OPTIMAL DESIGN FOR WATER AND POWER CO-GENERATION IN REMOTE AREAS USING RENEWABLE ENERGY SOURCES AND INTELLIGENT AUTOMATION

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ABSTRACT

In this paper a reverse osmosis desalination plant for brackish water powered by renewable energy sources, and a diesel generator as back-up will be described. The whole system serves as a laboratory prototype for testing new automatic control methods to increase the plant reliability, which is crucial in remote arid areas. The necessary steps for the design of an optimal co-generation of both water and electricity such as the decision support system, modelling and simulation of the system and developing a fault tolerant control system will be depicted. The overall goal is to provide a cost optimal way to produce water and energy under the regional and technical boundary conditions.

Keywords: reverse-osmosis desalination, hybrid energy, decision support, fault tolerant control, energy management.

1. INTRODUCTION

The use of reverse osmosis (RO) plants for water desalination is becoming more popular especially in remote arid areas, where grid electricity might be unavailable. In this case hybrid energy sources, such as wind and solar energy, are used to generate the necessary electricity for running the RO-plant and for the domestic use of the living community.

Reverse Osmosis (RO) desalination plants powered by renewable energies and electricity co-generation have been intensively studied in the past ten years (Seeling-Hochmuth 1998). They seem to be a very convenient solution for de-central small communities in remote arid regions. Nevertheless, the state of the art indicates that the current product development does not include optimal systems engineering and that plants are not thought to be tolerant in the presence of faults, malfunctioning or operator mistakes. This is however of crucial importance in remote areas where skilled personnel are normally absent in such areas. When the plant fails, severe difficulties can be caused to people, who depend on it.

To tackle this problem a consortium was built within the framework of the European co-funded project OPEN-GAIN (2007) with the main goal to develop a new model-based optimal system design approach to economically improve the overall performance, dependability, reliability and availability of co-generating water-electricity plants powered by renewable energy sources for remote arid areas using a high level of automation to meet specific cost requirement (Gambier, Wolf, Badreddin, 2008).

Based on this goal a desalination plant powered by renewable energy sources was built and installed in Borj-Cedria in Tunisia. A decision system was developed to support the designer by choosing and sizing the different components of the plant. A library for the design and simulation of reverse-osmosis desalination processes was also built. A fault tolerant control concept which allows running the reverse osmosis plant in case of faults based on hybrid control was introduced. An energy management system that coordinates the usage of the different energy sources according to weather forecast, battery charge levels and user's consumption profile of water and electricity was designed. As a brackish water source, a 30 meter deep water well was digged. In the following the plant and the individual steps towards the optimal cogeneration of water and electricity system will be handled.

2. PLANT DESCRIPTION

A reverse-osmosis desalination plant that produces 24 m^3/day was installed in Borj-Cedria (figure 1). The plant has been constructed and equipped with additional sensors to cope with the control algorithm and system monitoring. The RO-plant and the community are supplied by electricity from a bank of batteries, that are charged by the wind turbine and the photovoltaic modules, which present the renewable energy sources. The batteries are arranged in serial and parallel configuration to give 630Ah at 48V. The PV-modules are arranged in 3 parallel strings with 9 PV-modules in series for each string to give a total power of 15kWp (figure 2). The wind turbine is of 15kW and installed on a 25m tower. If the available charge level of the batteries is low and at the same time wind and solar irradiation are not sufficient to start the RO-plant, the diesel generator is switched on to supply the RO-plant and community with electricity and to load the batteries.

This is actually the role of the energy management system, which will be described later.

For the connection of the plant components an AC-bus architecture was chosen (figure 3), where the power delivered by all the energy conversion systems and the battery is fed to the standalone grid. The AC-bus architecture allows building up of larger power systems with multiple energy units distributed along the grid. This offers a theoretically unlimited expandability and reduction of distribution line costs and decentralized location of renewable energy generators.

