Design and Simulation of Wind Turbine System to Power RO Desalination Plant

Divya Jose, S. Berclin Jeyaprabha

Abstract: Desalination is the process that removes dissolved minerals (including salts) from seawater or brackish water. Existing water desalination processes are either thermal or membrane technology. Wind power is one of the most popular form of renewable energy for water desalination. The proposed system is driven entirely by renewable energy sources . It converts wind energy directly into kinetic energy so as to drive brackish water through pre-treatment units and a RO desalination unit. Most of the existing desalination plants uses wind power as an auxiliary energy supply. The direct use of wind energy in an RO desalination system is done in this work. This project aims to develop a simple, cost-effective water desalination system for small scale remote area applications. In conventional systems the electric power was used to run the system instruments for data acquisition and control. The incorporation of the hybrid system to power the data acquisition and control instruments is a solution for this.

Index Terms: Wind Energy, RO System, Desalination, Renewable Energy

I. INTRODUCTION

Water is a valuable natural resource and its shortage is a serious problem being faced now a days. Decision making on the water supply method are based on technical and economic evaluation of various alternatives. Desalination process of brackish and sea water is one of the most widely applicable methods to meet water demand and it is today widely applied in areas with water scarcity. Desalination is a process by which dissolved minerals (including salts) are removed from seawater or brackish water. Seawater is having a total dissolved solids (TDS) concentration of about 35,000 milligrams per liter (mg/L). Brackish water has a TDS concentration range between 1,000 mg/L and 10,000 mg/L. Water is fresh when its TDS concentration is below 500 mg/L, which is the secondary drinking water standard in the some places. Salinity is sometimes expressed by the water's chloride concentration, which is about half of its TDS value. Desalination process is an important element of the hydrologic cycle, which provides the freshwater supply for the entire world. In the hydrologic cycle, water is brought to the earth's surface by precipitation and returned, free of dissolved minerals, to the atmosphere by evaporation and condensation.

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Water desalination to produce potable water from seawater or brackish water by engineered processes has become increasingly important because many regions throughout the world suffer from water shortages. [1]

Substances such as calcium sulphate in feed water will have low solubility in warmer water, and they leave solution as the temperature rises. Scales will be formed on the equipment surface. Using a lower operating temperature wil reduce the scale problem but not without decreasing the thermal efficiency. Much research and development on scale control are required. A major problem in the membrane processes is the fouling, which is the plugging of membrane surfaces by organic and inorganic substances present in the feed water. Fouling prevention requires the pretreatment of feed water or the addition of antiscalants substances. The three most common membrane-cleaning methods are hydraulic, mechanical, and chemical treatments. In hydraulic cleaning, the flow direction (back-flushing) is used to remove fouling at the membrane surface. Mechanical cleaning is done with sponge balls. In chemical cleaning, the membrane is washed with chemical agents, like acid for mineral scale or alkali for organic matter. New fouling resistant membrane materials now are being developed by studying the physicochemical and biological interactions between membrane surface and foulants as well as the anti fouling agents.

II. DESALINATION DRIVEN BY WIND ENERGY

Renewable energies are expected to have a flourishing future and an important role in the domain of brackish and seawater desalination in developing countries. Throughout the world a trend to intensified use of desalination as a means to reduce current or future water scarcity can be observed. Water scarcity, which occurs not only in arid regions, can be characterized as a mismatch between water supply and water demand. Over a billion people worldwide lack access to sufficient water of good quality. As the fastest-growing source of electricity generation in the world in the 1990s, wind energy has been given great attention in the United States. Wind energy is a form of kinetic energy or $KE = ½ MU^2$, where KE is wind energy, M is the mass of air, and U is wind speed. [3] When the wind pushes on the rotors of a windmill, the blades capture energy. The mass of air moving through a windmill in unit time can be calculated as: $M = \rho AU$, where A is the area swept by the windmill rotor. The power output of an ideal windmill increases with the area swept A or square of the diameter of the rotor, and with the cube of the wind velocity. Actually the wind is not completely stopped but rather is only slowed down, and there is loss of energy . The power output of a windmill is in the range of 30% to 35% of wind energy input.

