown.

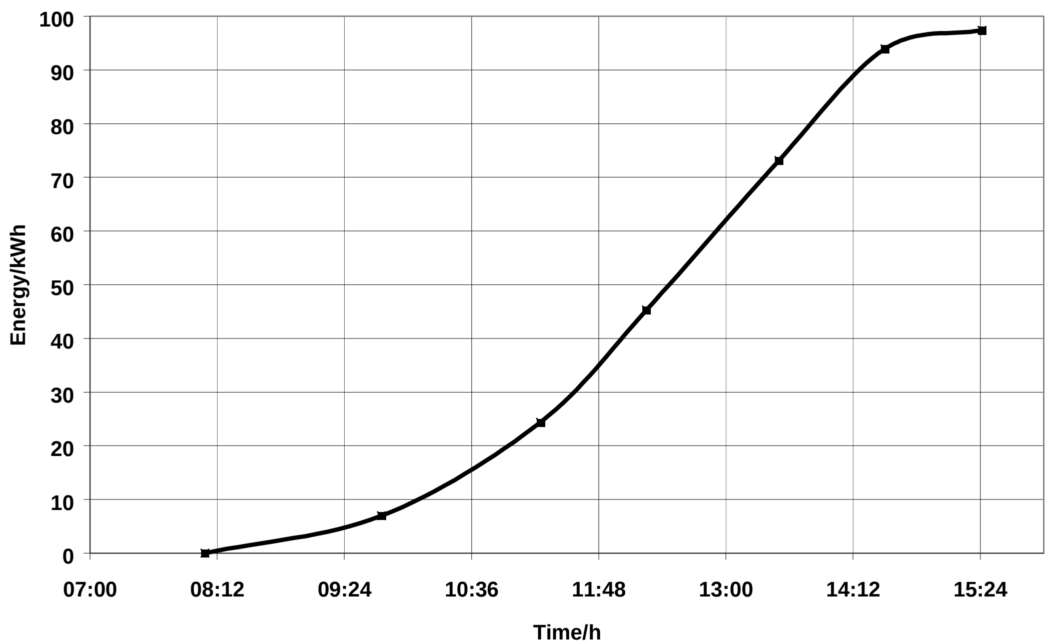

Figure 15: Cumulative thermal energy production on a sunny day in November 2001

As the figure shows, the curve has the same shape as the electrical curve in Figure 12. However, the energy production is much higher (nearly 100 kWh), even though the area is nearly the same. This shows that heat production from the sun is much more efficient than electrical energy production; therefore, in situations where heat is needed, solar collectors should be used.

The total thermal energy production in November is shown in Figure 16. This curve is also similar in shape to the electrical one in Figure 13. As the figure shows, more than 1.1 MWh thermal energy was produced in November.

In the spring, the tank could not be used as a calorimeter because the energy production was too high. Instead, the produced heat was delivered to one of the 150-m deep wells. The temperature of the well has now increased from 8.5°C to 13.5°C.

