ENERGY TRANSITION IN ALGERIA'S DESERT: CURRENT STATE AND FUTURE PERSPECTIVES.

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ABSTRACT

In remote areas in Algeria's Desert; the energy system is based on the production and distribution of electric energy locally by diesel generators and isolated networks. This solution is attractive because it is less expensive than connecting to the national grid (interconnected). Besides the old energy model of fossil fuels economically was not yet profitable, this model was broken by the technology. So we are looking at a complete redesign of the energy system. The energy transition is one of solutions which can adopt for new energy system. Indeed the energy transition becomes an objective imposed by the depletion of fossil resources and environmental requirements.

The energy transition roadmap presented in this paper is based on the solar energy and as energy source and hydrogen as a vector of energy. Algeria enjoys the sunshine throughout the year and the largest groundwater reserves in the world. The Solar-H_2 project ,that propose in this paper, aims to explore the solar as energy source and hydrogen as a vector of energy for replace the electrical energy provided by fossil fuels (diesel & gas). However the energy transition will not happen in the short term, even if the resources and potential of renewable energy is sufficient, because the cost is too expensive, thus we need to persuade oil, gas and coal companies to see their futures in energy transition. To sum up, the energy transition will be economically feasible, if it is done gradually.

KEYWORDS

Energy Transition; Isolated Systems; Renewable Energy; Solar Energy; Hydrogen.

1. INTRODUCTION

In view of the post-oil, and the exhaustion of the fossil energy resources; which would begin to be felt around 2030; Algeria is obliged to use new solutions that can replace fossil fuels (oil, gas). Besides, there are technical and economic problems related to electrical energy produced by diesel in remote desert community in south Algeria, such as high fuel prices, repetitive breakdowns in generators…etc. To this end, we are looking at a complete redesign of the energy system. The combination of the solar as energy source and hydrogen as a vector of energy in a mix-energy system can to solve the disadvantages and constraints related to the problems of intermittency of some renewable sources and maturity of certain technologies. So the future of electricity is going to be hybrid.

1.1. Production capacity of Isolated Grids in south Algeria

The Isolated Grids (IG) can be defined as all the electrical networks (high and/or Medium voltage networks), which powered by a power plant (diesel or gas turbine), which can operate autonomously. This type of autonomous grids is facilitated the renewable energy integration. Currently, the power production system in Isolated-Grids is composed mainly of diesel generators; then and, it is reinforced by mobile gas turbines at some sites where gas networks are available. According to report published in December 2015 by the company responsible for operation of isolated electricity networks SKTM/SONELGAZ, the production capacity was increased from 384 MW in 2012 to reach 528 MW in 2014, including 320MW by Diesel and 208MW by gas turbines, distributed over 26 Isolated-Grids.

Table 01: Total installed capacity of diesel & gas electricity in Isolated-Grids [01]

Production methods	**Capacity (MW)**	**Rate (%)**
Diesel generators	**320**	60.6
Gas turbine	**208**	39.4
Total	**528**	100

Total installed capacity of fossil electricity is developed to reach 528 MW in 2014; this power helped to cover a peak demand easily which reached 208 MW with comfortable reserve [01].

1.2. Overview on Specificity of Electrical Consumption in Isolated Grids

The specific climatic conditions of the desert, in particular the high temperatures in summer, have a great influence on the pattern of consumption in the isolated grids of south Algeria. These high temperatures that sometimes exceed more than 50 degrees, lead to the widespread use of air conditioning, which operate at full capacity in certain periods; it contributes significantly to the increased pick demand and substantially weaken the production system.

