DP-1 REVIEW

ON

"SIMULINK MODEL OF SOLAR PV BASED WATER ELECTROLYSIS"

Master of Technology

In

Electrical Engineering

By

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CANDIDATE'S DECLARATION

I hereby declare that the dissertation entitled **"Simulink model of PV based water electrolysis"** submitted to the Department of Electrical Engineering, Atmiya University, in partial fulfilment of the requirements for the award of the Degree of **Master of Technology** in **Electrical Engineering** under the supervision of **Prof. Dhaval Raval,** Associate Professor, Department of Electrical Engineering, ATMIYA UNIERSITY.

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CERTIFICATE

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I

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I hereby certify that the work presented in this thesis is an authentic record of my own efforts and I am totally responsible for the contents. In the event of any controversy, I will be solely responsible. My thesis supervisor is not accountable in any way for any academic dispute as a consequence of this, that may arise at a future date.

I would also like to thank the almighty God, my parents, fellow classmates and friends for their help and moral support without which this work would have been impossible.

YASHVANTKUMAR KHUMAN

II

Abstract

In recent years, demand of battery based Electric Vehicle increases also the electricity production by solar panels also emerging. The battery storage system has lass life time also its waste has harmful effect. There is need of clean energy storage system with long lifetime and better energy storage capacity. It will take a variety of solutions but one tool that's gaining traction is green hydrogen green hydrogen is hydrogen that's been produced exclusively from renewable power the hydrogen is a pollution free fuel. We can use this hydrogen to generate electricity by fuel cells or we can store them in high pressure tank. Water is the main source we can use to produce hydrogen gas this process is water electrolysis. We can use renewable energy sources to split water into hydrogen gas and oxygen. The PEM electrolyser is simulated in this project. This project simulated with PEM electrolyser stack, water storage tank and hydrogen storage tank with solar PV module.

Keywords: Hydrogen energy storage, battery, electric vehicle, PEM electrolyser, water electrolysis, solar PV module

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NOMENCLATURE

Capex - Capital Expenses

PEM – Proton Exchange Membrane

Opex - Operational Expenses

SPE - Solid Polymer Electrolyte

OCV – Open Circuit Voltage

PV - Photovoltaic

Chapter 1
Introduction

1.1 BACKGROUND

The 21rst century has witnessed increased population growth rates and rapid advancements in technology. Earth is facing worst climate change effects e.g., global warming, ozone layer decrement that is rising the global temperature. The main challenge is to drop the carbon emission. We need solutions to reduce this carbon emission. The hydrogen can be an solution to make this happen. The renewable sources can be used to produce pure hydrogen or green hydrogen gas. Hydrogen can be used in steel or chemical iron industries where it can be used as burning fuel. Hydrogen can store the renewable energy like battery storage system but it has more long-life time and more storage capacity than battery energy storage systems. This sored energy can be use in our homes to store renewable energy which may be wasted if we are serious about decarbonisation if we are serious about going into a world which have zero carbon emission. There is no choice but using hydrogen renewable energy can get you so far actually up to 50 to 60 reductions in total emission in the world because there are a lot of other industries and downstream products which are still emitting but have nothing to do with renewable energy and hygiene could be the solution. The catch because hydrogen is very reactive. It's not found freely in nature it only exists combined with other elements for example water is a combination of two hydrogen atoms and one oxygen atom [10]. Hydrogen can be extracted from water by electrolysis process. In today's scenario, the hydrogen is extracted from fossil fuels but the molecules of hydrogen are clean. that's why

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green hydrogen is so appealing but producing it is still very expensive and although costs are comedown number of other challenges remain including the lack of storing facilities to transport and fuel cell which is used in cars to convert hydrogen gas stored energy into electricity to run the cars are very expensive still solutions are coming and overcoming some of these challenges could propel the hydrogen market to 2.5 trillion in direct revenues by 2050. Hydrogen can be produced in a number of different ways experts categorize the sources and processes by which hydrogen is derived using colours the overwhelming majority of hydrogen today is produced from fossil fuels brown hydrogen is made from coal in a process known as gasification grey hydrogen accounts for three quarters of all hydrogen production in the world and is extracted from natural gas via a method known as steam methane reforming a downside to both these processes is that they emit large amounts of co2 blue hydrogen is also made from fossil fuels but incorporates carbon capture and storage technology another way to produce green hydrogen is by the electrolysis of water that device which split water molecules into oxygen and hydrogen using an external source of electricity i.e., renewable energy sources are used. The hydrogen production and storage combined with a global push towards sustainability means that green hydrogen is becoming much mush needed for different industries and nations which are seeing the potential. Europe is the leader part of the green deal which is up to one trillion euros of incentives of green initiatives in the next 10 years give or take half of it is actually being directed to hydrogen so close to a half a trillion of euros in the next 10 years. China actually has strong targets to increase quite energy production and also, they are moving their car from combustion engine technology to hydrogen base furl cell technology. South Korea and Japan also carrying several research on hydrogen fuel cell an automotive market. The US president-elect Joe Biden has also made a big pledge to fight climate change we're going to invest 1.7 trillion dollars in securing our future so that by 2050. The United States will be 100 clean energy

economy back in October. The energy department of USA also investing 100 million dollars to do research on fuel cell technologies and hydrogen production technologies. Hydrogen fuel must be transformed into electricity by a device called a fuel cell stack before it can be used to power a car inside each individual fuel cell the process looks something like this hydrogen drawn from an on-board pressurized tank reacts with a catalyst most often [10]. This catalyst is made from expensive platinum as the hydrogen passes through the catalyst it's stripped of its electrons which are forced to move along an external circuit and consequently produce an electrical current this electrical current is then used by the electric motor to power the car the only by product is water vapour of course the advantage of hydrogen fuel cell cars over conventional cars is the possibility of having a zero carbon footprint but if you have to go through the trouble of converting hydrogen to electricity to use it in cars why not just use battery powered cars [10]. The difference between a battery electric vehicle and a hydrogen fuel cell vehicle is that you essentially get a much faster refuelling times five minutes for the hydrogen fuel cell vehicle compared to 45 minutes for the battery vehicle you also with a hydrogen fuel cell vehicle get about five times better energy storage per unit volume and weight so that frees up more room in the automobile for other things passenger space storage space and also allows you to go further [10]. So, you're going to get along the ranges with a fuel cell vehicle experts believe that hydrogen fuel cell vehicles can be especially effective when it comes to long-haul trucking and other hard to electrify sectors such as freight shipping and long-haul air travel all applications where using heavy batteries would be inefficient the larger the vehicle or the device that you're talking about the bigger the advantage to hydrogen. Comparison of energy systems with operating and maintenance, cost of system is given in fig.1 [8].

