

# **Experimental Study of Wave Shape and Frequency of the Power Supply on the Energy Efficiency of Hydrogen Production by Water Electrolysis**

Dhafer Manea. H. Al-Hasnawi<sup>1</sup>

Alternative and Renewable Energy Research Unit, Technical Engineering College of Najaf, AL-FuratAL-Awsat  
Technical University, Najaf, Iraq<sup>1</sup>

**ABSTRACT:**The purpose of this work is minimizing the electrical power dissipation during water electrolysis by finding the best frequency and wave form can be used in water electrolysis process. Where experimentally investigate the three wave forms are used namely, sine, triangular and rectangular. The effect of wave frequency is also investigated as well as the effect of amplitude and comparison between conventional DC power supply and rectangular wave form power supply to electrolysis. The results show the best efficiency factors of electrolysis and maximum volume flow rate of hydrogen product by using rectangular wave form in range (40Hz – 50Hz). Also using power source in the form of a rectangular wave can get high energy and faraday efficiency factors compared with using direct current.

**KEYWORDS:**hydrogen production, water electrolysis, hydrogen fuel.

## **I. INTRODUCTION**

One of the important application of renewable energy is used the hydrogen as fuel, high number of research work hard to use hydrogen energy because it clean, efficient, and available but the production of hydrogen is the problem. The research development and innovation activities that many industrial companies and research centres are developing the production of hydrogen by using water electrolysis [1–5].

Alfredo Ursu'a et al (2009) [6], They are used the different topologies of power supplies to analysis the energy consumption and efficiency of commercial alkaline water electrolyser, the first topology is used thyristor – based (ThPS) and the second topology is used transistor – based power supplies (TrPS). Where tested the commercial alkaline water electrolyser by two topologies (ThPS) and (TrPS), the results show that the cell energy consumption lower when it is supplied by the (TrPS) and increase efficiency.

Shimizu et al.(2006) [7] conducted their experiment to test the behaviour of a cell while the voltage was applied in the form of ultra short pulses. Their goal was to reach higher cell power (increase the gas production rate) without reducing the efficiency. They placed platinum electrode plates 3 cm apart from each other in a 1M KOH aqueous solution. Electrolyte temperature was maintained to  $293 \pm 2$  °K throughout the experiment. The results were compared for the cases of using a conventional DC, and an ultra-short pulse power supply with an output pulse width of about 300 ns. Output frequency and peak voltage of this power supply were adjustable from 2 kHz to 25 kHz and 7.9 V to 140 V respectively.

Mazloomi S.K., NasriSulaiman (2012) [8] they are steady the factors that effect on water electrolysis efficiency such as electrolyte quantity, temperature, pressure, electrical resistance of the electrolyte, electrode material, separator material, and applied voltage wave form. Where in this paper used two applied voltage wave form, the first used conventional DC power supply and the second used an ultra-short pulse in frequency range (2 KHz 25 KHz) and

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

voltage range (7.9V-140V). The results were recorded and compared in both cases show that the using an ultra-short pulse power supply rising input power of the system but the efficiency increase because lowering the peak voltage.

Brad (1980) [9], and Armstrong and Henderson (1972) [10] Introduced very similar equivalent circuits for an electrolysis cell. These circuits consider the electrical impedance of the electrolysis system to be in a non-linear form. Existence of capacitive and faradic elements is the reason of such consideration. Moreover, it is more common to conduct the electrolysis process by applying a pure DC waveform to the cell which is suitable to test linear impedances and ohmic loads. Therefore, according to the mentioned equivalent circuits, the effect of applying other forms of voltage might lead to interesting and important findings.

BiswajitMandal and et al (2012) [11], studied indicates that maximum production was achieved at a particular frequency of 60 kHz as shown in "Table-1". These experimental results reveal an additional significant feature of water splitting by electrolysis that the pulsating DC input destabilizes the H-O bond at a particular frequency and facilitated water splitting. This might be due to electrical polarization process. Placement of a pulse-voltage potential using a pulse width modulator inhibits or prevents electron flow from within the Voltage Intensifier Circuit causes the water molecule to separate into its component parts momentarily and pulling away orbital electrons from the water molecule.

Table-1: The maximum production was achieved at a particular frequency of 60 kHz [11]

Power efficiency (%)	Surface area of cathode (cm <sup>2</sup> )	Production rate (cm <sup>3</sup> /min)	Frequency (kHz)	Input current (A)	Input voltage (V)
9.60	59.6	15.020	No pulse, continuous DC	2	12.65
9.07	59.6	14.200	2.25	2	12.65
11.63	59.6	18.190	3.70	2	12.65
10.97	59.6	17.170	3.90	2	12.65
11.73	59.6	18.360	17.20	2	12.65
12.12	59.6	18.970	17.35	2	12.65
6.65	59.6	10.400	47.00	2	12.65
12.87	59.6	20.133	60.00	2	12.65
8.24	59.6	12.900	69.50	2	12.65
11.88	59.6	18.580	89.73	2	12.65

KavehMazloomi and et al (2012) [12], Thy studied the physical, chemical, and electrical properties of water electrolysis cell and its effects on the efficiency of electrolysis of water. Where the objective of this work is to give information to minimize the electrical power dissipation during water electrolysis process. Where studied the effect of electrolyte quantity, temperature, pressure, electrical resistance of the electrolyte, electrode material, separator material, and applied voltage wave form on the efficiency of water electrolysis process.

The literature review show that all researches study the effect of applied voltage wave form on the efficiency of electrolysis by using conventional Dc power supply or an ultra-short pulse power supply used electrical circuit as thyristor-based (ThPS), transistor-based power (TrPS), and pulse modulator. In the present work is to study experimentally the effect of applied power supply on the efficiency of water electrolysis process. Where using two applied power system, the first using the conventional DC power supply and the second using DC function generator device to change the power supply, wave form (triangular wave form, sin wave form, and rectangular wave form), frequency, and amplitude and then calculate the efficiency factors of water electrolysis process and compared the results with the result of conventional DC power supply and other steady.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

## II. THE PRINCIPLE OF ELECTROLYSIS

In the conventional DC electrolysis of water, hydrogen is generated as a result of electron transfer from the cathode electrode to adsorbed hydrogen ions on the electrode surface. This electrolysis occurs when the applied voltage between the anode and the cathode exceeds the water decomposition voltage of about 1.6 V, the sum of the theoretical decomposition voltage of 1.23 V at room temperature and the overvoltage of about 0.4 V depending on electrode materials and other factors. DC electrolysis is a diffusion limited process and the current flow in water is determined by the diffusion coefficient of ions. It is therefore difficult to increase the input power for a constant volume electrochemical cell without reduction in electrolysis efficiency.[7]

It is almost common for electrolysis systems to use a steady or smooth DC voltage to decompose an electrolyte. According to the Ohm's law, applied DC voltage U causes the current I to pass through the electrolyte with the resistance of R. Hence, the common method of current or current density regulation is by the application of a certain voltage to a cell.