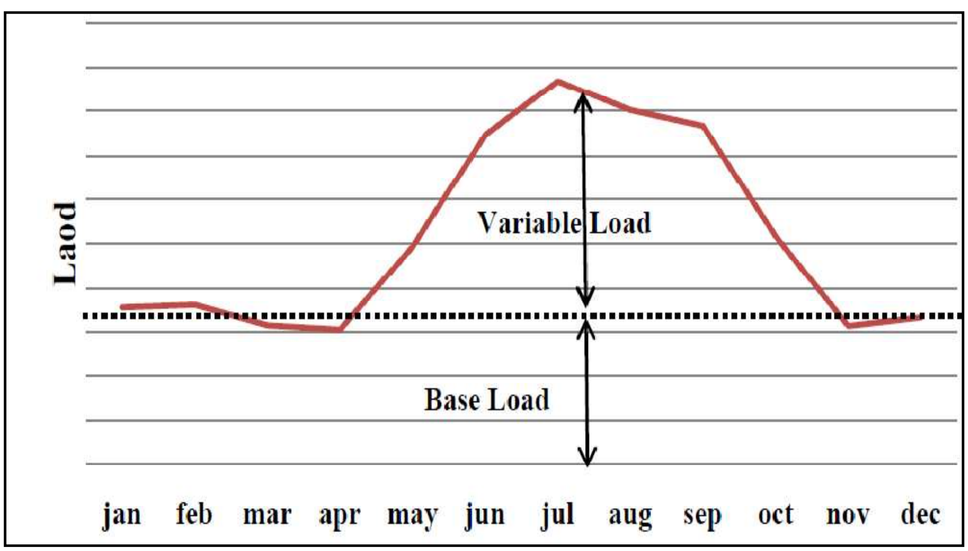

Figure 01: Typical Annual Load Profile of Micro Isolated Grid.

Note that the problem does not necessarily lie in the overall annual consumption but in the distribution of the burden. Indeed the isolated Grids load curve is characterized by high load in summer, against a low consumption in other seasons (spring, and winter). Indeed peak load in summer can triple that of winter as shown in figure 01.

1.3. Energy Resources in Algeria

From its privileged geographical location, Algeria has a very important potential of renewable energy, especially solar potential. The sun is almost available on the entire Algerian territory; while the wind availability is highly dependent on local characteristics. Another natural resource may be added to renewable energy resources; it is an important groundwater deposit (Aquifer).

Table 02: Different Energy Potentials in Algeria [02] [03].

Regions	**Coastal**	**Highlands**	**South (Desert)**
Area (%)	4	10	86
Average sunshine duration (h / year)	2650	3000	3500
Average energy received (kWh / m^2 / year)	1700	1900	2650
Recoverable average wind energy (TWh / year)	1	4.5	31.5
Exploitable Groundwater Quantity (m^3 / year)	_	0.12 billion	0.88 billion

Both the duration of sunshine and the groundwater can put the foundation stone for the energy transition project which can replace the fossil energy. In addition, the extent of territory is allowed to implant solar power plants massively and without encumber.

If the wind potential is not omnipresent as solar energy but it is not negligible. In fact, we can assess the wind potential of each region by implementation the measurement stations of wind speed; from these results we select suitable sites.

2. DIFFERENT ELEMENTS FOR ENERGY TRANSITION

The objective of this work is to design a sustainable energy system able to cover the electricity needs which currently produced from fossil fuels (diesel & gas). This objective is achieved if the design will base on the mix energy system, so the future of electricity is going to be hybrid. For this purpose we are studying the different hybridizations of isolated grid in renewable energies available in Algeria's desert. The coupling of a renewable source such as solar energy with a clean source as hydrogen in sustainable energy system represent a hope for energy transition project.

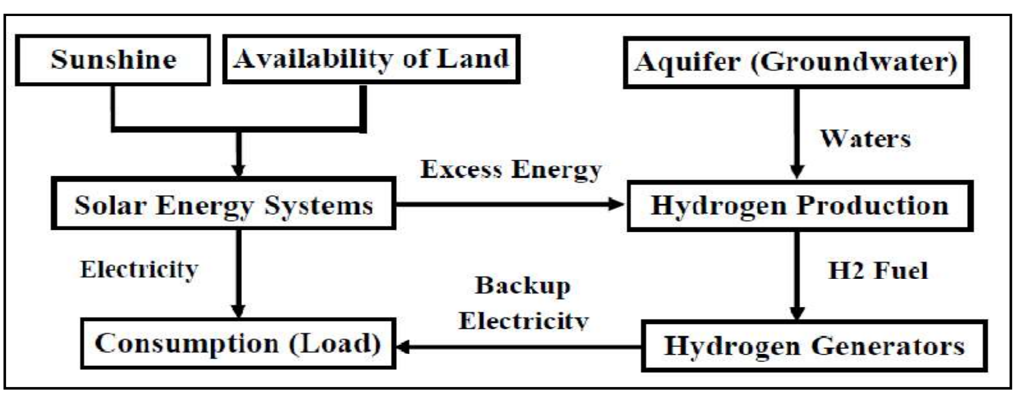

Figure 02: Flowchart of Solar-H_2 Project.