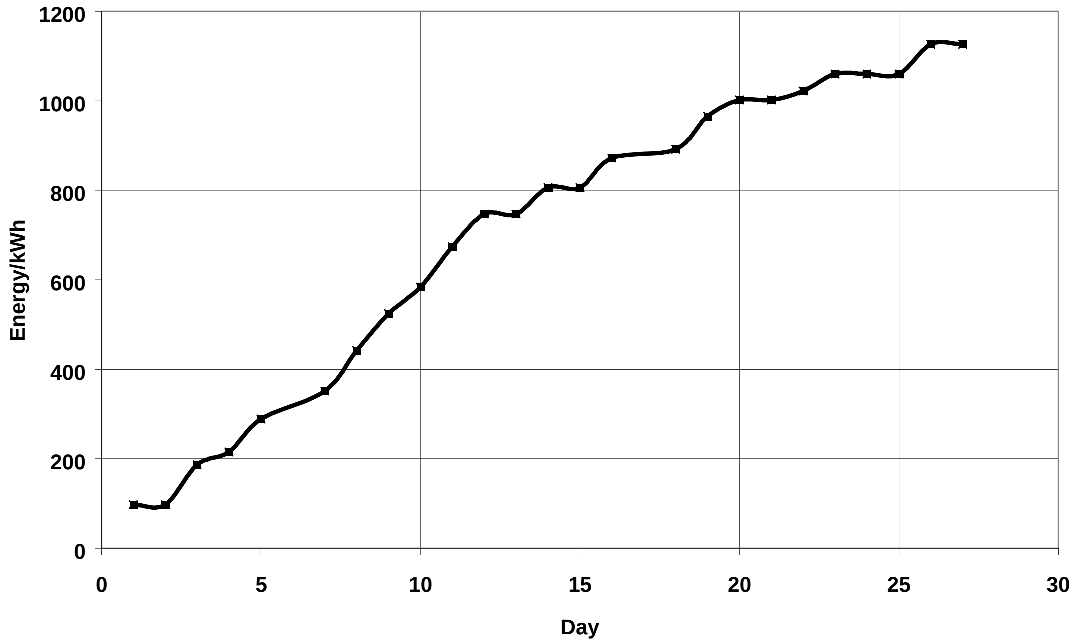

Figure 16: Cumulative thermal energy produced in November 2001

The high-pressure electrolyser is a prototype built by Norsk Hydro Electrolysers. In collaboration with Norsk Hydro, problems encountered during start-up and initial operation have been identified and corrected. The main problems have been related to the pressure balance in the system. The electrolyser must be purged with nitrogen before start-up to remove oxygen. In the purging sequence, a low level in the hydrogen separator and a high level in the oxygen separator occurred. The purging pipeline had to be rebuilt in order to create symmetric pipelines for both separator systems. The electrically operated on/off valves for the purging sequence did not work properly, and had to be replaced by more robust pneumatic operating valves. The instrument tubing for level measurements in the separators introduced noise and had to be replaced too. The purging sequence is now operating properly.

During the summer 2002, there have been heavy thunderstorms. This has caused only minor problems, mainly due to peak overload in the instrument connection chamber. The failure was easily corrected.

So far, the Energy Park has been operating satisfactorily with only minor corrections. Since it is quite flexible, it can be adapted as needed.

A student group has been working in a project with the aim of comparing the polycrystalline and amorphous cells under different operating conditions. As expected, they concluded that the efficiency of the crystalline cells was much higher than that of the amorphous cells under most conditions. However, more work has to be done in this area, hopefully by new student groups.

The Park is now generating a lot of data. However, the Energy Park staff is not large enough to handle all of these data alone. We invite domestic and foreign students to complete their thesis work on the Energy Park. Students from Germany have already made important contributions.

6. PUBLIC ACCEPTANCE

So far, a total of 4,500 people have visited the Energy Park at Dømmesmoen. This includes school classes, members of the Norwegian Research Council, Government representatives, and interested parties from research institutions, environmental organizations and universities.

Two national seminars on renewable energy were held in connection with the Energy Park, one in 2001 and one in 2002. A total of 80 participants from industry, research organizations, the Research Council, universities, Government, and other authorities attended both seminars. The plan is to make it a yearly event.

There have been no difficulties in obtaining operating licenses from Norwegian authorities; we followed the normal procedure for buildings, piping structures, and electrical structures. In fact, the local authorities were strongly interested in the park and were very helpful. The electrolyser was delivered with an operating license from the manufacturer, Norsk Hydro Electrolysers.

7. FUTURE POTENTIAL AND FUTURE PLANS

The strength of the Energy Park is its flexibility and the fact that it contains both a thermal system and an electrical system. This enables us to study integrated energy systems based on solar energy. New energy crops have been planted, which will make it possible to study bioenergy in the future.

Stand-alone energy systems for islands are becoming increasingly important, especially in connection with wind power. Examples are the planned energy systems in the islands Røst and Utsira in Norway. Data from the windmill park at Lindesnes can be used together with data obtained from the Energy Park.

Optimization of the high-pressure electrolyser with respect to “green energies” is an important project within hydrogen technology. Although problems with the electrolyser and limited manpower have delayed the project, it is scheduled to begin in the near future.

Because the Energy Park will have a nearly unlimited supply of hydrogen, different applications of hydrogen will be studied, especially in connection with fuel cells. An alkaline fuel cell will be installed in the near future. Long-term testing under different conditions will take place. A similar study performed with PEM cells is planned, once we establish contacts with interested PEM cell producers.

A student group has also constructed and completed some preliminary experiments with a combustion chamber for a gas turbine. It was quite successful, and a new student group is slated to connect the chamber to the gas turbine.

Catalytic burning is another aspect of hydrogen technology. In co-operation with the University of Oslo, a research group at HiA is studying catalysts for electrolytic hydrogen production. The research focus of the group could be expanded to include catalysts for fuel cells and perhaps also for catalytic burners.

8. CONCLUSION

The aim of the Energy Park is to demonstrate solar energy for the public. In addition, it is a tool for education and research in renewable energy. The park has already proven to be a success. Since it was opened in June 2000, 4,500 people have visited the park, and this positive trend is expected to continue. The Energy Park has played an important role in the success of the national seminars on renewable energy.

The park is flexible, and combines both thermal and electrical applications. In addition, hydrogen technology will play an important role in the park. The electrolyser for hydrogen production is already installed, and a fuel cell will be installed in the near future. Some problems have been encountered and have solved. Because the park is a research tool, new challenges are expected. The data acquisition system is made flexible and can easily be expanded. The measured results will be presented on the screen as virtual instruments. The screen will be connected to Internet, enabling the results to be followed all over the world. The park produces a lot of data, which will have to be analyzed. This could be an important area of research for Ph.D. students.

9. CONTACT INFORMATION

Project Coordination	Agder University College Groseveien 36, NO-4878 Grimstad, Norway Tel. ++4737253000
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