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Low-Cost Cloud Enabled Wireless Monitoring System for Linear Fresnel Solar Plants [†]

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Abstract: This paper presents the design of a cost-effective online wireless monitoring system of two Linear Fresnel solar plants (LFR) located in two different countries. The first LFR plant is installed in SEKEM medical center near Belbis city, Egypt, while the second one is installed in the campus of the University of Palermo, Italy. The proposed system is a standalone system that reduces the interaction of labors as it offers online wireless monitoring for important parameters of the LFR such as solar irradiance, ambient temperature, outlet and inlet collector temperature and heat transfer fluid flow. For that purpose, a Wireless Sensor Network (WSN) based on Arduino Mega boards coupled with XBee modules are used. The ZigBee XBee modules operate at 2.4 GHz, which have the advantages of being low cost and relatively low power consumption. The wireless nodes are supplied by solar paneled power banks, and send the data to a Cloud in order to monitor both LFR plants remotely. The proposed system has been implemented and tested successfully before the future deployment on the LFR plants.

Keywords: Linear Fresnel solar plant; wireless sensor networks; ZigBee; cloud; monitoring

1. Introduction

Renewable energy technologies have gained tremendous attention globally stimulated by the need of replacing the fossil energy systems, in spite of the fact that its availability varies across space and time. They are clean sources of energy derived from plentiful and unlimited sources that have a much lesser negative impact on environment than conventional fossil energy technologies. Several renewable energy sources exist that are in use such as hydropower, biomass, geothermal, solar energy and wind power [1]. Energy from the solar radiation has the largest potential for providing abundant, clean, safe, and reliable power.

There are several kinds of solar energy techniques that are currently available. The most common techniques are PhotoVoltaic cells/panels (PV) and Concentrated Solar Power (CSP). PVs are

well-known electronic devices used to generate direct current electricity from solar radiation [1]. CSP systems are employed to reflect and concentrate sunlight onto receivers that collect solar energy and convert it into heat. Then it can be used to produce electricity via a steam turbine or a heat engine driving a generator. The CSP systems are advantageous over the PV technology by having higher conversion efficiencies, low investment cost, inherent thermal storage to work during the off hours [2]. There are four categories of CSP technologies that can be classified into line and punctual focus technologies according to the distribution of the focused solar radiation on a receiver [3]. Also, it can be classified into a single and two axes tracking technologies according to the sun tracking mechanism [4].

Monitoring and performance analysis of solar plants are crucial aspects to observe the stability and performance of the system. Monitoring plays an important role in decreasing the cost of operation and maintenance as well as ensuring faults detection and increasing the energy production efficiency [5,6]. Monitoring of the status of solar plants can be implemented either by using interface cables [7], wireless communications [8], or both [9]. Conventional wired monitoring system provides the security, speed and reliability for data transmission [10]. However, it suffers from technical limitations for its installation and the material cost is comparatively higher than using wireless monitoring systems. In addition to the costs of the wires, expenses for trenching, lightning protection, protection against rodents, and maintenances are also integrated [11]. The application of wireless communication technologies in PV plant and consequences of cost reduction make it an attractive technique for CSP plants [12]. Even so, there are no works in the literature reporting the application of Wireless Sensor Networks (WSN) to CSP plants, and specifically, no research has yet applied wireless communications to monitor the performance of Linear Fresnel Reflectors (LFR), which comprised on the category of the single axis tracking and line focus technologies.

This work proposes a low cost WSN-based monitoring system for LFR plants. The designed wireless nodes are based on ZigBee communication technology and are supplied by solar paneled power cells. The nodes are built on Arduino-compatible boards, and the employed sensors provide information regarding the efficiency, stability, fault detection, safety and security of the LFR plants. Also, in order to monitor remotely the LRF plants, the collected data is sent through a Gateway node to a specifically designed and developed Cloud and web-based monitoring system.

2. Linear Fresnel Solar Plants

LFR is a recent entrance technology of CSP based usually on small scale projects. It composes of many long rows segments of flat mirrors, which focus the light onto a fixed elevated tubular receiver running parallel to the reflector rotational axis. Segments are aligned horizontally and track the sun position such that the tubular receiver is illuminated (i.e. heated) without need to be moved. A second reflector can be installed on top of the receiver tube to enhance the captured sun light.