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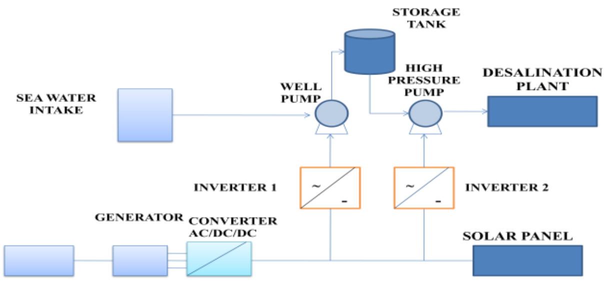

Fig. 1 Block diagram of wind powered desalination system

Wind power is the one most popular form of renewable energy for water desalination process. Due to high wind speed fluctuation, most existing desalination plants use wind power only as an auxiliary energy supply, by connecting the plants to electricity grid such that electricity could be used when the wind power would not be enough for plant operation. Feron investigated the direct use of wind energy in an RO desalination system. He evaluated the system performance by mathematical modeling analysis under the following two assumptions:

(1) The system operation is considered intermittent, depending on wind availability

(2) The feed water pressure is considered variable, depending on the prevailing wind speed.[1]

The development of potable water from underused resources such as brackish water and seawater is predicated on the use of desalination techniques. Desalination has the potential to address current and future water needs, but it has been plagued by high cost, which makes it non-competitive with natural resources used today. Of the available desalination techniques (RO, multistage flash (MSF), multi-effect distillation (MED), electro dialysis (ED), and vapour compression (VC), RO consistently has the highest demonstrated energy efficiency, typically 3–4.5 kWh/m. Even with its higher efficiency, energy cost still accounts for roughly 45% of the cost of water (COW) in RO-based systems.

A likely candidate for replacing traditional RO desalination systems is a hybrid approach where renewable energy sources (RES) such as wind energy and photovoltaics (PV) are coupled with an RO desalination system.The COE associated with transmission and distribution is avoided by coupling energy generation directly to RO systems with RES. Hence, the COE of desalination systems can be significantly reduced. Energy generation costs associated with photovoltaic systems (PV) are still high, but wind energy cost is projected to reach $0.04/kWh, which will make wind desalination cost competitive.

III. WIND SYSTEM

A whole wind energy system can be sub divided into following components:

1. Model of the wind,
2. Turbine model,
3. Shaft and gearbox model,
4. Generator model and
5. Control system model.

The first three form the mechanical part of the wind objectives. The generator forms the electro-mechanical link between the turbine and the power system and the control system controls the output of the generator.

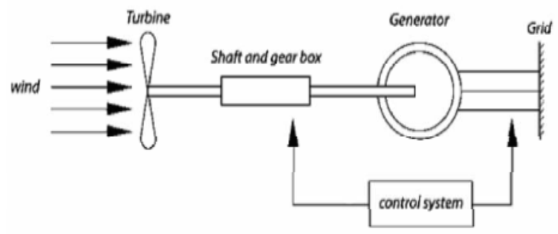

Fig. 2 Wind Turbine Generator System

IV. DYNAMIC MODELING OF THE WIND TURBINE

The wind turbine is characterized by no dimensional curves of the power coefficient (Cp) as a function of both the tip speed ratio(λ) and the blade pitch angle(B). Fully utilization of the available wind energy, the value of (λ) should be maintained at its optimum value. Therefore, the coefficient of power corresponding to that value will become maximum also. The turbine model represents the power capture by the turbine. The power in the wind (Pw) in an area is given by,

$$P_{w}=0.5\rho A v^{3} \quad (1)$$

where

P_w is power in the wind (W)

ρ is air density (kg/m3)

A is the turbine swept area (m^2)

V is the Wind speed (m/s)

