Performance Study of Self-sufficient and Renewables Based Electricity Supply of a Hospital in the Near East Region

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***Abstract*-- Stand alone wind-diesel power systems can be an attractive solution for the supply of remotely located consumers or the provision of enhanced energy independence. This study presents the dynamic behavior of a hybrid power system containing a prior wind generator and a supplementary generator set driven by a combustion engine, thus independently and economically supplying electrical load demand for the main hospital in Gaza-Strip – Palestine. Accumulator bank and electrolyzer plus hydrogen storage tank are added as short term and long term storage devices – respectively – in order to balance power in the system. To analyze the behavior of the above mentioned power system, the measurements for wind speed were taken from a meteorological station located in the relevant coastal area, for relatively more than one year; correspondingly, the electrical load shape of the hospital had been recorded in high temporal resolution. Stored hydrogen is injected to the generator set under a prescribed scenario of operation. The simulation results prove that continual electricity supply at low emissions and high degree of energy independence is possible.**

***Index Terms*-- battery-bank; generator set; hydrogen storage tank; renewable energy; stand-alone system; wind turbine.**

I. Introduction

Over the past few years, the total electricity needs have steadily been on the rise. Recent studies are expecting that conventional sources of primary energy will be rare, if not exhausted, thus encouraging scientists and engineers to find alternative and sustainable sources of energy. Moreover, environmental aspects play an important role to limit the green house effect gases exhausted by the fossil fuelled power plants. To achieve this, many projects have been supported to develop technologies to exploit, as efficiently as possible, clean energy sources. The technology with the greatest impact in this area is the wind power generation. Such alternative sources of energy are not required to fully replace conventional types everywhere; rather, they are useful to be a supplementary factor besides traditional sources, especially in developing public utilities – hospitals and water pumps – and rural areas where strong conventional energy grids do not yet exist or some external restrictions prevent demands to be supported. In these places, many diesel generators are used to meet the load demands. Nevertheless, several problems occur such as the extra cost to transport the fuel to the target area.

Transportation system breakdown is another problem to support the continuous need of fuel to the electric power generator. Furthermore, continuing escalation in the fuel price make it cost effective to use the renewable energy sources. Thus, they can play an important role in the future.

Wind-diesel power systems are the most appropriate hybrid systems utilized in weak or isolated power systems. The first commercial application of High-Penetration, No Storage, Wind-Diesel (HPNSWD) technology was installed in 1999 by Northern Power System (Vermont, USA) on St. Paul Island, Alaska [1]. One of the main challenges with these types of power systems is the reliability and quality of the produced power [2]. As a matter of fact, fluctuations in the output power result from variations in the wind speed. One way to overcome this problem is to include different kinds of energy storage (e.g., accumulator batteries for small appliances, or generation and storage of hydrogen gas by electrolysis and pressure tank – respectively – and use of this gas for a combustion motor driven generator).

Storage technologies which are based on hydrogen production and utilization – that is expected to be used for very different applications – constitute some interesting advantages in terms of cost, independency and environmental effects [3].

Combination of short term and long term energy storage devices has many advantages. A battery-bank can be used to meet the peak power demands as well as eliminate the fluctuations to the input power of the electrolyzer; hence, the size of the electrolyzer can be minimized while its life-time expectancy will evolute. A large electrolyzer is inefficient to respond to the fast changes and high peak power excess [4]. Thus, the combined energy storage system can be operated more efficiently than a single hydrogen storage system.

The Near-East region – especially Palestine – was selected as the area of study. Availability of appreciable wind speeds and solar radiations drew the attention of engineers to use the clean sources of energy to face the continuous lack of the produced power. Incredible increase of populations together with growth of societal development forced the responsibles to think in detached power systems. Unstable political situations and the age of the local power grid are also strong reasons

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standing behind such kind of systems totally isolated and independent from the local power grid. Thus, the 'small wind' applications became more and more popular in the remote areas within these last years. Actually, wind turbine usage is proved to be competitive regarding the traditional energy sources, i.e. a diesel generator set [5]. The main hospital in Gaza-Strip, Palestine, is taken as case study here. The Alshiefa hospital is located near the coastal area in Gaza city. It serves more than 40% of Gazian people.

The objective of this work is to develop an efficient wind-diesel hybrid power system for the previously mentioned application. The system should be able to deliver the power demand, as well as have an effective and intelligent strategy for storing and re-using the surplus power in the bi-fold storages. To achieve that, a Fuzzy Logic Controller (FLC) followed by a time estimator and a prescribed re-use of hydrogen – respectively – are applied. In the following section, the plant description of a stand-alone hybrid wind-diesel power system is briefly outlined. Section III introduces the mechanism of storage and re-use of the excess power. A simulated model of the Alshiefa hospital electricity supply as a possible real application is clarified in section IV, while discussion of some of the obtained results will be found in section V. Lastly, section VI is dedicated to the conclusion, summary, and outlook.

II. Plant Configuration

A typical stand-alone hybrid wind-diesel power generation system is illustrated in Fig. 1. Four main components are contained in the proposed system which are: wind turbine with induction generator (main source of energy), combustion engine driven synchronous generator set (frequency governor as well as supplementary and backup power source), accumulator bank and hydrogen path including electrolyzer and storage tank (short-term and long-term energy storage, respectively). FLC together with the time estimator play an important role in controlling the flow of excess power towards the battery-bank and the electrolyzer as will be seen later. Stored hydrogen is injected – according to a pre-defined strategy – in the combustion engine driving the generator, thus also leading to extensive energy independency – which is the main target.

