A Review of Future Fuel Cell Electric Vehicles and Challenges Related to Morocco

KHALDI HAMZA[1]*, MOUNIR HAMID[1], BOULAKHBAR MOUAAD[2,3,1]
Research Team EMISys, Research Centre ENGINEERING 3S
[1]Mohammed V University in Rabat, Mohammadia School of Engineers, MOROCCO
[2]Université de Pau et des Pays de L'Adour, E2S UPPA, SIAME, Pau, FRANCE
[3]Université Mohammed V, École Nationale Supérieure d'Arts et Métiers, Rabat, MOROCCO

Abstract: - According to estimates from Madrid, Paris and Berlin, Morocco wants to provide Europe with substantial amounts of solar energy and green hydrogen in the future, paving the way for climate neutrality. Morocco is a leader in climate and energy policy in Africa, as well as in the rest of the world. The Maghreb state is pursuing aggressive CO2 reduction targets and has been a major participant in international climate talks, hosting COP22 in Marrakech in 2016. By the end of 2020, the country had built just over 40 percent renewable capacity, and this is expected to reach 52 percent by 2030. Morocco's energy policy plan has now added an ambitious new goal: it aspires to become the global market leader in green hydrogen production. With the growing demand for this new zero-emission fuel, hydrogen manufacturing is a solid bet for the future. In addition, the Kingdom has set ambitious targets for reducing CO2 emissions and integrating electric vehicles as the main solution to reach the 2030 targets. This paper aims to provide a better understanding of fuel cell electric vehicles as well as explore the future of FCEVs in Morocco through an in-depth analysis of the Moroccan hydrogen roadmap. In addition, a SWOT analysis was detailed to determine the key success factor to encourage the adoption of FCEVs in the Kingdom. In the same sense, this paper represents an overview of electric vehicles established for the future realization of prototype FCEVs by our team, this through the integration of the fuel cell in a solar electric vehicle, possibly providing a hybrid power system.

Key-Words: - FCEVs, fuel cell, hydrogen, green energy, electric vehicles, COP22, SWOT analysis.

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1 Introduction

The alarming state of the planet today directs us towards important energy and environmental issues, the energy demand continues to increase while our environment has reached an almost irreversible pollution threshold, and the inappropriate behavior of people has led us to change our perspective, it isn't more a question of modifying our inadequate use of energy, but rather of changing energy source and switching to a new source of renewable energy, which is less harmful to the environment and will be able to compensate the years spent destroying our ecosystem by fossil sources responsible for global warming. This phenomenon is due to the increase of greenhouse gas emissions into the atmosphere, some predictions concluded that the consumption of fossil fuels still represents 78% of the energy consumption in 2040. Mobilization of private and government organizations, as well as experts and researchers, were requested, and several studies have been carried out in this direction to facilitate this energy transaction, the Paris Agreement on climate change was established in December 2015, for which 195 countries unified their environmental goals and agreed to keep global temperature rise well below 2 ◦C , [1].

This climate change is one of the major social disadvantages of the last decades, and the mobility sector is one of the most concerned sectors by these releases, as the transport sector accounts for 25% of the global energy consumption, [2]. The rapid decline of underground oil resources that is occurring with the overuse of fossil fuels is considered another major problem for the transportation sector, [3], [4], [5]. The alternative solution of battery electric vehicles (BEV) seems to be a reliable solution to face this energy crisis, in this sense several types of energy sources and technology have emerged, and they are special vehicles. electric vehicles, hybrid electric vehicles, fuel cell hybrid vehicles, fuel cell hybrid vehicles + photovoltaic panels, and various other renewable energy systems [6], [7], [8]. The development of this type of vehicle is undoubtedly a good initiative to be taken to accelerate the energy transition, [9], so the use of different non-fossil energy sources in an electric vehicle is essential, the following table represents the different power choices. for electric vehicles and specifically fuel cell vehicles, their advantages, and their disadvantages:

Table 1. Power supplies used in FCEVs [10]

Type	Unit	Energy density (Wh/kg)	Lifetime (Year)	Advantages/ Disadvantages (+)/(−)
Generation	FC	Very high	20–25 years	• High-efficient energy generation (+) • Modular and compact (+) • Smooth power output (+) • Expensive (−)
	PV	Medium	15–20 years	• Clean and silent (+) • Intermittency of power output (−) • Bulky for a vehicle (−)
Storage	Battery	High	4–6 years	• Portable and rechargeable (+) • Useful for a limited time (−) • Recharging time (−)
	UC	Very low	10–20 years	• Rapid response (+) • Short-term energy storage (−)
	Flywheel	High	5–10 years	• High-speed charging capability (+) • High power rating (+) • Long charge time (−) • Heavyweight (−)
	SMES	Low	25–30 years	• High power output (+) • Short duration energy storage (−) • High-cost (−)

Several studies in this area have been published. Mustafa et al, [10]. Provide an overview and study on fuel cell electric cars, including topology, power electronics converters, energy management systems, technical problems, marketing, and future implications. Jérôme Bernard, [11], conducts extensive research on fuel-cell hybrid cars, including their dimensions and control systems. Jinwu Gao and colleagues Fuel cell hybrid propulsion system and control difficulties, as well as the development, [12]. Koushik Ahmed and colleagues, [13] As grid-connected generators, investigate hydrogen fuel cells using proton exchange membranes. Daisy D. Bettner and others, [14]. Models of proton exchange membrane fuel cell systems are being developed for vehicle simulation and control. Similarly, the authors of [15] suggest that the challenge for battery makers for FCEVs is to develop a battery system with the power capabilities of an ultra-capacitor UC but the energy capability of a battery. Daisie D. Xueqin Lü et al., [16], present a thorough assessment of hybrid power systems for PEMFC-HEV issues and methods.