Component	Cost		Life Time	O&M
PV Panels	113747.17	RS/KW	25 Years	1%
Fuel Cell	298387.91	Rs/KW	30000 Working Hours	0.5%
Electrolyzer	372984.89	Rs/KW	15 Years	0.5%
Hydrogen Tank	42518.51	Rs/Kg	15 Years	0.5%
Lithium ion battery	34970.64	Rs/KWh	746 @ 80% DOD	0.5%

Figure 1 : Comparison of different energy storage system

The generation of electricity by the solar panels depends on solar radiation and weather conditions a seasonal mismatch. This energy needs to be stored. The battery storage improves the seasonal mismatch of the solar panel energy generation. Battery storage system has less ability for long term energy storage whereas hydrogen gas energy storage systems are very capable to store the energy for long-term and better storing capacity.

1.2 OBJECTIVES

The main objective of this project is to model a Solar PV based water electrolysis system and analyse its results and impacts when connected to the solar panel. This model is done using MATLAB/Simulink. The anode, cathode, membrane, electrolyser voltage needs to be model. Various characteristics like, hydrogen rate, hydrogen storage tank pressure, efficiency are need to be simulated and analyse the performance of electrolyser.

Chapter 2
Theoretical Overview

2.1 ELECTROLYSIS PRINCIPLE

In history between A.D. 1800-1834 Alessandro Volta invented the voltaic pile whereas W. Nicholson and A. Carlise discovered water electrolysis process. Faraday found formulation of electrolysis laws. In 1869, some scientists invented Gramme machine therefore, water electrolysis became a cheap method. In 1927, Norsk Hydro developed a industry level electrolyser. In 1948, first pressurized industrial alkaline electrolysers made by Swiss company. In 1967, scientists zero gap design for water electrolysis.

2.1.1 FUNDAMENTALS OF WATER ELECTROLYSIS

The amount of hydrogen produced in an electrolyser is related t the electrical current density. This amount is electrical current flow per electrode area, and it measured as Ampere per sq. cm. The high value of the current density the higher the voltage required and the cost of the electricity per kilogram of hydrogen conversely, high voltages decrease the overall size of the electrolyser and therefore the cost of the equipment. The enthalpy valuation ΔH represents the energy necessary for the electrolysis to take place [1]:

$$\Delta H(T, P) = \Delta G(T, P) + T * \Delta S(T, P) \tag{1}$$

Power supply

H_2

$2H^+ + 2e^- \rightarrow H_2 \uparrow,$
$E^0 = 0.0\ V$

H^+

O_2

$H_2O \rightarrow 2H^+ + 2e^- + \frac{1}{2}O_2 \uparrow,$
$E^0 = 1.23\ V$

H_2O

Cathode: Pt

Anode: Ir/Ir oxide

Proton exchange membrane

Thermodynamics for water electrolysis

$\Delta H^0 = 286\ kJ/mol$
$\Delta S^0 = 0.163\ kJ/mol$
$\Delta G^0 = 237\ kJ/mol$

Reversible potential at 25°C

$$V_{rev} = -\frac{\Delta G^0}{nF} = 1.23\ V$$

Thermoneutral potential at 25°C

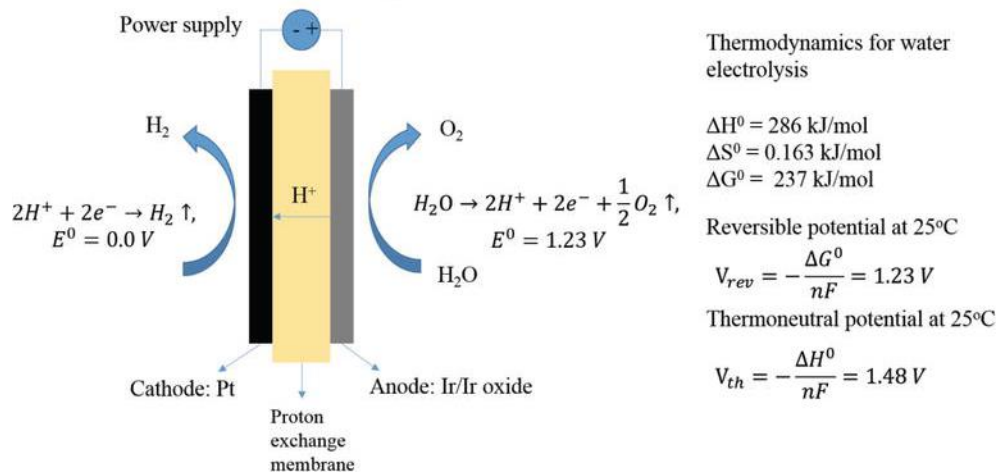$$V_{th} = -\frac{\Delta H^0}{nF} = 1.48\ V$$

Figure 2 : Energy balance in water electrolysis process(1 atm, 298K)

The part of this energy (eq. 1) is equivalent to free energy of Gibb's is provided in form of electrical energy as equation 2. The Gibb's free energy s positive so that the reaction is non-spontaneous. Another part of eq. 1 comes from the environment in the form of heat. Where, T is the temperature.

The voltage needed to decompose the water molecules, or the so-called reversible potential is needed (Vrev) which is related to the free energy of Gibbs:

$$W = \Delta G = F * n * Vrev \tag{2}$$

Where, F is the Faraday's constant and n is the number of electrons exchange in the electrolysis reaction [10].

For the electrolysis reaction of one mole water under standard conditions the reversible voltage is equal to 1.23 volt.