The solar-H_2 project based on three following elements:

Solar: The choice of solar energy is based on: the wide distribution of this natural resource, the abundant across the Algerian territory, the maturity of the solar energy industry PV and then the positive correlation between solar energy production profile and demand cycle. According to a new report from Bloomberg New Energy Finance (BNEF) in 2016, the solar power cost are beginning to outperform diesel and natural gas and new solar energy projects in emerging markets cost less to build than wind turbine.

Surface (Areas): Algeria has a vast desert territory which is allowed to implant solar power stations massively and without encumber.

Water: The existence of an important aquifer (groundwater) in the Algerian Sahara opens the door to the production of hydrogen and uses it as an important vector of energy.

2.1. Energy Transition Roadmap

The concept of energy transition project is based on several aspects including: natural energy resources, infrastructure and logistics of energy, techniques, knowledge and energy development….etc. In other words, the engagement in energy transition project should be carried out with the knowledge of technical and economic solutions, in according to following steps:

- Benchmarking the energy potentials and natural resources available (solar, wind, water….etc.)
- Analyzing the consumption and production profiles; then and selecting the technical and feasible solutions.
- Accurate statistics and financial studies to assess the overall cost of the project and determine the average cost per kWh produced and predict the response time of investment.

From the above steps, the roadmap of energy transition in Isolated-Grids of south Algeria is based on hybridization with renewable and clean resources and scheduling in three phases according to load profile.

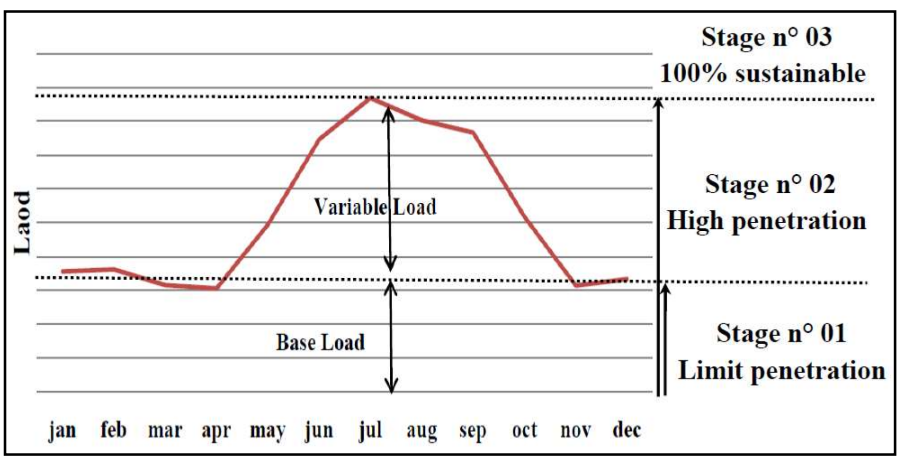

Figure 3: Solar-H_2 Project phases.

The first step has been selecting the best renewable energy technologies that are able to adapt to the south Algeria's climatic conditions. This step aims to improve the performances of the old energy system and reduce their dependence on fossil fuel.

The second stage is step to resign the old energy system and rebuilt it on renewable and sustainable resources. Indeed, the insertion massive of renewable energies must be following by storage system for solve the problem of matching consumption / production and increase the rate of hybridization (high energy penetration). Last stage is step to transition to 100% sustainable energy and abandon fossil fuels in favor of renewable and clean energy.

The performance of hybridization has been measured by renewable Energy Penetration Rate (EPR) which is the ratio between renewable energy produced and total power delivered [04]. The penetration rate can also be both the Power Penetration (instantaneous) and the Energy Penetration (daily or yearly).