This study aims to comprehensively evaluate the power supply of fuel cell vehicles, and more specifically to study the energy chain of this type of vehicle. A fuel cell system is structured in a complex way, it is first necessary to study the operating conditions of the PEMFC to understand how to use it. The multitude of circuits and converters in fuel cell systems represents the major obstacle to the advancement of this process, the optimized use of auxiliary systems as well as the intelligent management of all operators is necessary to obtain a safe and reliable operation, Without forgetting that the development of new materials can also influence the performance of the PAC, of course, the use of some materials with more conductivity and resistance to high temperature allows to move to a more accelerated regime which involves an increase in the kinetics of the reaction and then an increase in the performance of the cell.

In this work, a review of the literature is given for FCEVs, the first part summarizes the typical operation of a fuel cell and assesses the different losses of the internal system, then part two highlights the layout of a fuel cell stack and illustrates the different circuits used for the operation of all the stack. Then, part 3 represents the structure of a fuel cell power plant and highlights the different models and designs used for these FCEVs, the multitude of solutions proposed is interesting and can give us a clear idea of the technical needs of this new system. Finally, the last part consists of highlighting the hydrogen roadmap in Morocco and discussing the opportunities and challenges of the integration of FCEVs in the Moroccan market through a SWOT analysis and the current work of our team.

2 Principle of Operation

Chemical energy (hydrogen and oxygen) is converted into electrical energy by PEM fuel cells. This electrochemical process is known as backwater electrolysis, [17], [18], [19], [20], [21], [22], [23], [24], [25], [26]. A redox reaction between oxygen (oxidizing agent) and hydrogen produces electrical energy (reducing agent). The anode is responsible for oxidation, whereas the cathode is responsible for the reduction. A membrane that functions as an electrolyte separates these two processes. The cathode receives gaseous oxygen (or, more broadly, air), whereas the anode receives hydrogen gas. During operation, the reaction can be represented as follows [11], [27]:

- Anode oxidation: $H_2 \rightarrow H^+ + 2e^-$

- Cathode reduction: $O_2 + 2H^+ + 2e^- \rightarrow H_2O$

- The overall redox reaction is: $H_2 + \frac{1}{2}O_2 \rightarrow H_2O + \mathbf{Heat}$

The two electrons released by the hydrogen molecule generate electricity. Hydrogen protons H+ pass through the membrane that separates the anode from the cathode and recombine with electrons and oxygen atoms at the cathode, the following diagram summarizes the principle of operation of the fuel cell (elementary cell):

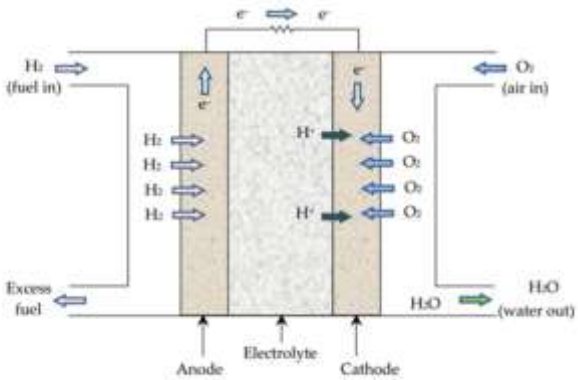

Fig. 1: Construction of a typical PEMFC [12]

Fig. 2 (a) shows the typical structure of a single PEMFC, including the anode and the cathode flow field plates, gas diffusion layers (GDLs), catalyst layers (CLs) and proton exchange membrane (PEM).

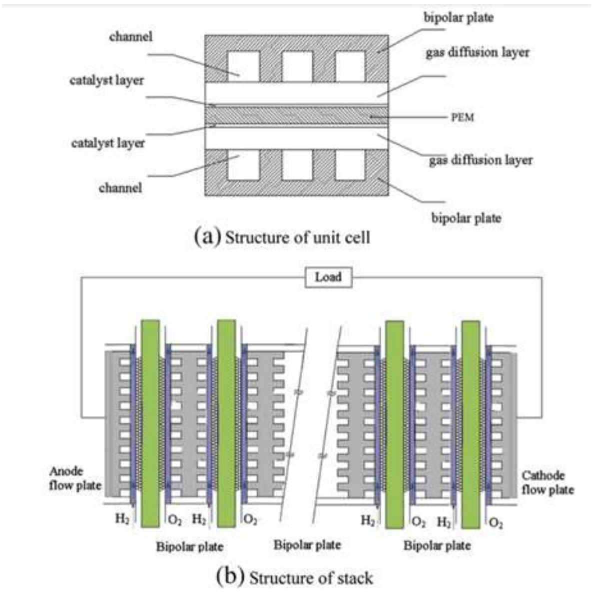

Fig. 2: Schematic diagram of fuel cell [28]

2.1 Electrical Characteristics of PEMFCs

In practice, for standard temperature and pressure conditions (1 atm, 25 °C), the unladen voltage is slightly below 1 V, [29].

The polarization curve is a fuel cell's electrical characteristic. It reflects the cell's voltage as a function of current density and is affected by the operating temperature, reactant pressure, and membrane humidity. So, the current density i_{PAC}(A/cm²) is defined by: $\boldsymbol{i_{PAC}} = \frac{\boldsymbol{I_{PAC}}}{\boldsymbol{A_{cell}}}$

With I_{PAC} the current of the fuel cell and A_{cell} the active surface of a membrane. Classically, if all cells have identical electrical behavior, the total voltage of the fuel cell V_{PAC} is given by:

$$V_{PAC}(I_{PAC}) = N_{cell}.V_{cell}(I_{PAC})$$

With V_{cell} the elemental voltage of a cell and N_{cell} the number of cells. Thus, the gross power P_{PAC} provided by the fuel cell is given by:

$$\boldsymbol{P_{PAC}(I_{PAC}) = V_{PAC}(I_{PAC}).I_{PAC}}$$

The polarization curve of the fuel cell is as follows:

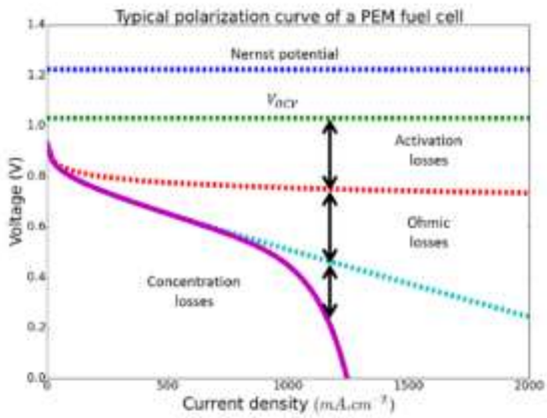

Fig. 3: The polarization curve of PEMFC [30]

This polarization curve can be broken down into 3 distinct zones, each characterized by preponderant voltage drops, [11]:

- **Voltage drops by Activation:** The right electrochemical reaction crosses an activation threshold to initiate.
- **Ohmic voltage drop:** Ohmic voltage drops are caused by the electrical resistance of the membrane and by the electrical resistance of the bipolar electrodes and plates assembly.
- **Voltage drops by Concentration:** Voltage drops by concentration result from a lack of reagents. When the current density becomes high, the diffusion of gases in the electrodes is no longer fast enough to sustain the reaction.

The following table shows us the different electrical characteristics of the fuel cell according to the experience menu in [13]:

Table 2. Electrical parameters of the fuel cell [16]

Items	Parameters	Ratings
Electrical power	Maximum (kW)	5.99
	Rated (kW)	8.33
Electrical properties	Internal resistance (Ω)	0.08
	Exchange current (A)	0.29
	Nernst voltage (V)	1.129
	Terminal voltage (V)	32 to 60
	Operating current (A)	0 to 225
	Nominal life voltage (V)	42
Common properties	Efficiency (%)	50 to 55
	Lifespan (h)	20,000

2.2 Fuel Cell System

This fuel cell system (FCS) must be supplied with hydrogen and air, the membrane must be permanently humidified, and the heat produced must be evacuated. The role of the auxiliary components is to ensure the proper functioning of the fuel cell. Four main circuits make up a PAC system [14]:

- ✓ **The hydrogen circuit (closed circuit):** It supplies the anode with hydrogen gas. Hydrogen not consumed at the exit of the FCS can be reinjected at the inlet of the FCS via a recirculation pump.
- ✓ **The air circuit (open circuit):** it supplies the fuel cell with oxygen, a compressor injects air into the cathode.
- ✓ **The cooling circuit:** The cooling circuit is an essential part of the fuel cell system. The heat produced by the FCS can represent more than 50% of the power losses for high currents. In addition, the temperature difference between the ambient air and the fuel cell (80°C) does not promote heat exchange, which represents a significant technical constraint for automotive applications.
- ✓ **The water circuit:** The humidification of the membranes is done by the incoming gases (air and hydrogen) via the water circuit. Water also contributes to the cooling of the fuel cell as it passes through the heat exchanger.

It is essential to take into consideration the type of hydrogen storage used, it directly influences the structure of a PAC, there are many types of storage, and the most important are, [11]:

- ➢ **Storage in the gaseous form:** hydrogen is stored in metal tanks or composite materials, pressurized between 300 bar and 700 bar. It is the simplest and least expensive solution for storing hydrogen.
- ➢ **Storage in liquid form:** Hydrogen is stored in liquid form at very low temperatures (-253 °C) in cryogenic tanks.
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- ➢ **"Solid" storage:** Hydrogen can be stored in metal hydride tanks. A metal hydride captures hydrogen molecules when it is under pressure and releases them when its temperature is increased. The main disadvantage of this solution is the large mass of the tank.
- ➢ **Storing hydrogen in nanostructures and nanotubes** is also a promising solution, but the actual hydrogen absorption capacity is a controversial topic and seems far removed from the needs of the automobile.

The architecture of the classic FCS is given by the following figure [14]:

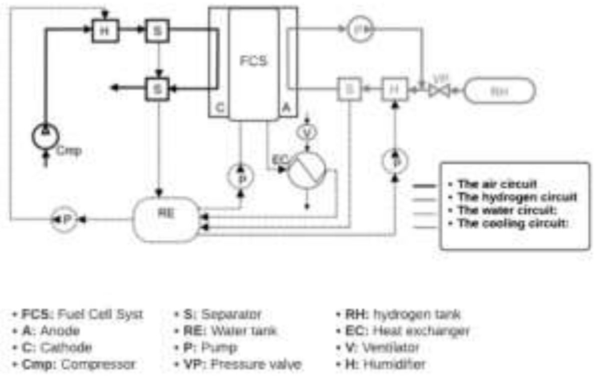

Fig. 4: Classical Fuel Cell system architecture

Figure 5 shows the structure of a fuel cell studied in [12], which typically includes a hydrogen and air supply system, a fuel cell pack, a cooling system, a humidity management system, an electric charging system, and a hydrogen storage tank.

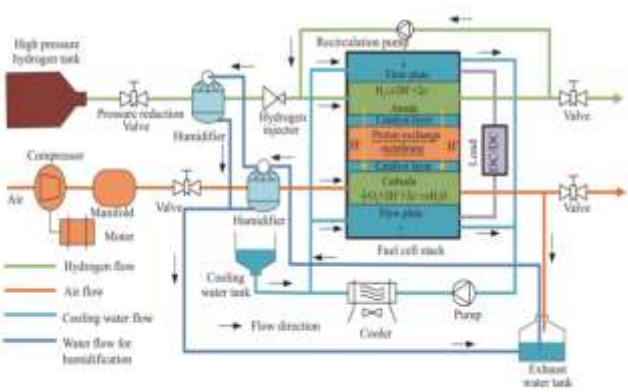

Fig. 5: A typical structure of FCs [12]

Fuel cell temperature and current density, PEM humidity, hydrogen/oxygen ratio, and accompanying pressure must all be altered and maintained to maintain an efficient, continuous, and stable electrochemical reaction in a fuel cell. Otherwise, the lifetime and efficiency of the fuel cell will not be achieved. The start-up phase depends entirely on the initial kinetics of the chemical reaction between water and hydrogen. After this phase, the fuel cell switches to the permanent phase, which depends mainly on the flow of water, hydrogen, and air. With a constant and well-controlled flow, the fuel cell will continue to work properly, but since the components of the system have limited constraints, in particular the membrane which needs permanent humidification to avoid a decrease in its water content, we have to use additional processes to regulate the operating parameters without degrading the fuel cell constituents like the solution proposed in this illustration.

