© April 2018 | IJIRT | Volume 4 Issue 11 | ISSN: 2349-6002

A Hybrid Grid Connected PV/PEMFC/Battery Distributed Generation System With Fuzzy Control Strategy

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Abstract— **This Thesis describes the power control strategies of a fuzzy controlled grid connected hybrid photovoltaic and proton exchange membrane fuel cell distributed generation system with battery as energy storage device. The primary source of energy for the hybrid distributed generation system is from photovoltaic cell and proton exchange membrane fuel cell and the battery acts as a complementary source of energy. The hybrid distributed generation system is connected to a grid through power electronic interfacing devices. A Matlab/Simulink model is developed for the grid connected hybrid distributed generation system, fuzzy controlled power electronic DC/DC and DC/AC converters to control the flow of power on both sides. Simulation results illustrate the performance of the hybrid system following the load demand and operating the system near unity power factor.**

I.INTRODUCTION

The penetration level of green and renewable energy sources/distributed generation units are expected to grow in the near future as there is a probability of rundown conventional fuels for power generation. The distributed generation is classified as renewable and non-renewable. The distributed generation sources such as Fuel cells, Wind and Solar energy are increasing daily due to increase in demand for electrical power [1]. These energy sources are environmental friendly, reduces transmission and distribution losses, peak load shaving, can be used as backup sources and etc. Fuel cell is a promising device as it is efficient, modular and can be placed at any site for improving system efficiency [2] but it has slow start-up response. Solar energy is an important renewable energy source [3] but the intermittent nature of this technology is a major issue. The availability of energy is driven by weather and cell temperature but not on the loads of the systems

RENEWABLE ENERGY:

Renewable energy is energy which is generated from natural sources i.e. sun, wind, rain, tides and can be generated again and again as and when required. They are available in plenty and by far most the cleanest sources of energy available on this planet. For e.g.: Energy that we receive from the sun can be used to generate electricity. Similarly, energy from wind, geothermal, biomass from plants, tides can be used this form of energy to another form. Merits And Demerits of Using Renewable Energy are as follows:

MERITS:

1. The sun, wind, geothermal, ocean energy are available in the abundant quantity and free to use.
2. The non-renewable sources of energy that we are using are limited and are bound to expire one day.
3. Renewable sources have low carbon emissions, therefore they are considered as green and environment friendly.
4. Renewable helps in stimulating the economy and creating job opportunities. The money that is used to build these plants can provide jobs to thousands to lakes of people.

DEMERITS:

1. It is not easy to set up a plant as the initial costs are quite steep.
2. Solar energy can be used during the day time and not during night or rainy season.
3. Geothermal energy which can be used to generate electricity has side effects too. It

can bring toxic chemicals beneath the earth surface onto the top and can create environmental changes.

4. Hydroelectric provide pure form of energy but building dams across the river which is quite expensive can affect natural flow and affect wildlife.
5. To use wind energy, you have to rely on strong winds therefore you have to choose suitable site to operate them. Also, they can affect bird population as they are quite high.

II. CONCEPT OF RENEWABLE ENERGY RESOURCE

A natural resource qualifies as a renewable resource if its stock (quantity) can increase over time. Natural resources which qualify as renewable resources are, for example, oxygen, fresh water, solar energy, timber, and biomass. But they can become non-renewable resources if more of them is used than nature can reproduce in the same time at that place. For example ground water may be removed from an aquifer at a greater rate than that of new water flowing to that aquifer. Removal of water from the pore spaces may cause permanent compaction (subsidence) that cannot be reversed. Human consumption and use at sustainable levels primarily uses renewable resources versus non-renewable resources.

FUEL CELL;

A fuel cell is an electrochemical cell that converts a source fuel into an electrical current. It generates electricity inside a cell through reactions between a fuel and an oxidant, triggered in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained.

Fuel cells are different from conventional electrochemical cell batteries in that they consume reactant from an external source, which must be replenished[1] – a thermodynamically open system. By contrast, batteries store electrical energy chemically and hence represent a thermodynamically closed system.

Many combinations of fuels and oxidants are possible. A hydrogen fuel cell uses hydrogen as its fuel and oxygen (usually from air) as its oxidant. Other fuels include hydrocarbons and alcohols. Other oxidants include chlorine and chlorine dioxide

Fuel cells come in many varieties; however, they all work in the same general manner. They are made up of three segments which are sandwiched together: the anode, the electrolyte, and the cathode. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electrical current is created, which can be used to power electrical devices, normally referred to as the load.

