Design and Implementation of a 12 kW Wind- Solar Distributed Power and Instrumentation System as an Educational Testbed for Electrical Engineering Technology Students

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Abstract- **The main objective of this paper is to report and present design and implementation of a 12 kW solar- wind hybrid power station and associated wireless sensors and LabView based monitoring instrumentation systems to provide a teaching and research facility on renewable energy areas for students and faculty members in Electrical Engineering Technology (EET) programs at the University of Northern Iowa (UNI). This new ongoing project requires to purchase a 10 kW Bergey Excel-S wind turbine with a Power Sink II utility intertie module (208 V/240V AC, 60 Hz), eight BP SX175B 175W solar PhotoVoltaic (PV) panels, and related power and instrumentation/data acquisition hardware. A 100 ft long wind tower to house the new wind turbine is available at UNI campus. Furthermore, the electricity generated by this power station will be used as a renewable energy input for a smart grid based green house educational demonstration project to aid the teaching and research on smart grid and energy efficiency issues. 330:038 Introduction to Electrical Power/Machinery, 330:166 Adv Electrical Power Systems, 330:059/159 Wind Energy Applications in Iowa, 330:059/159 (2) Solar Energy Applications and Issues, and 330:186 Wind Energy Management are the classes that will use this proposed testbed. There are also workshops planned for the area Science, Technology, Engineering, and Mathematics (STEM) teachers as well as local farmers' education and training on wind and solar power systems. Previous workshops organized by UNI Continuing and Distance Education have been very successful. The hybrid unit contains two complete generating plants, a wind-turbine system and a PV solar-cell plant. These sources are connected and synchronized in parallel to the UNI power grid as part of laboratory activities on wind-solar hybrid power systems and grid-tie interactions.**

The proposed project is part of a program initiative to improve our laboratory facilities to better reflect on the current and future renewable energy technologies. The proposed testbed will allow students to be educated and trained in the utilization of real-time electrical power systems and additionally will allow them to gain valuable "hand-on" experience in setting up a real- time data acquisition system specifically in grid- tied wind- solar power systems. Since Iowa's solar energy resources are higher in summer, this will provide an excellent complement to the load demand when summers are not windy.

Key Words:Renewable energy, Solar-wind hybrid power station, Wind Energy Management

I. INTRODUCTION:

Energy is available in two different alternatives, nonrenewable (coal, fuel, natural gas) and renewable energy (RE) (solar, wind, hydro, wave) sources. Especially, after the industrial revolution, in the 19th century, first coal and then fuel oil are used as primary energy sources for the needs of modern communities.

Towards the end of 20th and beginning of the 21st centuries, interest has risen in new and renewable energy sources especially wind energy for the electricity generation. Wind energy is welcomed by the society, practical, economical and environmentally friendly alternative. After the 1973 oil crisis, the RE sources started to appear in the agenda and hence the wind energy gained significant interest. Faced with energy crises in 1973, western countries began to search for their own clean and (RE) sources (wind, solar, biomass, etc.) which are effective but they must inevitably compete against the conventional energy sources. In this competition, energy sources with huge and renewable raw materials have the advantage in the long run. Atmospheric environment is polluted due to thermoelectric power plants, and petroleum materials since the industrial revolution. The pollution crises are the catalysts for the search and development of RE sources.

Continuing to use fossil fuels is bound to pollute the atmosphere, and consequently, unwanted greenhouse emissions and climate change effects will come to dominate every part of the earth. Currently the fastest developing energy source technology is the wind energy. Because wind energy is renewable and environment friendly, systems that convert wind energy to the electricity have developed rapidly. Wind energy is an alternative clear energy source compared to the fossil fuels that pollute the lower layer of atmosphere. It is, therefore, advisable to exploit clean energy resources for many nations in the world to try to keep their environment friendly. Wind energy is widely used in many countries such as the USA, Germany, Spain, Denmark and India. It seems that the wind power is esteemed in these countries as the most perspective branch of the electric power industry.

Hybrid renewable energy systems (HRES) are becoming popular for remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. Economic aspects of these technologies are sufficiently promising to include them in developing power generation capacity for developing countries. Research and development efforts in solar, wind, and other renewable energy technologies are required to continue for, improving their performance, establishing techniques for accurately predicting their output and reliably integrating them with other conventional generating sources. The paper describes methodologies to model HRES components, HRES designs and their evaluation. The trends in HRES design show that the hybrid PV/wind energy systems are becoming gaining popular. The issues related to penetration of these energy systems in the present distribution network are highlighted.