In a recent EU-funded project, Small scale Thermal Solar districts for Mediterranean communities (STS-MED), a solar multi-generation approach has been implemented in four different countries (Cyprus, Egypt, Jordan and Italy), each characterized by different collectors and different integration scenarios [13].

In this work we consider two LFR plants where PLC and SCADA systems are used for monitoring and control. The first one, installed in Egypt, includes LFR collectors (model IDEA 1FC-1832) (see Figure 1) with a total area of 296 m^2 . It consists of a single Linear Fresnel solar collector, thermocline storage tank, 4 kW organic Rankine cycle (ORC), and 35 kW thermally driven chiller. The second plant, which includes the also LFR collector, has been commissioned in the campus of the University of Palermo, Italy (see Figure 2). It consists of three identical LFRs, thermocline ternary molten salt tank, 10 kW ORC, and 23kW LiBr chiller. The plant has a total collector area of 480 m^2 . Specifications of both plants are given in Table 1.

The subsystems of multi-generation LFR plants that require adequate monitoring and control are, mainly, the sun tracking system, Thermal Energy Storage (TES) System, outlet temperature of HTF along the solar collector, power generation and cooling generation.

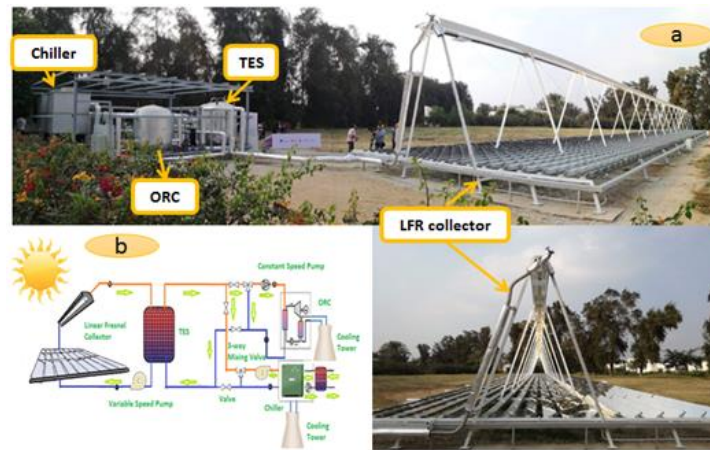


Figure 1. Sekem LFR solar plant, in Egypt.

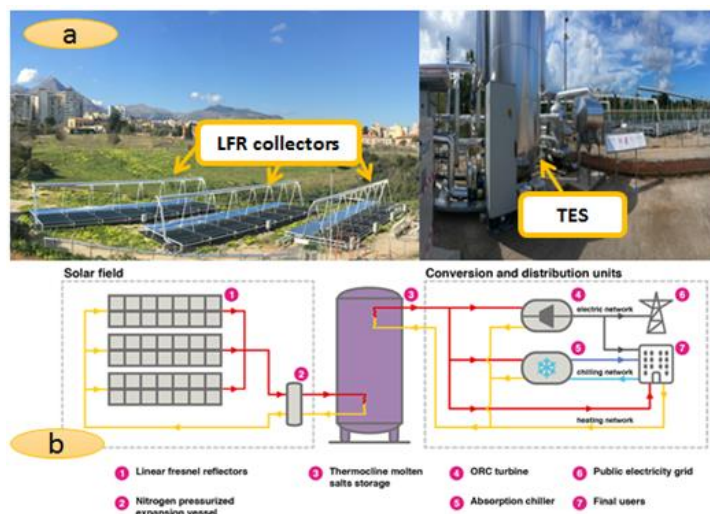


Figure 2. Palermo LFR solar plant, in Italy.

Table 1. Data specification of LFR plants.