If temperature and pressure condition vary the thermodynamic parameters varies that is to say the amount of electrical and thermal energy required to thermal reaction to occur.
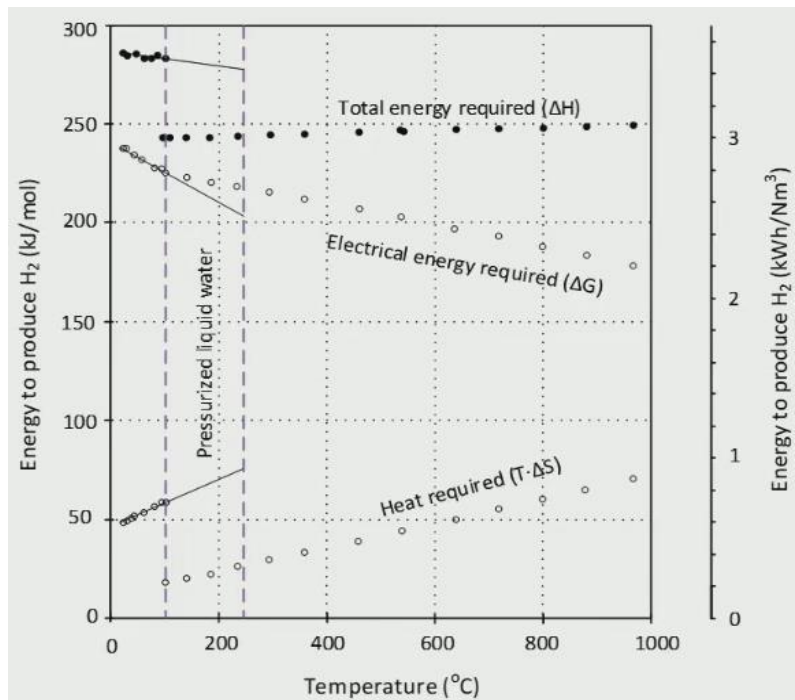
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Figure 3: The different energy required in the water splitting reaction (1 bar)

As shown in the *fig. 3*, we can clearly see that the electrical demand is reduced as the temperature at which the electrolysis takes place increases. We can notice this reduction much more significant when electrolysis process occurs with water vapour rather than liquid water. This electrical demand corresponds to the positive Gibb's free energy change which decreases when increasing temperature. However, as we can see in the fig. 3 that the variation in the total energy required to split 1 mole of water is negligible over the temperature variation of operating range [1]. In addition, the variation of entropy over the temperature range is also negligible and positive. Therefore, the entropy contribution and T time's entropy variation increases with temperature variation. The discontinuity is observed on the enthalpy variation and TΔS at 100℃ and 1 bar are due to water vaporization. As a conclusion, the high value of operating temperature decreases the voltage required to dissociate the water. That's why high valued temperature water electrolysis is in development because electrolysis required less electricity with high temperature.

Electrochemical water splitting:

The water dissociation process is a non-spontaneous transformation process or endergonic transformation. However, the system requires external energy source i.e., electricity. This is known as an endergonic transformation and the instrument used for this electrolysis process is known as electrolyser [1]. The water dissociation reaction is the sum of two redox half reactions which depends on electrolytes pH level. Therefore, the water dissociation reaction is into two redox half reactions [3]. As shown in the fig. 3 we can say that the alkaline medium electrode potential is shifted along the electrode potential axis as compared to acidic medium this shifting impact stability of material from which electrodes are made. Acidic medium corrodes most of metals which needs to change by platinum metals. These metals are carbon nano particle base platinum for hydrogen evolution reaction and iridium dioxide for the oxygen evolution reaction whereas for alkaline medium need nickel and cobalt metal and oxide hydroxide are used. The kinetics of water splitting redox reactions for alkaline an acidic media shown in fig.4 which shows-
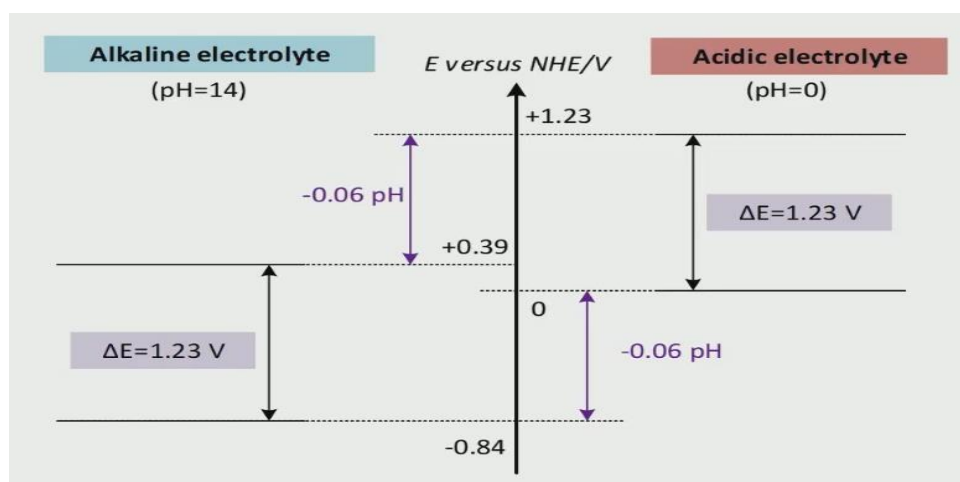

Figure 4 : Redox reaction potential and electrolyte pH

the temperature main responsible parameter which affects the efficiency and the dissipation of heat happening in the electrolyser. The kinetics of Oxygen reaction

increases if the temperature of water increase. Therefore, the system acts as reversible when T is higher than 700 °C. The voltage behind the water electrolysis process is mainly,