A. Wind Turbine

As indicated earlier, the wind turbine acts as the main source of energy as it is often the case in such detached power systems [1]. A variety of wind generators in the relevant power range (100 kW up to 5 MW) based on different

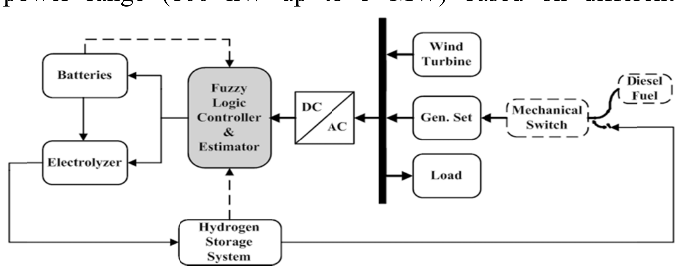

Fig. 1. Stand-alone wind-diesel power system (main components).

aerodynamic and electrical principles are commercially available. As the wind speed fluctuates, the output power follows the variations of the wind speed as a cube function of the rotor speed as indicated in (1) [6, 7].

$$P_{WT} = \begin{cases} 0.5 \cdot c_p(\alpha\ ,\beta) \cdot \rho \cdot A \cdot V_{wind}^3 & (V_c \le V \le V_r) \\ P_{nom} & (V_r \le V \le V_f) \\ 0 & (V \le \mathrm{V}_c \text{ and } V \ge V_f) \end{cases} \quad (1)$$

where

P_{WT} : Mechanical output power of the turbine (Watt),
c_p : Performance coefficient of the turbine,
ρ : Air density (kg/m³),
A : Turbine swept area (m²),
V_{wind}: Wind speed (m/s),
α : Tip speed ratio of the rotor blade tip speed to wind speed,
β : Blade pitch angle (deg.)
V, V_c, V_f, V_r : wind speed estimated at height h, cut-off speed, furling speed, and rated speed in (m/s), respectively.

The maximum value of c_p (0.48) is achieved for $\beta = 0$ deg. and $\alpha = 0.81$. For more details see [8].

B. Generator Set

Dual-fuel engine as source of energy is not fully environmental-sustainable – especially with diesel mode – but it can be committed flexibly and independently from natural circumstances, for instance running on diesel fuel only during long low wind periods which are very rare; furthermore, such generator set plays an important role in the stand-alone hybrid systems since it regulates the frequency in the system.

The impact of the wind turbine on diesel fuel consumption is not obvious as it might at first seem. The simplest way to estimate fuel saving would be to determine first how much fuel is required to produce a kWh of electrical energy under rated conditions of the diesel mode generator set. One might then assume that for every kWh produced by the wind turbine there should be a pro rata drop in diesel fuel consumption. This is not the case, however, because the efficiency of the generator decreases at low load, causing more fuel to be consumed for a given amount of produced energy. To a rough approximation, fuel consumption at no load is 15-30% of the full load value, and the relationship for intervening loads is almost linear or quadratic. Note that the no load fuel consumption to rated fuel consumption ratio is engine dependent, with the larger values corresponding to the smaller engines. A decrease in power generation will actually result in a reduction in fuel use, but it is typically closer to 2/3rd of the amount that would be calculated in the simple way described above. The actual fuel saving at decreased loadings depends on such factors as the size, type, and the age of the engine [9].

Detailed representations of the dual-fuel engine and the modes of operation will be discussed later.

C. Energy storage system

One of the main challenges for such isolated power systems is choosing the most appropriate strategy for storing the excess energy. Not only the economical and environmental aspects play an important role in selecting the most suitable storage devices, but the functionality of each individual technology as well as cost considerations can also determine the proper ones.

For instance, customary accumulators are expensive and only appropriate for small scale storage, i.e. covering day/night cycles of smaller photovoltaic based systems [10]. They can also act as short term energy buffer which is the main function in our work. The actual charging status of an accumulator bank can be determined by an observer based model which is run in parallel and tuned from time to time for definite (full) charging statuses, e.g. [11].

Longer term and larger scale storage can be achieved by, e.g., electrolysis and hydrogen storage [12]. Water can be decomposed into its elementary components by passing the surplus electric current between two electrodes separated by an aqueous electrolyte [13]:

$$H_2O + electrical\ energy \rightarrow H_2 + \frac{1}{2}O_2 \qquad (2)$$

Under ideal circumstances it requires 39.4 kWh of electricity and 8.9 liters of water at normal conditions (25° C and 1.0133 Bar) to produce 1 kg of hydrogen. The maximum efficiency can never be reached because the process is never perfectly ideal due to thermodynamics as well as material limitations. The current electrolyzer efficiencies generally are in the range of 52% to 82% [14]. The charging status of hydrogen storage can be simply determined by measurement of internal pressure.

Shape of the hydrogen storage vessel, the liner of the external surface and the type of the storage media are now the highest challenges concerning the design and build-up of a hydrogen storage system. For more details, see [15]. Fig. 2 illustrates a vertical section for one of the newest technologies of storage vessels.