## III. EXPERIMENTAL WORK

The experimental study in this work has been conducted at the Hydrogen Laboratory of the Alternative and Renewable Energy Research Unit in Technical College of Najaf. This laboratory is equipped with Hydrogen / Fuel Cell experimental kit manufactured by IKS Photovoltaic GmbH Company, Germany, Fig.1. The Specification of electrolysis are (Hydrogen production= 5 ml/min, Oxygen production=2.5 ml/min, Power=1.16 W, gas storage=50ml H<sub>2</sub>; 50 ml O<sub>2</sub>, and weight=305g). The electrical properties of the electrolysis can be seen best when examining the current-voltage characteristic curve. It will be examined more closely in this experiment. A function generator is to supply power to the electrolysis instead of direct current supply from transformer already found with experimental kit. An oscilloscope, voltmeter, ammeter, stop watch, and gas storage are used to measure the frequency, wave form, amplitude, voltage, current, time, and volume of hydrogen product respectively from electrolysis as well as a PC to interface with the experimental kit as shown in Fig.2.

The volume flow rate of hydrogen production is measured while the energy efficiency and Faraday efficiency factor of the electrolysis are calculated from the recorded data.

Experiments are conducted with different wave forms and frequencies at constant amplitude. The effects of these parameters on performance of electrolysis are compared with the standard results of experimental kit. The energy efficiency factor is defined and formulated accordingly. This factor is calculated using "equation 2.1".

$$\eta_E = \frac{E_{ch}}{E_{ele}} \quad (2.1)$$

Where:  $E_{ch}$  is the chemical energy  
 $E_{ele}$  is electrical energy

The electrical energy used is calculated using "equation 2.2".

$$E_{ele} = U * I * t \quad (2.2)$$

Where: U is voltage (volt)  
I is current (amp)  
t is time (sec)

For the calculation of the chemical energy, the molar volume and the fuel value of the hydrogen are stated. The chemical energy is calculated via the fuel value of hydrogen which equals 286 kJ/mole [13]. One mole of hydrogen has a volume of  $V_m=22414$  ml at 1 bar and 0°C or  $V_m = 24414$  ml (with 1 bar and 20°). [13]

The chemical energy used is calculated using "equation 2.3".

$$E_{ch} = H_{0(V)} * V_{exp} \quad (2.3)$$

Where:  $V_{exp}$  is the volume production of hydrogen experimentally (ml)

For the calculation of the chemical energy  $H_0$  the fuel value of H<sub>2</sub> gas is related to the volume as shown in "equation 2.4" [11]

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

$$H_{0(V)} = H_o * \frac{1}{V_m} = 286 \frac{\text{KJ}}{\text{ml}} * \frac{1 \text{ mole}}{24414 \text{ ml}} = 11.71 \frac{\text{J}}{\text{ml}} \quad (2.4)$$

Now by the substitution of "equations 2.2, 2.3 and 2.4" in "equation 2.1" the energy efficiency factor of electrolyser is given by "equation 2.5"

$$\eta_E = \frac{V_{\text{exp}} * 11.71 \left[ \frac{\text{J}}{\text{ml}} \right]}{U * I * t} \quad (2.5)$$

The Faraday efficiency factor is the ratio between the quantity of gas actually produced  $V_{\text{exp}}$  and the quantity of gas to be expected theoretically  $V_{\text{theo}}$  as shown in "equation 2.6".

$$\eta_F = \frac{V_{\text{exp}}}{V_{\text{theo}}} \quad (2.6)$$

One mole of hydrogen is produced from two moles of hydrogen ions so that the expected theoretically  $V_{\text{theo}}$  is given by "equation 2.7".

$$V_{\text{theo}} = \frac{I * t * V_M}{z * F} \quad (2.7)$$

Where: I: current supply to electrolysis

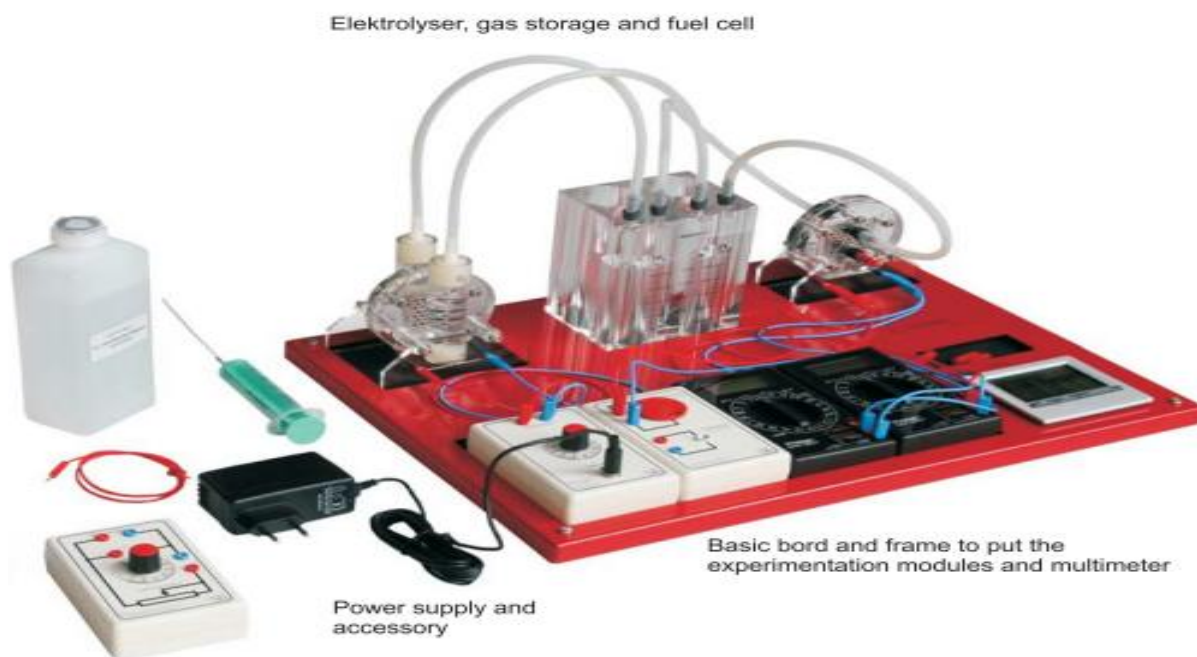
t: Time

z: two moles of hydrogen ions.