Solar and wind energy are non- depletable, site- dependent, non- polluting, and potential sources of alternative energy. Utilization of solar and wind power has become increasingly significant, attractive and cost-effective, since the oil crises of early 1970s. However, common drawback with solar and wind energy is their unpredictable nature. Standalone photovoltaics (PV) or wind energy system, do not produce usable energy for considerable portion of time during the year. This is mainly due to dependence on sunshine hours, which are variable, in the former case and on relatively high cut-in wind speeds, which range from 3.5 to 4.5 m/s, in the latter case resulting in under utilization of capacity [1]. In general, the variations of solar and wind energy do not match with the time distribution of demand. The independent use of both the systems results in considerable over-sizing for system reliability, which in turn makes the design costly[2].

II. MODELING OF HYBRID RENEWABLE ENERGY SYSTEM COMPONENTS

Various modeling techniques are developed by researchers to model components of HRES. Performance of individual component is either modeled by deterministic or probabilistic approaches [3]. General methodology for modeling HRES components like PV, wind, and battery is described below:

III. HYBRID PHOTOVOLTAIC/ WIND ENERGY SYSTEM

Wind and PV systems rely on highly transient energy sources and exhibit strong short-term and seasonal variations in their energy outputs. They, thus, need to store the energy produced in periods of low demand, in order to stabilize the output, when the demand is high. While batteries are most commonly used for this purpose, they typically lose 1–5% of their energy content per hour and thus can only store energy for short periods of time . There are presently no practical means available for long-term storage of excess electrical energy produced by the RE sources.

Few studies are related to the use of hydrogen for the electrical energy produced by RE sources such as wind and solar power .

Standalone commercial PV or wind, do not produce usable energy for considerable portion of time during the year. Combination of PV and wind in a hybrid energy system reduces the battery bank and diesel requirements. Feasibility of hybrid PV/ wind energy system strongly depends on solar radiation and wind energy potential available at the site. Various feasibility and performance studies are reported to evaluate option of hybrid PV/wind energy systems [1,4,5,6,7]. PVs array area, number of wind machines, and battery storage capacity play an important role in operation of hybrid PV/ wind-diesel system while satisfying load. Nehrir et al. [8]presented computer-modeling approach for evaluating the general performance of hybrid PV/ wind energy system. Celik [9] proposed a technique to evaluate performance of hybrid PV/ wind energy system using synthetically generated weather data. Kolhe et al. [10] elaborately discussed the analytical model for predicting the performance of hybrid PV/ wind energy system with hydrogen energy storage for long-term utilization.

Optimum size of hybrid PV/wind energy system can be calculated on an hourly basis or on the basis of daily average power per month, the day of minimum PV power per month, and the day of minimum wind power per month. Ai et al. [11] presented method for optimum size of hybrid PV/wind energy system. Performance of hybrid PV/wind energy system was compared on hourly basis; by fixing the capacity of wind generators, yearly Loss of Load Probability **(**LOLP) with different capacity of PV array and battery bank were calculated. Trade off curve between battery bank and PV array capacity for given LOLP helps to find optimum configuration at least cost.

Various optimization techniques such as linear programming [12], probabilistic approach[13], dynamic programming[14], multi-objective [15] were used by researchers to design hybrid

PV/wind energy system in a most cost effective way. In order to calculate reliability/ cost implications of hybrid PV/ wind energy system in small isolated power systems Karki and Billinton [16] presented a Monte- Carlo simulation approach. Samarakou et al. [17] compared results of two optimization techniques based on simplex and other algorithm for hybrid PV/ wind energy system.

Al-Ashwal and Moghram [18] presented a method for assessment on the basis of LOLP to decide an optimal proportion of PV and wind generator capacities in hybrid PV/wind energy system; optimal system combination was selected on the basis of capital cost and annual autonomy level. Autonomy level of the system is defined in terms of LOLP and is been used to find system configuration[19]. Protogeropoulos et al. [20] developed general methodology by considering design factor such as autonomy, for sizing and optimization. The authors also calculated battery size requirements to achieve desired level of autonomy by using system performance simulation model. It is observed that for achieving high autonomy, a backup generator is required and in turn reduces battery storage capacity.