D. *Fuzzy Logic Controller and Time Estimator*

Fuzzy logic allows describing complex systems using knowledge and experience in simple natural-language-like rules. It does not require any system modeling or complex math equations governing the relationship between inputs and outputs. It provides also an alternative solution to non-linear control because it is closer to the real world. Non-linearity is handled by rules, membership functions, and the inference process which results in improved performance and simpler implementation.

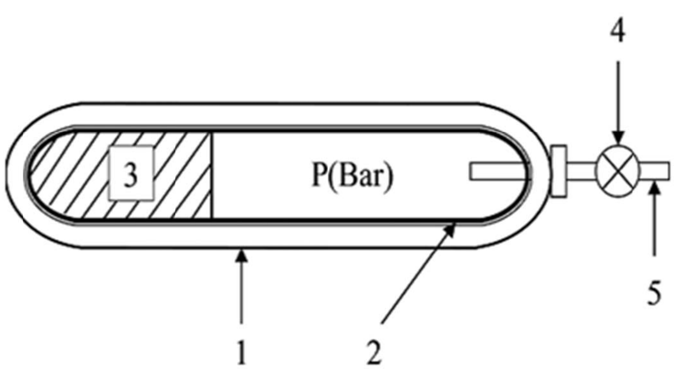

Fig. 2. A schematic view of the hybrid hydrogen storage vessel: (1) carbon fiber and epoxy resin, (2) thin aluminum liner, (3) hydrogen storage alloy, (4) valve, (5) tube for hydrogen [15].

Regarding the proposed system, storing the surplus energy should be managed in the way that the electrolyzer is working efficiently. Fuzzy logic controller and time estimator are used to determine the actual power set-point of the electrolyzer, while the battery-bank has to be kept on an appropriate charging level in order to cover the remaining rapid power fluctuations. The time estimator controls not only the power set-points of the electrolyzer, but it limits also the minimum allowed time duration before changing the set-point and before switching ON/OFF the electrolyzer, both in order to reduce material stress and therefore enhance lifetime expectancy. The following section contains more details about the strategy of the energy storage taking into account some considerations.

III. Excess Power: Mechanism of Storage and Re-use

As mentioned before, excess power has to be efficientely stored to be used in the times of deficiency. The work strategies of the electrolyzer followed by the time estimator and the dual-fuel generator set control the process of energy storage and re-use, respectively.

A. *Fuzzy control of electrolyzer and time estimator*

The ease of formulation of logical operation rules containing imprecise verbal expressions makes fuzzy logic an appropriate means for plant control. Thus, a fuzzy logic controller was used to achieve a situation dependent and efficient split of the power excess in the proposed system by targeting the operation set-point of the electrolyzer. FLC relates the controller output to the inputs with a list of (IF-THEN) rules. Accumulator State Of Charge (SOC), pressure of the hydrogen tank and the power excess are the three inputs to the FLC, while the output is the percentage of the power excess split. Fig. 3 illustrates the fuzzy logic control analysis method [16].

There are 23 fuzzy logic rules used to derive the power split percentage forwarded to the time estimator. Table I presents some example rules of FLC that are applied in the system described in this paper.

As will be seen later, the response of the fuzzy logic controller is widely fluctuated. Such ripples are not preferred to drive the electrolyzer. Thus, to increase the efficiency and the life time of the electrolyzer, the time estimator has to burnish the portion of excess power entering the

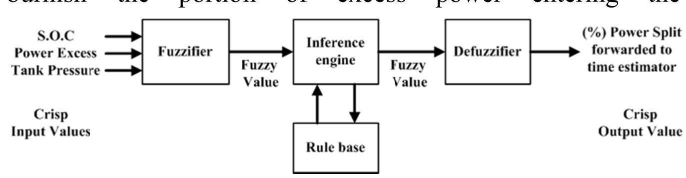

Fig. 3. Structure of fuzzy controller [16]; the output is forwarded to the time estimator, which then provides certain operational set-points of the electrolyzer.

TABLE I
Excerpt of Rule base of fuzzy logic controller

IF (SOC is Empty) THEN (Tank is Zero)
IF (SOC is E-Medium) and (Pressure is Dangerous) THEN (Tank is Zero)
IF (SOC is F-Medium) and (Pressure is Medium) and (Excess is Abundant) THEN (Tank is High)
IF (SOC is Full) and (Pressure is not Dangerous) THEN (Tank is High)

electrolyzer by constraining operation periods and set point changes, see Fig. 4. For more details about fuzzy control of the electrolyzer and the time estimator, refer to [17].

B. Dual-fuel Generator Set

A dual-fuel combustion engine – originally – is a diesel engine that has been fitted with additional devices allowing it to utilize gaseous fuel as a supplemental fuel. This engine type is a true diesel and requires some level of diesel fuel for ignition of the gas as main fuel, in practice around 1% of the total energy of the fuel [18].

The dual-fuel engines have a number of advantages. A primary benefit is that of fuel flexibility, operating with cleaner cheaper gaseous fuel when available and on diesel alone when necessary.