Data	LFR Egypt	LFR Italy
Latitude	30°25'05.5"N	38°06'01.0"N
Longitude	31°38'07.8"E	13°20'37.3"E
Elevation	35 m	50 m
DNI per year	1958 kWh.m ⁻²	1703 kWh.m ⁻²
Aperture area	299.50 m ²	483.84 m ²
Thermal oil	Therminol 66	Paratherm NF
Peak power	115 kW	190 kW
Receiver length	52 m	84 m
Working temperature	140 °C	270 °C

3. Monitoring System Architecture

The proposed monitoring system of the LFR plants deployed in Egypt and Italy is presented in Figure 3. The WSN consists of many nodes distributed in different zones of the plant, creating a ZigBee network in a mesh topology. This topology will provide the full coverage of the area of interest as well as high degree of redundancy [14]. Figure 3 shows schematically the designed wireless monitoring system.

The ZigBee-based WSN nodes (see Figure 4a) will be deployed in each of the LFR plants. The collected data is sent to the wireless network coordinator (see Figure 4b), which will send the

information to the Cloud via Ethernet connection, for its control and monitoring in the Public University of Navarre (UPNA), Spain (it could be also monitored from Egypt and Italy).

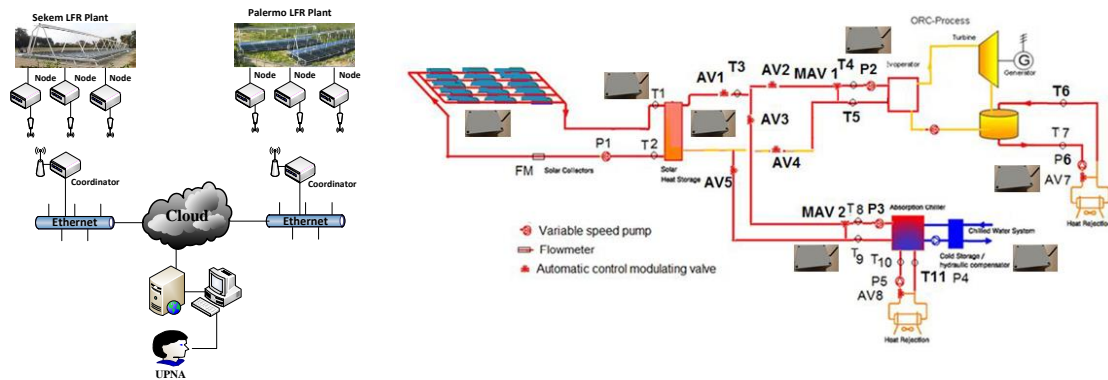


Figure 3. Communication architecture of the proposed monitoring system (left), and proposed WSN for the LFR plant monitoring system (right).

3.1. Hardware

This section gives the details on the different system components and sensors, and their implementation in the experimental setup. For the goal of monitoring fault detection, minimum time delay, safety and security, several low-cost sensors have been employed. All sensors are based on Arduino (or compatible boards) and the most relevant are shown in Figure 4a. Digi’s XBee-PRO operating at 2.4 GHz band have been employed as RF modules. The Arduino sensor shield allows the employed Arduino Mega boards to be integrated easily with sensors and XBee modules. The collected data by the network coordinator (see Figure 4b) is transferred to the Internet, and therefore to the Cloud, through an Ethernet shield.