Free energy electrolysis or thermodynamic voltage

$$Erev(T,P) = \frac{\Delta G(T,P)}{nF} \tag{3}$$

Enthalpy or thermo-neutral voltage

$$Vt(T,P) = \frac{\Delta H(T,P)}{nF} \tag{4}$$

The different values of cell voltages which is applied to PEM cell occur difference situations. when (U_{cell}(T,P) > E(T,P)) the current starts to flow and heat is produced in PEM cell internally due to the different heat dissipation sources. The expenses to design the electrolyser for this condition (U_{cell}(T,P) > E(T,P)) or voltage levels is high because the low value of current density. If we continue increasing the cell voltage until it higher than enthalpy voltage, the current density increases raising also the value of heat produced.
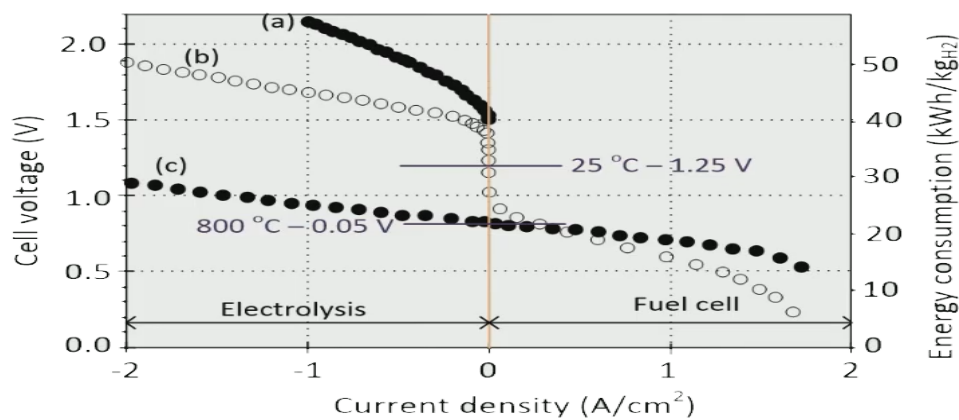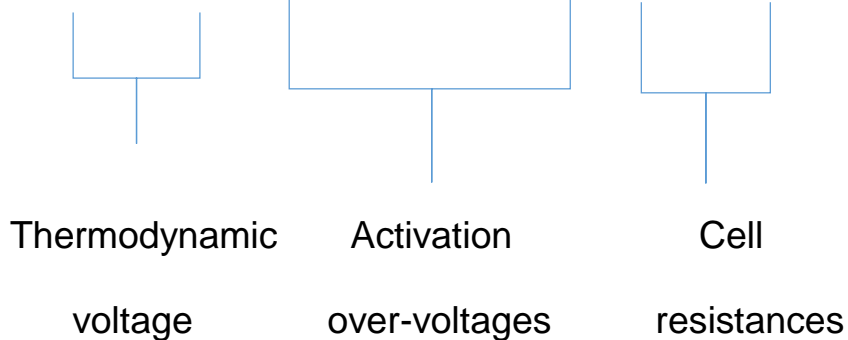
Figure 5 : I-V characteristics for a. Alkaline electrolysis, b.PEM electrolysis, c. Solid oxide electrolysis

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2.1.2 EFFICIANCY OF ELECTROCHEMICAL WATER SPLITTING

Sources of energy dissipation in electrolysis:

There are many causes which degrade the energy in the electrolyser cell in the form of dissipation due to the heat transfer between electrolyte interfaces and also by the movement of electrons and hydrogen ions. These are the most dissipative terms along with electrical conductivity. The analytical expression for cell voltage is given by,

$$v_{cell}(i) = \frac{\Delta G(T,P)}{2F} + n_A^a(i) + |n_A^c(i)| + i\sum Rcell \qquad (5)$$

Thermodynamic voltage   Activation over-voltages   Cell resistances

where, i is current density and V_{cell} is the cell voltage involves which is a function of i (A/cm^2). The first term is the thermodynamic voltage of water electrolysis induced per mole. Activation over voltages is at anode and cathode. The absolute value of this term Is taken because the cathode activation voltage is negative. Finally, the last term is the sum of differences of the electrolysis cell. This includes the resistances in the anode and cathode region, also across electrolyte region and current carrying metal conductors i.e., electrodes and wires connecting them. The fig.5 shows the general shape of the polarization curve measured during water electrolysis process under 298K temperature and 1 bar pressure. The free energy electrolysis or thermodynamic voltage is 1.23V [1]. When the voltage of electrolyser become greater than this voltage current start to flow in electrolyser cell. Extra electrical power is needed to fulfil the heat losses by internal resistances of the cell [1].
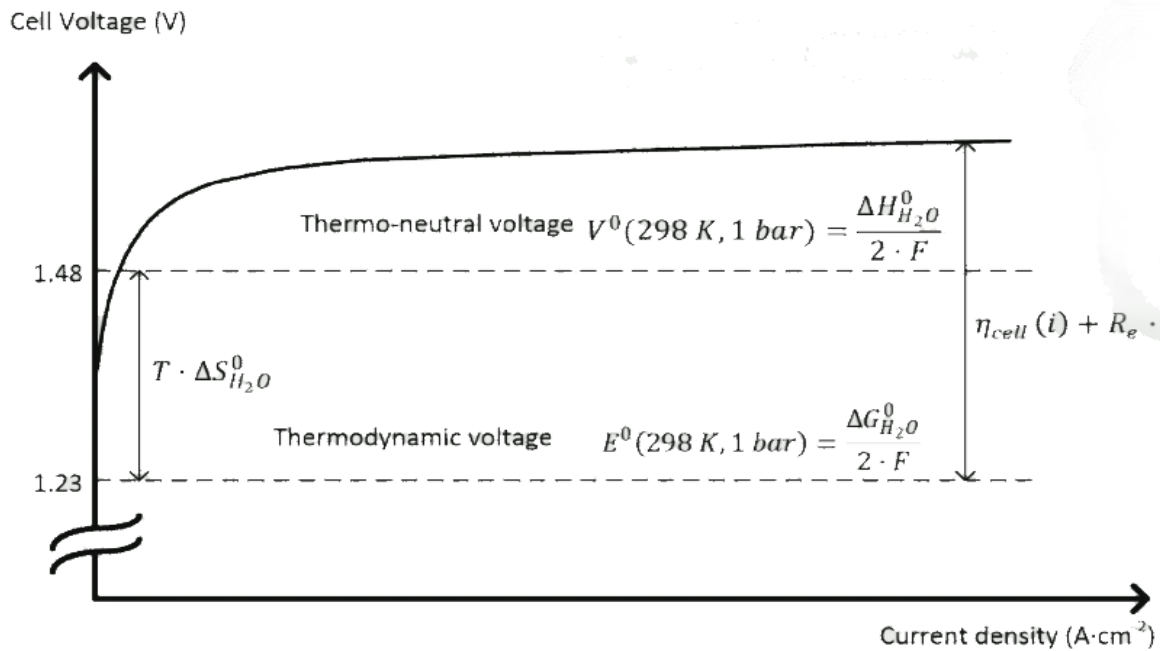
Figure 6 : polarization curve of water electrolysis (1 bar, 298K)

At lower current densities, voltage drops due to resistance of electrolyser are small whereas charge transfer over voltages is maximum. The lower limit shown in the polarization figure is due to this charge movement between anode and cathode. In water electrolysis process, the anodic over voltage is larger than the cathodic voltage because the kinetics of the oxygen evolution reaction are much lower than that hydrogen evolution reaction. And if the current density increases then the current transfer resistance will decrease, and the vaporization curve will become more linear. As this point, the shape of the curve depends on the ohmic resistance of the electrolyser cell. The electrical and ionic resistances are key parameters [1].

