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A small scale education experiment kit with wind generator-PEM electrolyser system and modelling

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Abstract

A small scale experiment wind energy kit is prepared in order to introduce renewable energy applications. The kit consists of a wind turbine with horizontal axis, a direct current (dc) motor as generator and variable wind excitation system. Performance characteristics of the wind system are defined for different wind speeds. It is found that at the highest 10 m/s wind excitation, the maximum turbine mechanical power from wind is about 0.30 W at 5.3 V., maximum output power of the generator is about 0.18 W and maximum electrical efficiency is about 7% at 4.27 V., wind turbine power coefficients C_p are 12.53% under maximum turbine mechanical power, 12.06 % under maximum electrical efficiency cases. Also mechanical frictional losses of system are considered and added to analysis. The wind kit is also operated with a proton exchange membrane (PEM) type electrolyser for hydrogen production. The outputs of generator, inputs of PEM electrolyser and its rate of hydrogen formation characteristic are measured and modelled separately. Overall system is defined in MATLAB/Simulink. Operating points of PEM electrolyser on wind system kit are predicted by modelling. Relative errors are about 1-4% for voltage, 0.6-3% for current at 5.7-10 m/s wind interval. The rate of hydrogen production of wind generator-PEM electrolyser system is analyzed with respect to input wind speeds. The rate of hydrogen formation of the system is 0.4 ml/min at 10 m/s wind speed. The system kit has small scale, low performance and inexpensive tools, but it can be used not only for education but also for research tests about similar systems. Approaches in the study can be applied to systems with larger and special devices to carry out their performance tests.

Key Words: *Wind generator, hydrogen, PEM electrolyser.*

1. Introduction

Recently, problems such as global warming, greenhouse effect, pollution, have caused the interest in renewable energy systems (solar, wind, etc.) to increase. Furthermore the hydrogen which is a popular and clean energy source, can be produced from electrical energy in these renewable energy systems using water electrolysis.

Electrolyser is a device that is used to produce hydrogen from water via electrolysis. In return, fuel cells convert stored hydrogen and oxygen /or air to electricity directly. Hence, renewable energy and hydrogen systems are employed in integrated form [1-5]. One of these renewable energy applications is wind hydrogen system. Some experimental sets with wind turbine are constructed to indoor laboratory research and training applications [6,7]. In this paper, an educational experiment set is prepared in order to inform new generation and students about clean and renewable energy applications. The set is based on the wind- hydrogen energy conversion. Additionally the chance of academic research is expected by means of the sets for indoor studies about similar wind energy topics. Experiments and other details on the set are given in below sections.

2. The experiment kit

The educational experiment set consists of two main parts that are wind generator and proton exchange membrane (PEM) type electrolyser systems. In PEM type device, platinum electrodes are separated by an electrolyte which is made from thin polymeric membrane such as nafion. In wind generator system, 0.3-12 V. max.150 mA permanent magnet direct current (dc) motor is used as dc generator. Wind turbine is made from hard plastic and thin material with 7cm diameter with eight wings. The width of blade is 0.8 cm and its twist angle is about 30^o constant along the radius. A fan is added to the wind set for wind excitation. The PEM hydrogen system is used as both generator and electrolyser. In this study, the PEM hydrogen system is operated as electrolyser for hydrogen production by water electrolysis. The PEM device is single cell with max. 2V., 1 A. for electrolyser mode. The principle schema of the set is given in Figure 1.

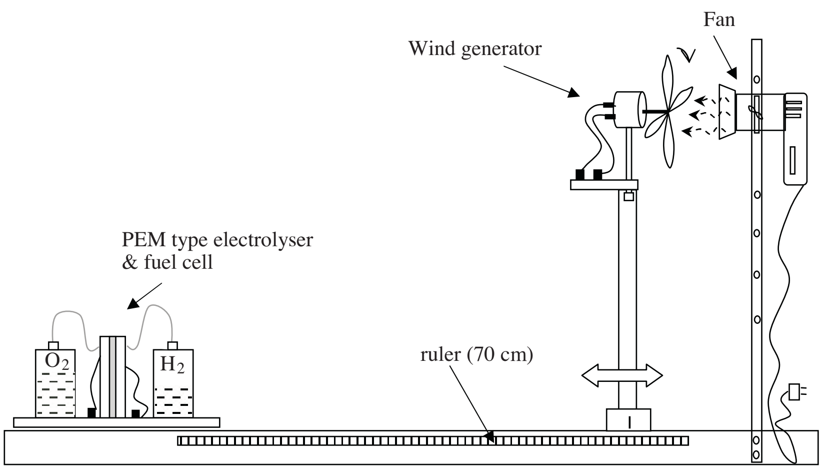

Figure 1. The principle schema of the wind generator -PEM electrolyser set.

The horizontal axis wind turbine position is in the face of wind stream which is delivered from the hair–dryer fan machine. Both the fan and turbine centre heights are the same level, with respect to ground. The distance between fan and wind turbine is variable and it is scaled according to different wind speeds (m/s) using by a ruler. A digital anemometer is used to measure wind speeds. In order to measure hydrogen formation, oxygen and hydrogen tanks are scaled. The electrolyser system can be maintained by wind generator set under wind speeds. Accuracy of multimeters employed for measurements are ±0.5% +2 digit and ±1% +2 digit for dc voltage and current respectively. Output current-voltage (I-V) characteristics of the wind generator, can be defined using a variable resistive load bank with 2-1000 ohms.