The tank is filled with hydrogen at high pressure (up to 35 or 70 MPa), but it remains gaseous. A finely regulated pressure reduction valve located between the hydrogen tank and the fuel cell supplies the fuel cell with hydrogen gas at the appropriate pressure. The remaining hydrogen flowing through the anode of the fuel cell, on the other hand, is pushed to the inlet of the hydrogen line by the recirculation pump. The hydrogen is almost completely oxidized for energy production using this process. To provide a very high-pressure airflow, the air supply system uses a compressor powered by a high-speed motor. on the other hand, are attempting to minimize the size of fuel cells by eliminating the humidifier while managing the humidity of the PEM, [31].

There is also a new architecture of the proposed FCS, as in [13]:

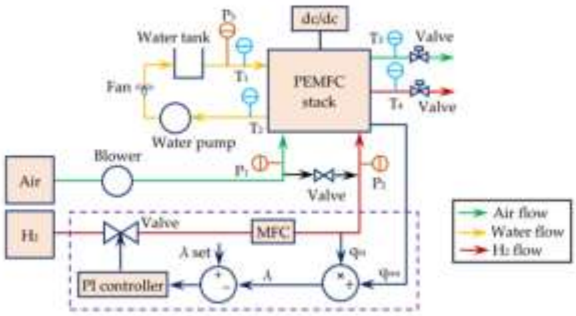

Fig. 6: The new architecture of the proposed FCS

This novel FCS is a PEM FC system with a fuel cell stack, DCDC converter, gas flow model, water pump, and other components. To regulate the flow of hydrogen gas, a mass flow controller was employed (MFC). Simultaneously, a fan was utilized to force air into the cathode chamber. The direct current was then delivered from the fuel cell stack using an electrochemical approach. To remove the remaining gas, a mechanical valve was employed. To keep the temperature in the stack stable, a water-cooling system was utilized. Because the PEMFC chamber had a thin layer, excessive pressure may harm the stack. As a result, it was critical to monitor and control the pressure differential between the anode and cathode chambers. Two valves were installed at the far end of the gas line to control air and fuel pressure. Pressure sensors P1, P2, P3, and P4 measure flow rate, whereas temperature sensors T1, T2, T3, and T4 detect temperature. The dotted region depicts the fuel flow control structure, which marks the PEMFC stack's exit, [13].

The auxiliary components are therefore essential for the proper functioning of the fuel cell and consume part of the energy produced by the fuel cell. The net power available at the output of the FCS (P_{sysPAC}) is a function of the gross power P_{PAC} and the power consumed by the auxiliary components P_{aux}:

$$P_{sysPAC}(I_{PAC}) = P_{PAC}(I_{PAC}) - P_{aux}(I_{PAC})$$

These power losses induced by the power consumption of the auxiliary components affect the overall efficiency of the system. The following figure illustrates these losses and the dependence of the polarization curve on voltage and current, as well as the dependence on efficiency and power:

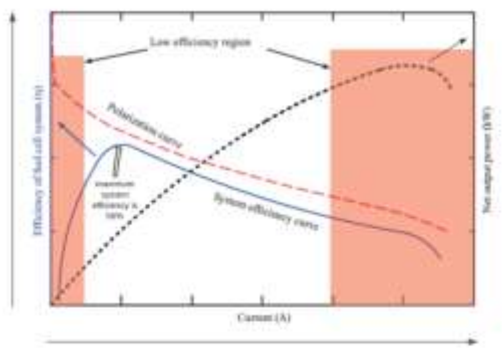

Fig. 7: Efficiency and net output power as functions of load current in a fuel cell system [32].

The following table shows examples of the global physical parameters of fuel cell stack:

Table 3. Physical parameters of fuel cell stack [13]

Items	Parameters	Ratings
Rated values	Utilisation of H_2 and O_2 (%) Composition of fuel and air (sLpm)	99.56 and 59.3 60.38 and 143.7
Composition percentage	Fuel Oxidant	99.95 21
Flow rate	Fuel and air (Lpm)	50.06 to 84.5 and 300 to 500
Supply pressure	Fuel and air (bar)	0.5 to 5 and 1
Implementation	Service life (h) Operating temperature (°C)	2000 −20 to +40
Physical	Mass (kg) Dimension (mm)	Approx. 80 0.4 × 0.6 × 1.6
Outflowing	Water collected (Lpm)	75

2.3 Fuel Cell Powertrains

Fuel cells can be seen as a replacement for batteries in pure battery electric vehicles. Thus, the fuel cell vehicle has an all-electric powertrain topology, with the primary power source being the fuel cell [33], [34], [35]. A typical diagram of a fuel cell powertrain for a passenger car is shown in Fig. 6:

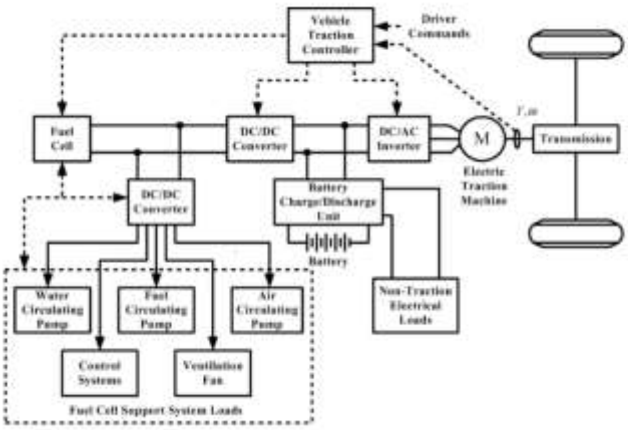

Fig. 8: Schematic of a fuel cell-based power system [36]