At the anode a catalyst oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot. The freed electrons travel through a wire creating the electrical current. The ions travel through the electrolyte to the cathode. Once reaching the cathode, the ions are

APPLICATIONS:

POWER:Fuel cells are very useful as power sources in remote locations, such as spacecraft, remote weather stations, large parks, rural locations, and in certain military applications. A fuel cell system running on hydrogen can be compact and lightweight, and have no major moving parts.

Because fuel cells have no moving parts and do not involve combustion, in ideal conditions they can achieve up to 99.9999% reliability. This equates to around one minute of down time in a two year period. Since electrolyses systems do not store fuel in themselves, but rather rely on external storage units, they can be successfully applied in large-scale energy storage, rural areas being one example. In this application, batteries would have to be largely oversized to meet the storage demand, but fuel cells only need a larger storage unit (typically cheaper than an electrochemical device).

COGENERATION:Micro combined heat and power (MicroCHP) systems such as home fuel cells and cogeneration for office buildings and factories are in the mass production phase. The system generates constant electric power (selling excess power back to the grid when it is not consumed), and at the same time produces hot air and water from the waste heat.

MicroCHP is usually less than 5 k We for a home fuel cell or small business.

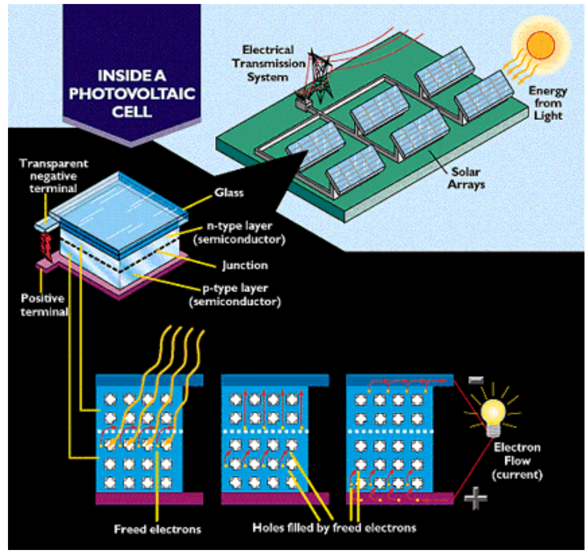
OTHER APPLICATIONS:

- Providing power for base stations or cell sites
- Off-grid power supply
- Distributed generation
- Fork Lifts
- Emergency power systems are a type of fuel cell system, which may include lighting, generators and other apparatus, to provide backup resources in a crisis or when regular systems fail. They find uses in a wide variety of settings from residential homes to hospitals, scientific laboratories, data centers, telecommunication equipment and modern naval ships.
- An uninterrupted power supply (UPS) provides emergency power and, depending on the topology, provide line regulation as well to connected equipment by supplying power from a separate source when utility power is not available. Unlike a standby generator, it can provide instant protection from a momentary power interruption.
- Base load power plants
- Electric and hybrid vehicles.
- Notebook computers for applications where AC charging may not be available for weeks at a time.
- Portable charging docks for small electronics (e.g. a belt clip that charges your cell phone or PDA).
- Smartphone with high power consumption due to large displays and additional features like GPS might be equipped with micro fuel cells.
- Small heating appliances.

III. SOLAR CELLS

Solar cells (as the name implies) are designed to convert (at least a portion of) available light into electrical energy. They do this without the use of either chemical reactions or moving parts.

STRUCTURE: Modern solar cells are based on semiconductor physics -- they are basically just P-N junction photodiodes with a very large light-sensitive area. The photo voltaiceffect, which causes the cell to convert light directly into electrical energy, occurs in the three energy-conversion layers.



solar power generation

The first of these three layers necessary for energy conversion in a solar cell is the top junction layer (made of N-type semiconductor). The next layer in the structure is the core of the device; this is the absorber layer (the P-N junction). The last of the energy-conversion layers is the back junction layer (made of type semiconductor).