3. The wind system modelling and measurements

3.1. Wind power-generator modelling and tests

The typical wind turbine-generator systems outputs (such as power, voltage, current, rotational speed etc.) strongly change with electrical load, wind speed and the turbine shape which is used. Fundamental expressions relating to wind energy conversion are given below [8].

$$P_w = (1/2).\rho.A.\nu^3 \tag{1}$$

$$P_{mech} = (1/2).\rho.A.\upsilon^3.C_p = P_w.C_p \tag{2}$$

where, The P_w : potential wind power, ρ: air density (1.29 kg/m^3), the υ : wind speed (m/s), A : circular area of the wind turbine with horizontal axis (m^2), C_p : power coefficient of the turbine and P_{mech} : turbine mechanical power delivered by wind .

For a permanent magnet dc generator driven by a wind turbine, the steady state dynamic model equations can be defined as:

$$V = K.\omega - I.R_s \tag{3}$$

$$T_{rot} - K.I - T_o = B.\omega \tag{4}$$

From equation 3 and 4:

$$V = K.\frac{(T_{rot} - T_o)}{B} - I.(\frac{K^2}{B} + R_s) \cong V_{oc}(wind) - I.R_{eq} \tag{5}$$

$$P = V.I \tag{6}$$

From equations (3), (4) and (6), the P_{mech} can be rewritten.

$$P_{mech} = T_{rot}.\omega = \underbrace{K.\omega.I}_{\text{electrical power}} + \underbrace{T_o\omega + B.\omega^2}_{\text{frictional losses}} = P + I^2.R_s + P_{fr} \tag{7}$$

Where, K: voltage coefficient of the generator (V.s/rad) and it is equal to torque coefficient for permanent magnet machine, ω : angular speed (rad/s), R_s : armature winding resistance (ohm), T_{rot} : rotational torque generated by the wind (N.m) , T_o : minimum term of starting torque (N.m), B: friction coefficient of the system (N.m.s/rad), V: output voltage of generator (V.), I: output current of the generator (A.), V_{oc} : open circuit voltage of the generator (V.), P_{fr} : frictional mechanic loss, P: electrical power output of the generator and R_{eq} : equivalent inner resistance that causes voltage to drop. When the voltage V is very low, the generator current I, goes to the short circuit current I_{sc} during the time generator is loaded.

For our system, the wind turbine is direct coupled to generator shaft and they rotate together. The turbine rotational torque T_{rot} is equal to applied shaft torque of the generator. As seen from the equation 7, the P_{mech} mechanical turbine power includes the mechanical frictional losses and the stress of reverse motor action due to electrical torque (K.I) when the generator is loaded, in which time, the shaft speed ω, decreases with the current I, as seen equation 4. This reverse motor action corresponds to electrical armature winding heat loss $I_s^2.R_s$ and output power of generator P.

Coefficient C_p, changes with wind speed and depend on wind turbine configuration (radius, wing schema, area and etc.) for a generator. The terms of ω and T_{rot}, are functions of these turbine coefficients. Both ω and T_{rot} affect to the P_{mech} and then generator outputs (I, V). With some losses, the voltage V is related with rotational speed ω for a wind speed υ. The current I is related with the rotational torque T_{rot} too. Hence they determine generator output power P.

For most practical cases, values of torque and rotational speed are defined according to wind speeds for a wind turbine and generator machine [9]. In the study, output current –voltage (I-V) characteristics of the generator are measured for different wind speeds using variable resistor. From I-V curves measured, values of V_{oc} and I_{sc} are taken for each wind speed sampled. For modelling on each pair of V_{oc} and I_{sc}, a linear curve is drawn to the experimental I-V curve. This approach can be seen to be suitable when the equation 5 is considered where the relationship between V and I is linear. I-V curves of both model and measurement are given in Figure 2 for different wind speeds. The R_s is defined as about 10 ohm for our generator. In equation 5, the R_{eq} is higher than the R_s. Thus according to Figure 2, ratios of V_{oc} and I_{sc} values are higher than the value of R_s.

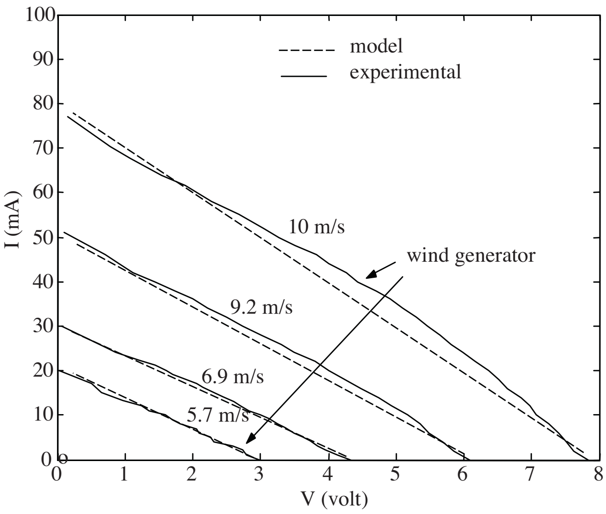

Figure 2. Wind generator I-V curves for experiment and model.