The charging converter progressively converts the low voltage DC generated by the fuel cell to the needed voltage at the input of the three-phase DC / AC inverter. Inverters adjust the speed and torque of the electrical gear that powers the vehicle by converting direct current into variable voltage, variable frequency, and three-phase power. During the fuel cell preheating stage, the hybrid structure in the figure additionally includes a battery (for regenerative braking) that supplies a DC input voltage to the DC / AC inverter, [35]. The secondary battery is charged from the power generated by the fuel cell as soon as the fuel cell system is turned on [37], [38].

Even in emergency scenarios, the battery system delivers electricity. As a result, it performs a dual role. The traction controller sends control signals to fuel cells, DC / DC converters, and DC / AC inverters based on speed and feedback torque signals as well as driver directions. This controls the traction motor's speed and torque. Fuel cell electricity is also utilized to power the equipment load (BOP) of fuel cell systems, such as pumps, fan motors, and motor actuators, as shown in Figure 6. The DC / DC converter boosts the fuel cell voltage to that of the main DC bus, [39]. During transitions like as starting and accelerating, the battery delivers initial peak power. An appropriate DC / DC converter and a DC / AC inverter supply a range of DC and AC loads from the primary DC bus. The driving motor is controlled by the motor controller, [15].

We found a different model on [10], the following powertrains structure is studied on this review:

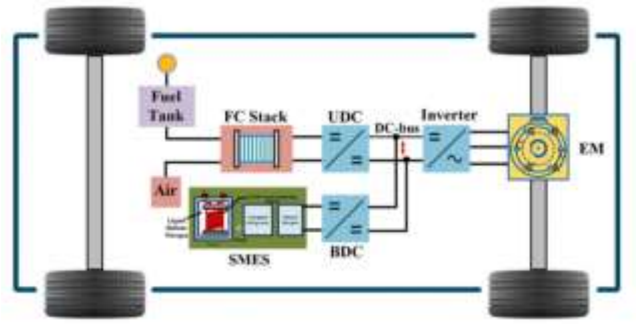

Fig. 9: Powertrain of FC + SMES hybridization [10]

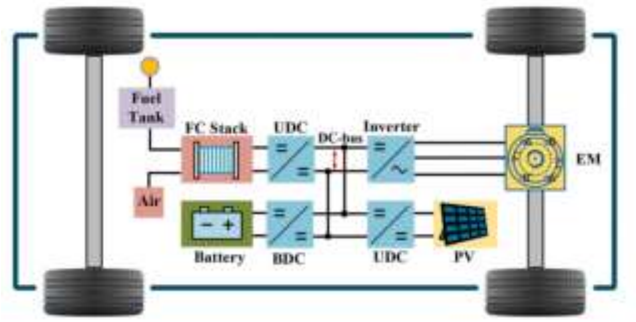

Fig. 10: FC + Battery + PV architecture [10]

Fig 9 shows the powertrain of FC + SMES hybridization. This topology does not still investigate hybrid FC powertrain applications. However, in the next years, it is expected to use a SMES unit together with an FC stack. SMES performs energy storage through a magnetic field that is created by a direct current flowing on a superconducting coil. SMES has shorter charging and discharging time compared to other storage technologies. Besides, it has quite high charge/discharge cycles and an almost 95% power conversion ratio, [40]. However, SMES currently has high costs that constrain its application with fuel cell Vehicles, [41].

In this type of structure illustrate on Fig 10, PV photovoltaic panels generate DC voltages connected to the DC bus with a unidirectional converter for the hybridization of the FC with the Battery and PV, [42], [43]. In the FC + Battery + PV architecture, the FC is used as the main source and the PV panel is considered the additional energy generator. Unidirectional converters link FC and PV to the DC bus. A two-way converter connects the battery to the DC bus. The amount of electricity generated by PV panels varies with the amount of solar radiation, the temperature, and the orientation. According to this, the produced PV power either feeds the electric motor directly or charges the battery. On the other hand, the sudden fluctuations in PV panel output can be assumed by the UC because of its high-power density, providing low power fluctuations.

A second model is proposed in [16] using PEMFC as a major power source as well as lithium batteries and the SC supercapacitor as secondary energy sources. The following figure shows the structure of the energy chain connected to the fuel cell:

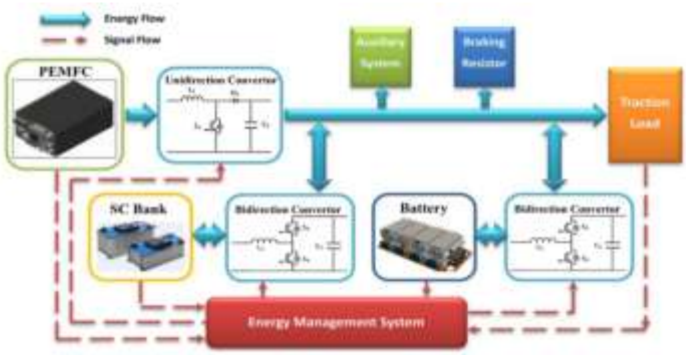

Fig. 11: The structure of the energy chain connected to the fuel cell

PEMFCs are supposed to produce peak power for a brief period during ascent or acceleration. The suggested energy management system "EMS" may be guaranteed by the conclusion, [16]. Low frequency components have the necessary power. The battery powers several low-frequency components, which reduces the impact of POFCs. During this time, supercapacitors (SC) can transport high frequency components that might harm the PEMFC. To offer the essential compatibility and performance for propulsion systems, the SC can compensate for the sluggish output of the mains with quick output response and high-power density, [44]. As a result, the energy storage device's battery life is restricted, and the cost is considerable.

