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Smart energy for smart irrigation

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ABSTRACT

This paper investigates the possibility of reducing the cost of irrigation by utilizing techniques, methods and practices that are common to the smart energy systems. A software platform that couples the smartness of the irrigation systems with the smartness of the energy systems is designed, implemented and evaluated. The resulting simulation engine allows large scale and very detailed experimentation where irrigation experts specify energy effective configurations that lead to the reduction of the irrigation cost through smart utilization of Renewable Energy Sources (RES).

1. Introduction

Irrigation has been around for as long as humans have been cultivating plants. Irrigation procedures mainly depend on the water availability, while water requirement is the main parameter for calculating equivalent energy demand.

Direct coupling of agricultural processes with RES have been considered for centuries. In principle, it reduces energy cost, by consuming the free energy offered by RES and often going off the grid, in a micro-grid form or as energy autarky islands (Hiatt et al., 2011).

Water use efficiency and energy use efficiency are the main focuses of two recent innovations known with the, surely overloaded terms smart irrigation and smart grid. The already existing and rapidly emerging smart irrigation systems (for example http://waterbee.iris.cat) offer significant water savings. They commonly consist of an agriculture model that based on data from a wireless network of sensors controls the operation of irrigation in a rather precise manner. It is no surprise that there is no unique definition of the Smart Grid. Our study is based on the following definition provided by the U.S. Department of Energy. *Smart grid is a fully automated power delivery network that monitors and controls every customer and node, ensuring a two-way flow of electricity and information between the power plant and the appliance, and all points in between. Its distributed intelligence, coupled with broadband communications and automated control systems, enables real-time market transactions and seamless interfaces among people, buildings, industrial plants, generation facilities, and the electric network.*

Agricultural activities involve several important, from the energy viewpoint, sectors. However, the formation of a robust and sustainable electrical power grid allows the utilization of RES to cover the energy needs of these sectors. This leads to their electrical autarky[1] which remains a very challenging problem. The imposed challenges depend on several characteristics associated with various issues varying from the legal requirements, to the effect of the various topological and land-use parameters.

There are many applications that may benefit from a balanced energy/agricultural system. These include: heat produced through solar and biomass technologies and consumed for crop drying, greenhouse, livestock farms and water heating, electricity produced through solar, biomass, wind and hydro based technologies and consumed for water pumping (wells, ponds, streams), irrigation sprinklers, controls, security and task lighting, ventilation, feed or product handling, equipment, refrigeration, battery charging, air condition, compressors for fish farming, fans for crop drying, greenhouse heating, etc.

The main objective of this paper is to provide a practical tool that allows us to elucidate several issues concerning the various characteristics of the coupling of smart grid with smart irrigation. More specifically, a simulation approach based on RES (solar panels, wind turbines) installations for serving agricultural and when needed residential loads is proposed. This approach utilizes a

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[1] Autarky is the state of an organization that is sufficient for satisfying its energy needs and forbids any import of energy from the power grid.

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software platform capable of simulating technical and financial aspects of the proposed installation. The authors design and develop a prototype implementation of such a platform and use it for our initial experimentation which indicates that the irrigation and to a great extent the agricultural sector, can potentially be a very challenging area of RES research and development, especially when liberalized auction-based energy market is involved.

The rest of this paper is organized as follows. In Section 2 the related efforts that motivate our study and develop the appropriate background are presented. In Section 3 the system design is considered and in Section 4 the main features of GridLAB-D are described in detail. Section 5 contains the main characteristics of our prototype implementation and the proposed integrated system. Associated elementary simulation results are given in Section 6 and our concluding remarks are presented in Section 7.

2. State of the art

Several agricultural projects around the globe emphasize on the need for further research and development towards the improvement of irrigation applications, in terms of better energy management and reduced cost. Below the ones that are of importance to our efforts are presented.

A sizing procedure for calculating the variables involved in a solar panel installation for agricultural processes is presented in Morales and Busch (2010). Vick and Almas (2011) proposes methods for the irrigation management via a central coordinator. Based on several parameters, this coordinator suggests various alternative implementations involving solar and/or wind energy, also taking advantage of storage ability of excess energy and water storage in surface reservoirs for future irrigation and other on-farm uses. It proposes a partitioning of the irrigation system between a winter crop and a summer crop that leads to an improved match between the wind turbine and the PV solar array power generation required for water pumping applications. The design and the operation of such an application depends on a set of crucial parameters that includes monthly energy demand for different crops, the size of wind turbine or/and PV array, the average monthly evapotranspiration, the average monthly rainfall, average hourly wind speed for different heights, average monthly air density, power curve and many others.