3.2. Definition of mechanical turbine power by wind and the efficiency

In order to have an idea about wind turbine performance with respect to wind speeds, the term of P_{mech} can be determined for different wind speeds and electrical loads. In most cases, the term of mechanical power P_{mech}, can be simplified by ignoring frictional losses P_{fr} for example in [7]. But the term of P_{fr} can be considered and calculated in this study. Specific machine parameters of K,B and T_o are used to determine rotational (frictional) loss, net mechanical turbine power and wind turbine power coefficient [10,11]. It is difficult to define these parameters and needs some equipments like dynamometer, tachometer. However in this study, mechanical power and loss terms can be obtained without those parameters and equipments by using a practical approach that is based on the well known fundamental machine expressions.

In order to make this, the permanent magnet dc generator is operated as motor without wind turbine. The term of P_{fr} is a function to shaft speed ω for other constant parameters of the machine, T_o and B. On the other hand, the term of ω determines the induced voltage e_r for a K parameter of the machine for both generator and motor mode. Also the e_r is reverse induced voltage in motor mode. Hence the P_{fr} is related to e_r. Under no load case, the relationship between input current I_o and terminal voltage V_o of the motor is given by equation 8.

$$V_o = I_o.R_s + K.\omega = I_o.R_s + e_r \tag{8}$$

When the motor is operated at no load, it demands an input power P_o which is the consumed electrical armature winding heat loss and frictional loss as given in equation 9. It is to be noted that electrical heat loss at magnetic core of the machine is neglected.

$$P_o = V_o.I_o = \underbrace{I_o^2.R_s}_{\text{heat loss}} + \underbrace{e_r.I_o}_{f\text{ rictional loss}} \tag{9}$$

From equations 7 and 9, the term of P_{fr} can be defined by equation 10. Also in the equaition 10, by using equation 8, the term of ωcan be rewritten with terms of e_r and machine constant K.

$$P_{fr} = e_r.I_o = T_o\omega + B\omega^2 = T_o\left(\frac{e_r}{K}\right) + B\left(\frac{e_r}{K}\right)^2 \tag{10}$$

The last expression of equation 10 is a polynomial function and its variable is the term of e_r for machine constant parameters K,T_o and B. The equation 10 is a result of fundamental well known machine expressions above. The frictional loss P_{fr} is obtained experimentally by measuring both e_r and I_o pairs and applied to equation 10. Also, the P_{fr} can be modelled by using curve fitting based on experimental data of e_r and I_o. To measure e_r and I_o is easier than to obtain specific machine parameters such as B,T_o and K, which are used to obtain P_{fr}. For our kit, no load voltage –current (V_o-I_o) characteristic of the motor is measured and then modelled empirically by equation 11. This model is for $\omega > 0$.

$$I_o = 14.8(10^{-3}) + 1.6110(10^{-3})(V_o - 0.54) \tag{11}$$

Variations of V_o-I_o are given in Figure 3 for model and experiment.

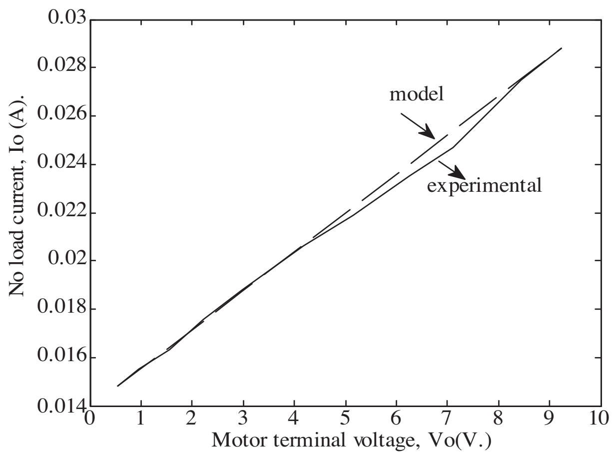

Figure 3. V_o-I_o characteristics at no load for experiment and model.

From V_o-I_o characteristic, values of e_r and P_{rf} corresponding to each pair of V_o and I_o can be calculated by using equation 8, 10, 11. The e_r-P_{rf} characteristics of the motor are given in Figure 4. To estimate P_{fr}, there is very good agreement between experiment and empirical modelling. Additional profiles of curves in Figure 4, agree with structure of last expression with variable e_r at the equation 10.

As wind generator case, from output I-V characteristics given by Figure 2 under different electrical loads for a given wind speed, instantaneous values of e_r are found as in equation 12.

$$e_r \text{ (generator) } = V + I.R_s \tag{12}$$

In order to find values of P_{fr} corresponding values of e_r, equation 12 is substituted in equation 8.When the expression of V_o obtained, is applied to equation 11, the new expression of I_o with term of e_r is given in equation 13.

$$I_o = \left[\frac{14.8 + 1.6110(e_r - 0.54)}{1 - 1.6110R_s.10^{-3}}\right].10^{-3}(A.) \tag{13}$$

When the I_o in equation 13 is substituted in equation 10, values of P_{fr} can be determined. Therefore values of P_{mech} are found by equation 7 for a given electrical load case and wind speed. The V-P_{mech} curves are given by Figure 5 for different wind speeds.