The electrolysis of water performance analysis can be done by their thermo-neutral voltage points which are shown in fig. 6. These points represented on current voltage characteristics at this point the entropy needed to split water is fulfilled by internal heat losses of the electrolyser cell. In other words, this is the current density at this the thermo-neutral potential is same as the electrolyser cell voltage. When the operating temperature is close to environmental condition, the

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kinetics of the oxygen evolution are as low and the water oxidation to oxygen mostly a reversible process. This is the case in PEM and alkaline electrolysers. If we give current density to the PEM and alkaline cells the cell voltages increase fast until it reaches their thermo-neutral point at relatively low current density [3]. We can see in the fig. 6 in the left. This means that they involve thermal range of operation the current density values range required from external energy source is narrow for both PEM and alkaline electrolyser cell. As we can see in the fig.6. This electrolyser usually operates above the electro-neutral voltage in exothermic mode and the heat loss is therefore satisfy into the internal dissipation [3]. In the other hand, at elevated temperature the kinetics of the oxygen evolution reaction are much faster. This situation is given for the case of solid oxide water electrolysis. As a result, we can observe as much as lower.
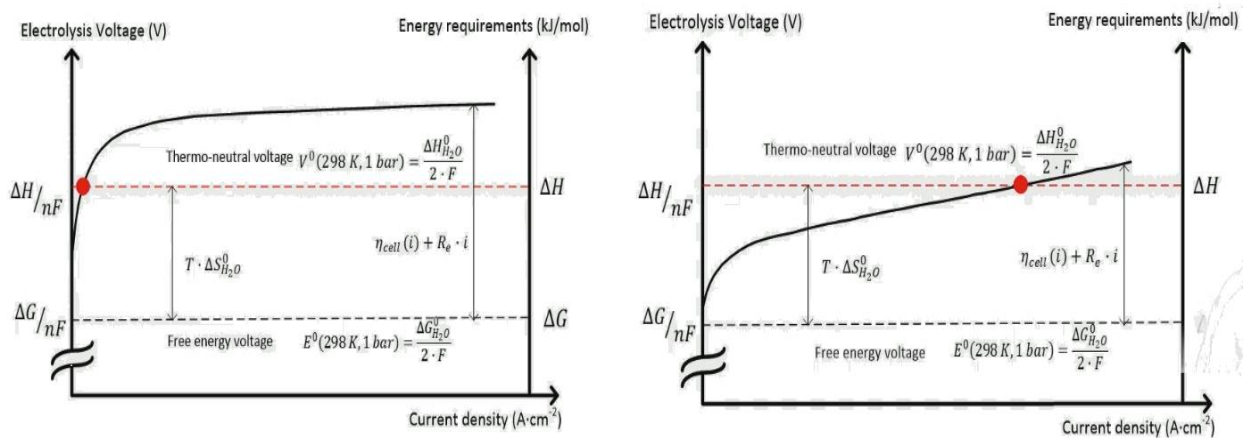
Figure 7 : Thermo-neutral voltage barrier for PEM and alkaline (left) and solid oxide(right) water electrolysis.

electrolyser cell voltage increment which depends on the current density as compared to bot PEM and alkaline electrolyser. We can see this behaviour in the fig. on the right. The thermal neutral voltage is now reached at sometimes elevated current densities. Therefore, then the thermal operating range will operate the electrolyser cell in three modes. The first one is endothermal mode where the heat dissipated loss can be met by the external source of heat which offering possibilities to use the waste heat energy sources. Secondly, we have

autothermal mode where the excess heat dissipated loss insist to by external dissipation and no more cooling required. The last opportunity is exothermal mode where the heat demand is provided in terms of by the DC energy source in dissipation loss term be in cell cooling required [3].

ENERGY EFFICIENCY:

In order to minimize capital expenses, the electrolyser cell need to operate at high value of current density. However, if we increase the current density value then the electrical energy provided to the electrolyser cell is dissipated as heat energy. This reduces the efficiency and performance of the cell and increases operating expenses. From a practical viewpoint Capital expenses and operating expenses must be balanced for the current density value i.e., I = 1 A/sq. m. is a good reference value. The water electrolysis cell efficiency is defined as the ratio of theoretical amount of energy required to the real amount of energy required to split one mole of water [1]. In equation the real amount of energy $W_r = V_{cell}*I*t$ [1].

$$\epsilon = \frac{Wt}{Wr} \quad \begin{cases} W_r = V_{cell}*I*t \\ W_{t,\Delta G} = E*I*t \\ W_{t,\Delta H} = V*I*t \end{cases} \quad \text{Where,} \quad \begin{array}{l} V_{cell} = \text{Actual cell voltage} \\ I = \text{current in A} \\ t = \text{duration for which current applied} \end{array}$$

(6)

In the other hand the theoretical energy W_t can be defined in two ways and $W_{t,\Delta H.}$ If we consider the free energy voltage it is compute as a thermodynamic voltage $W_{t,\Delta G} = E*I*t$. in the other hand, it can also be defined from the thermoneutral voltage $W_{t,\Delta H} = V*I*t$. If we substitute this expression in the general definition, we get their equation shown in eq. (7) deepening upon the voltage use to compute the efficiencies [1].

$$\epsilon_{\Delta G}(T,P,i) = \frac{E(T,P)}{Vcell(T,P,i)} \qquad \epsilon_{\Delta H}(T,P,i) = \frac{V(T,P)}{Vcell(T,P,i)} \qquad (7)$$

If we use low value of current density to operate the cell then the electrolyser cell efficiency will be obtained close to 100 %. This efficiency will decrease as the current density value starts to increase.

Other efficiency definition includes the Faradic efficiency which is the measure of current flowing efficiency in the electrolyser cell.

The main purpose of the separators is to prevent hydrogen ions from recombination with oxygen gas. These separators should be glass proof [1]. However, in the real situation the solubility of glasses in the liquid electrolyte media is limited but not equal to zero. In fact, the hydrogen and water mass transfer across the cell separator occurs at high value of current density and on high value of operating temperature [1]. This result into the diffusion of hydrogen ions from cathode to anode and oxygen from anode to the cathode across the separator [1]. The flow of hydrogen and oxygen across the separator being proportional to the diffusion coefficient of each molecules in the media. When this phenomenon occurs, the hydrogen ions reaching at the anode chamber through the separator may react with oxygen chemically or be deoxidise at the anode. In other hand, the oxygen reaching at the cathode chamber may chemically react with the hydrogen or may reduce electrochemically at the cathode chamber. From global point of view this is partially decrease the faradic or chemical cell efficiency [1].. For this reason, the Faradic efficiency of electrolyser cell must be measured to improve the design and efficiency of the cell.