2.2. Hybridization with a limited penetration

The choice of solar energy for hybridization isolated networks is based on the wide distribution of this natural resource, abundant throughout the entire Algerian territory, the maturity of the solar PV industry and the correlation positive between solar energy supply and consumption, thus the global spot price for PV panels reached as low as US$0.5 per Wp. The limited hybridization aims to compensate a parity of load by using solar PV and the curtailment of production profile. Indeed the peak power of the PV system is limited in such a way that never reaches base load. The nominal power of the PV system is defined in according to base load (show fig 01):

$$P_{PV} = \alpha \times P_{Base} \qquad 01)$$

The solar Energy Penetration Rate is an important factor to determine the performance of hybridization; in general, it is defined by the Energy Penetration Rate (EPR).

$$EPR = \frac{E_{PV}}{E_{Total}} \qquad (02)$$

With, E_{PV}: the energy produced by the solar PV generators (kWh / year); and E_{Total}: total energy product (kWh / year).

2.3. Hybridization to High Penetration

The profitability of hybridization needs to increase the renewable Energy Penetration Rate which is possible only by increasing the rated power of the solar PV system; hence it becomes a main generator. However, the presence of the fossils generators is indispensable for feeding when either shortfall due to unfavorable weather conditions or sunset (backup supply). These backups' generators aim to compensate of production and load fluctuations, securing the production system and then the regulation of voltage and frequency. So the rating power of the diesel generators is defined by the maximum load (peak).

In this context, the sizing approach for the rating power of solar PV power plant is based on the maximum value of load, P_{max} (sum of basic and variable load, show fig 01):

$$P_{PV.rate} = \xi \times P_{load.\max} \qquad (03)$$

Where, ζ is a variable of optimization.

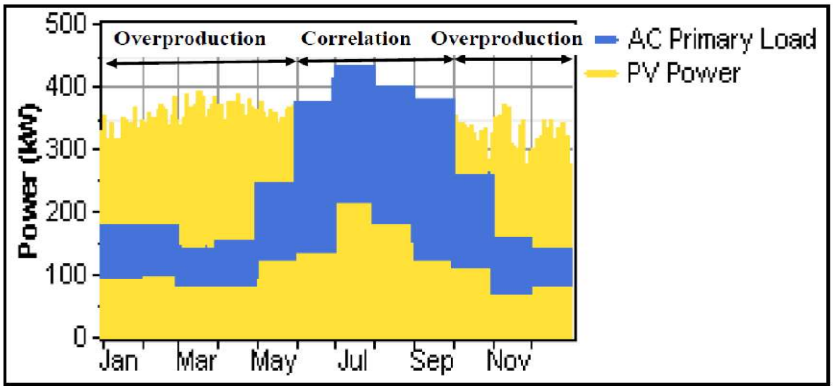

Figure 04: Load curve and photovoltaic power production over a year.

There are two types of variations, the daily variations, meaning the difference between day and night, and the seasonal variations, because the sun's irradiation in the winter is not the same as in the summer. But even if there is no sun, we expect our energy need to be always covered. The solar energy problem does not necessarily lie in the overall annual production but in the distribution of this production and their adaptation to the daily and seasonal load variation. On the author hand, the load profile of Isolated-Grids is influenced by the temperature variation. Hence it has peak consumption in summer, and low consumption in the others seasons (spring, autumn and winter). This peak consumption is due to the massive use of air conditioning during periods of high temperature. The most significant feature of the isolated network load curves is the correlation between the load and the solar energy system production in summer; this feature has a positive impact on the performance of the hybridization project as shown in fig 3.

2.4. Justification the Choice of Energy Storage System

Renewable energy sources such as solar and wind, are depended on an intermittent resource; and often the profile of energy generation does not coincide with the demand cycle. In case of limited hybridization systems is not any problem because the solar PV system was seized in such a way that its production never exceeded the base load. Nevertheless, the High hybridization still has many problems. The problem of High hybridization system is not the amount of energy produced by solar energy, but it is the balance between this energy produced and demand. Managing the balance between electrical supply and demand is a complex problem which results in inherent monetary value of electricity changing by the hour and intermittence of solar energy resources. The Energy storage can be used to match the output of solar energy with any load profile. The choice of storage technology for any particular renewable energy source application is based on several criteria, including available power and energy capacity, reaction time, autonomy and life, as it should be clean (clean). One important feature is storage time or discharge duration (autonomy). However, if these technologies are to be widely adopted, the technologies must also be economically profitable. That is why we need some kind of storage, able to cover the demand even when there is no sun. All in all, the energy transition need to storage technology which can ensure the energy autonomy for isolated-grid (large scale long-duration storage). In this case, there are three technologies can respond to this requirement:

- Pumped Hydro storage (PHS)
- Hydrogen fuel Storage
- Compressed Air Energy Storage (CAES).