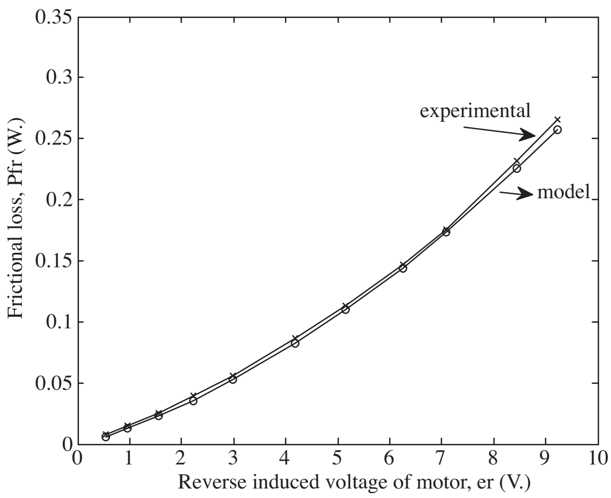

Figure 4. Characteristics of e_r-P_{fr} for experiment and model.

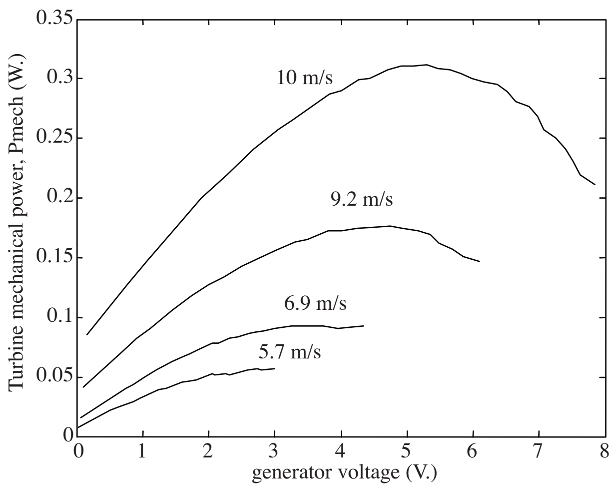

Figure 5. The V-P_{mech} curves at different wind speeds for the set.

In Figure 5, curves of P_{mech} are plotted between 0-V_{oc} voltage values for each wind speed excitation. For open circuit voltage case, electrical powers (P and armature winding heat loss) of the generator is zero. In this case, the P_{mech} corresponds to frictional power P_{fr}. Also this P_{fr} is maximal due to maximum rotational shaft speed ω. On the other hand in short circuit case, the P is very low again, armature heat loss is maximal but the rotational speed ω is minimal due to maximal current (reverse electrical torque K.I). Hence the P_{fr} is minimal. These characteristics agree with equation 4. As shown from the Figure 5, maximal values of P_{fr} increase with wind speeds. Because normally the more the wind speed, the more the rotational speed ω. Also the P_{mech} rises with wind speeds.

For each wind speed sampled, maximum value of $P_{mech(\max)}$ are found. The Figure 6 displays both υ -P_w curve and the υ-$P_{mech(\max)}$ curve. The approaching of the $P_{mech\ (\max)}$ values to the wind power P_w values at variations of wind speed in Figure 6, gives an idea about the ability of a wind turbine for energy conversion from the wind. The ratio of P_{mech} and P_w is C_p in equation 2. The P_w rises with wind speed faster than the P_{mech} due to its cubic depend on the wind speed. Additionally the net mechanical shaft power is limited by higher P_{fr} at higher wind speeds. In these cases, the generator should be more electrically loaded so that P_{fr} gets lower due to higher currents, thus improving the electrical efficiency.

At wind speeds less than about 4.9 m/s, no electrical power is delivered from our wind generator set. Characteristics of V-P are given in Figure 7 for the kit.

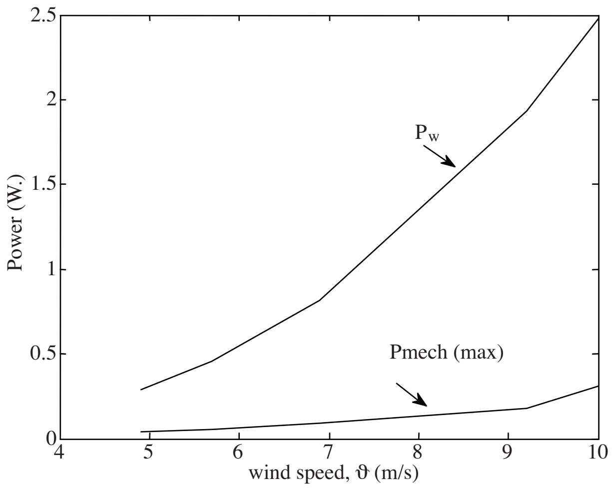

Figure 6. Characteristics of υ -$P_{mech(\max)}$ and υ – P_w for the set.

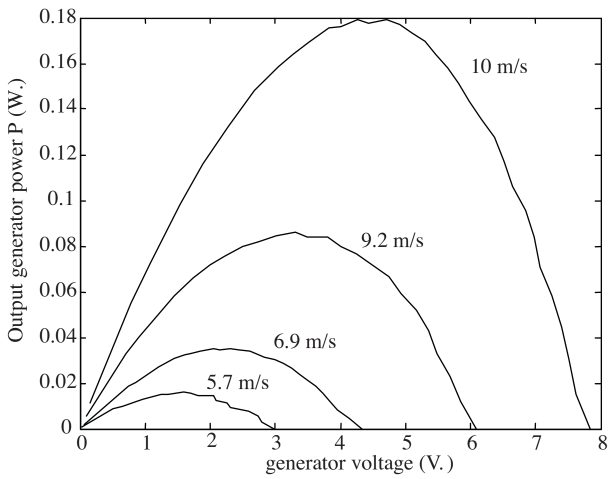

Figure 7. V-P curves at different wind speeds for the kit.