1) Engine Characteristics and Operating modes [18]

a) Hydrogen Gas Mode

- Running on gas and diesel pilot fuel injection.
- Automatic and instant trip to diesel mode in alarm situation without loss of engine power and speed.
- Transfer to diesel mode on request at any load without loss of engine power and speed.
- Automatic trip to diesel mode after a pre-determined number of minutes at engine loads below 15% (5 minutes are taken in this study).

b) Diesel Mode

- Running on diesel fuel injection.
- Transfer to hydrogen gas mode on request.
- Automatic transfer to hydrogen gas mode at loads below 80% without loss on engine power and speed.

Fig. 5 illustrates the modes of operation of the dual-fuel engine.

IV. Modeling and Simulations

For the investigation and implementation of proper plant control the application of a simulative model of the complete system is required. Regarding the case study pursued here, Matlab/Power System Blockset (PSB) is used for this issue.

PSB is a graphical tool that allows building schematics and simulation of power systems in the Simulink environment. PSB is used to represent common components and devices found in electrical power networks. Fig. 6 illustrates the Simulink model of the power system of the Alshiefa hospital.

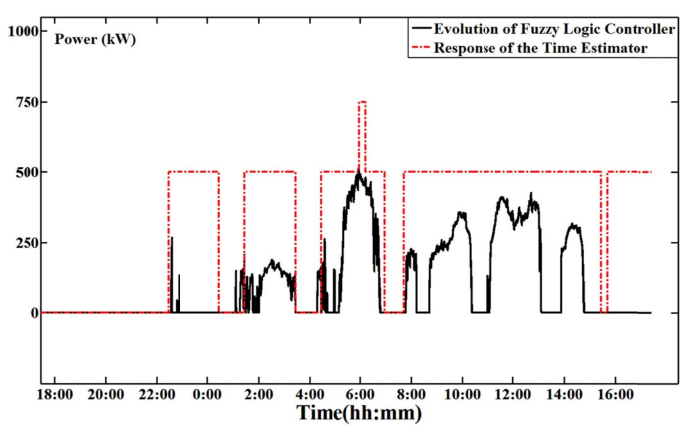

Fig. 4. Output signal of FLC and response of the time estimator (i.e. power set-points finally given to the electrolyzer), in black and red colors, respectively [17].

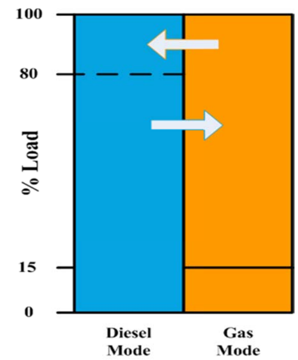

Fig. 5. Modes of operation of the dual-fuel engine [18].

Choosing the wind turbine model plays an important role to simulate the behavior of the renewable energy. Different model descriptions simulate the wind turbine output power. Linearized [19] or quadratic [20] equations can represent the output power of smaller wind turbines. More precisely, and applied here, the produced power is represented by (1) which describes the power generated by the wind turbine according to aerodynamics.

Three main parts constitute the dual-fuel generator – traditionally diesel generator as mentioned earlier. Fig. 7 illustrates the synchronous generator with automatic voltage regulator (AVR), connected to the dual-fuel engine with the speed governor. More details about the dual-fuel engine system can be found in [18].

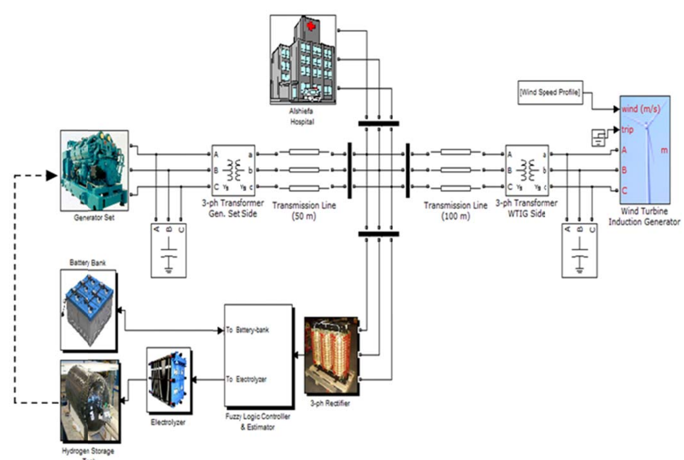

Fig. 6. Simulink model of the power system of the Alshiefa hospital.

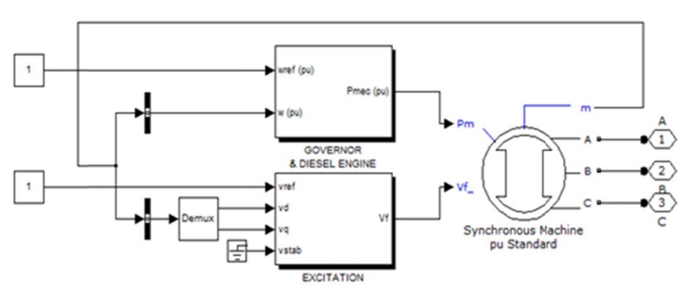

Fig. 7. Simulink model of dual-fuel generator [21].

As shown from Fig. 6, two main paths are introduced for the rectified and controlled excess power. The detailed models – for such devices given in Matlab/Simulink – decrease dramatically the simulation speed. So, simplified models – which improve the simulation speed – were applied for long term simulations.