Table 03: Parameters for long-term Energy Storage Technologies [04, 05].

Energy storage device	Pumped hydro	Hydrogen fuel	Compressed Air Energy
Capacity (MW)	100-1000	0.1 -1	0.1 - 1000
Duration of storage	Six months	Long term	More than year
Lifetime	30 years	40000 hours	30 years
Duration of discharge	12hours	Hours as need	4 – 24 hours
Round up efficiency (%)	80	50 - 60	60 - 75
Cost	2500-3000 $/kw	4.03$/kg	517$/kw
Operating temperature	Normal atmospheric	50 – 120 °C	Normal atmospheric

Pumped hydropower can provide large amounts of energy for long durations, and Compressed Air Energy can respond to demand in milliseconds making them ideal for distribution networks and small scale hybrid systems. But hydropower depends on specific geographies as water has to be pumped uphill, and Compressed Air Energy currently cannot be scaled in a cost effective way to store energy for a town or city.

The introduction of hydrogen as an energy carrier for storage of solar energy is of interest, particularly for the development of these energy sources. The most future energy support according to scientists and industrialists will undoubtedly hydrogen. By their sustainability, hydrogen remains the most promise for storage of renewable energy. The couplings of a renewable source such as solar energy with a clean source such as hydrogen is represented a appropriate and reliable energy solution for Isolated-Grids. The features of hydrogen can especially enable long-term storage of large amounts of carbon-free power which is a significant advantage over lithium ion batteries.

Hydrogen fuel Storage technology is a technique for converting surplus clean energy from solar panels or wind farms into hydrogen, which can be blended with natural gas and utilized in everything from home appliances to power plants. The renewable fuel can also be converted to methane for use in a natural gas pipeline and storage system or used in hydrogen fuel cell vehicles.

Table 04: Comparison between Hydrogen and Fossil Fuel [05].

Fuel	Energy [kj/g]	Energy [kj/l]
Gasoline	43.5	30590
Diesel	42.7	29890
Natural Gas	52.02	31.7
Hydrogen	119.9	10

As the table shows, fossil fuels have high energy density properties, are stable and reliable. But fossil fuels are depleting and their use is detrimental to our environment. on the other hand, hydrogen has an even better gravimetric energy density compared to fossil fuels, but it is a very light gas, so the volumetric energy density is much lower. That is one of the reasons it has not been widely used until now. However, if we compare batteries and hydrogen for the energy storage of solar energy, batteries have a lower energy density and assume a much higher initial investment than hydrogen. Also, hydrogen can effectively be produced from solar energy by utilizing electrochemistry. This is why the concept of Solar-H_2 project is interesting and being adopted for Isolated-Grids application.

2.5. Role of the Hydrogen as Vector Energy in Solar-H2 Project:

Hydrogen as an energy vector is an interesting solution to the seasonal fluctuations of the load curve because it provides seasonal storage of renewable energy excess production with virtually unlimited storage capacity. Hydrogen – fueled combustion engines are a currently available technology for short-term applications including distributed utility applications, renewable matching, minimize the generation capacity and spinning reserve.