Electrical efficiency of wind turbine- generator system η can be defined by equation 14. Figure 8 shows operating voltage V- η curves at different wind speeds for the kit.

$$\eta = \frac{P}{P_w} \tag{14}$$

According to characteristics in Figure 7 and Figure 8, there is a critical value of V where the η and the P have maximum value for each wind speed. These voltage values change with wind speeds. The wind speed is sampled as 5.7-10 m/s. For example for the highest 10 m/s wind excitation, maximum turbine mechanical power $P_{mech(\max)}$ delivered from the wind power is 0.3111 W at 5.3 V., maximum output power of the generator $P_{(\max)}$ is about 0.1793 W and maximum electrical efficiency $\eta_{(\max)}$ from wind power to output power of generator is 7.22%. The $\eta_{(\max)}$ and $P_{(\max)}$ correspond to same operating voltage 4.27 V. but $P_{mech(\max)}$ and $P_{(\max)}$ exist at different operating voltages for same wind speed (see Figure 5, Figure 7 and Figure 8). In Table 1, mechanical turbine power P_{mech}, frictional loss P_{fr}, electrical armature winding heat loss $I^2.R_s$, generator output power P, operating voltage V, electrical efficiency η and power coefficient of turbine C_p are given for both $P_{mech(\max)}$ and $P_{(\max)}$ cases at 10 m/s wind speed in the kit.

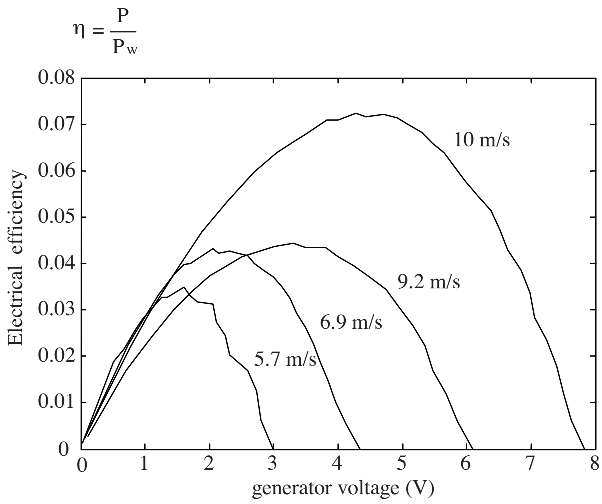

Figure 8. V- η curves at different wind speeds for the set.

Table 1. Wind system power sharing at $P_{mech(\max)}$ and $P_{(\max)}$ cases at 10 m/s.

Wind speed 10 m/s	P_{mech} (W.)	P_{fr} q(W.)	($I^2.R_s$) (W.)	P (W.)	V (V.)	η	C_p
$P_{mech(\max)}$ case	0.3111	0.1313	0.0102	0.1696	5.30	0.0683	0.1253
$P_{(max)}$ case	0.2994	0.1024	0.0176	0.1793	4.27	0.0722	0.1206

The optimum voltage shift between $P_{mech(\max)}$ and $P_{(\max)}$ results from mechanic frictional loss and initial electrical of the generator. This requires an optimisation among wind-turbine-generator. These losses should be minimal for system performance development.

4. Tests on the PEM type electrolyser and modelling

The input I-V characteristic (response) of PEM type electrolyser is measured using an adjustable power source. Input currents are defined at different applied voltages (0-2 V.) In this characteristic, there is a critical voltage at which the current flow starts. According to this test, input characteristic of the PEM electrolyser is modelled by equation 15. I-V characteristics for experiment and model are given in Figure 9.

$$I = \begin{bmatrix} 0 & V \leq 1.4769473 \\ 3.0645(V - 1.476973) & V > 1.4769473 \end{bmatrix} (A.) \tag{15}$$

The rate of hydrogen formation (ml/min) is noted down according to input power (V.I=watt). Figure 10 shows the variation of rate of hydrogen formation (v_H) with the input power P of the electrolyser.

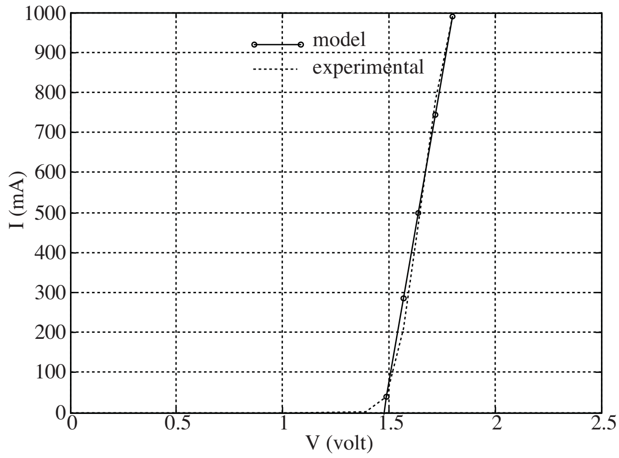

Figure 9. Input I-V characteristics of the PEM electrolyser for measurement and model.