Hybrid PV/wind energy systems are also designed not only for meeting electricity requirements but also for meeting fresh water requirements through desalination [21]. Sontag and Lange [22] made an attempt towards improving the prospects for utilizing renewable energies in combination with energy supply system, for the power and heating requirements of a residential complex.

Above studies reveals that hybrid PV/wind energy system are proving to be very promising worldwide. In view of system costs, contribution of PV is small as compared to the share of wind.

IV. PROJECT DESCRIPTION

This project proposes construction of a 12 kW wind-solar power and instrumentation system where a 10 kW Bergey Excel-S with Power Sink II utility intertie module (208 V/240V AC, 60 Hz) and a solar PV array of 2 kW at UNI campus. This will help EET undergraduate and graduate students to complete enhanced hands-on activities on wind-solar hybrid power systems, grid-tie interaction, and investigation of ac/dc interactions between conventional and renewable energy systems. Furthermore, the electricity generated by the power station will be used as renewable energy input for a smart grid based green house educational demonstration project under planning at UNI campus to aid the teaching and research on smart grid and energy efficiency. Besides the wind-solar power system, the proposed system also includes battery storage, LabView based data acquisition hardware/ software, and wireless sensor networks. Currently there is a 100-ft long steel tower available at the project location at UNI and it will be used to house 10 kW Bergey Excel-S wind turbine. The system will be designed and implemented with the following goals:

- To be completely different from conventional electrical power labs and to be fresh and interesting using wired and wireless sensors providing communication among existing 1.5 kW wind/ solar power system, the proposed 12 kW wind-solar system and the main computer that provides data acquisition and monitoring through wireless sensors, LabView software and NI FPGA data acquisition module.
- To be intimately related to real-world power issues such as power quality and ac/dc power interactions. Fluke power quality analyzer for handy use is available for AC voltage and current monitoring.
- To show a complex, interrelated system that is closer to the "real world" than the usual simple systems covered in educational labs.
- To motivate learning by introducing such elements as energy, environmental and economic concerns of practical interest to the students and workshop attendants on wind/solar power systems.
- To promote wind energy technologies since the major source of electrical power in the wind/solar hybrid power system will be from the wind.

V. ESTABLISHMENT OF A WIND/PV HYBRID UNIT:

The hybrid unit contains two complete generating plants, a wind-turbine system and a PV solar- cell plant. These sources are connected and synchronized in parallel to the UNI power grid as part of laboratory activities on wind-solar hybrid power systems and grid- tie interactions. The overall project block diagram is presented in Figure 1.

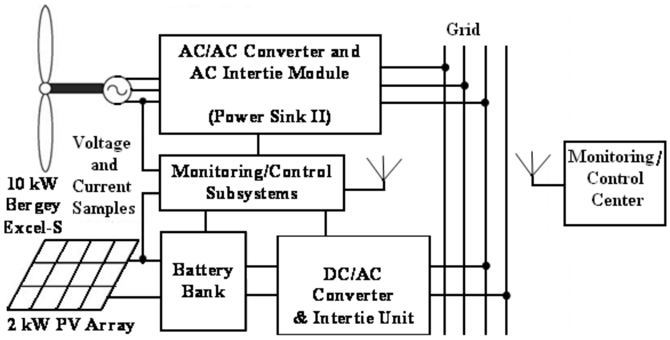

Figure 1. Proposed 12 kW wind-solar power system at UNI

The wind turbine is installed at the top of an existing steel tower which has a height of approximately 100 ft. The wind turbine depicted is a 10 kW Bergey Excel-S with its grid-tie intertie module called "Power Sink II" and the solar panels depicted number twelve in all with a capacity of 175W Watts each. A best case scenario of 12X175 W which means a total DC power of 2,100W is available theoretically from PV panels, although this would be equal or less than 2,000W due to location of solar panels. The instrumentation panel depicted monitors the outputs of the generator using digital panel meters.

Figure 2. Proposed wireless communication setup among two wind turbines, PV power system located at southwest side of the ITC building, and the main computer located in ITC10 room.