OPERATION:

Solar cells are characterized by a maximum Open Circuit Voltage (Voc) at zero output current and a Short Circuit Current (Isc) at zero output voltage. Since power can be computed via this equation:

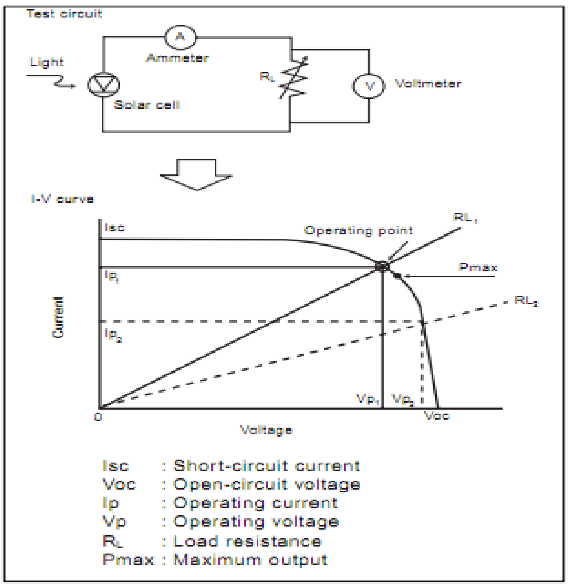
$P = I * V$

Then with one term at zero these conditions (V = Voc / I = 0, V = 0 / I = Isc) also represent zero power. As you might then expect, a combination of less than maximum current and voltage can be found that maximizes the power produced (called, not surprisingly, the "maximum power point"). Many BEAM designs (and, in particular, solar engines) attempt to stay at (or near) this point. The tricky part is building a design that can find the maximum power point regardless of lighting conditions.

OUTPUT CHARACTERISTICS OF SOLAR CELLS:

The output characteristics of solar cells are expressed in the form of an I - V curve. An I - V curve test circuit and typical I - V curve produced by the circuit are shown below.

The I-V curve is produced by varying RL (load resistance) from zero to infinity and measuring the current and voltage along the way. The point at which the I-V curve and resistance (RL) intersect is the operating point of the solar cell. The current and voltage at this point are Ip and Vp, respectively. The largest operating point in the square area is the maximum output of the solar cell.



APPLICATIONS:

- Calculators
- Indoor clocks
- Remote control units
- Indoor digital thermometers
- Other indoor consumer products which have a low power consumption

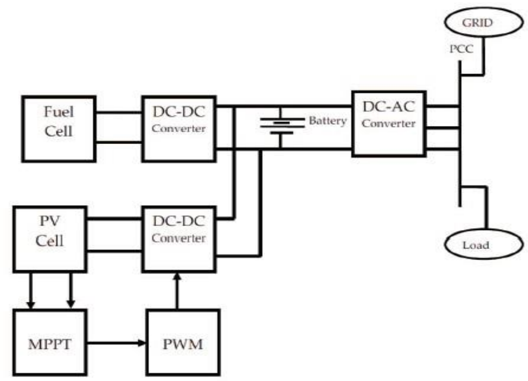
IV. SYSTEM MODELLING

The grid connected hybrid system consists of a PV/PEMFC/Battery hybrid source with the main grid connecting loads at the Point of Common Coupling (PCC) as shown in Figure.1. The PV/PEMFC/Battery and the dc–dc converters are connected on the common DC bus which is coupled at the dc side of a dc/ac inverter. *(i)Proton Exchange Membrane Fuel Cell Model* A fuel cell operates like a battery by converting the chemical energy into electrical energy, but it differs from a battery in that as long as the hydrogen and oxygen is supplied it will produce DC electricity continuously. Fuel cells play a vital role in distributed generation because of their advantages such as high efficiency, no pollutant gases and modular structure flexibility.

Block Diagram of Grid connected Hybrid system

$$E = E_{Nernst} - V_{act} - V_{ohm} - V_{conc} \quad (1)$$

Where ENerst is the "thermodynamic potential" of Nerst, which represents the reversible (or open-circuit) voltage of the fuel cell The performance of the fuel cell is affected by many parameters and one important



parameter is reactant utilization, Uf [6] and is given by equation (2)

The Nernst's equation and ohm's law determine the average voltage magnitude of the fuel cell stack and is given by equation (3)

$$V_{fc} = N_0\left(E_0 + \frac{RT}{2F}\left(\ln\left(\frac{P_{H_2}P_{O_2}^{0.5}}{P_{H_2O}}\right)\right) - rI_{fc}\right) \quad (3)$$

$$U_f = 1 - \frac{q_{H2}^{out}}{q_{H2}^{in}} = \frac{q_{H2}^{r}}{q_{H2}^{in}} = 2K_r I \quad (2)$$