The efficiency of the battery-bank is considered constant (75 %) including the inverter efficiency. On the other hand, the electrolyzer efficiency is taken constant here at 75 %. The produced hydrogen is stored in a vessel. The produced pressure of the hydrogen tank is obtained from the following equation [22]:

$$P_V - P_{V_i} = \int Z \cdot \frac{N_{H_2} \cdot R \cdot T_V}{M_{H_2} \cdot V_V} \tag{3}$$

where

P_{V_i} : is the initial pressure of the hydrogen in the vessel,

Z : is the compressibility factor of the hydrogen,

N_{H_2} : is the hydrogen flow in (moles/sec.),

R : is the ideal gas constant,

T_V, V_V : are the vessel temperature and volume; respectively,

M_{H_2}. : is the molecular mass of hydrogen.

Note that the compressibility factor is equal to 1 when the pressure is lower than 140 Bar [22], which is not exceeded by a so called high pressure electrolyzer that was assumed here in order to obviate an additional compressor. The vessel temperature is considered to be constant at room temperature (300 K). Fig. 8 illustrates the Simulink diagram for the hydrogen storage tank.

V. Results and Discussions

A. Wind and load profiles

As mentioned before, the case study performed concerns independent power supply of the main hospital in Gaza-Strip. The Alshiefa hospital is located at the west part of Gaza city near the sea. The city has one of the best wind potential in Gaza-Strip. The originally measured annual mean wind speed at height h_r of 5 m – to be re-calculated according to (4) – is approximately 7 m/s, while the minimum monthly average wind speed is 5.4 m/s. Fig. 9 shows the monthly average wind speed values from August, 2010 to July, 2011 for the proposed location. Equation (4) is useful to convert the anemometer data recorded at certain level to the estimated hub center (h = 56 m).

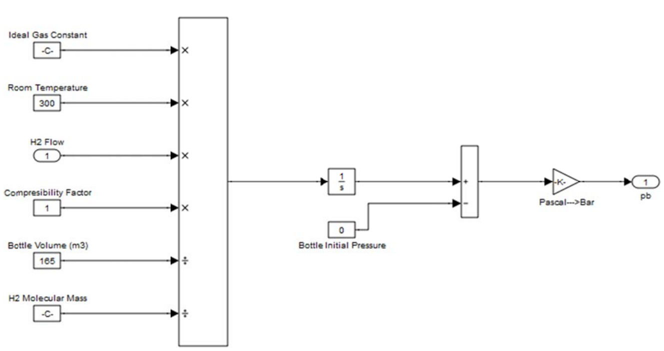

Fig. 8. Simulink model for hydrogen storage tank [22].

$$V = V_r \cdot (h / h_r)^{\alpha} \tag{4}$$

where V_r is the wind speed measured at reference height h_r and α is the ground surface friction coefficient which was set to 1.4 at the proposed location.

A sample of slightly more than one year wind speed data is illustrated in Fig. 10. It was collected according to the wind speed records taken from August, 2010 to September, 2011. Records were measured every hour for the whole time.

Fig. 11 shows the measured electrical load profile for the hospital during a day. The load data were taken every two minutes in December, 2009. It was identified that the daily electrical load profiles are almost the same during the year cycle; this is evident since the clinic service continues 7 days a week. According to the consumption records, the peak load is fairly higher than 800 kW, while the daily consumed energy is about 11 MWh.

B. Optimization and Components Sizing

As indicated previously, the example stand alone power system consists of a wind turbine, a generator set, an energy storage system, and an electrical load. The sizing of the relevant components (based on Particle Swarm Optimization, as described in [23]) has resulted in a combustion engine driven generator with 800 kW, while the wind turbine induction generator was rated at 1150 kW. These two sources of energy are connected to the variable load through short cable connections.

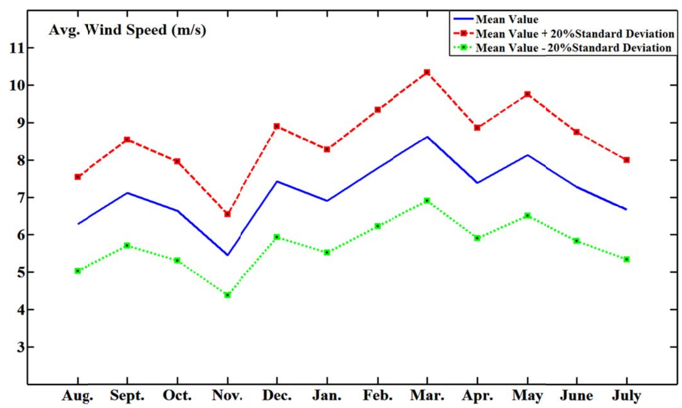

Fig. 9. Average monthly wind speed values at coastal area – Gaza.

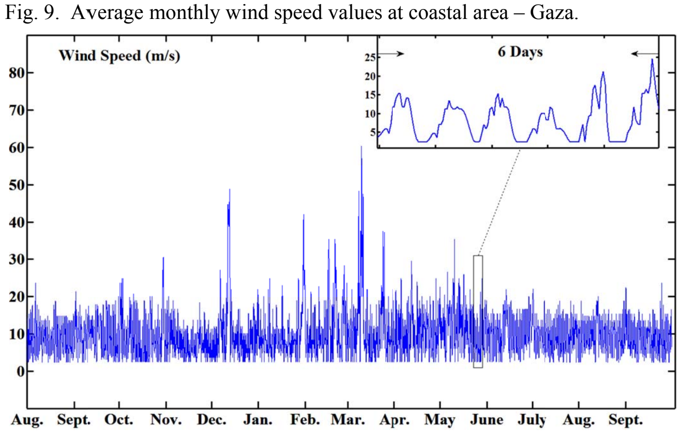

Fig. 10. Recorded wind speed data (from August, 2010 to September, 2011); the small excerpt window showing more details is for the same periods of time as those in Fig. 13 – 17, so that they can immediately be compared.