A 10kW wind turbine was chosen for its low maintenance and many safety features. One of the low maintenance features is the turbine's permanent magnet generator and an internal governor. The turbine generates 10 kW when turning at its rated speed of 13 m/s (29 mph). The illustrative pictures of the proposed system are shown in Figure 2. The turbine's blades are made of three fiber glass blades that will intentionally deform as the turbine reaches its rated output. This deformation effect changes the shape of the blade, causing it to go into a stall mode, thus limiting the rotation speed of the alternator and preventing damage in high winds. Another feature of the wind turbine is a sophisticated internal regulator that periodically checks the line voltage and corrects for low voltage conditions. The PV solar panels are 24V DC units and were chosen for their ultra clear tempered glass that is manufactured for long term durability. As widely known, one of the largest problems in systems containing power inverters is power quality. This problem becomes serious if the inverter used in the system does not have a good sinusoidal waveform output and causes problems such as harmonic contamination and poor voltage regulation. According to the IEEE (a professional society which codifies such issues) standards, a maximum of 3 to 4% total harmonic distortion (this is a quantitative measure of how bad the harmonic contamination is) may be allowed from inverter outputs. However, many inverter outputs may have much more harmonic distortion than what is allowed. The inverter used in the solar PV system has a power rating of a 2.5 kVA. The battery banks from PV modules will contain 12 deep-cycle lead-acid batteries connected in necessary series/parallel combinations. There are currently enough number of deep cycle batteries available at former UNI wind-PV project as well as solar electric boat R&D laboratory.

To monitor and store the voltage, current, power, and harmonic contamination data, two Fluke power quality analyzers (types 39 and 41) are used in the system. In addition, permanently mounted AC/DC digital panel meters form part of the system's instrumentation. Figure 3 shows functional block diagram of the existing 1.5 kW wind-PV hybrid power system that the proposed new system will also interact. A major difference between the existing wind- PV system shown in Figure 3 and the proposed system shown in Figure 1 is much larger wind power output, using wireless sensors, and wireless communication among wind turbines, PV modules and the main computer. Adding solar power into a wind power system will increase the reliability of the overall system for summer seasons where no wind or less wind is available for Iowans.

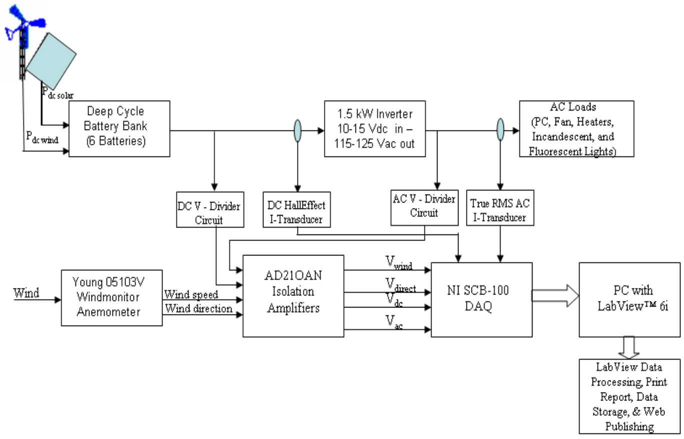

Figure 3. Instrumentation and Data Acquisition Functional Block Diagram

A. Initial Study On Wind Power Capacity For A 10 kW Bergey Excel-S Wind Turbine and Solar Power From 2kw PV Array:

Table 1. Based on an initial study

Period	Average Speed (mph)	Air Density *	Average Wind Power Density (W/m2)	Capacity Factor (%)	Estimated Output for Period (kWh)
Annual	13.50	1.233	229	21.65	18,835
Jan	14.62	1.291	278	26.45	1,867
Feb	14.35	1.286	276	25.65	1,642
Mar	15.00	1.252	295	27.27	1,986
Apr	15.16	1.222	316	27.45	1,981
May	13.58	1.193	223	21.15	1,616
Jun	12.63	1.174	175	17.39	1,306
Jul	11.51	1.163	124	12.97	1,017
Aug	11.13	1.168	110	11.63	907
Sep	12.07	1.182	144	14.99	1,119
Oct	13.21	1.216	192	19.45	1,458
Nov	14.14	1.252	268	24.40	1,718
Dec	14.31	1.285	275	25.49	1,808

Using Iowa Energy Center's wind assessment study, (www.energy.iastate.edu/Renewable/wind/) the following table is obtained to provide information on average wind speed and estimated annual energy output (kWh). An estimated energy amount of 18, 835 kWh wind power is expected to be harnessed as shown in Table 1. Based on an initial study, an estimated amount of 3,325 kWh of electrical energy would be available from 2kW PV arrays that will be part of wind-solar hybrid power system.