Similar to the above, Stambouli et al. (2014) presents a modernized irrigation system, already in operation, coordinated by a central management operator. The central system involves elementary remote control that manages the automated frequency controlled pumping stations, while an on-demand program schedules irrigation processes for different farms. More specifically, it collects the desired schedule in terms of irrigation hours and days of the week and adjusts the pumping system and piping network operation by opening hydrants and valves accordingly. A district central managing office is responsible for paying all the electricity and maintenance expenses, which then distributes them according to the total water volume consumed by each farm.

Among other papers, Shivrath et al. (2012), Glasnovic and Margeta (2009) and Kelley et al. (2010) present sizing and optimization algorithms focusing on evaluating technical (dependent on soil, climate, geography, agriculture, and hydro-geology) as well as economical (dependent on the electricity price, life cycle cost of investment) feasibility of solar and/or wind energy installations for irrigation purposes. More specifically, in Kelley et al. (2010) a technical and an economic feasibility analysis for PV solar irrigation systems is performed, in order to emphasize the use of solar energy for irrigating purposes compared to conventional diesel engine as well as grid powered irrigation systems. It is based on an analytical mathematical model, in a way that can be applicable to any geographic location and crop type. Technical feasibility is determined from the maximum power required for irrigation purposes which highly depends on the crop type and the geographic location. On the other hand, economic feasibility is determined in terms of life-cycle costs of the PV solar irrigation system compared to diesel and grid based irrigation systems. The results exhibit that the success of a PV solar application depends on the size of the overall farming size and the variations of the irrigation needs. The results from the economic feasibility analysis illustrate the superiority of PV solar applications compared to the diesel-engine and grid powered irrigation systems, despite the high capital costs of PV systems. As the price of solar panels decreases, the PV irrigation systems become more and more economically attractive. Several examples cases are examined, showing the benefits of the PVP applications compared to other system types.

In Glasnovic and Margeta (2009), two Croatian regions with different hydrogeological and meteorological data are examined. It presents a systematic approach in sizing as well as optimizing a PV solar array system. Considering a whole range of factors, climate, soil, hydrological and agricultural a mathematical model utilizing dynamic programming for optimal sizing is derived. This model is formulated as an objective function couples with a set of constraints in terms of the factors mentioned above. Furthermore, a major effort is devoted to show how and in what extent these factors influence the determination of financially acceptable plant areas for irrigation purposes. The results obtained for two regions, one with continental climate and the other with coastal climate can be summarized as follows: warmer climates with increased temperature and solar radiation require larger water quantities for irrigation since they have the drawback of increased evapotranspiration.

Shivrath et al. (2012) proposes a design and an optimization process of the cost of a hybrid wind/solar renewable system for drip irrigation purposes, based on various operating and design parameters. These design parameters are the pumping system specifications as well as the drip irrigation specifications. Meteorological data concerning the design of both the solar PV system and the wind turbine system are also utilized for sizing purposes. Finally, a battery bank calculation is presented. The cost optimization procedure is formulated by an objective function for minimizing a particular cost function consisting of the optimum number of solar panels and wind turbines, subjected to certain limitations and constraints obtained by the pumping and irrigation specification and requirements. The proposed design and optimization algorithm is executed on Microsoft Office Excel 2007. The authors conclude that when combined, solar and wind renewable sources enhance the reliability of the system, and lead to battery bank reduction increasing its lifetime.

Vishwa et al. (2015) is an up-to-day literature review of PV solar water pumping systems for irrigation purposes. The advantages of solar water pumps are illustrated compared to hand pumps or internal combustion engine pumps, that is, easy installation, zero maintenance, long useful life, no fuel, no contamination. It is shown that compared to diesel powered water pumps, solar powered pumping systems are less expensive over a life cycle of 10 years. This review focuses on specific issues like the evaluation, monitoring and performance improvement of the different components of a PV system. It considers.

1. the dependency of the irrigation process on soil type, PV system sizing for the particular crop considered.
2. Meteorological data such as solar radiation air temperature, wind speed, and relative humidity.
3. Operational specifications like irrigation scheduling from which water requirements converted into electrical energy requirements.