However, the turbine captures only a fraction of this power. The power captured by the turbine (i.e., the mechanical power)(Pm) can be expressed as

$$P_m=0.5\, C_P\, \rho\, A\, v^3 \quad (2)$$

where C_p is a fraction called the power coefficient. The power coefficient represents a fraction of the power in the wind captured by the turbine.

$$C_p= c_1\left(\frac{c_2}{\lambda_i} - c_3\,\beta - c_4\right) e^{\left(\frac{-c_5}{\lambda_i}\right)} + c_6\lambda \quad (3)$$

The coefficients c1 to c6 are: c1 = 0.5176, c2 = 116, c3 = 0.4, c4 = 5, c5 = 21 and c6 = 0.0068.

The tip speed ratio (TSR) of the turbine, defined as

$$\lambda=\frac{\omega R}{v} \quad (4)$$

The amount of aerodynamic torque (T) in Nm is given by the ratio between the power extracted from the wind (P_m), in W, and the turbine rotor speed (ω), in rad/s, as given

$$T=\frac{P_m}{\omega} \quad (5)$$

The wind energy system extracts the wind energy and converts it to the electrical energy. The output power of wind energy system varies depend on the wind speed. Due the nonlinear characteristic of the wind turbine, it is a challenging task to maintain the maximum power output of the wind turbine for all wind speed conditions. There are extensive researches concerning with the approaches to track the maximum power point of the wind turbine called as MPPT (Maximum Power Point Tracking) control.

There are three common MPPT methods

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a) Perturb and observe (P&O) or hill climbing searching
b) Wind speed measurement (WSM)
c) Power signal feedback (PSF)

A. PERTURB AND OBSERVE (P&O) METHOD

In the P&O method, the rotor speed is perturbed by a small step, and power output is then observed to adjust the next perturbation on the rotor speed. A constant step is being introduced in the perturbation process. A variable step is employed by taking into account the slope of power changes. Models are then used to simulate the MPPT algorithm to track the maximum power of the wind turbine (permanent magnet generator). The main contribution is in the model of DC-DC converter or the buck converter which is developed in rather details and allows the MPPT controller output (duty cycle) to adjust the ratio of voltage input-output of the converter side. When the duty cycle is varied, the input voltage of the buck converter or the output voltage of the generator allows the changes in the system.[3]

In the PMSG, the output current and voltage are proportional to the torque and rotor speed. Thus perturbing or varying the output voltage of the generator will cause the varying in rotor speed. Perturbing the voltage could be performed by adjusting the duty cycle (PWM signal) of the buck converter. The P&O algorithm operates by varying the duty cycle of the buck converter, thus varying the output voltage of the wind generator, and observes the resulting power to increase or decrease the duty cycle in the next cycle. If the increase of duty cycle results in an increase of the power, the perturbation signal value is the same as the the old cycle value. If the perturbation duty cycle produces a decrease of the power, then the direction of perturbation signal is the opposite from the previous cycle. [5]

B. MODIFIED HILL-CLIMBING FUZZY-BASED TECHNIQUE

Modification of the hill-climbing searching method uses a FLC-based algorithm. The proposed controller is designed to take advantage of hill climbing simplicity and eliminate all the mentioned drawbacks.

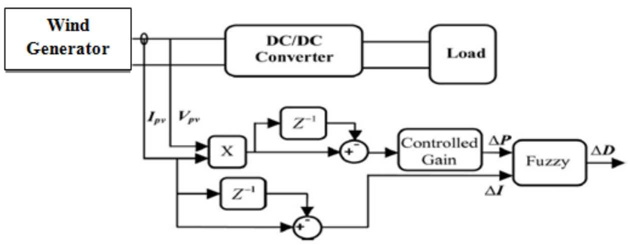

Fig .3 Modified hill climbing fuzzy-based technique

The inputs of the FLC are
$\Delta P = P(k) - P(k-1)$
$\Delta I = I(k) - I(k-1)$
and the output equation is
$\Delta D = D(k) - D(k-1)$

where ΔP is the change in wind output power , ΔI is the change in output current , and ΔD is the change in boost converter duty cycle . To ensure that the wind output power does not diverge from the optimum point during varying weather conditions, ΔP is made to pass through a gain controller to reverse its direction. The variable inputs and output are divided into four fuzzy subsets: positive big (PB), positive small (PS), negative big (NB), and negative small (NS). So algorithm requires 16 fuzzy control rules; these rules are based on the regulation of hill-climbing algorithm. To operate the fuzzy combination, Mamdani's method with Max–Min is used.[4]