- The following lab activities are planned to be completed in this proposed testbed.
- Power Curve Determination of 10 kW Bergey Excel-S.
- Annual Ave energy production using the data from anemometer
- Transient phenomena due to sudden load changes
- Voltage, current, power (V, I, P)measurements at both DC and AC buses
- V, I, P transients due to sudden load changes at AC power grid
- Overall System Efficiency Measurement and Monitoring
- Vibration Monitoring using NI9234 Sensor Module that includes monitor vibrations on the turbine structure at the base and on the nacelle.
- Yearly Wind Speed, Direction, Temperature Monitoring and Data Storage
- Strain monitoring, a common technique for determining structural health since this information is becoming increasingly more important in the wind turbine industry.
- Wind turbine noise impact measurements using NI sound and vibration analysis software. This data is commonly used to ensure that the wind system complies with standards such as IEC 61400-11:2002.
- Temperature measurement to be used for preventive and predictive maintenance.
- Power quality monitoring: It can degrade as a result of wind speed, turbulence, and switching events. This will include monitoring peak power output, reactive power, voltage fluctuations, and harmonics.
- AC/DC Power system interactions due to sudden source and load changes.
- Temperature changes impact to overall system efficiency.
- Wireless sensors networks impact to overall system response during source and load fluctuations as well as sudden wind changes. Any new control schemes as advanced senior (capstone) design projects to be developed to monitor and control frequency and voltage of the AC grid.

The electricity generated by the power station will be used as renewable energy input for the smart grid based green house educational demonstration project to aid the teaching and research on smart grid and energy efficiency. Thus, in the phase II stage of the proposed project, the following electrical/ electronic devices and materials will be required to set up a seamless interface between the wind- solar power station and the smart grid based green house: COTS actuators, power and energy meters, cabling, conduits, junction boxes, CBs, switches, frames, digital displays, power supplies, sensors (temperature , humidity, vibration, solar radiation, air flow), AD/DA converters, microprocessor development kit, and other miscellaneous materials needed for intelligent circuitry, measurement, data acquisition, and monitoring.

VI. CONCLUSION

A complete 12 kW wind-solar power and instrumentation/data acquisition system will be completed and synchronized with the AC power grid at the university campus. Due to a number of unexpected permit requests from the university physical and facility planning offices, the project is delayed about two months. Expected completion is scheduled as September 30, 2010. Two solar foundations are constructed. Students designed and built custom-made PV frames and steel material used in the frame construction is cut, welded, painted and ready to be installed. The wind tower and wind turbine sections of the project will be completed by September 15, 2010.

The objectives of a typical wind power education in a Baccalaureate degree program should include the following subject matters; basic mathematics, physics, statistical analysis, computer programming, electrical circuits, analogue devices, digital electronics, conventional and renewable energy fundamentals, electrical machines, power electronics, programmable logic controllers (PLCs), electro mechanics, measurement and protection fundamentals, power transmission lines, power system interactions, and instrumentation/interface using wired/wireless sensors and networks. This proposed wind-solar testbed will foster an excellent learning experience for the undergraduate and graduate students.

The wireless sensors collecting data on wind, temperature, vibration, sound, voltage, current, power, load changes at both wind and solar power systems will communicate with NI data acquisition hardware and the main computer. This LabView based instrumentation and data acquisition system will also provide data to a dynamic web site in real-time. This will provide a remote access to the wind-solar power system by all permitted institutions requesting real-time data. A number of case studies on the PSCAD-EMTDC simulation of wind-solar power system will be prepared and embedded to instructional material.

The proposed equipment is part of a program initiative to improve our laboratory facilities to better reflect on the current and future renewable energy technologies. The proposed testbed will allow students to be educated and trained in the utilization of real-time electrical power systems and additionally will allow them to gain valuable "hand-on" experience in setting up a real-time data acquisition system specifically in grid-tied wind-solar power systems. Since Iowa's solar energy resources are higher in summer, this will provide an excellent complement to the load demand when summers are not windy.

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REFERENCES

[1] M.A. Elhadidy and S.M. Shaahid, Promoting applications of hybrid (wind+photovoltaic+diesel+battery) power systems in hot regions, Renew Energy 29 (4) (2004), pp. 517–528.

[2] G. Notton, M. Muselli and A. Louche, Autonomous hybrid photovoltaic power plant using a back-up generator: a case study in a Mediterranean Island, Renew Energy 7 (4) (1996), pp. 371–391.