F: 96486 As/mole

Exemplar based inpainting technique is used for inpainting of text regions, which takes structure synthesis and texturesynthesis together. The inpainting is done in such a manner, that it fills the damagedregion or holes in an image, with surrounding colour and texture. The algorithm isbased on patch based filling procedure. First find target region using mask image and then find boundary of target region. For all the boundary points it defined patch andfind the priority of these patches. It starts filling the target region from the highestpriority patch by finding the best match patch. Thisprocedure is repeated until entire target region is inpainted.

The algorithm automatically generates mask image without user interaction that contains only text regions to be inpainted.



**Fig.1.** Hydrogen / Fuel Cell Experimental Kit

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

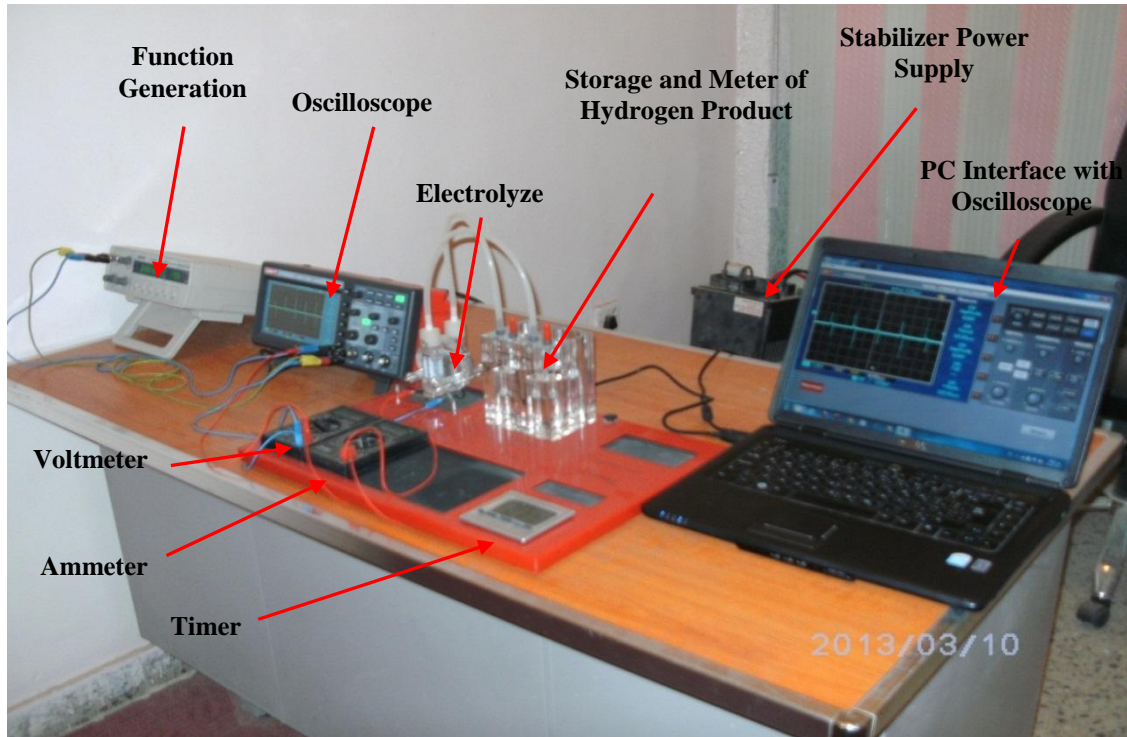


Fig.2: Experimental Rig

## IV. RESULTS AND DISCUSSIONS

### 1. Effect of Wave Form

"Fig.3" shows the effect of frequency on hydrogen production yield for different wave forms at constant amplitude (2V). The results show that the volume flow rate of Hydrogen product decreases as the frequency is increased for the rectangular wave form and equal to zero for sine and triangular wave form for all range of frequency. The figure also shows that the rectangular wave form gives better yield than other two forms at low frequencies however the difference becomes insignificant at higher frequencies. This may be due to the high power associated with the rectangular form.

"Fig.4" shows the variation of Faraday efficiency factor and energy efficiency factor with frequency for the three wave forms. The results show that both factors show the same behavior and approximately same values. Both efficiencies decrease with increasing frequency for the rectangular wave form and equal to zero for the other wave forms. The results of "Fig.3" and "Fig.4" show that the rectangle waves form have maximum volume flow rate and maximum energy and faraday efficiency factors at low frequency range compared with other waves form. The rectangular wave is shown in "Fig. 5".