Research results presented in [45] proposes research for linking energy storage and/or fuel cells to the DC bus of FCVs. The secondary voltage doubler is selected to double the gain, minimize transformer size, and efficiently reject low-frequency DC harmonics. The illustration below depicts the design of a fuel cell power unit:

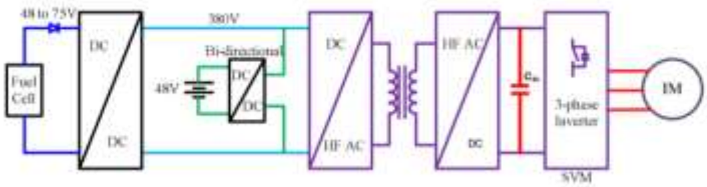

Fig. 12: Architecture for an FCV or signal amplifier BEV with fixed DC bus [45]

Figure 12 illustrates a different FCV or BEV signal amplifier layout with a fixed DC bus and a controlled low-voltage fuel cell ranging from 32V to 68V. A DC converter is used to provide a constant DC bus voltage from the fuel cell's alternating current voltage. The quantity and size of the overall system may be expanded by adding this converter, but the construction and management of the bidirectional charger and inverter are easy in comparison to the previous system, this additional bi-directional DC-DC converter is used to interface the energy storage system (ESS) with the high-voltage DC bus, i.e., the batteries and supercapacitors that are connected, to provide transient power during cold start and acceleration, and absorb power during braking.

The fuel cell converter accepts 48-75V input and has a set output voltage. Because the converter's voltage gain is largely constant, designing the converter for optimal efficiency under these operating circumstances is simpler. Controlling three-phase inverters and traction motors is simple with a constant voltage. The DC absorbs low-frequency harmonics (at least 5th order) into the DC bus, resulting in a nearly constant DC in the fuel cell, [45].

3 The Different Models of Fuel Cell Vehicles Marketed

FCEVs (Fuel Cell Electrical Vehicles) commercially available until today, their manufacturers and their specific features are detailed in Table 4:

Table 4 Commercial FCEVs produced by manufacturers [10]

Appearance	Title	Year (Interval)	Type (#)	Plug (Y/N)	Range (km)	Motor (Type)	Top speed	FC (Type)	FC Power
	Honda FCX-V4	2002–2008	Type III	No	260–310	Induction motor	150 km/h	PEMFC	78 kW
	Ford Focus FCV	2008–2011	Type II	No	320	Induction motor	129 km/h	PEMFC	85 kW
	Nissan X-Trail FCV	2003–2013	Type II	No	350	Synchronous motor	Not given	PEFC	90 kW
	Mercedes-Benz A F-Cell	2005–2007	Type I	No	160–180	–	132 km/h	PEMFC	–
	Chevrolet Equinox FC	2007–2009	Type II	No	310	Permanent magnet motor	141 km/h	PEMFC	93 kW
	Honda FCX Clarity	2008–2015	Type II	No	390	Brush-less dc motor	130 km/h	–	100 kW
	Mercedes-Benz B F-Cell	2010–2014	Type II	No	310	–	132 km/h	PEMFC	–
	Hyundai Tucson FCEV	2014-Now	Type II	No	594	Induction motor	160 km/h	PEMFC	100 kW
	Toyota Mirai FCEV	2015-Now	Type II	No	480	Induction motor	160 km/h	PEMFC	114 kW
	Nissan e-Bio Fuel Cell	2016-Now	Type II	Yes	600	–	–	SOFC	5 kW
	Honda Clarity	2019-Now	–	Yes	590	PM Synchronous Motor	178 km/h	PEMFC	103 kW
	Mercedes-Benz GLC F-CELL	2020-Now	Type II	Yes	478	Induction electric motor	160 km/h	PEMFC	100 kW
	Hyundai Nexo	2020-Now	Type IV	Yes	570	Interior PM Synchronous Motor	179 km/h	PEMFC	95 kW
	Gumpert Aiways Nathalie	2021-	Type II	Yes	820	Brush-less dc motor	305 km/h	DMFC	130 kW

The types defined in Table 4 and in the figure below, are classified according to the fuel cell vehicle power supply mode.

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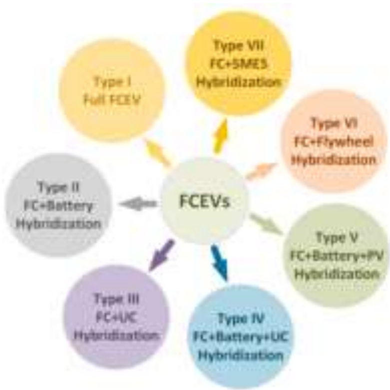

Fig. 13: Topological classification of FCEVs according to power supplies, [10].

As shown in evolution, most passenger car manufacturers have been developing FCEVs in recent years. Manufacturers such as General Motors, Toyota, and Honda generate their own FC stacks and other companies such as Ford, Mazda, DaimlerChrysler, Mazda, Hyundai, Fiat, and Volkswagen buy from FC manufacturers. In the specification of available FCEVs, battery hybridization (Type II) is currently more widely preferred. Moreover, recently, plug-in FCEVs have been generated by manufacturers Honda, Hyundai, and Mercedes. PEMFC is the most common FC stack and its rating increases day by day for FCEVs. The table shows that Toyota, Honda, and Mercedes have PEMFCs higher than 100 kW while the Honda FCX-V4 produced in 2002 uses a PEMFC in rating of 78 kW [10].