V. DESALINAION

Desalination is a process of separation used to reduce the dissolved salt content of saline water to a usable level. All desalination processes contains three liquid streams namely the saline feedwater which is the brackish water or seawater, the low salinity product water, and very saline concentrate or brine (brine or reject water).The saline feedwater is taken from oceanic or underground water sources. It is separated into the low-salinity product water and very saline concentrate two by the desalination process. The use of desalination overcomes the problems faced by many coastal communities, which includes having access to a practically inexhaustible supply of saline water but having no way to its usage. Although some chemical substances dissolved in water, like calcium carbonate, can be removed by chemical treatment, other common chemical constituents, like sodium chloride, requires more technically complicated and sophisticated methods, collectively known as desalination process. In the past days, the difficulty and expense of removing various dissolved salts from water made saline waters an impractical source of potable water was a very complex process. However, in the starting of the 1950s, desalination began to appear to be economically practical for ordinary use, under certain circumstances and environments.[7]

The product water of the desalination process is generally considered with water less than 500 mg/1 dissolved solids, which is suitable for most of the domestic, industrial, and agricultural uses. A by-product of desalination is brine or saline concentrate. Brine is a concentrated salt solution (with more than 35 000 mg/1 dissolved solid) that must be disposed with great care, generally by discharging into deep saline aquifers or surface waters with a very high salt content. Brine can be diluted with treated effluent and can be disposed of by spraying on golf courses and/or other open space areas.[8]

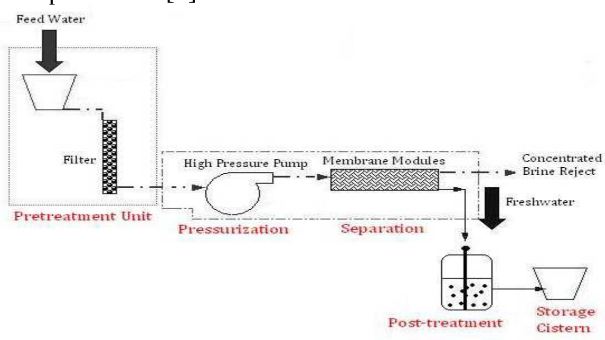

Fig.4 Reverse osmosis plant

VI. SIMULATION

The tools used for computer simulation is MATLAB 7.9/Simulink 7.4 and IMSDesign. Steps involved in simulation are Wind generator system is simulated and measured the aerodynamic torque. Maximum power point tracking is used as the controlling scheme

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1) A cuk converter is designed and simulated
2) Power conditioning unit is simulated in which the DC voltage is converted to AC and power is conditioned to the required value using a step up transformer.
3) RO system is simulated using IMSDesign software and the purity of the water is confirmed.

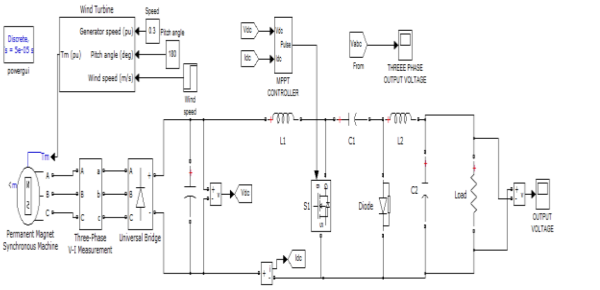

Fig .5 Overall simulation diagram

VII. RESULTS

A 1.1kw wind turbine with base wind speed of 8m/s has been considered. The power output from the turbine was 1020w and the torque was 9Nm.