2.1.3 TEMPERATURE AND PRESSURE DEPENDENCE

Electrolysis voltage as function of temperature:

As we have seen entropy, enthalpy and free energy changing are function of both temperature and pressure. As a result, the thermodynamic voltages defined previously are dependent on temperature and pressure as well as energy efficiency [1]. The maximum value of temperature accessible for low temperature

technology which holds between $100 - 130 \, ^\circ C$ comes from material constrains [1].
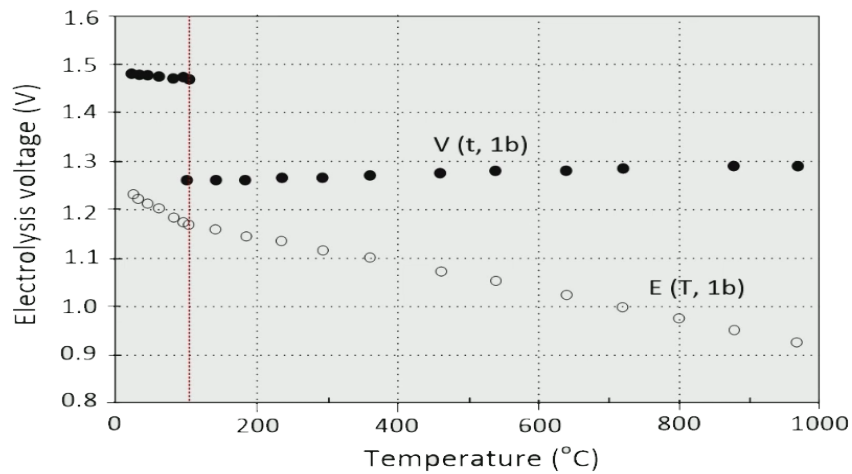
Figure 8 : Role of operating temperature on E(T) and V(T) of water (P=1 bar)

and not from the vaporization of water which can easily be managed by appropriate pressurization. i.e., the maximum temperature is 90° C because high rated polymers lose all mechanical stability above 100° C [1].

Electrolysis voltage as function of pressure:

As for the pressure dependence we can say that the free energy voltage E is affected by pressure as it increases 200mV at 298 K when the pressure variation from 1bar-100 bar. However, the pressure variation effect on enthalpy remains limited. Electrochemical compression need very less energy cost and which remain less.

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Figure 9 : energy demand for different pressure hydrogen at 60 C*

When varying the working pressure of the electrolyser two situation arises. The first option is that the water electrolysis is done at atmospheric pressure and after that compress the gaseous hydrogen by external compressor [1]. The other option is that to develop pressurised electrolysers which can di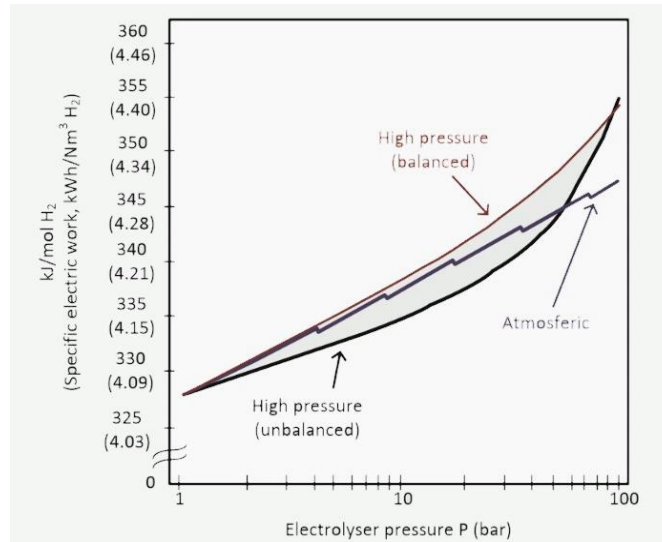rectly produce the pressurised hydrogen gas at the desire pressure value [1]. This is called directly electrochemical compression and it can be done using a balanced high pressure or unbalanced high pressure water electrolyser. In the first option the balanced high pressure system water electrolysis produces hydrogen and oxygen which are at the same pressure [9]. On the other hand, the second option, the unbalance high pressure system delivers pressurised hydrogen gas and O_2 gas at atmospheric pressure. As we can see in the fig. 9 a comparison of compression energy required by the three difference approaches prevails that the pressure up to 40 bar pressure unbalance water electrolysis process need less energy than other two approaches [9]. However, for pressure higher than forty bars pressurized water electrolysers consume more energy than the energy consumed by atmospheric pressurize electrolysers which is coupled to mechanical compressor. Nevertheless, the energy consumption difference is small but the other arguments i.e., gas purity management may be a parameter by which the technology for a particular application can be appropriately decided.

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2.1.4 ELECTROLYSER TECHNOLOGY

An electrolyser cell can be defined as galvanic cell which has two metallic electrodes placed opposite to each other with electrolytic layer medium placed in between to them. This electrolytic layer can be formed by ions dissolved ion conducting polymers in liquid solvents. When the electrolyser cell operates a continuous current pass in the cell. The energy source connected externally to the cell the electrons are act as charge carriers whereas in internal cell the mobile ions of electrolyte acts as charge carriers. The electrons cross the cell interfaces will induce the redox transformation of interest in other words the oxygen and hydrogen evolution reactions. The electrolytic cells are grouped to raise the working voltage forming an electrolytic cell or a stack. In addition to electrolyser cell connection, the cells help the polar plates that act as gas distributor of the cell. They are also called gas flow distribution channel and current collectors. The stack is completed with several adjustment bars into final place that acts as the structure. This stack is the nucleus where electrochemical reaction takes place. However, the electrolysers include also other elements such as power control systems, flow control of reaction and safety product and elements. In the fig, 10 we can see 3 three types of cell concept which are usually used in industries.

Gap Cell Design: This design has simplest structure and conventional. In this cell design, the two electrodes are oppositely placed in an electrolyte of liquid form. A separator is introduced in a interpolar gap to prevent the spontaneous recombination of reaction products. That is to say by flow of current the gaseous substance with bubble from formed across interfaces. These two electrodes have gap between them in which diaphragm of large scale placed which let gases above it freely but need to ensure that the ohmic losses should be less. The chain of bubble when increase the film with highly resistive nature of gas is formed over the electrode's interfaces. Therefore, the maximum value of current density is usually limited in this kind of cell.

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Zero Gap Design: This design is best suitable for gas involving electrodes. In this type of electrolyser cells, the electrodes have porous type material. The distance between the two electrodes is reduced by fitting these electrodes directly on the separator surface. This design reduces the ohmic losses. In this case, the pours on electrodes release the gaseous products at the back side. Here, due to less distance between electrodes the operating current density can be large. This cell design needs liquid electrolyte also it has disadvantage that it cannot operate properly with acidic medium.