[3] S.H. Karaki, R.B. Chedid and R. Ramadan, Probabilistic performance assessment of autonomous solar–wind energy conversion systems, IEEE Trans Energy Convers 14 (3) (1999), pp. 766–772.

[4] Giraud F, Salameh ZM. Steady-state performance of a grid-connected rooftop hybrid wind–photovoltaic power system with battery storage. IEEE Trans Energy Convers 2001;16(1):1–7.

[5] Bhave AG. Hybrid solar–wind domestic power generating system—a case study. Renew Energy 1999;17(3):355–8.

[6] D.B. Chia, B.L. Yong, R.K. Rajkumar, V.K. Ramachandaramurthy, Design of a PV/Wind Hybrid System for Telecommunication Load in Borneo Region, 9. International conference on environment and electrical engineering, 2010 Prague, Czech Republic, pp. 73-76, ISBN 978-1-4244-5374-0

[7] McGowan JG, Manwell JF, Avelar C, Warner CL. Hybrid wind/PV/diesel hybrid power systems modeling and South American applications. Renewable Energy: World Renewable Energy Congress, June 1996 at Colorado USA, 1996, p. 836–47.

[8] M.H. Nehrir, B.J. LaMeres, G. Venkataramanan, V. Gerez and L.A. Alvarado, An approach to evaluate the general performance of stand-alone wind/photovoltaic generating systems, IEEE Trans Energy Convers 15 (4) (2000), pp. 433–439.

[9] A.N. Celik, Optimization and techno-economic analysis of autonomous photovoltaic–wind hybrid energy systems in comparison to single photovoltaic and wind systems, Energy Convers Manage 43 (18) (2002), pp. 2453–2468.

[10] R. Chedid, H. Akiki and S. Rahman, A decision support technique for the design of hybrid solar–wind power systems, IEEE Trans Energy Convers 13 (1) (1998), pp. 76–83.

[11] B. Ai, H. Yang, H. Shen and X. Liao, Computer-aided design of PV/wind hybrid system, Renew Energy 28 (10) (2003), pp. 1491–1512.

[12] R. Chedid and Y. Saliba, Optimization and control of autonomous renewable energy systems, Int J Energy Res 20 (1996), pp. 609–624.

[13] A.D. Bagul, Z.M. Salameh and B. Borowy, Sizing of stand-alone hybrid wind–photovoltaic system using a three-event probability density approximation, Solar Energy 56 (4) (1996), pp. 323–335.

[14] A.R.D. Musgrove, The optimization of hybrid energy conversion system using the dynamic programming model—RAPSODY, Int J Energy Res 12 (1988), pp. 447–457.

[15] R. Yokoyama, K. Ito and Y. Yuasa, Multi-objective optimal unit sizing of hybrid power generation systems utilizing photovoltaic and wind energy, J Solar Energy Eng 116 (1994), pp. 167–173.

[16] R. Karki and R. Billinton, Cost-effective wind energy utilization for reliable power supply, IEEE Trans Energy Convers 19 (2) (2004), pp. 435–440.

[17] M.T. Samarakou, M. Grigoriadou and C. Caroubalos, Comparison results of two optimization techniques for a combined wind and solar power plant, Int J Energy Res 12 (1988), pp. 293–297.

[18] A.M. Al-Ashwal and I.S. Moghram, Proportion assessment of combined PV–wind generating systems, Renew Energy 10 (1) (1997), pp. 43–51.

[19] H.X. Yang, L. Lu and J. Burnett, Weather data and probability analysis of hybrid photovoltaic–wind power generation systems in Hong Kong, Renew Energy 28 (11) (2003), pp. 1813–1824.

[20] C. Protogeropoulos, B.J. Brinkworth and R.H. Marshall, Sizing and techno-economical optimization for hybrid solar photovoltaic/wind power systems with battery storage, Int J Energy Res 21 (1997), pp. 465–479.

[21] D. Manolakos, G. Papadakis, D. Papantonis and S. Kyritsis, A simulation-optimization programme for designing hybrid energy systems for supplying electricity and fresh water through desalination to remote areas case study: the Merssini village, Donoussa Island, Aegean Sea, Greece, Energy 26 (7) (2001), pp. 679–704.

[22] R. Sontag and A. Lange, Cost effectiveness of decentralized energy supply systems taking solar and wind utilization plants into account, Renew Energy 28 (12) (2003), pp. 1865–1880.