4 Discussion and Overview

The use of fuel cell-type systems becomes a major challenge in recent studies, firstly, we presented a single PEMFC cell and explained the operation of this new power system, the internal losses of the system are the main cause of limiting the efficiency to 55%, so we can always improve and increase the efficiency of the system by finding a plausible solution to decrease the internal losses such as activation voltage drop, ohmic voltage drop and concentration voltage drop. There are in [45] several auxiliary solutions to these losses such as the use of batteries for transient power demands to compensate for startup and deceleration losses, or a supercapacitor for peak power demands and thus compose the degradation of the system, or sometimes both, which leads studies to effectively develop an alternative system capable of efficiently managing fuel cell operations.

Part 2 gives us a brief idea of a fuel cell pack, which highlights the complexity of the system, there are already 4 circuits in the FCS, the hydrogen circuit, the water circuit, the air and cooling circuit; these circuits are essential for the operation of batteries in a car, but the effective use of these circuits can compensate for some losses such as ohmic voltage drops and concentration drops, certainly, some studies [14], [13], [12] led us to the use of thermal and hydraulic sensors, for the effective evaluation of air and hydrogen flows and the maintenance of humidity favorable to the PFSA (Nafion) membrane, it is a matter of effectively managing the circuits and creating favorable operating conditions for the fuel cells.

Other avenues propose material modifications, the use of appropriate materials in the membrane could increase the operating temperature and thus the reaction kinetics because the problem here is that operating a PEMFC at a temperature close to the boiling point of water involves two-phase water, the water condenses and floods the gas diffusion electrodes when the humidification is too high or it is operated at high temperature, with higher water the vapor pressure in the feed gas stream can only be achieved by pressurizing the Nafion membrane, [46]. The solution of switching to membranes operating at high temperatures, such as PBI, is still very attractive. HT-PEMFC systems can simplify the fuel cell structure but are still in the research stage, [47], [48]. Changing the materials of the bipolar plates to improve the electrical and thermal conductivity of these plates can also influence the kinetics and response of the system, [49], [50].

Part 3 represents the configuration of the energy chain of hydrogen vehicles, these different concepts clearly show us that the number of auxiliaries is gradually increasing, but the issue of management is still obvious, we need to create an intelligent and efficient management system to enable the reliable use of this new type of vehicle, The existence of converters and a large energy chain in the Fuel cell for the transmission leads us to use almost all the solutions discussed previously [10], [12], [13], [14], [15], [16], [40], [41], [45]. The change of materials, conditioning favorable to the batteries, and a system of management and control of the auxiliaries and components are essential for mastering this new process.

5 Case Study: Morocco

With its geographical position and outstanding wind and solar capacity, Morocco can capture 2 to 4% of the global green hydrogen market and become an exporter by 2030, [49]. The objective of this section is to give a better understanding of the

hydrogen sector and power to x in Morocco. In addition, it shows that Morocco's ecosystem is challenging for the integration of FCEVs and how far is it ready for the promotion of FCEVs. Otherwise, [51], gives more details about the future of power to X in Morocco, while [52] details the economic assessment of hydrogen production potential from solar energy in Morocco.
According to a study carried out by the World Energy Council Germany, Morocco is among the countries with a high potential in terms of Power to X. Power to X requires an energy mix that allows plants to run for as long as possible during the 24 hours. Solar energy can cover about 30% of the need. If we add the contribution of wind power, we can reach 50%. This means that up to 70–80% can even be achieved if storage is used.

As part of the hydrogen / PtX roadmap, Morocco will develop a roadmap for hydrogen and PtX products that encompasses the power to mobility, a roadmap for hydrogen technology and associated PtX goods for Morocco, and set sustainability standards. As a result, the Moroccan industry must adapt quickly to the changing requirements and restrictions of the green mobility market, where mobility power is one of the finest possible solutions to promote the national mobility policy.

5.1 Current progress on Morocco

5.1.1 Morocco and IRENA

The International Renewable Energy Agency (IRENA) and the Kingdom of Morocco (MEME) today vowed to expand relations and develop renewable energy expertise in order to speed up the June 2021 energy transition, [53]. Specifically, IRENA and Morocco will collaborate to strengthen the country's green hydrogen economy, with the goal of Morocco becoming a significant producer and exporter of green hydrogen. The agreement calls for IRENA and MEME Morocco to collaborate on technical and market overview research, the creation of a public-private collaboration model for hydrogen, the study of the development of new hydrogen value chains, and green at the national and regional levels. Create the groundwork for hydrogen trading.
Partners will also conduct collaborative research to study the socioeconomic advantages of renewable energy, with an emphasis on the establishment of new value chains, the creation of national jobs, and lessons gained elsewhere in the area. increase. Morocco is dedicated to expanding South-South cooperation in accordance with IRENA's worldwide objective through exchanging experiences, and information, and boosting regional initiatives among peers and experts.
In general, IRENA and Morocco will collaborate to create the Kingdom's policy and regulatory framework for renewable energy and energy efficiency. Both the Sustainable Energy Access Coalition Initiative and the Climate Investment Platform (CIP) are contributing to climate financing by developing a robust portfolio of projects that are more financially viable and simpler to fund.

5.1.2 Morocco Portugal

Consolidated Contractors Company (CCC) of Greece and Fusion Fuel of Ireland propose to create an $850 million green hydrogen-powered ammonia facility in Morocco, the biggest hydrogen plant announced in the North African country to date, [54].
By 2026, the project is planned to generate 183,000 tonnes of green ammonia and 31,000 tonnes of green hydrogen per year. Fusion Fuel's off-grid solar-to-hydrogen HEVO Solar generator will provide green hydrogen.
Following the conclusion of a feasibility assessment, work on the project is planned to begin in 2022. The project is anticipated to cost $850 million in total. The scheme's offtake arrangement will be managed by commodity trading corporation Vitol.