PEM Cell Design: In this the separator used has thin design and made of ion conducting polymer. This polymeric film has two main functions mainly it combines the electrical ions from two electrodes i.e., anode to cathode and other function is to separate the gaseous species. The main thing to notice here is that this design does not contain any type of liquid electrolyte. The electrodes used have porous type which coated with catalyst layers on both the sides. PEM cell is more efficient than liquid electrolyte cells, but it has more geometrical constrains because electrolyte is needed to fit well and though the membrane thickness need to be adjusted to place the components very precisely inside the cell. This different also contribute to make polymer electrolyte technology more expensive. As a conclusion we can say that in general the problems presented by the materials affect the development of electrolysers. The cell must be thin, electrically insulated and resistant to corrosion and the reaction speed depend on the electrode material. Therefore, the use of catalysts electrodes significantly reduces the energy consumed. The cell quality must be optimized aggregately to maintain good energy efficiency and long term accurate operational performance. Ideally, in the range between 10^4 and 10^5 hours' time interval.

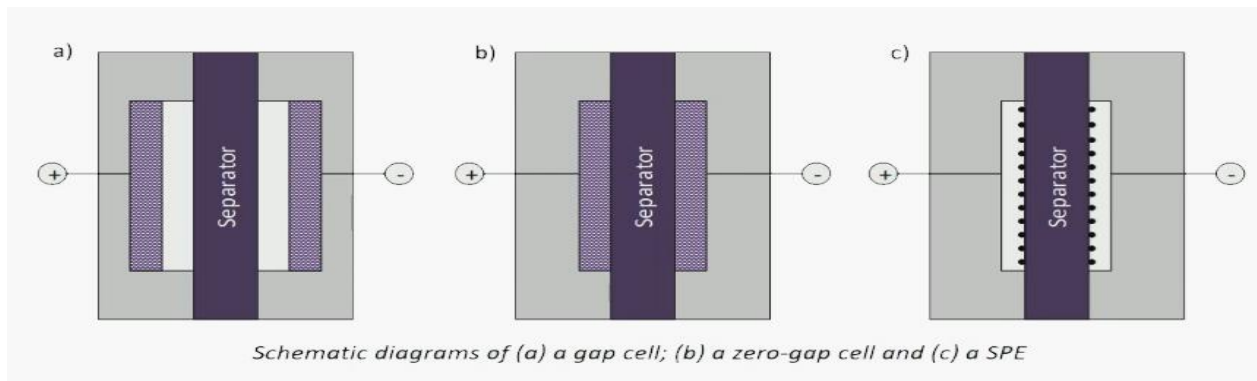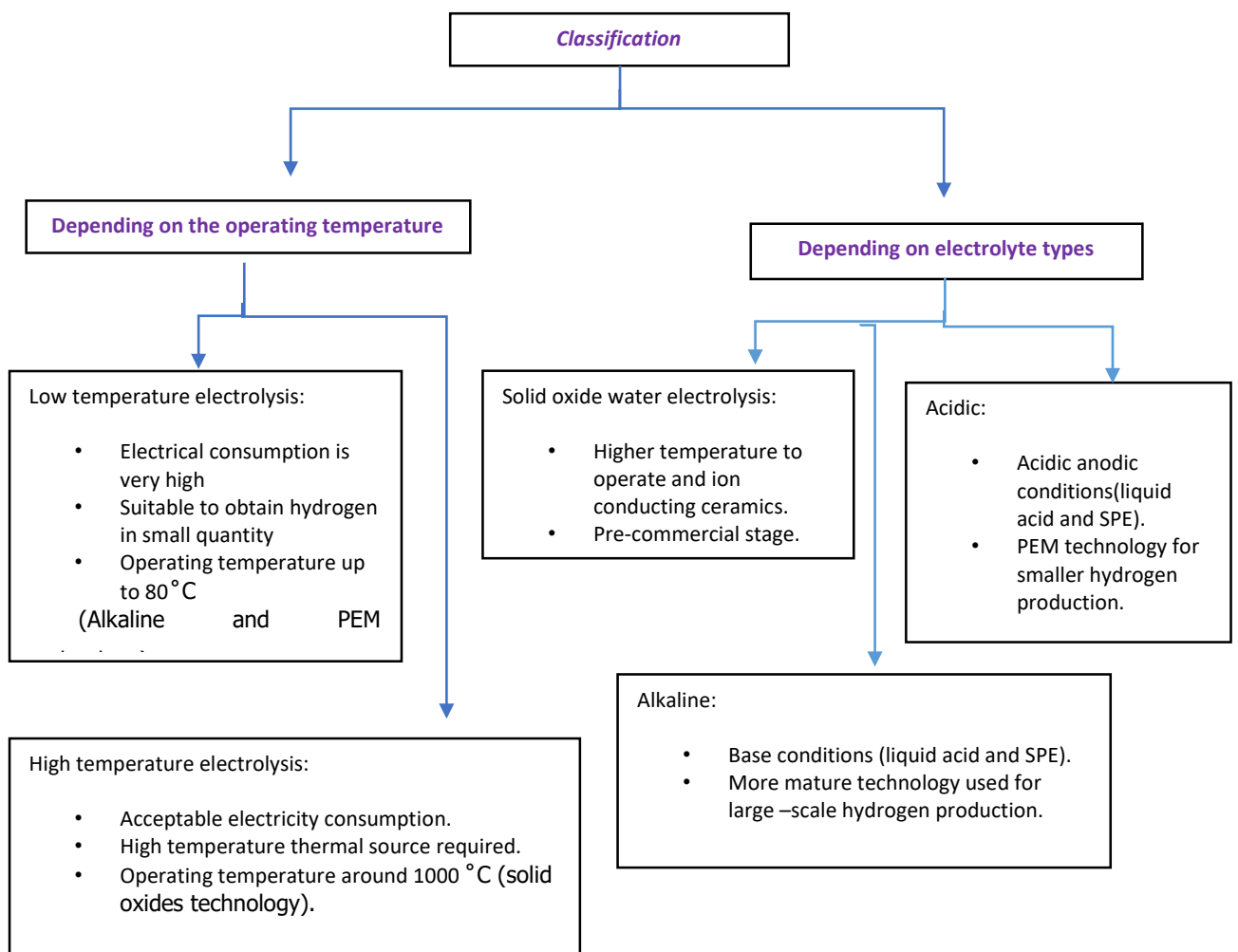Schematic diagrams of (a) a gap cell; (b) a zero-gap cell and (c) a SPE