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

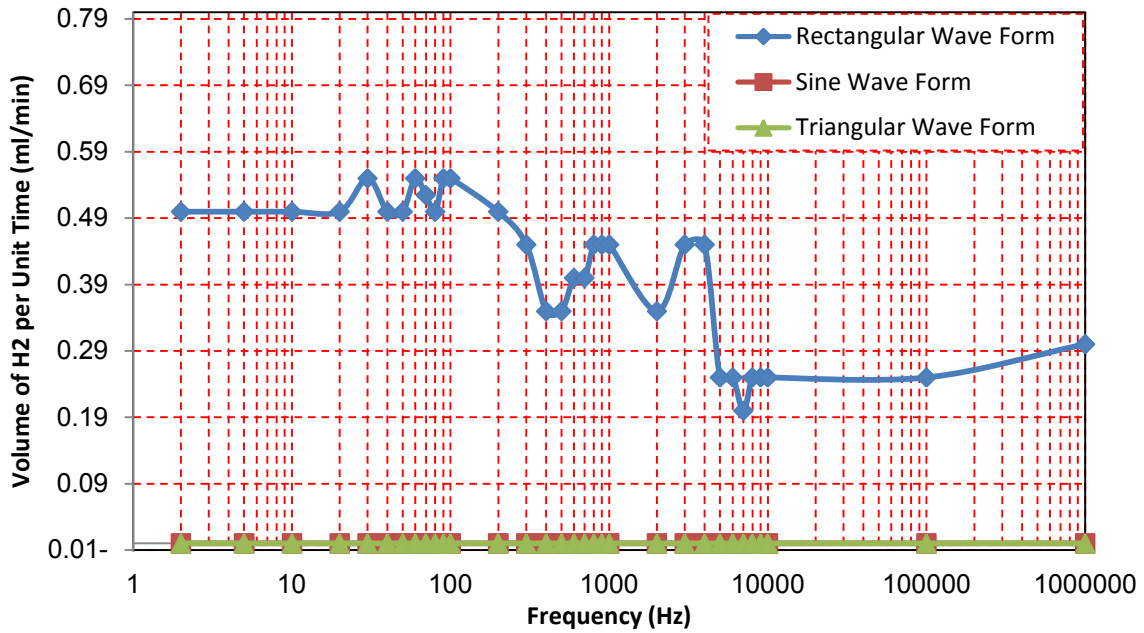


Fig.3: Effect of Frequency on Volume Production Rate of Hydrogen for Different Wave Forms and constant amplitude (2V)

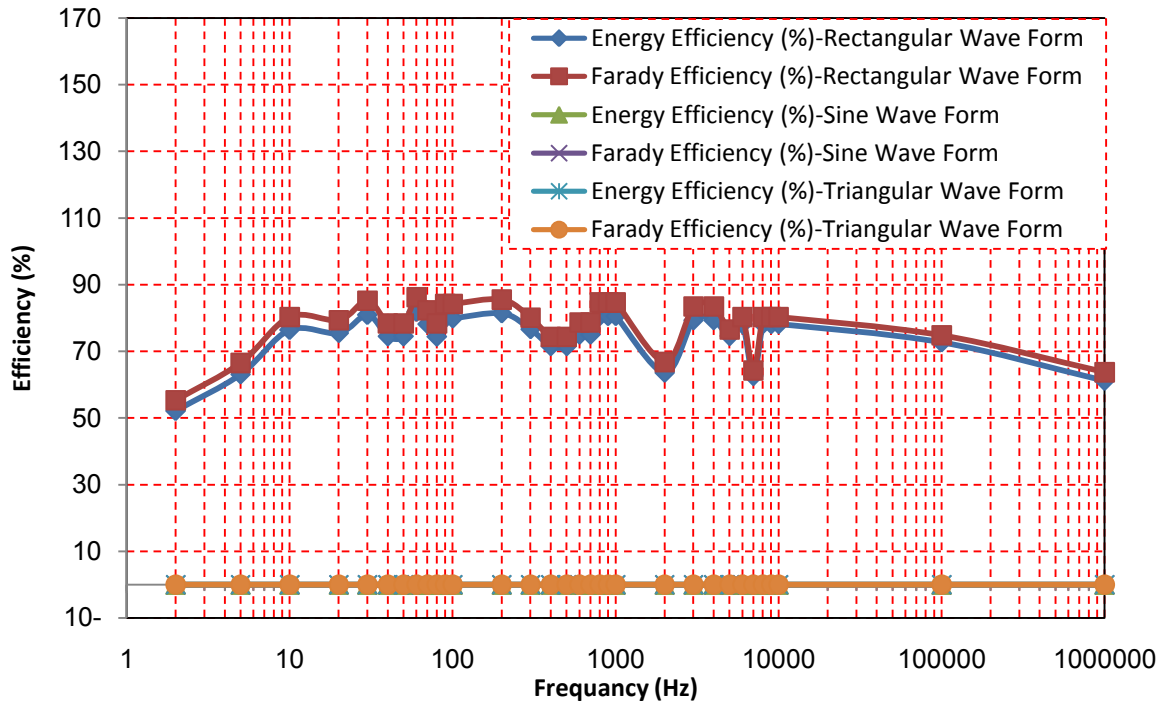


Fig.4. Energy and Faraday Efficiency factors vs. frequency for different waveforms and constant amplitude (2V)

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

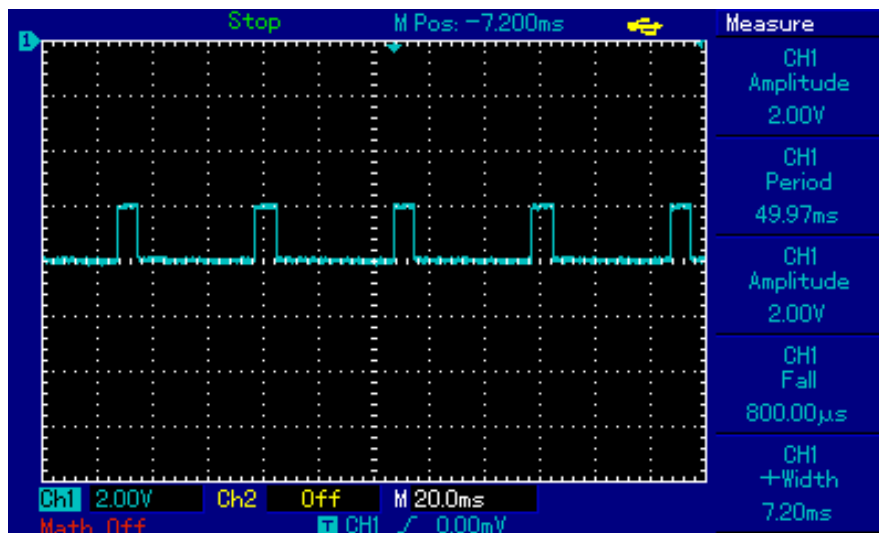


Fig.5: Rectangle Wave Form Shape at constant amplitude

### 2. Effect of Frequency

"Fig.6" shows the variation of volume production rate of hydrogen with frequency for the rectangle wave form at constant amplitude of 2V. The results show that the maximum production rate in the frequencies range (30 Hz -100 Hz) and decreases as the frequency increases.