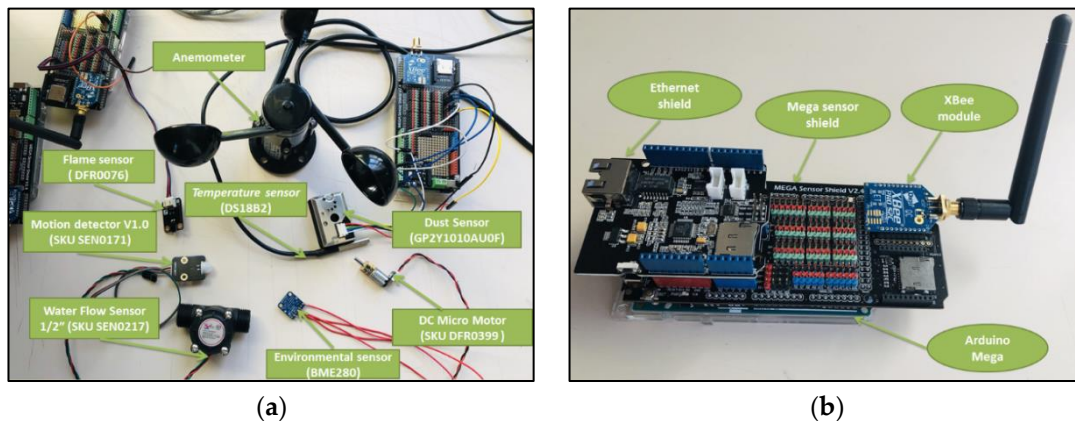


Figure 4. Employed hardware for the wireless ZigBee nodes: (a) Sensor nodes components; (b) Coordinator node.

Since the LFR plants are in construction when this study was carried out, a test-bed was proposed (prior a future deployment in the LRF plants) in order to assess the reliability and the performance of the designed WSN and the complete architecture of the monitoring system. For that purpose, wireless nodes (8 sensor nodes and 1 coordinator/gateway) were deployed within the UPNA campus, distributed in three different buildings and gardens. The duration of the tests was 3 hours, using different sampling intervals depending on the sensor type. The results showed that the 99.7% of the packets arrived successfully to the Cloud.

3.2. Cloud-Based Monitoring

Monitoring is performed with the aid of a cloud-based system. The usage of a cloud-based solution allows us to dispense with large and costly computing infrastructures, while offering an adequate scalability and adaptation to the specific computational needs. A specific cloud infrastructure has been developed, located at the campus of the Public University of Navarre. This infrastructure includes six TTL Teknoslim computers, equipped with Intel i5-7500 quad core processors, with 16 GB of RAM and two hard disks (a 256 GB SSD, and a 1TB HDD). The proposed monitoring system is based on well-known and –proven open-source tools, and includes the following components: an Apache NiFi component, in charge of data flow managing; an Apache Kafka component in charge of handling real-time data; a MySQL relational database; a MongoDB non-relational database; and a Grafana platform for analytics and monitoring. Figure 5 (left) shows the components and flow of the cloud-monitoring system.

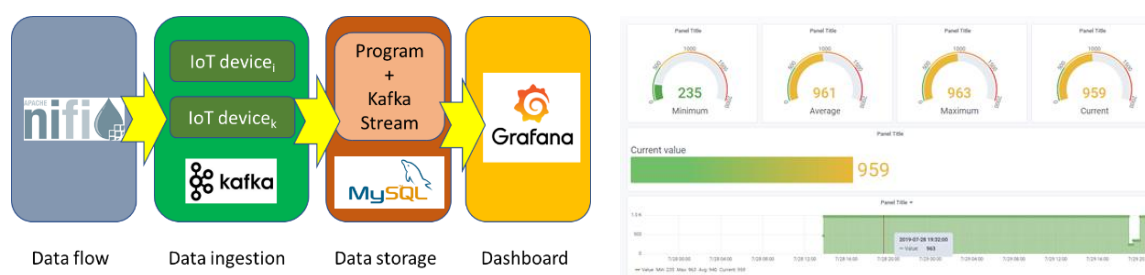


Figure 5. Components of the monitoring system and the graphic interface implemented in Grafana.

Finally, analytics and monitoring are then provided by a web-based Grafana platform, which collects the information from the MySQL database and provides structured and useful information over an interactive dashboard. The (web) access to this dashboard is restricted to users, since just authorized ones can either edit or view the dashboards. The frequency of information refresh can be configured according to the changing monitoring needs. Figure 5 (right) shows a screenshot of the monitoring system.

4. Discussion

This work proposed a wireless cloud-based monitoring system for LFR plants in order to facilitate remote monitoring and control. The monitored parameters are displayed on a web-based graphic interface for its analysis and processing. The WSN nodes are suited to measure various key parameters of LFR plants. The system can be configured with different sampling times and it is easily scalable to any number of measurement points, which renders it highly versatile. The test of the system has been successful, and the deployment on the real plants will be reported in future works.

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