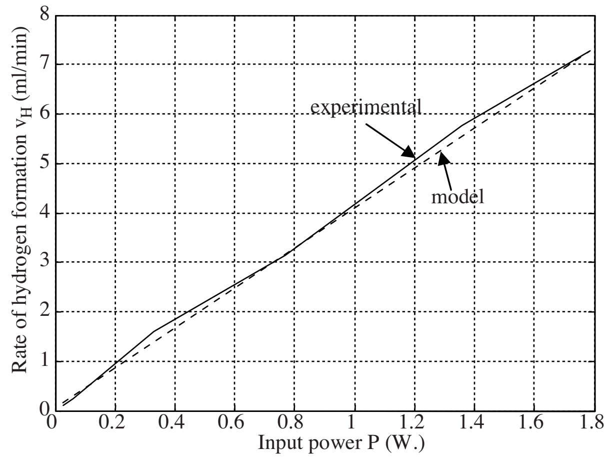

Figure 10. The rate of hydrogen formation v_H versus input power P.

The characteristic in Figure 9 seems like a linear function. Even if I-V relationship is approximated as linear (equation 15), the resulting P-v_H curve is nonlinear (logarithmic), however, an error resulting from linear relationship seems to negligible for a particular interval, as given in literature [12]. Hence, P-v_H relationship is defined by equation 16. In the study, the coefficient K_H is found as 4.02 ml/(min.W.).

$$v_H = K_H.P \tag{16}$$

5. Operation of PEM electrolyser with the wind generator kit

The PEM electrolyser is powered by wind generator for hydrogen production. The power transfer flow diagram of the overall system is given by Figure 11. Operating points of the electrolyser are measured and also can be predicted by general system modelling for different wind speeds. PEM electrolyser operates at intersection points between output I-V curves of the wind generator and input I-V characteristic of the electrolyser.

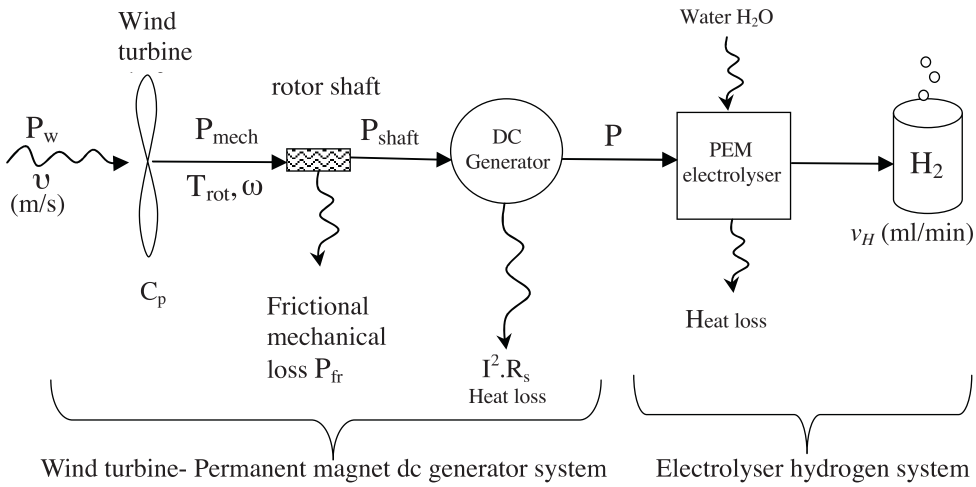

Figure 11. Principle power flow diagram of the overall system.

Model equations of wind generator and electrolyser sets, are defined in MATLAB/Simulink program for prediction analysis. Figure 12 shows MATLAB/Simulink model for wind generator-PEM electrolyser system.