"Fig.7" shows the variation of the energy and faraday efficiency factors with frequency at constant amplitude. Where note the maximum energy and faraday efficiency factors in range (40 Hz -50Hz) and at low frequency the efficiency factors decrease because the current draw from electrolyze is high and the behaviours at high frequency are fluctuated and drop in other range.

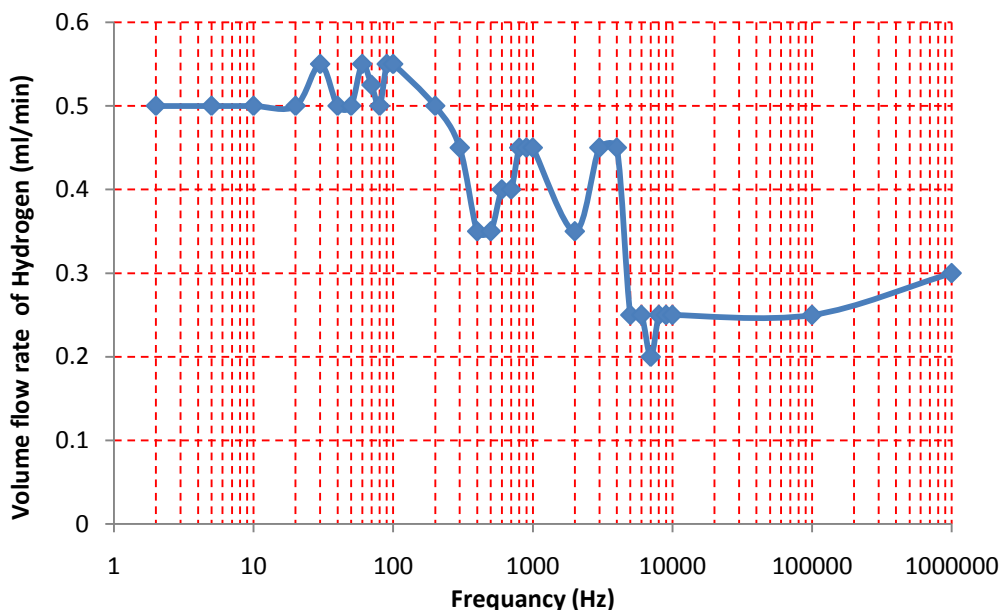


Fig.6: Variation of Volume Production Rate of Hydrogen with Frequency at Constant Amplitude of (2V) and rectangular wave form

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

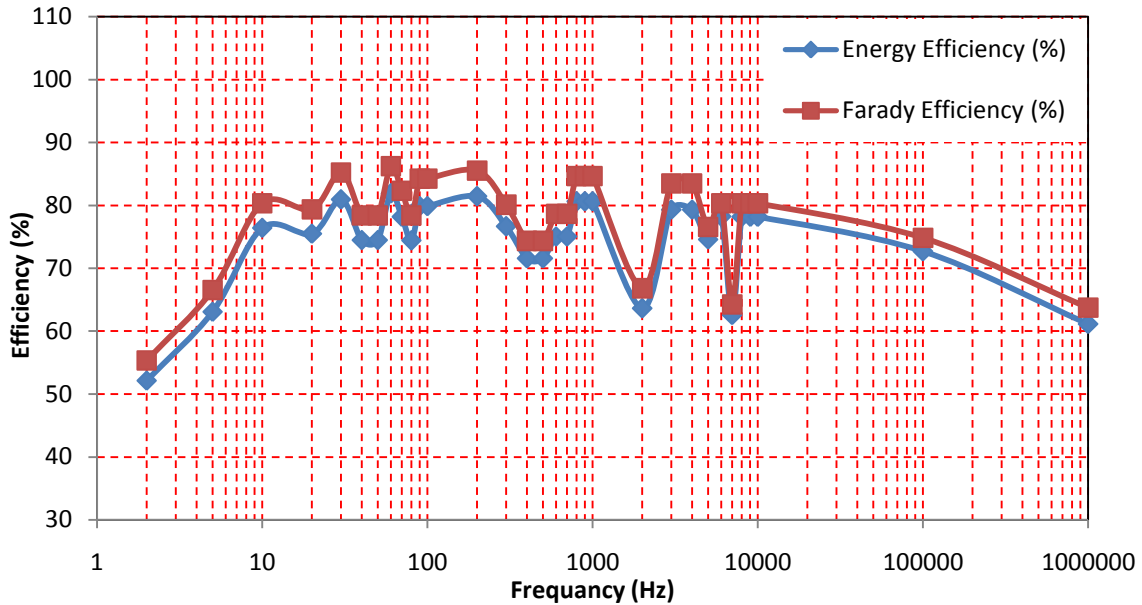


Fig.7: Variation of Energy and Faraday Efficiency Factors with Frequency for Constant Amplitude of (2V) and rectangular wave form

### 3. Effect of Amplitude

"Figs.8, 9, and 10" show the variation of volume production rate of hydrogen, energy efficiency factor and Faraday efficiency factor respectively with amplitude at difference values of frequency. The figs show that these parameters increase with amplitude until 2 V and then level up after this value. This may be the characteristics of the fuel cell used in this work.