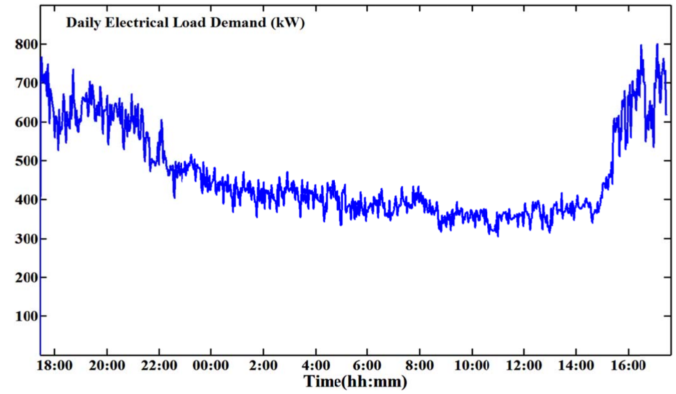

Fig. 11. Daily electrical load demand for Alshiefa hospital.

The corresponding size of the battery-bank should be 1.44 MWh, while the volume of the cylindrical hydrogen storage tank is 165 m^3 – maximum capacity is 63 MWh of the surplus energy – and can withstand 140 Bar as maximum pressure at electrolyzer output. The nominal power of the high-pressure electrolyzer is 1000 kW.

With this sizing of plant components, the annual diesel fuel consumption would be only 530 tons/year instead of 1690 tons/year with pure diesel based generation (i.e. not yet having the produced hydrogen re-used as fuel); the fuel saving with hydrogen re-use is much higher, as to be seen later.

Fig. 12 represents the characteristics of the (S66-1.25MW, Suzlon) wind turbine – the data of which were used in the simulations. For more details, refer to [24].

C. Simulation Results and Discussions

The simulation results shown in the following have been obtained in Matlab-Simulink environment using SimPowerSystem toolbox.

It is clear from Fig. 12 that the rated wind speed is 14 m/s for the wind turbine induction generator with a nominal power of 1250 kW. This means that the wind turbine induction generator produces its maximum power (1250 kW) only when the available wind speed is above 14 m/s and below the cut-off speed of 25 m/s. Fig. 13 illustrates the amount of the electrical power that was produced during the whole period of time from the wind turbine; the simulation resolution was set to 1 hour.

In consequence, the dual-fuel generator set produces electricity – either by diesel fuel or hydrogen gas – in order to cover the instantaneous deficit electrical power. Fig. 14(a) illustrates the shared amount of the electrical power produced from the diesel fuel, while Fig. 14(b) shows the amount of power produced during the hydrogen gas mode, respectively. More precisely, the produced amount of the electrical energy from both modes of operation – for the whole period of operation – would be 660 MWh and 1065 MWh sequentially for diesel mode and hydrogen gas mode.

It is observed in Fig. 15 that the electrical load sometimes increases sharply. In order to avoid dangerous levels of hydrogen pressure, a 200 kW additional resistive load for hot water preparation is connected to the system directly when the pressure of the hydrogen tank exceeds a certain limit (in our case 120 Bar); this can be seen in Fig. 15 in the months of

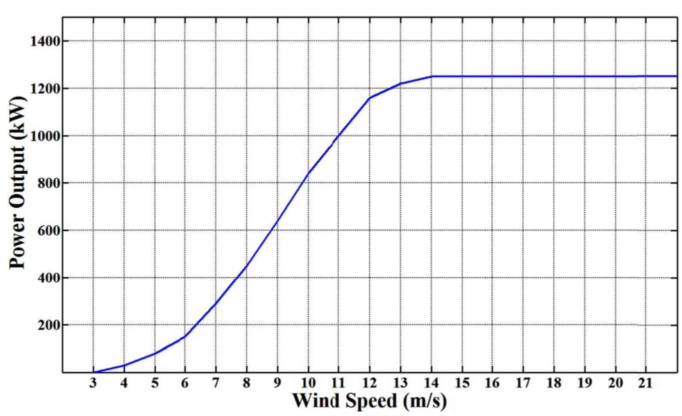

Fig. 12. Characteristics of S66-1.25MW wind turbine, Suzlon.

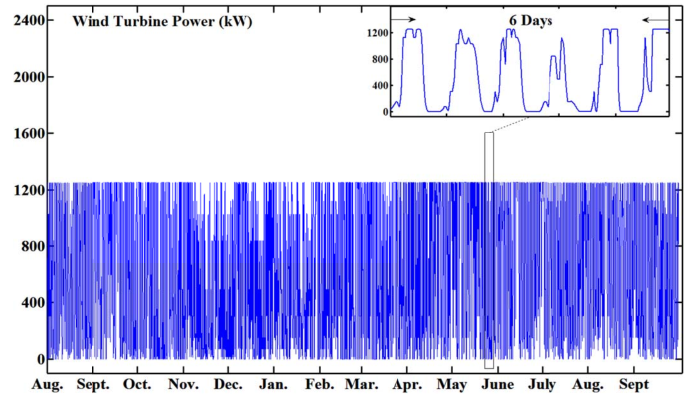

Fig. 13. Delivered power by the wind turbine.

