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Techno-economic analysis of hybrid power system sizing applied to small desalination plants for sustainable operation

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Abstract

Water and energy are two inseparable commodities that govern the lives of humanity and promote civilization. Energy can be used to produce water in case of scarcity in water. Ironically most of the places that are water stressed are also energy stressed. The cost of extending grid power may be prohibitively high in those cases. Rural/remote locations like hills and islands multiply the problem to a larger magnitude. Use of renewable sources like solar, wind, biomass and other locally available energy sources is the only solution. But these renewable sources are of intermittent nature and have poor availability. Hence, it is practically difficult to produce water with a single source of energy. Naturally, combining two or more sources of energy, known as hybrid power system, is the next available option. This paper carries out a techno-economic analysis of various sizing combinations of systems with solar photo voltaic, wind energy and stored energy in batteries for production of drinking water from a brackish water source. The system can operate the RO plant whenever the power is available, produce drinking water and store in a tank. This paper analyses the model of the entire hybrid power system in MATLAB to simulate the performance of the hybrid power system for different combinations of capacities. Results of the analysis under various input conditions are analyzed.

Keywords: Renewable energy; Hybrid power system; Desalination; RO; Solar; Wind

1. Introduction – desalination and energy

Water, energy and environment are essential inputs for sustainable development of society (Delyannis, 2003). The availability of fresh water is an important issue in many areas of the world. The ocean is the only perennial source of water. Their main problem is obviously its high salinity. The removal of salinity is accomplished by several desalination methods. But, all the desalination processes require significant quantities of energy. It is a common phenomenon that certain packets of the country that are water stressed are also power stressed at the same time. These remote parts do not have conventional source of power and costs of extending the electricity grid to these places are very high. Fortunately, most of such locations have exploitable renewable sources of energy that could be used to drive desalination processes (Nagaraj and Swaminathan, 2012).

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Renewable energy systems utilize sources available locally and freely for production of energy. Production of fresh water using desalination technologies driven by renewable energy systems is thought to be a viable solution to the water scarcity at remote areas characterized by lack of potable water and conventional energy sources like heat and electricity grid. Also they are environmentally friendly (Garcia-Rodriguez, 2003). Desalination systems cannot be compared with conventional systems in terms of cost without taking site specific factors into consideration. They are suitable for certain locations and will certainly emerge as widely feasible solutions in due course of time (Huneke and et al., 2012).

This paper analyses various aspects of small capacity hybrid power system for supplying electricity and clean water demand in rural and remote areas by using minigrid hybrid power system consisting of renewable energy (solar photovoltaic cells & windmill) and battery with a brackish water reverse osmosis desalination plant as load connected to the hybrid power system.

2. Modeling the renewable energy systems

There are a variety of renewable energy sources identified and utilized at various levels. These cover solar energy which includes thermal collectors, solar ponds and photovoltaic, wind energy and geothermal energy. Major share being from solar photo voltaic and wind energy, we shall discuss only these systems.

2.1. Solar photovoltaic

Photovoltaic effect was discovered in selenium way back in 1839. The photovoltaic (PV) process converts sunlight directly into electricity. A PV cell consists of two or more thin layers of semiconducting material, most commonly silicon. When the silicon is exposed to light, electrical charges are generated and this can be conducted away by metal contacts as direct current (DC).

The Luque and Hegedus model of PV cell is given by the equation below and Table 1 gives the description of symbols used.

$$I = I_{SC}\left[1 - \exp\left(\frac{V - V_{\propto} + IR_s}{V_t}\right)\right] \tag{1}$$

$$I_{SC} = I^*_{SC}\frac{G}{G^*}\left[1 + \frac{dI_{SC}}{dT_c}(T_c - T^*_c)\right] \tag{2}$$

$$T_c = T_a + C_t G_{eff} \tag{3}$$

$$C_t = \frac{\mathrm{NOCT}(^\circ\mathrm{C}) - 20}{800\ \mathrm{W/m^2}} \tag{4}$$

$$V_{\propto} = \left[V^*_{\propto} + \frac{dV_{\propto}}{dT_c}(T_c - T^*_c)\right]\left[1 + \sigma_{\propto}\ln\left(\frac{G_{eff}}{G_{\propto}}\right)\ln\left(\frac{G_{eff}}{G^*}\right)\right] \tag{5}$$

$$R_s = \frac{V^*_{\propto} - V^*_M + V_t\ln\left(1 - \frac{I^*_M}{I^*_{SC}}\right)}{I^*_M} \tag{6}$$

$$P_v(t) = NpvVm(t)Im(t) \tag{7}$$

PV equipment has no moving parts and as a result requires minimal maintenance and has a long life. It generates electricity without producing emissions of greenhouse or any other gases, and its operation is virtually silent.

2.2. Wind energy

Wind energy is basically by the pressure differences in atmosphere due to solar power. The wind turbine technology is highly mature and available in commercial scale. Small wind turbines play crucial role in distributed and decentralized energy systems. The production can be improved by using novel control strategies and better energy storage systems.

The wind energy is modeled using the below relation. Table 2 gives the description of symbols used.

$$P_w(t) = \begin{cases} 0\ (v < v_{in}) \\ a_1v^2 + b_1v + c_1\ (v_{in} \leqslant v < v_1) \\ a_2v^2 + b_2v + c_2\ (v_1 \leqslant v < v_2) \\ a_3v^2 + b_3v + c_3\ (v_2 \leqslant v < v_{out}) \\ 0\ (v > v_{out}) \end{cases} \tag{8}$$

2.3. Reverse osmosis (RO) desalination using solar PV and wind energy

The photovoltaic technology can be connected directly to a RO system. The factors that determine economics are the plant capacity, cost of extending electricity grid and the concentration of the salt in raw water (Thomson and Infield, 2003; Tzen et al., 1998). RO is the desalination process with the minimum energy requirements. Wind power is abundant in coastal areas. Hence wind power desalination is a promising option (Al Suleimani and Nair, 2000; Habali and Saleh, 1994; Miranda and Infield, 2003). The disadvantage of wind energy and solar energy is that they are intermittent (stochastically varying) sources. This reduces the reliability of the power output and hence the water output also. Hence a hybrid power system with a combination of energy sources could be a possible solution. The RO plant is considered as a load because the plant can run as and when enough power is available from any of these sources, produce water and is stored in tanks. With this, we can keep the capacity of energy storage system like batteries to a minimum and hence increase efficiency and reduce costs.

2.4. Cost model of solar PV, wind and battery system

The cost model of the various energy sources is developed considering the capital cost per kW capacity. The

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