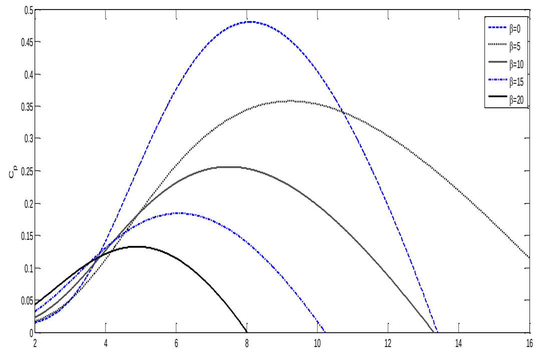

Fig. 6 The *Cp*-λ characteristics

It is observed that the obtained PMSG voltage waveform has been shown in figure, when the WTG system has been modelled with RL filter

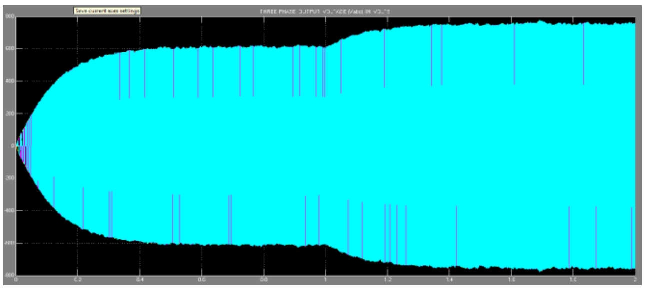

Fig.7 Three phase output voltage of PMSG

The output voltage of the cuk converter is 450v

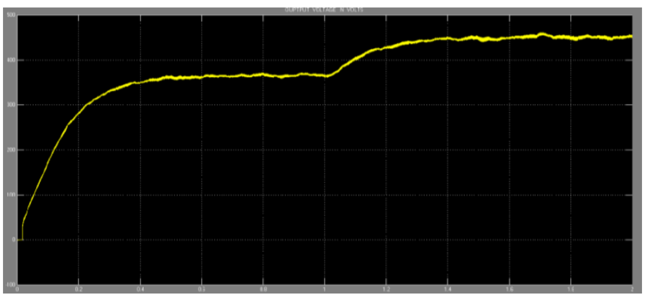

Fig.8 cuk converter output voltage

TABLE I. RESULT OF RO SYSTEM

RO program licensed to:				
Calculation created by:				
Project name:	MyProject		Permeate flow:	0.25 m3/hr
HP Pump flow:	1.7	m3/hr	Raw water flow:	1.7 m3/hr
Feed pressure:	1.5	bar	Permeate recovery:	15.0 %
Feedwater Temperature:	30.0	C(86F)		
Feed water pH:	8.00		Element age:	3.0 years
Chem dose, ppm (100%):	0.0	H2SO4	Flux decline % per year:	7.0
			Fouling Factor	0.80
			Salt passage increase, %/yr:	10.0
Average flux rate:	10.0	lm2hr	Feed type:	Well Water

Stage	Perm. Flow m3/hr	Flow/Vessel Feed m3/hr	Flow/Vessel Conc m3/hr	Flux l/m2-hr	Beta	Conc.&Throt. Pressures bar	Conc.&Throt. Pressures bar	Booster Pressure bar	Element Type	Elem. No.	Array
1-1	0.0	1.7	1.6	2.9	1.02	1.3	0.0		SanRO-HS2-4	2	1x2
1-2	0.2	1.6	1.4	24.0	1.19	7.0	0.0	6.0	SanRO-HS2-4	1	1x1