Figure 1: Reverse-Osmosis Desalination Plant

Figure 2: Photovoltaic modules

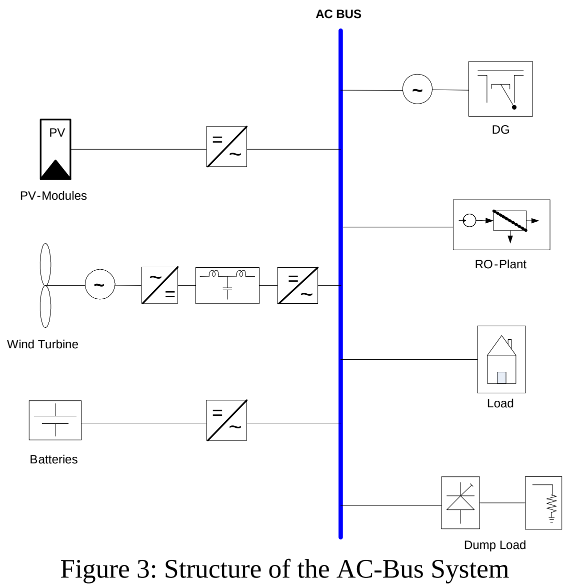

Figure 3: Structure of the AC-Bus System

3. DECISION SUPPORT SYSTEM

The Decision Support System (DSS) is a tool for the system implementation under site conditions taking into account energy efficiency, cost effectiveness, socio-economic impact and environment protection. A decision support tool is necessary to solve the problem of decision-making for engineering design.

The DSS integrates a database that hosts relevant meteorological, technical and market data for the design and evaluation of the hybrid energy system. The solar irradiation data, and wind speeds and directions were recorded, as well as the user’s demand for water and electricity for more than one year, and integrated into the DSS database. The technical data and prices of several types of plant components from market leading manufacturers are also considered in the database. The database can be extended to included greater number of component types and manufacturers.

A multi-criteria optimization algorithm is implemented to adequately size the system components under the given site and market conditions. The DSS tool was developed by the group of Prof. Dionysis Assimacopoulos at the National Technical University of Athens in Greece (Kartalidis, Arampatzis, Assimacopoulos, 2008).

4. LIBRARY FOR MODELING RO-PLANT

The objective of modeling the RO-plant is to develop computer models that can be used for dynamic simulation of RO-plant to test different configurations, as well as control strategies (Palacin, Tadeo, Salazar, de Prada, 2009) and fault detection and accommodation algorithms. The models are provided as a library of components that can be interconnected in order to simulate different configurations of the plant, which can be used for sizing, component specifications and controller design. The group of Prof. Cesar de Prada at the University of Valladolid in Spain has developed the library OSMOSIS that runs under the professional simulation software package EcoSimPro (Palacin, Tadeo, de Prada, Syafiie, 2008). The tool enables modeling and simulation of pre- and post-treatment processes as well as the desalination membranes. The bacterial growth and scaling of the membranes can also be modeled and simulated. This allows also for planning cleaning strategies of the membranes.

5. FAULT TOLERANT CONTROL

In case faults of the RO-plant take place due to scaling, faulty pumps, leakage, etc., it is required that the RO-plant keeps on producing water even it has to work at reduced capacity. This due to the fact that a total failure of the plant can not be afforded, especially in remote arid areas, where the skilled personnel to repair the plant, are not available. The group of Prof. Essam Badreddin at the Automation Laboratory of the University of Heidelberg has developed the fault tolerant control (FTC) system. A model-based fault tolerant control strategy was utilized to design a control strategy on the supervisor level that allows the plant to keep produce water when subject to faults. The idea to introduce the supervisor is because of the necessity to design a dependable system. The design of the supervisor was carried out applying hybrid control and discrete events supervision strategies. The supervisor includes a diagnosis unit, which is responsible for the detection and identification of faults, and a recovery unit that adjusts the control to the faulty system by carrying out a controller switching. For modeling of the hybrid system, a hybrid automaton was used (Gambier, Blümlein, Badreddin, 2009).

6. ENERGY MANAGEMENT SYSTEM

As different energy sources are used to run the RO-plant, an energy management system (EMS) is necessary for the optimal administration of the energy sources, which appear in hybrid form (wind, PV, diesel and batteries). The main duty of the manager is to decide in an optimal way, how the different energy sources have to be combined according to forecasting information of weather and demand of both energy and water, and the current conditions of subcomponents and loads, etc. In other words, the EMS should maximize the power utilization from renewable energy resources and the minimize fuel consumption of the diesel generator by reducing the number of switching on the diesel generator taking into account the system safely within its constraints. The group of Prof. Sami Karaki at the American University of Beirut in Lebanon has developed the architecture for the EMS and its real time implementation using genetic algorithm as an optimizer (Karaki, Bou Ghannam, Mrad, Chedid, 2010).

7. CONCLUSION

This project OPEN-GAIN offers a solution to cost optimal co-production of energy and water using renewable energy sources (PV, wind) besides diesel generators as a conventional energy source in remote arid areas. Cost optimization is achieved through a high level of automation, which is necessary to adapt the working conditions to the strongly varying renewable energy supply, and remote maintenance. The approach is based on thorough modeling of the processes and offers a large degree of flexibility in the design to meet different production requirements.

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