5.1.3 Morocco Germany

The agreement, which links the Moroccan Ministry of Energy Transition and the German Ministry of Economic Cooperation and Development, intends to promote the sector of green hydrogen generation and to establish research and investment initiatives on the use of this environmentally friendly energy source, [55].
The very first two projects, which have already been stated in the statement of intent, will be carried out within the framework of Moroccan-German economic cooperation.
It relates to the Moroccan Solar Energy Agency's (MASEN) "Power-to-X" initiative to manufacture green hydrogen, as well as the construction of a research platform on "Power-to-X," knowledge transfer, and skill training in collaboration with the Institute for Research in Solar Energy and New Energy (IRESEN).

5.2 Main Actions Carried Out by Morocco

I. The formation of the National Green Hydrogen Commission, which will bring together public and private players. Launch of a study to develop the Green Hydrogen Roadmap, scheduled for completion in May 2020.

II. Efforts have been made to implement a pilot project for green ammonia production.
III. Development of an integrated approach to manufacture green ammonia through the re-use of renewable energy sources.
IV. Preparations are underway for the hosting of a major scientific and technology conference on "Green Hydrogen."

5.3 A Roadmap on the Table

Beyond exports, green hydrogen will also allow Morocco, in the medium term, to decarbonize its industrial sector, in particular the phosphate fertilizer industry, by avoiding, in the long term, the import of 2 million tons of ammonia, [55].
In addition, in the medium and long term, it adds, hydrogen will help decarbonize the national transport sector (land and maritime logistics, and aeronautics) through the two green hydrogen and methanol components. In addition, Morocco could develop the production of green fuels such as diesel or kerosene.

5.4 Establishment of the National Green Hydrogen Commission

First, the members of the GreenH2 Cluster are industries, universities, and research centers, including technology platforms incubated by the University Mohammed VI Polytechnic (UM6P) and the Institute for Research in Solar Energy and Renewable Energy (IRESEN).
The objectives of the GreenH2 Cluster. In addition to contributing to the emergence of a national green hydrogen ecosystem, this platform, the first of its kind on the African continent, will position Morocco as a regional hub, the leader in the production and export of green hydrogen and its derivatives, as the two ministries proudly point out. They also indicate that it will help federate the national ecosystem to develop a green industrial sector with high-added value.
Among other missions, the GreenH2 cluster will have to strengthen the technical and technological capacities of national actors for the production, operation and development of green hydrogen and its derivatives, says the newspaper, which adds that it will also contribute to the promotion of Moroccan green hydrogen at the national and international levels while accompanying the national commission of green hydrogen for the creation of a regulatory framework incentive for the development of a sector.

6 SWOT Analysis

The objective of the realization of a SWOT analysis is to deeply study the weak points and strong points responsible for the speed of integration of fuel cell electric vehicles in the Moroccan market. Table 4 gives a better understanding of this analysis.

Table 5. FCEVs integration SWOT analysis

Strengths	Weaknesses
- Savings in terms of consumption - Environmentally friendly - Reliable thanks to its low-wear motor - High efficiency	- High cost of ownership - Pollution in manufacturing process - The investment and supply component - No FCEV local brand in Morocco - Electrolyzer technologies
Opportunities	**Treats**
- Lunch of project "Power-to-X" to produce green hydrogen proposed by Masen and the establishment of a research platform on "Power-to-X" - Morocco's target to reach 30% of it's fleet 100% by 2030 - Increase in the price of diesel - Predicted growth of electric vehicles because of the adoption of green consumption patterns	- No charging infrastructure - Hydrogen price increase - Lack of legal text in Morocco for the integration of FCEVs - The threat of substitutes products

7 Current Work

After the study and development of a solar electric vehicle in the laboratory of the Mohamadia School of Engineering, the EMISYS team participated in the Moroccan Solar Race Challenge and twice won the first national place behind 3 places won by two French teams and another Turkish. In the sense of competitiveness, we have thought to better configure the solar vehicle by moving from an electric vehicle to a hybrid vehicle, which can use two power systems based on solar energy, certainly using a battery and a fuel cell we can have sufficient autonomy, power and higher performance than the previous model, but the complexity of this system makes the challenge more difficult. A preliminary study of this type of vehicle is strictly necessary to understand the obstacles of this type of process, then a simulation and in-depth study of fuel cell hybrid vehicles are necessary to properly configure the design of this new car, then finally tests and targeted tests on our vehicle to make the system functional and adjust the latest modifications to have an optimized configuration. Some relevant web sites can be found in [54], [55] and [56].

Fig. 14: Participation in the Moroccan Solar Race Challenge

Fig. 15: EMISys solar car

8 Conclusion

Our Kingdom has set ambitious plans related to the reduction of CO2 emissions and the integration of electric vehicles as the main solution to achieve the objectives set by 2030, in this context this study was conducted to clarify the operation of new types of electric vehicles, mainly fuel cell vehicles, their development in the kingdom will allow an acceleration of the energy transition, and will transform an ambitious goal into a controlled routine, thus achieving a roadmap for green hydrogen, the new global trend to protect the climate will have a clear example of an emerging country achieving small and large goals simultaneously. Our research based on new scientific models have highlighted the different development structures of FCEVs, it is obvious that a large mobilization of researchers and experts is necessary to realize infrastructure and models in accordance with Moroccan use, different types of vehicles are exposed in a table to highlight the characteristics of each vehicle manufactured by the different multinationals that monopolize the sector of mobility, certainly even large automotive companies are more interested in this type of vehicle. The article illustrates in the first part the typical operation of a fuel cell and evaluates the different losses of the internal system, then the second part summarizes the layout of a fuel cell and highlights the different circuits used for the operation of the entire cell. Next, part 3 represents the structure of a fuel cell powertrain used for electric vehicles, and finally the last part which consists of a swot analysis to discuss the challenges and opportunities of integrating FCEVs into the Moroccan market.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

-Khaldi Hamza studied the state-of-the-art part and also the analysis of the existing models and future work.

-Mounir Hamid supervised the first author and helped to better structure the article.

-Boulakhbar Mouaad studied the part of the challenges to integrating the FCEVs in Morocco using the SWOT analysis method.