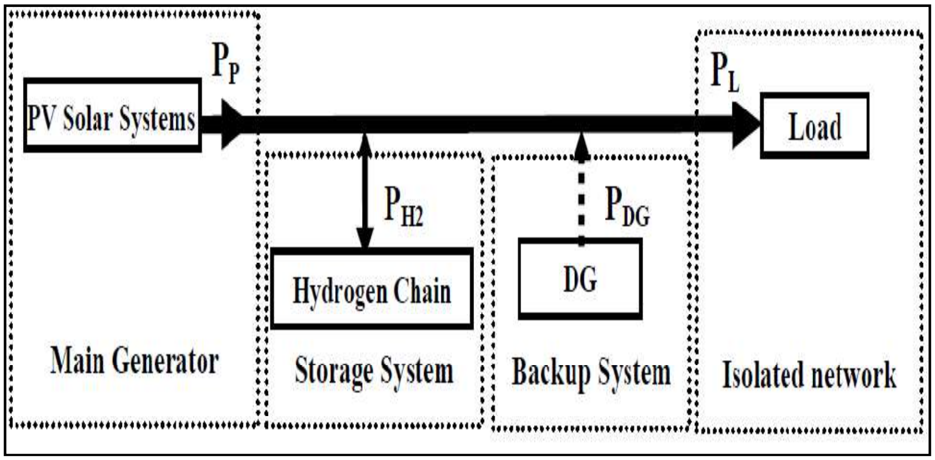

Figure 05: Concept of the High Penetration with Solar-H_2.

The power balance of the hybrid plant PV-H2-DG is expressed by:

$$P_L = \alpha_1 \times P_{PV} \pm \alpha_2 P_{H2} + \alpha_3 P_{DG} \qquad (04)$$

With P_{PV}, P_{H2} and P_{DG} are respectively the power generated by the PV solar plant, the power storage system and power backup generators. The variables α_1, α_2 and α_3 are depends on the state of charge, power generated by the PV solar system, the energy storage system, and backup power generators. These variables are responsible for optimization the power system elements.

The dimensioning of the hydrogen system's elements is accomplished by determining the nominal power of the electrolyzer and the tanks storage volume. The nominal power of the electrolyzer can define the difference between the maximum power of the PV generator, P_{PV} and the base power P_{Base}.

$$P_{EL} = P_{PV} - P_{Basic} \qquad (05)$$

The hydrogen storage tanks intended to store all he produced the electrolyzer; so the tank storage volume V_{H2} is calculated by:

$$V_{H2} = \frac{E_{EL}}{K_{EL}} = \frac{E_{PV} - E_{Bssic}}{K_{EL}} \qquad (06)$$

E_{EL}, E_{PV}: are respectively the energy absorbed by the electrolyzer (kWh / year) and the energy supplied by the PV system (kWh / year). K_{EL}: theoretical power consumption of the electrolyzer (kWh / m3).

In general, the role of hydrogen storage system is transformed the excess energy to a useful energy by transforming this energy into hydrogen fuel and re-use in electricity later. For this purpose the storage systems improve the performances of system, in particular the penetration rate which becomes:

$$EPR = \frac{E_{PV} + E_{H2}}{E_{Total}} \quad (07)$$

3. SOLAR-H2 PROJECT: FOR 100% SUSTAINABLE ENERGY SYSTEM

Given that renewable energy sources and hydrogen cycle are safe for the environment, these couples certainly offers the possibility of solving environmental problems and reduce the dependence on fossil fuels. It would strengthen the use of renewable energy, particularly solar energy, allowing the storage of such energy in a chemical form for a decoupled use of the place and time of the offer. The current problem of 100% renewable is highlighted by:

- Numbers uncertainties are inherent in the project, both technically and financially.
- A number of technical solutions are still in the experimental field
- The various experiments also are difficult to transpose
- Studies implemented require complex and highly diversified skills.

3.1. Hydrogen Powered Internal Combustion Engine Generators (HEG).

With minor modifications it is possible to replace petrol (gasoline) by Hydrogen as the fuel in an internal combustion engine. This has the major benefit of using well known, tried and tested power plant technology to reap the benefits of a zero emission power generation while avoiding all the technology risks, complications and expense of fuel cells. Hydrogen powered internal combustion engines can also be used with rotary generators to generate electricity as shown in the following diagram:

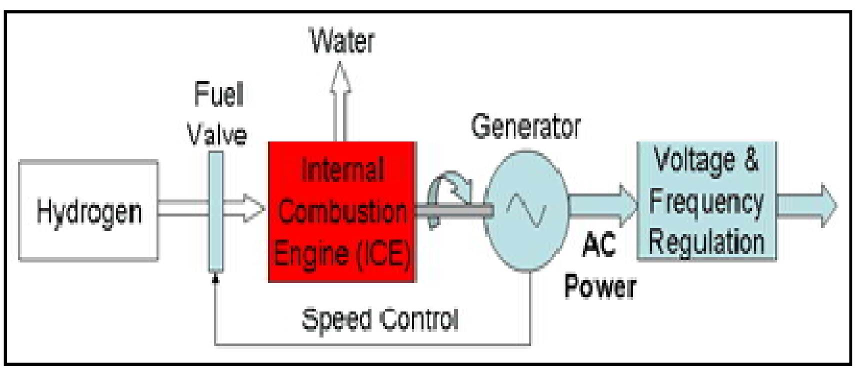

Figure 06: Hydrogen Powered Internal Combustion Engine Generators diagram (HEG) [06].

The transition to 100% sustainable energy system will be feasible if fuel cells are replaced by Hydrogen Engines Generators (HEG) which drives the electrical generators. Indeed, some samples are already marketed as those produced by the American company Hydrogen Engine Center [12]; and power up to one hundred kilowatts. The main advantage of this technology is that it has a predictive value equivalent to fossil fuel generators.

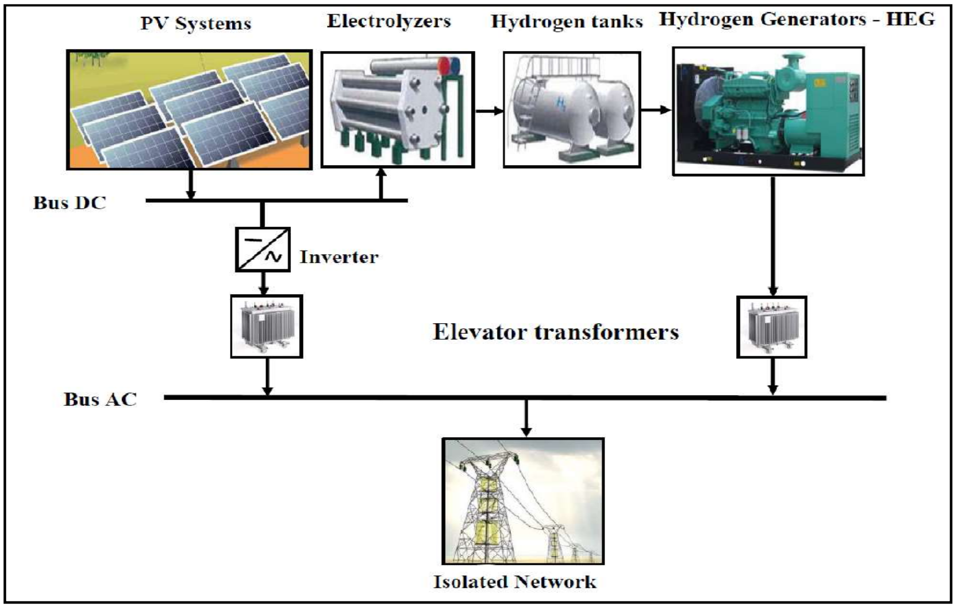

Figure 07: Application of Solar-H2 Project on the Isolated Networks.

Hydrogen and electricity together represent one of the most promising ways to develop sustainable energy systems in coupling the solar photovoltaic system with a hydrogen chain for hybridization the power plant has a significant energy and environmental potential for isolated grids in Algeria south. Hydrogen Engines Generators (HEG) is designed to matching production and load varies, securing the production system and then the regulation of voltage and frequency.

3.2. Solar-H_2 Project: Case study

In order to examine the performance of the proposed roadmap, we study a real case that is a small diesel power plant in the south of Algeria (location, Timimoun town, Adrar) which is a large province in central south of Algeria. This area is famous with very harsh climate, with extremely hot summers and extremely dry long winters. Thus, Sun is almost available. The latitude: 29° 15', the longitude: 00° 17'e and the Solar Radiation is approx 5, 84 Kwh/m2/day. The Micro Isolated-Grid is characterized in Table 04:

Table 04: Parameters of the diesel plant studied.

Installed power (kW)	Peak Load (kW)	Base Load(kW)	Variable Load(kW)
626	438	167	271

As show in above table and in fig 01; the specific load profile forces utilities to install over-seized energy capacities to cover the seasonal demand. Anyway, electricity demand varies, influenced by factors like time and temperature of day and season. The Isolated-Grids operator is prepared for surges in demand, with power generators on stand-by ready to crank up the power.