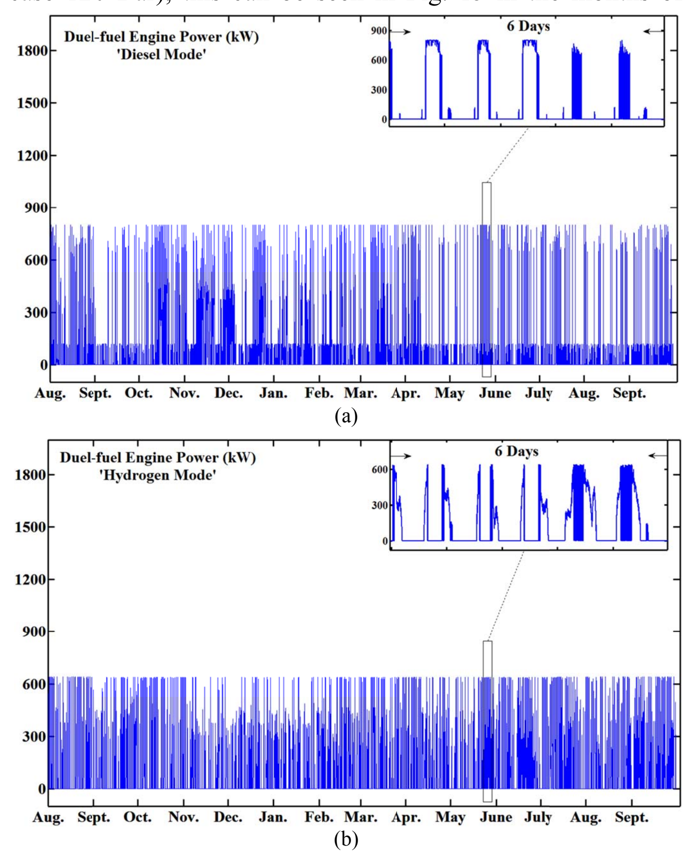

Fig. 14. Delivered power from dual-fuel generator set; (a) diesel mode; (b) hydrogen gas mode; for the ratio of maximal powers in diesel and hydrogen gas modes, respectively, see section III.

May, June and July. It continues at least 6 hours. Any instantaneous load increase within these periods of time – that exceeds the generator set nominal power – can be covered by the accumulator bank.

To investigate the effectiveness of the FLC in controlling the proposed energy storage system, electric power excess – Fig. 16 – should be considered. Fig. 17 shows the evolution of time estimator giving the set points of the electrolyzer. The difference between excess power and power absorbed by the electrolyzer is steadily compensated by the accumulator, see [17].

The SOC of the battery-bank and the development of the pressure of the hydrogen storage tank are illustrated in Fig. 18. It is observed that the SOC was specified to a certain level (720 kWh) at the beginning of simulation and is largely maintained on average. It is also noted the fast response to the variations in the battery-bank SOC – which is the idea behind it. The main role of the battery-bank in the proposed system is to work as a buffer of the excess energy to burnish the input power for the electrolyzer. Thus, it can readily deliver or absorb the power according to the input power of the electrolyzer. It can also deliver power to the electrical load to cover the sudden peaks and sharp variations.

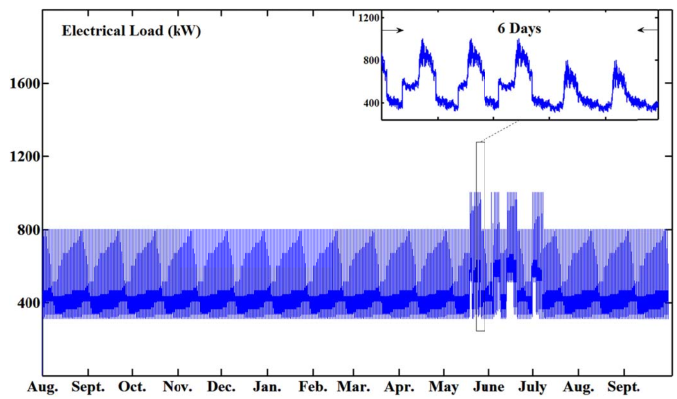

Fig. 15. Electrical load demand for Alshiefa hospital.

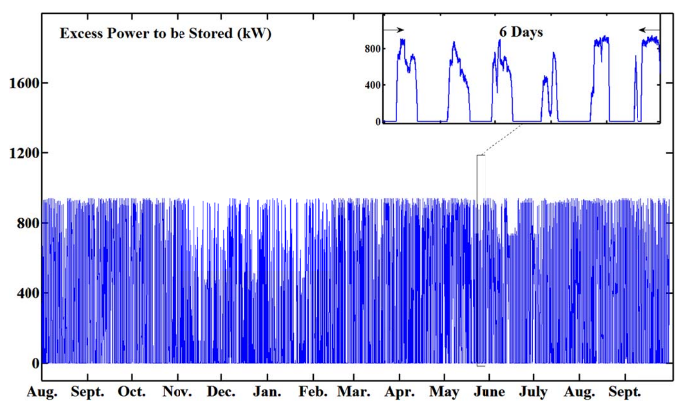

Fig. 16. Power excess to be stored.