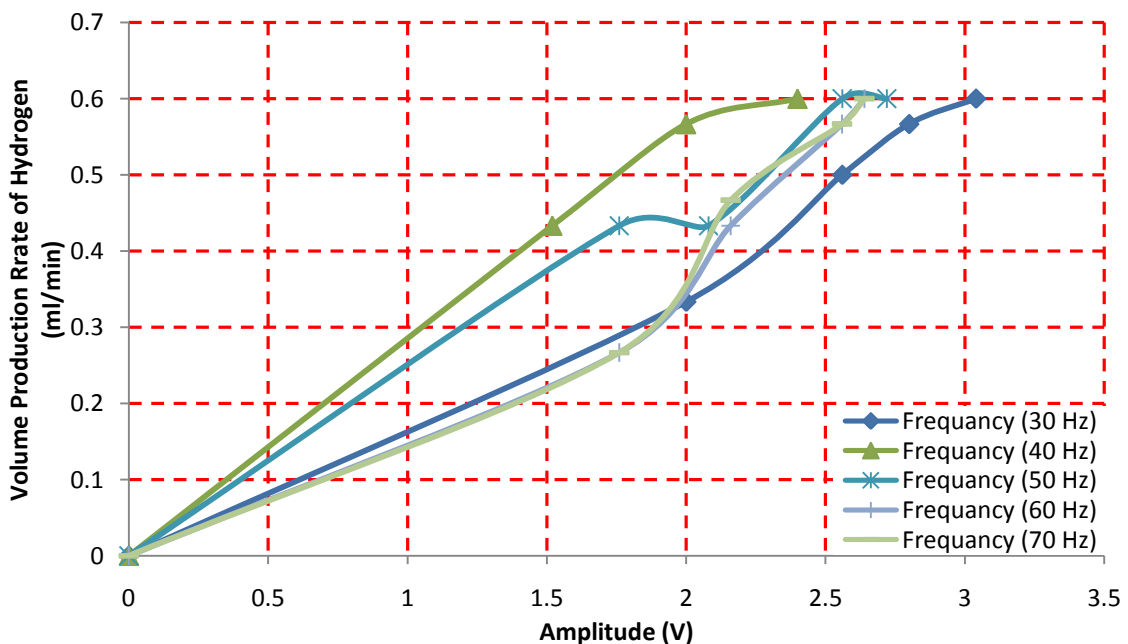


Fig.8: Variation of Volume Production Rate of Hydrogen with Amplitude at Different Frequencies



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

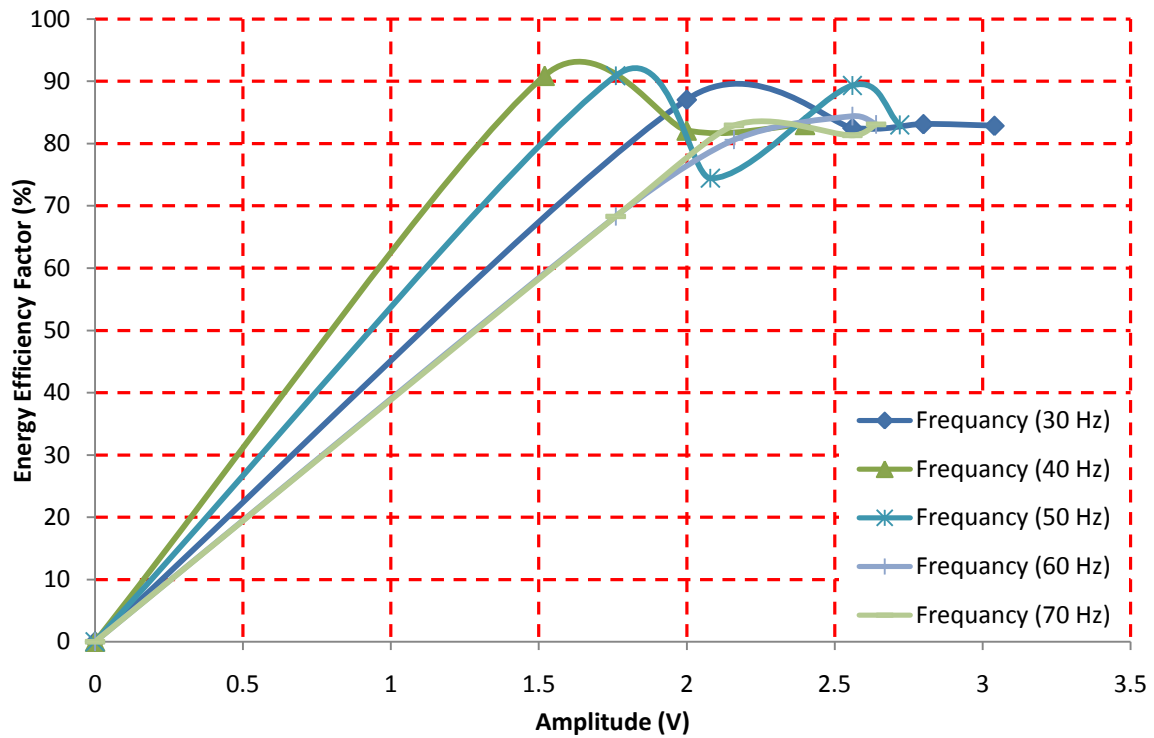


Fig.9: Variation of Energy Efficiency Factor with Amplitude at Different Frequencies

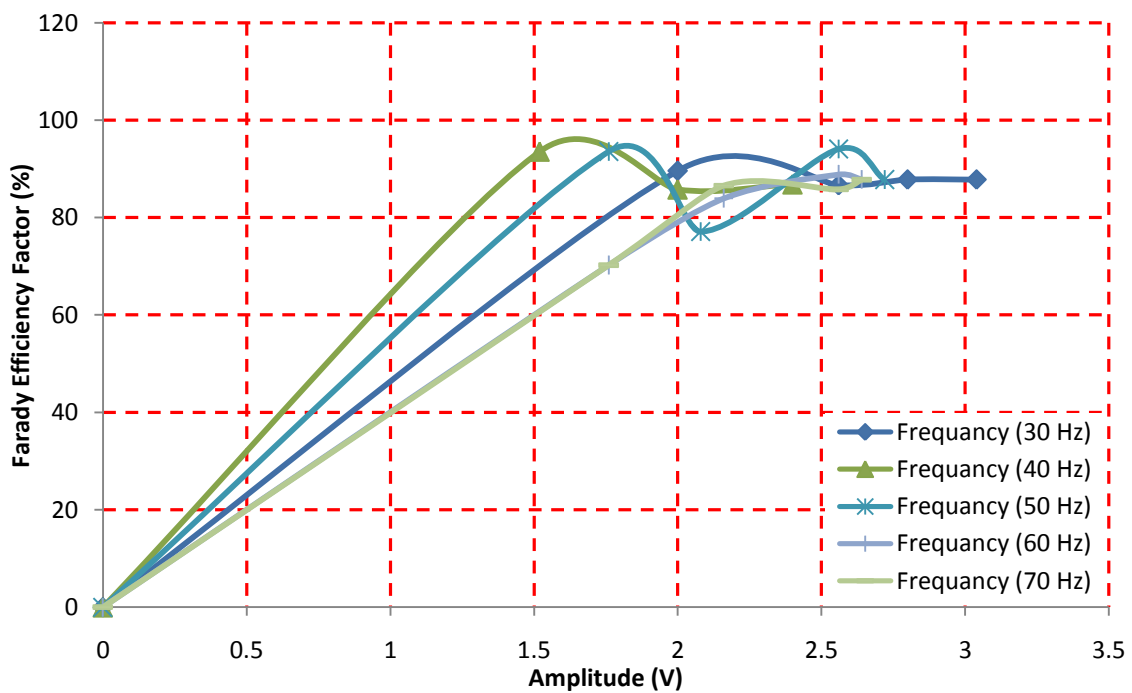


Fig.10: Variation of Faraday Efficiency Factor with Amplitude for Different Frequencies