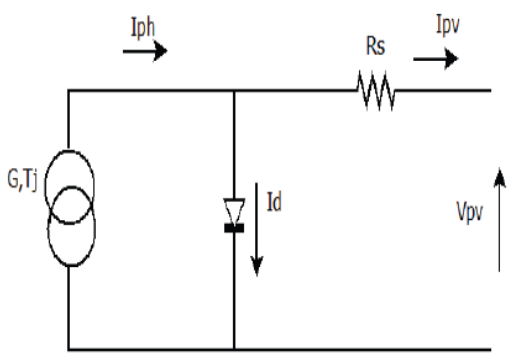
$$P_{H_2} = -\frac{1}{t_{H_2}}\left(P_{H_2} + \frac{1}{K_{H_2}}\left(q_{H_2}^{in} - 2K_r I_{fc}\right)\right) \quad (4)$$

$$P_{H_2O} = -\frac{1}{t_{H_2O}}\left(P_{H_2O} + \frac{2}{K_{H_2O}} K_r I_{fc}\right) \quad (5)$$

$$P_{O_2} = -\frac{1}{t_{O_2}}\left(P_{O_2} + \frac{1}{K_{O_2}}\left(q_{O_2}^{in} - K_r I_{fc}\right)\right) \quad (6)$$

PV Model

The equivalent circuit is a one diode model of a solar cell which consists of a diode and a current source connected in parallel with a series resistance Rs. The current source produces the photocurrent Iph, which is directly proportional to solar irradiance G. The two key parameters often used to characterize a PV cell are it's short circuit current and its open circuit voltage which are provided by the manufacturer's data sheet.



Equivalent solar cell model with Rs

The mathematical model [3] of PV cell can be expressed as

$$I_{pv} = I_{Ph} - I_0\left[\exp q\left(\frac{V_{pv} + I_{pv}.R_s}{AKT}\right) - 1\right] \quad (7)$$

Since Photocurrent I_{Ph} is directly proportional to solar radiation G

$$I_{Ph}(G) = I_{sc}\frac{G}{G_{ref}} \quad (8)$$

The short-circuit current I_{SC} of solar cell depends linearly on cell temperature

$$I_{sc}(T_j) = I_{scs}\left[1 + \Delta I_{sc}(T_j - T_{jref})\right] \quad (9)$$

Thus, I_{Ph} depends on solar irradiance and cell temperature

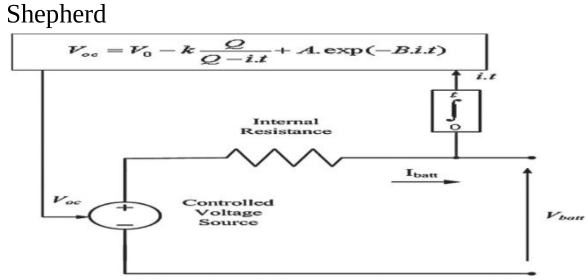
$$I_{Ph}(G, T_j) = I_{scs}\frac{G}{G_{ref}}\left[1 + \Delta I_{sc}(T_j - T_{jref})\right] \quad (10)$$

I_0 also depends on solar irradiation and cell temperature and can be mathematically expressed as follows:

$$I_0(G, T_j) = \frac{I_{Ph}(G, T_j)}{e\left(\frac{V_{oc}(T_j)}{V_t(T_j)}\right) - 1} \quad (11)$$

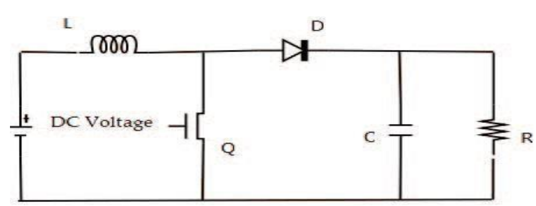
Battery Modelling

The battery is a device which stores energy in electrochemical form. Battery is used as energy storage device in wide range of applications like hybrid electric vehicles and hybrid power systems. In this paper, the battery energy storage is combined with hybrid PV/PEMFC distributed generation system. The battery model considered . The battery model used is based on voltage model proposed by Shepherd



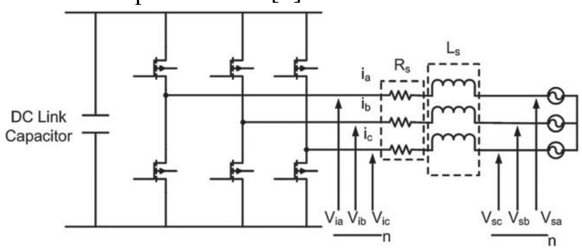
DC/DC Boost Converter Model

While connecting a fuel cell/ PV array to the grid it is necessary to boost the voltage. The boost converter shown in fig.4 is used for this purpose.