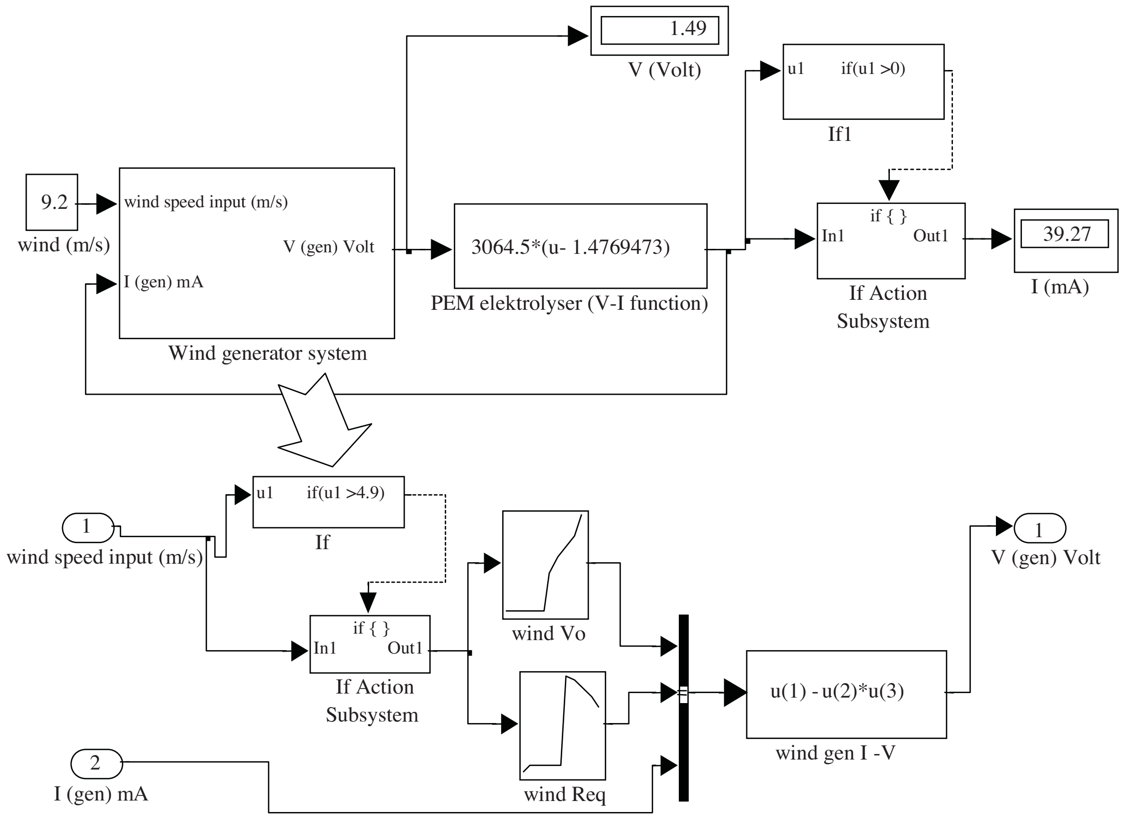

Figure 12. Wind generator- PEM electrolyser system in the Simulink.

According to analysis results, both measured and predicted operating points are given in Figure 13 for wind generator- electrolyser system. Also the Figure 13 shows that, operating points of the electrolyser match its individual input (response) characteristic. It is to be noted that, at wind speeds less than about 4.9 m/s the electrolyser is off for hydrogen production.

There is an agreement between measurement and model prediction. The relative errors for operating points of wind system-PEM electrolyser are given in Table 2 at different wind speeds sampled in the kit.

Table 2. Relative errors for operating points of PEM electrolyser in the kit.

Wind speed υ(m/s)	4.9	5.7	6.9	9.2	10
Relative error for V	off	-0.0423	-0.0265	-0.0136	-0.0122
Relative error for I	off	0.0377	0.0185	0.0066	0.0351

From these operating points, rate of hydrogen formations υ_H , can be defined according to wind speeds. After input power P for electrolyser is calculated, values of υ_H are found by equation 16. The $\upsilon - \upsilon_H$ curve is given in Figure 14.

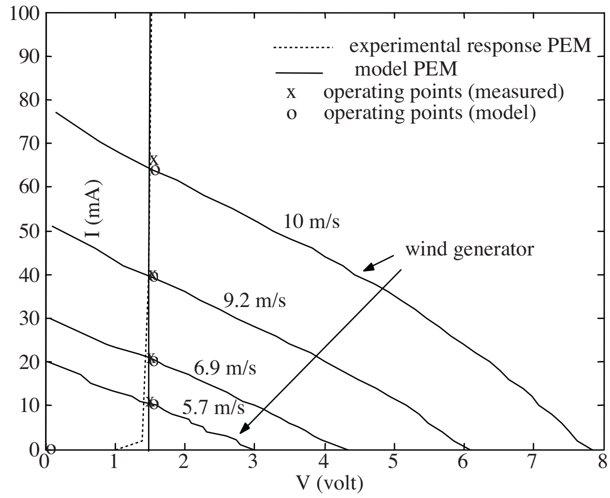

Figure 13. Operating points of the PEM electrolyser on the wind generator set.

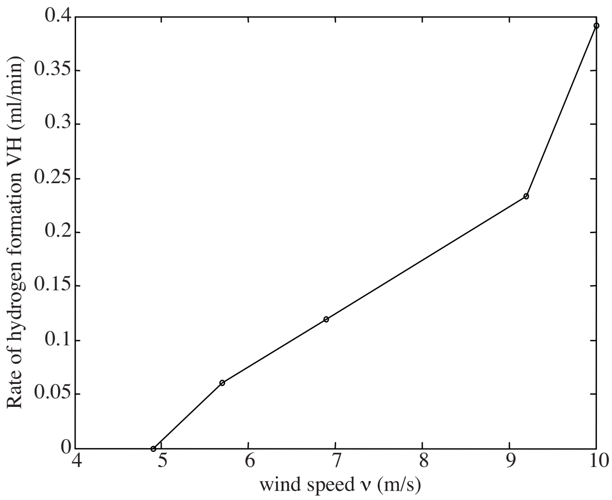

Figure 14. The $\upsilon - \upsilon_H$ curve on the system.

The rate of hydrogen formation increases with wind speed. More power transfer from wind system to electrolyser, the more hydrogen production. In our kit, the PEM electrolyser can not be operated at maximum power points of the wind generator for each wind excitation level due to its individual input characteristic. Characteristic matching between the generator and PEM electrolyser to tract maximum power can be done by using suitable electronic control device in practice and large applications.

6. Conclusion

An educational experiment wind generator kit is designed for hydrogen production by a PEM type electrolyser. The kit has no high performance with respect to wind turbine shape and generator. But using the wind generator kit constructed, output I-V characteristics of the dc wind generator, mechanical frictional loss of the turbine –generator system, mechanical power of the wind turbine characteristics and variations of electrical system efficiency are investigated at different electrical loads and wind speeds. The wind speed is sampled as 5.7-10 m/s. At the highest 10 m/s wind excitation, the wind system kit has about 0.30 W maximum turbine mechanical power from the wind power at 5.3 V., about 0.18 W maximum generator output power and about 7% maximum electrical efficiency at 4.27 V. In these cases, wind turbine power coefficient C_p is 12.53% for maximum turbine mechanical power, 12.06 % for maximum electrical efficiency of the wind system.