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

### 4. Comparing the Rectangle Wave Form with DC Power Supply

The results of the rectangular wave form source are compared with the results of a DC power source. "Fig. 11" shows the comparison of the hydrogen production rate for both sources. Which note that have more volume flow rate by using power source in the form of a rectangular wave in frequency ranges (40Hz – 50Hz).

"Fig.12" and "Fig.13" are explaining the profile of energy and Faraday efficiency factors with variation of current respectively. Where not the maximum energy and Faraday efficiency by using power source in the form of a rectangular wave in frequency ranges (40Hz – 50Hz) because the volume flow rate of hydrogen product increase while the current decrease so that the efficiency factors will be increase.

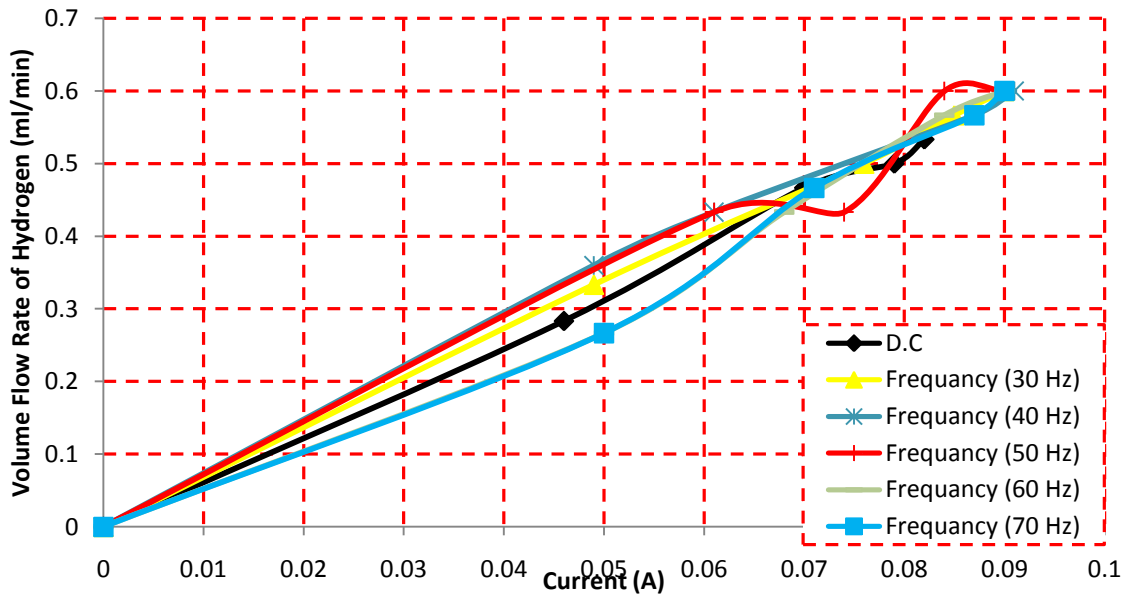


Fig.11: Variation of Volume Production Rate of Hydrogen with Current for Different Frequencies and amplitude

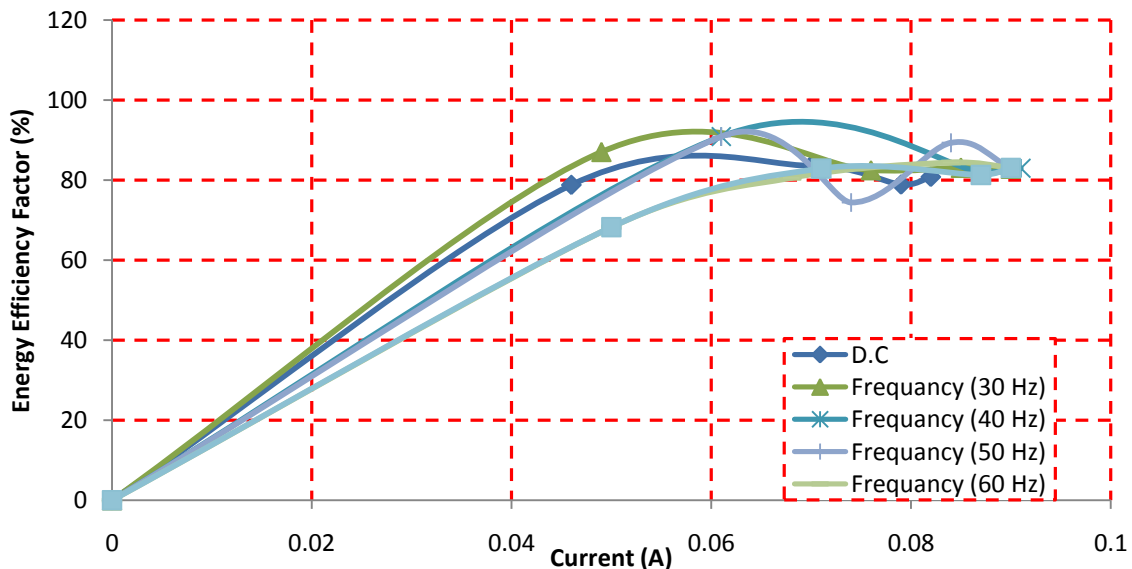


Fig.12: Variation of Energy Efficiency Factor with Current for Different frequencies and amplitude