DC/AC Inverter Model

The dynamic model of the voltage source inverter (VSI) is used. The DC/AC inverter is shown .To eliminate the harmonics filters are used in between grid and the inverter. The dynamic model of the VSC inverter is represented in [6]



V. POWER CONTROL STRATEGIES AND HYBRID SYSTEM

The power balance must always be controlled from sources to AC bus and to/from storage devices satisfying active and reactive power demand by the load. The equation (12) expresses the power balance equation that should be satisfied both at the DC-link and at the Point of Common Coupling (PCC).

$$P_{dg} = P_{pv} + P_{fc} + P_{batt}$$

$$P_{load} = P_{dg} + P_{grid} \quad \ldots\ldots (12)$$

$$Q_{load} = Q_{dg} + Q_{grid}$$

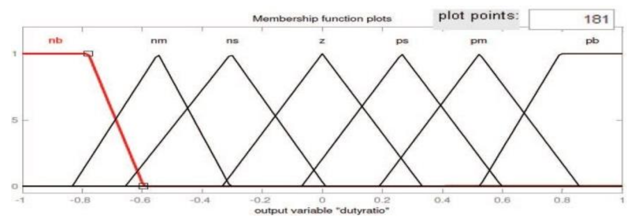
DC/DC Converter Controller using Fuzzy Logic:

The unregulated dc output voltage of the fuel cell is fed to the dc/dc boost converter. The voltage is boosted depending on the duty ratio. The duty ratio is controlled by the logic controller. The input to the fuzzy logic controller is the voltage error (reference-generated) and the change in the voltage error. The fuzzy controller then generates a control signal which is fed to the PWM signal generator. The boost converter generates the output voltage [5]. The membership functions for the duty ratio control of DC/DC converter is shown in fig.6 with seven linguistic variables such as, negative big, negative medium, negative small zero, positive small, positive medium & positive big.

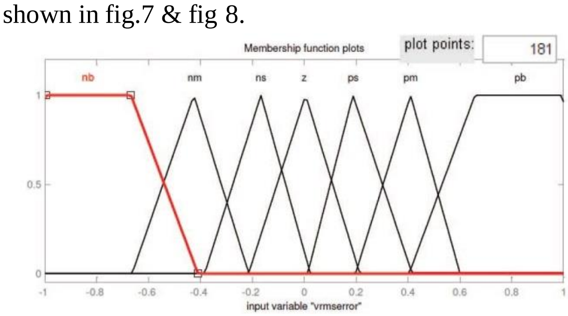
Membership functions for DC/DC Converter

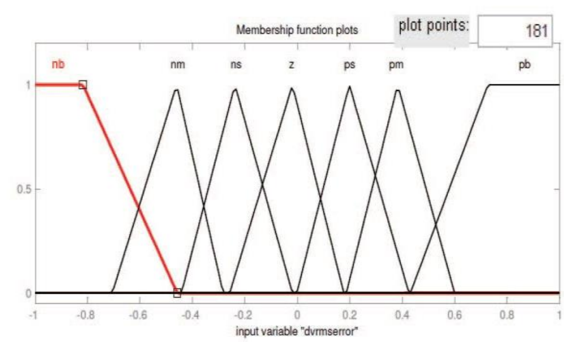
DC/AC Converter Controller using Fuzzy Logic:

The DC/AC converter shown in fig.5 has two controller units namely, voltage regulation control and active power control unit [6]. The inputs to the voltage regulation unit are rms voltage and its

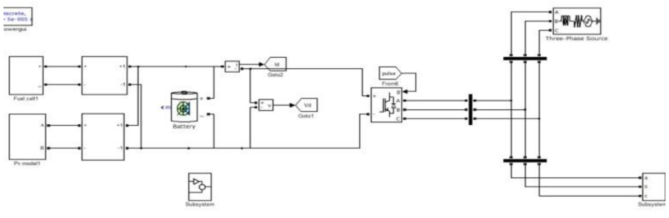


derivative and the output of the fuzzy controller is the current iqref. Similarly the inputs to the active power control unit are the active power error and its derivative and the current idref is the output of the fuzzy controller. For both the active power control and voltage regulation unit seven linguistic variables such as negative big, negative medium, negative small, zero, positive small, positive medium & positive big. The I/O membership functions are shown in fig.7 & fig 8.