Figure 10 : Design of various cell

2.1.5 CLASSIFICATON OF WATER ELECTROLYSIS PROCESS

Regarding the operating temperature there are two ways to perform electrolysis. In low temperature electrolysis the electrical consumption is very high of the order of energy contain in the hydrogen produce. This procedure is only suitable to obtain hydrogen 'in situ' in small quantities or including the integration with renewable energies in which available storing of a surplus potential is looked for. The cell has working temperature up to 80° C in alkaline electrolysers or proton exchange membrane electrolysers. On the other hand, in high temperature electrolysis electricity consumption being high begins to be acceptable. Here, water vapour and a high temperature thermal source such as concentrate solar or nuclear energies are required in order to obtain such a high temperature. Electrolysers also need to be modified to solid oxide. We can divide the water electrolysis process based on the type of electrolyte use in it. Alkaline electrolysers use liquid or solid polymer electrolyte and this electrolyser do not need any specific conditions to operate it can operate in base condition. As per the acidic based electrolysers here the acidic condition-based splitting of water by electrolysis takes place. In both liquid acid and SPE electrolyte such as a PEM could be used [2]. Finally, for solid oxide water electrolysis temperature required to operate are much higher typically around of 1273 K and ion conducting ceramic are used i.e., typically these ceramics are based on yttrium stabilized

zirconium (YSZ) or scandium stabilized zirconium [2]. As a general conclusion of this classification, we can say that the ambient temperature condition-based electrolysis of liquid water is use in both the alkaline and PEM technologies. On the other hand, solid oxide technology is normally used with water vapour. We can find two main commercial technology for water electrolysis which operates under low operating temperatures. These are alkaline electrolyser and proton exchange membrane-

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                          ┌─────────────────────┐
                          │    Classification   │
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Depending on the operating temperature

Depending on electrolyte types

Low temperature electrolysis:

- Electrical consumption is very high
- Suitable to obtain hydrogen in small quantity
- Operating temperature up to 80˚C

(Alkaline and PEM

Solid oxide water electrolysis:

- Higher temperature to operate and ion conducting ceramics.
- Pre-commercial stage.

Acidic:

- Acidic anodic conditions(liquid acid and SPE).
- PEM technology for smaller hydrogen production.

High temperature electrolysis:

- Acceptable electricity consumption.
- High temperature thermal source required.
- Operating temperature around 1000 ˚C (solid oxides technology).

Alkaline:

- Base conditions (liquid acid and SPE).
- More mature technology used for large –scale hydrogen production.

electrolyser technologies. If we compare these technologies shown in table 1. [1], then alkaline electrolyser is used for large-scale to produce hydrogen and it is commercially more available whereas proton exchange membrane electrolysers have solid polymer as electrolyte, and it is used to expand or increase hydrogen production capacity.

2.1.6 COMPARISON OF WATER ELECTROLYSIS TECHNOLOGIES [1]

Parameter	Alkaline with liquid electrolyte	Acidic with SPE (PEM)	Solid Oxide with oxygen ion conductor
Maturity	Commercial for large-scale use (MW-scale)	Commercial for small scale use (MW scale demonstrated)	R&D stage (precommercial)
Electrolyte	Typically, KOH aqueous solution (20%-35%)	PFSA polymer membrane	Ceramic membrane, typically based on yttrium stabilized zirconium (YSZ) or scandium-stabilized Zirconium
Electrode separator	Diaphragm made of polymeric and/or inorganic materials	Same as electrolyte	Same as electrolyte
Charge carrier	OH^-	H^+	O_2^-
Temperature range (°C)	40-90	50-90	700-1000
Typical current density (A/cm²)	0.2-0.5	0.6-2.5	0.5-1
Typical discharge H2 pressure (bar)	2-3	15-50, but up to 350 conceptually designed	10-40

OER catalyst	Mixed metal oxides, Ni/Co/Fe, $NiCo_2O_4$, $NiMoO_2$, La-SrCoO$_3$, Co_3O_4	Ir/IrOx/Ru (black, or supported on conductive noncorrosive material)	Lanthanum strontium manganite/YSZ component
HER catalyst	Ni	Pt (black, or supported on C)	Porous cement composed of YSZ and metal nickel
Demonstrated proven durability (years)	Up to 20	Up to 5	Upto to 1. Highly efficient high temperature electrolysis
Typical system efficiency at BOL (%HHV)	60-70	40-65	Up to 89

Table 1: Comparison of water electrolysis technologies

Chapter 3
Literature Review

N. Chennouf [12] proposes a solar photovoltaic based alkaline electrolysis system which has different NaOH concentrations which is fed by a solar panel. This is an experimental study of an alkaline electrolyser which is teste for different voltage and current input levels. This experiment is used to analyse the characterises of electrolyser cell with solar panels.

A. Awasthi [5] proposes a computational model of PEM electrolyser which is used to analyse the effect of operating conditions of cell on its performance. This model simulated in MATLAB/Simulink which has anode, cathode, voltage and membrane simulated models. The effect of temperature and pressure variation is analysed.

Atlam O. [13] proposes a Simulink model of from an experiment on PEM electrolyser cell. The model developed base on experimental results. The output I-V characteristics are modelled with respect to different value of temperature and irradiation based on experimental tests carried out on PEM cell. Hydrogen formation characteristics and input I-V characteristics are modelled using experimental tests. PV module is connected directly to the PEM cell.

Beainy A. [13] proposes an equivalent electrical circuit by analysis of PEM cell. This circuit is used to model the PEM cell in MATLAB/Simulink. The different characteristics such as I-V characteristics and hydrogen production rate vs input current is simulated in Simulink. This model is develop under temperature and pressure effects.

Conclusion

This report first describes the need of water electrolysis and its advantages to produce pure hydrogen gas. We need energy storage system that have long lifetime and can easily transportable also it should be environment friendly technology. The battery technology have less lifetime and the waste produce at the end is very harmful to environment as well as to human being. These disadvantages are removed by hydrogen storage technology which is being used in fuel cell power machines.

This project aimed at the mathematical model analysis of solar PV based water electrolysis technology which produces the hydrogen and store it to high pressure storage tank. The current is needed to split water which is supplied by the solar panel.

Future Work

➢ SOLAR PANEL MODELLING

➢ HYDROGEN STORAGE TANK MODELLING

➢ SIMULINK MODELS OF SYSTEM

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