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

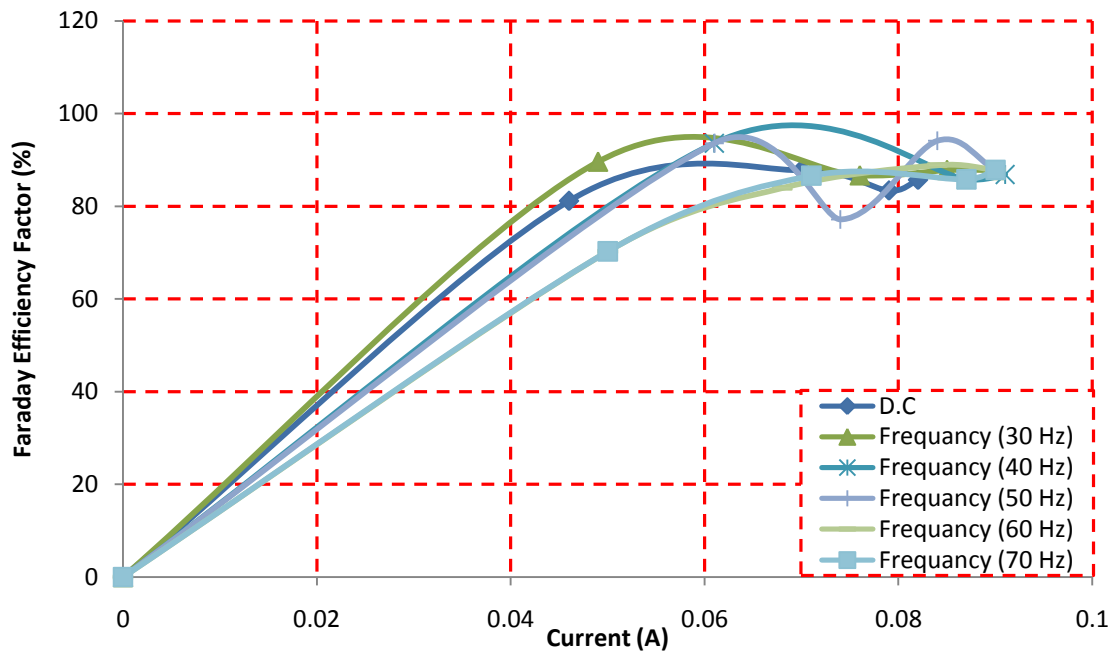


Fig.13: Variation of Faraday Efficiency Factor with Current for Different Frequencies and amplitude

### V. CONCLUSION

The purpose of this work is minimizing the electrical power dissipation during water electrolysis by finding the best frequency and wave form that can be used in the water electrolysis process. The effect of wave form on the performance of electrolysis shows that the rectangular wave has a greater impact than other wave forms. The best efficiency factors of electrolysis by using a rectangular wave form are in the range of 40 Hz – 50 Hz. The maximum volume flow rate of hydrogen product from electrolysis by using a rectangular wave form is also in the range of 40 Hz – 50 Hz. The hydrogen production rate by using a rectangular wave power source is more than the hydrogen production rate when direct current is used. The use of a rectangular wave power source gives higher energy and Faraday efficiency factors in comparison with direct current. Based on the experimental results, it can be concluded that the electrical circuit that gives the same wave form and frequency can be used in an application of water electrolysis process.

### REFERENCES

- [1] Conte M, Iacobazzi A, Ronchetti M, Vellone R., "Hydrogen economy for a sustainable development", state-of-the-art and technological perspectives, *J Power Sources*, pp.87–171, 2001.
- [2] Dunn S., "Hydrogen futures: toward a sustainable energy system", *World Watch* paper 157, 2001.
- [3] Elam CC, Padro CEG, Sandrock G, Luzzi A, Lindblad P, Hagen EF. "Realizing the hydrogen future", The International Energy Agency's efforts to advance hydrogen energy technologies, *Int J Hydrogen Energy*, vol.28, pp601–607, 2003
- [4] Barreto L, Makhira A, Riahi K., "The hydrogen economy in the 21st century", a sustainable development scenario, *Int. J Hydrogen Energy*, vol. 28, pp. 267–284, 2003
- [5] Barbir F, Plass HJ, Veziroglu TN., "Modeling of hydrogen penetration in the energy market", *Int. J Hydrogen Energy*, vol.18, pp.187–195, 1993.
- [6] Alfredo Ursu'a, Luis Marroyo, Eugenio Gubi'a, Luis M. Gandi'a, Pedro M. Die'guez, Pablo Sanchis, "Influence of the power supply on the energy efficiency of an alkaline water electrolyser", *International Association for Hydrogen Energy*, vol. 34, pp.3221-3233, 2009
- [7] Shimizu N, Hotta S, Sekiya T, Oda O. "A novel method of hydrogen generation by water electrolysis using an ultra-short-pulse power supply", *Journal of Applied Electrochemistry*, vol.36, pp.419–423, 2006
- [8] S.K. Mazloomi, Nasri Sulaiman, "Influencing Factors Of Water Electrolysis Electrical Efficiency", *Renewable and Sustainable Energy Reviews*, vol.16, pp.4257– 4263, 2012.
- [9] Brad AJ., "Electrochemical methods-fundamentals and applications", New York John Wiley; 1980.

## International Journal of Innovative Research in Science, Engineering and Technology

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 4, Issue 12, December 2015**

- [10] Armstrong RD, Henderson M.,” Impedance plane display of a reaction with an adsorbed intermediate”,. Journal of Electro-analytical Chemistry, vol. 39, pp.81–90, 1972
- [11] BiswajitMandal, A. Sirkar, AbhraShau, P. De, and P. Ray, "Effects of Geometry of Electrodes and Pulsating DC Input on Water Splitting for Production of Hydrogen" , International Journal Of Renewable Energy Research, Vol.2, No.1, 2012
- [12] KavehMazloomi, Nasri b. Sulaiman,andHosseinMoayedi, " Review Electrical Efficiency of Electrolytic Hydrogen Production", Int. J. Electrochem. Sci., vol. 7, pp.3314 – 3326, 2012.
- [13] HolgerKunsch and Michael Schroder, “Experiments on Hydrogen Technology”, IKS Photovoltaic GmbH, the H2 Trainer Junior, 2008.