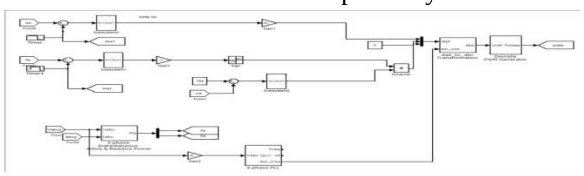




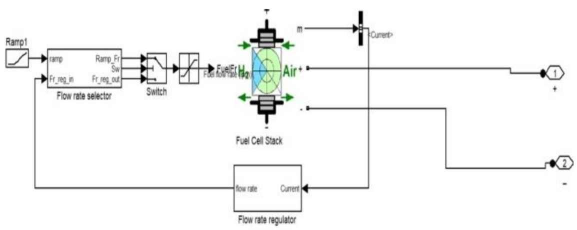
VI. SIMULATION MODELS AND RESULTS



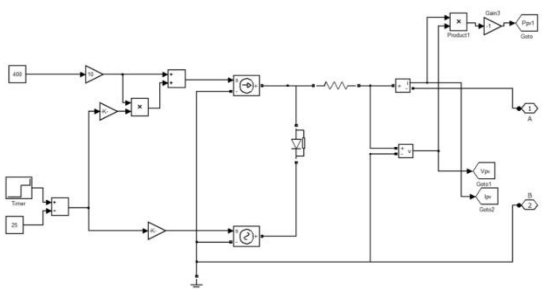
Simulink Model Of Proposed System



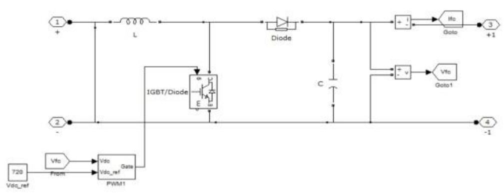
Control System For Pulse Generation



Fuel Cell Model



PV Model



Boost Converter

VII.CONCLUSIONS

The proposed work deals with the power control strategies of a fuzzy controlled grid connected hybrid photovoltaic/ proton exchange membrane fuel cell distributed generation system with battery storage. The battery responds quickly to load transients leaving the fuel cell to respond slowly.

The proposed MATLAB/SIMULINK based fuzzy controller tracks the reference real and reactive powers and allows the hybrid system to operate at or near unity power factor.

PEMFC Parameters	
Faraday's Constant	96487000 C/kmol
Hydrogen time constant(t_{H2})	26.1 sec
Hydrogen valve molar constant(K_{H2})	$8.43x10^{-4}$
K_r Constant=N0/4F	$9.9497x10^{-7}$
No load voltage (E_0)	0.6V
Number of cells (N_0)	384
Oxygen time constant (t_{O2})	2.91 sec
Oxygen valve molar constant (K_{O2})	$2.52x10^{-5}$
FC internal resistance (r)	0.126 ohms
FC absolute temperature (T)	343 K
Universal gas constant (R)	8314.47 J/kmol k
Utilization Factor (U_f)	0.8
Water time constant (t_{H2O})	78.3 sec
Water valve molar constant(K_{H2O})	$2.81x10^{-4}$
Battery Model parameters	
Maximum allowable terminal voltage	730 V
Minimum allowable terminal voltage	710 V
Operating Terminal Voltage	725 V
SOC,%	70
DC/AC Converter Parameters	
Nominal AC Voltage	400 V
Nominal Phase Current	125 A
Nominal DC Voltage	720 V
R_s	0.9 mΩ
L_s	0.01mH
F_s (Hz)	50 Hz
DC/DC Converter Parameters	
Rated Voltage (V)	200/650V
Resistance (R)	2.3Ω
Rated Power	50KW
Capacitance (C)	1.5 mf
Inductor (L)	415 µH

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