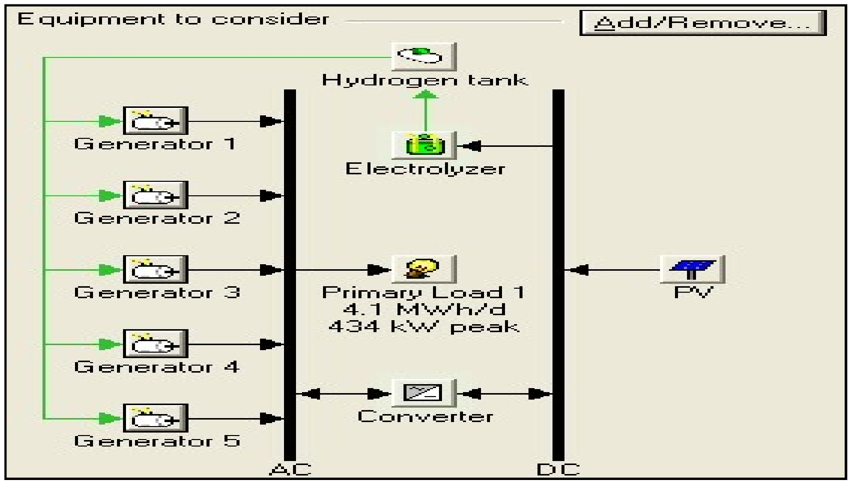

Figure 08: Case study of Solar-H_2 project.

The correlation between peak load and peak solar PV production curve in summer has a positive impact on performance and sizing of system components, this correlation allows increasing the rate of penetration to reach 48%, with an excessive energy negligible and without recourse to the system of storage. Moreover, a seasonal storage has an important role to carry off the over production from the troughs seasons to peak season (summer). On the other hand, dealing with these peaks and troughs will become increasingly difficult as diesel and/or gas power plants close down and more intermittent solar energy comes online. The hydrogen storage system works by using renewable or off-peak electricity to produce hydrogen fuel which is used to drive a Hydrogen Powered Internal Combustion Engine Generators to generate electricity.

Table 05: Simulation results of the case study.

Parameters	**Limited Penetration**	**High Penetration without storage**	**High Penetration with storage**	**100% Sustainable**
PV Power [kW]	230	500	800	1500
TPE [%]	28.3	47.8	81	97
Excess energy [%]	2.08	19.6	2.3	10.12
Fuel consumption [l / a]	524185	312105	312105	0
Total cost [$]	373500	0.56 million	8.5 million	20.2 million
KWh price [$ / kWh]	0.259	0.408	0.59	0.918
Greenhouse Gas Emissions [kg / year]	1,14 million	0.81 million	0.81 million	1095

The Hydrogen Powered Internal Combustion Engine Generators (HEG) has a key role in the energy transition; hence it is making that the 100% renewable system is possible and feasible. Although the cost of this alternative would be far too heavy, this results is presented a new model energy data which can be built upon in order to achieve energy self-sufficiency, by relying on sustainable and renewable local sources.

4. CONCLUSIONS

The Solar-H_2 project is based on coupling the solar energy as renewable generator, the hydrogen as renewable fuels, and the Hydrogen Powered Internal Combustion Engine Generators (HEG) as green backup generators. These couples certainly offer the possibility of energy transition and solve the environmental problems. The energy transition roadmap presented is established a techno-economic study and a strategic plan with clear objectives and a timetable for action.
Although; the transition to 100% sustainable energy system technically is feasible by inserting Hydrogen Powered Internal Combustion Engine Generators (HEG); but the cost of such a transition is not economically favorable because it is too expensive. For this purpose the transition to 100% renewable and sustainable energy system will not happen in the short term, even though Algeria (Sahara) has been enough renewable and natural potential resources for it. According to the roadmap presented in this study, the abandonment of fossil fuels in favor of renewable energies should be done gradually.

The energy transition not only is renewable and sustainable energy resource but also the energy efficiency and demand-side management can play important role in this transition. For this purpose, the future work will be including both the renewable energy and energy efficiency.

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