Electrical output I-V curves of the wind generator and input characteristic of the PEM electrolyser are measured and then modelled separately. For hydrogen production, electrolyser is operated with wind generator kit. To predict the operating points, general system is modelled in MATLAB/Simulink. According to model results, operating points of PEM electrolyser on wind system kit are predicted with small relative errors. Relative errors are about 1-4% for voltage, 0.6-3% for current. The rate of hydrogen production of wind system-PEM electrolyser kit is analyzed with respect to input wind speeds. When the PEM electrolyser is powered by our wind generator kit, it can produce hydrogen with 0.4 ml/min at 10 m/s wind speed. Other renewable energy devices such as photovoltaic cells can be integrated to the kit. The photo of experiment kit is given in Figure 15. Additionally this study shows that although the kit system is with small scale and made from simple inexpensive tools, it can be used for not only training but also academic investigations and tests about similar systems. If it is preferred, the kit is developed to larger scale dimensions by using bigger fan, turbine and generator. Hence facilities in laboratory can be expanded independently from difficult and unstable outdoor conditions. Approaches of the kit study can be applied to performance tests of large or/and special designed model devices such as turbine, generator etc.

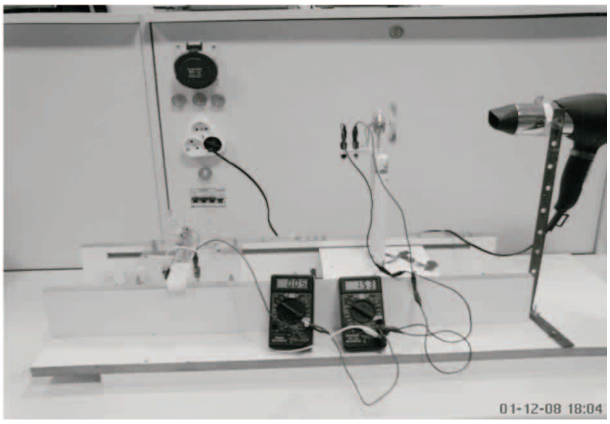

Figure 15. Photo of wind generator-PEM electrolyser set in the study.

The proposed approaches and experimental kit have been used in Electric Generation Techniques courses at faculty level. Related worksheets are given in [13,14] as sample. Students are be able to define net mechanical output power and losses of a permanent magnet dc motor and power coefficient of a wind turbine with dc motor and to model the overall wind turbine system with PEM electrolyser hydrogen production.

References

[1] M.Kolhe, K. Agbossou, J. Hamelin, T.K. Bose, " Analytical model for predicting the performance of photovoltaic array coupled with a wind turbine in a stand –alone renewable energy system based on hydrogen", Renewable Energy, Vol.28, pp. 727-742, 2003.

[2] D.B. Nelson, M.H. Nehrir, C. Wang, "Unit and cost analysis of stand –alone hybrid wind /PV/fuel cell power generation systems", Renewable Energy, Vol.31, pp. 1641-1656, 2006.

[3] M.Santarelli, M.Cali, S. Macagno,"Desing and analysis of stand-alone hydrogen energy systems with different renewable sources", International Journal of Hydrogen Energy", vol.29, pp. 1571-1586, 2004.

[4] E. Kasseris, Z. Samaras, D. Zafeiris, " Optimization of a wind –power fuel –cell hybrid system in an autonomous electrical network environment", Renewable Energy, Vol. 32, pp. 57-79, 2007.

[5] T. F. El-Shater, M.N. Eskander, M. T. El-Hagry, "Energy flow and management of a hybrid wind /PV/fuel cell generation system", Energy Conversion & Management, Vol. 47, pp. 1264-1280, 2006.

[6] O. Atlam, " Educational kit studies on renewable energy sources", DEMSEE 2007 (Deregulated Electricity Market Issues in South Eastern Europe)- Edited by L. Sevgi, Dogus University, No:2, pp. 32-40, 2007.

[7] L. Qihui, H. Yikang, Z. Rende, “ Imitation of the characteristics of the wind turbine based on DC motor”, Front. Electr. Electron. Eng. China (Higher Educational Press and Springer-Verlag), Vol.2 (1), pp. 361-367, 2007.

[8] S. Mathew, Wind Energy- Fundamentals, Resource Analysis and Economics, Verlag Berlin Heidelberg, Springer, 2006.

[9] H. Miland, R. Glöckner, P. Taylor, R.J. Aaberg and G. Hagen, “ Load control of a wind –hydrogen stand –alone power system”, International Journal of Hydrogen Energy, Vol. 31, pp. 1215-1235, 2006.

[10] K. Busawon, M. Jovanovic, L Dodson, “Power coefficient estimation in a wind energy conversion system “**,** 12th International Power Electronics and Motion Control Conference, Vols 1-4 pp. 721-725, 2006 .

[11] M. Monfared, H.M. Kocabadi, Rastegar H.,” Static and dynamic wind turbine similator using a converter controlled dc motor”, Renewable Energy Vol.33,pp.906-913, 2008.

[12] O. Atlam, “ An experimental and modelling study of a photovoltaic/proton- exchange membrane electrolyser system”, International Journal of Hydrogen Energy, Vol. 34, pp. 6589-6595, 2009.

[13] http://tef.kou.edu.tr/elektrik/yonetim/makale/gonderilenler/747.pdf

[14] http://tef.kou.edu.tr/elektrik/yonetim/makale/gonderilenler/748.pdf