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Ca	110.0	5.5	110.0	5.5	1.406	0.1	129.2	6.4
Mg	66.0	5.4	66.0	5.4	0.843	0.1	77.5	6.4
Na	143.0	6.2	143.0	6.2	8.753	0.4	166.7	7.2
K	25.0	0.6	25.0	0.6	1.912	0.0	29.1	0.7
NH4	1.0	0.1	1.0	0.1	0.076	0.0	1.2	0.1
Ba	0.700	0.0	0.700	0.0	0.009	0.0	0.8	0.0
Sr	0.000	0.0	0.000	0.0	0.000	0.0	0.0	0.0
CO3	2.1	0.1	2.1	0.1	0.000	0.0	2.5	0.1
HCO3	232.0	3.8	232.0	3.8	9.750	0.2	271.2	4.4
SO4	143.0	3.0	143.0	3.0	0.837	0.0	168.1	3.5
Cl	317.2	8.9	317.2	8.9	7.413	0.2	371.9	10.5
F	25.0	1.3	25.0	1.3	1.166	0.1	29.2	1.5
NO3	45.0	0.7	45.0	0.7	7.791	0.1	51.6	0.8
B	0.00		0.00		0.000		0.00	
SiO2	25.0		25.0		0.64		29.30	
CO2	3.29		3.29		3.29		3.29	
TDS	1135.0		1135.0		40.6		1328.2	
pH	8.00		8.00		6.65		8.06	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	4%	4%	4%
SrSO4 / Ksp * 100:	0%	0%	0%
BaSO4 / Ksp * 100:	2591%	2591%	3121%
SiO2 saturation:	16%	16%	19%
Langelier Saturation Index	0.91	0.91	1.11
Stiff & Davis Saturation Index	0.96	0.96	1.14
Ionic strength	0.03	0.03	0.03
Osmotic pressure	0.7 bar	0.7 bar	0.8 bar

VIII. CONCLUSION

Renewable energy sources (RES) for powering desalination processes is the most promising option especially in remote and arid regions where the use of conventional energy is costly or unavailable. Reverse Osmosis (RO) is the most suitable desalination processes that can be coupled with different renewable energy sources such as solar and wind. The electrical or mechanical energy required as primary energy input for the RO unit can be provided from a single wind turbine or a wind farm. However, reverse osmosis is the preferred technology due to the low specific energy consumption. Because of the variable nature of wind speed, it is found difficult to predict the energy output. So appropriate power control methods and conditioning systems are required so as to match the ratio of power input to desalination load. The design of the control system is the most critical and crucial step in the design of a desalination RO unit powered by wind energy.

Simulations of wind turbine generator system and RO system have been carried out. Simulation of proposed system is done by using MATLAB/Simulink and ROSA..

REFERENCE

1. B. Ali, M. Turki., and Belhadj.E '*'Energy Management of a Reverse Osmosis Desalination Process Powered by Renewable Energy Sources*'', Proceedings of the 16th IEEE International Conference on electrotechnicals, 2012,800–805.
2. Aryuanto Soetedjo and Abraham Lomi "*Modelling of Wind Energy System with MPPT Control*", International Conference on Electrical Engineering and Informatics,2011, Bandung, Indonesia
3. Azadeh Safari, Saad Mekhilef "Simulation and hardware implementation of incremental conductance MPPT With direct control Method using Cuk converter" IEEE Transactions on Industrial Electronics,2011, vol. 58, no. 4
4. Bourouni.K , Ben.M ''Design and optimization of desalination reverse osmosis plants driven by renewable energies using genetic algorithms'' ELSEVIER,2011, Renewable energy36,.936–950.
5. Eltawil.M , Zhengming.Z, and Yuan.L "A review of renewable energy technologies integrated with desalination systems", ELSEVIER,2009, vol. 13,.2245–2262.
6. Gerardo Vazquez, Gustavo Azevedo "Modeling of a Variable Speed Wind Turbine with a Permanent Magnet Synchronous Generator " IEEE International Symposium on Industrial Electronics,2009 , Vol.21, No. 2, pp. 786-794
7. Haganesh.B ,Mohan.S. "*Study on subsurface water quality in selected places in coimbatore*" ISSN 2,2012,2250-3498.
8. John.C, Rhodes.T, David.G Kerry.H and George.T. "Water Treatment Principles and Design" Edition2, ISBN, 2012, 0-471, 11018-3.

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