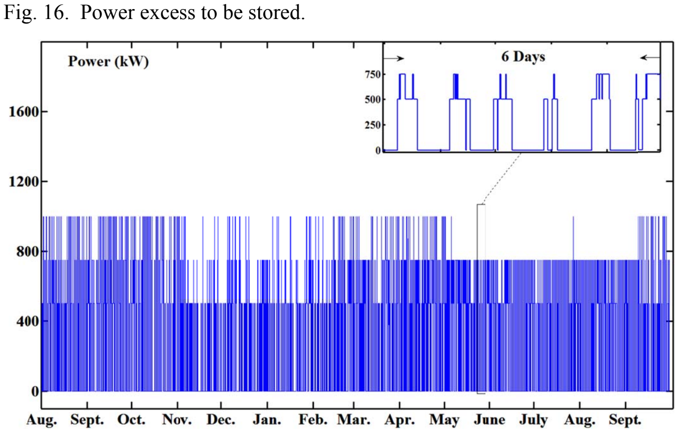

Fig. 17. Response of the time estimator.

It is clear from the obtained results that the proper sizing of the particular system components under pre-determined constraints and restrictions and the efficient management – storing and releasing – of the excess power improve the overall system efficiency and maximize the diesel fuel saving. Selection of the appropriate energy storage devices – accumulator-bank and hydrogen tank – yields also to a permanent supply of energy taking into consideration the maximum calm spell; i.e. the longest non-windy period of time in one year.

Table II illustrates the sharing amount of energy produced from the wind turbine E_{wind}, the diesel mode of the generator set E_{diesel} and the hydrogen gas mode of the generator set $E_{hydrogen}$, in addition to the energy consumed by the hospital $E_{hospital}$, respectively.

TABLE II
ENERGY SHARING (FROM AUGUST, 2010 TO SEPTEMBER, 2011)

Symbol	Value
E_{wind}	6375 MWh
E_{diesel}	660 MWh
$E_{hydrogen}$	1065 MWh
$E_{hospital}$	4715 MWh

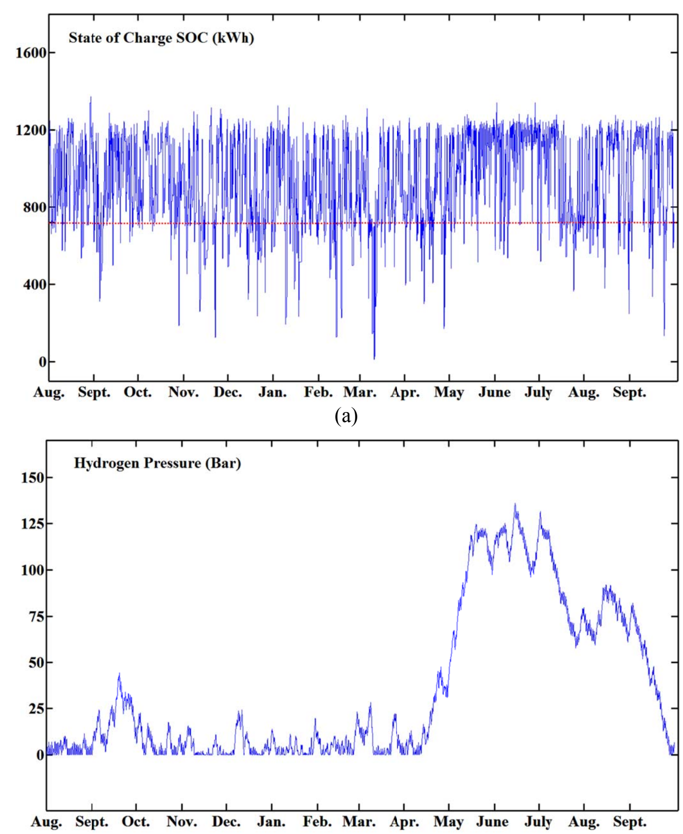

Fig. 18. (a) Charging state of battery-bank; (b) Pressure of hydrogen tank.

It is noticed that the diesel fuel consumption is only 280 tons instead of 1975 tons with pure diesel based generation for the same period of time. More deeply, one can strongly say that the proposed hybrid wind-diesel power system performs significant cost advantages in comparison with diesel fuel only; and this even under inclusion of the investment cost as shown in [23]. The corresponding fuel cost is relatively higher than 0.4 Million Euro, being less than 15% of a diesel-only solution (about 2.96 Million Euro) to provide independence of the public grid.

These impressive results – especially economically ones – encourage the responsibles to use such clean sources of energy, achieve fuel cost saving and relative independence of fuel delivery, as mentioned before.

VI. Conclusion, Summary, and Outlook

A hybrid wind-diesel power system was investigated in this paper, applied to a stand-alone electricity supply of the main hospital in Gaza-Strip as a relevant and realistic case study. MATLAB/Simulink models were introduced for the wind generator, dual-fuel generator set, hydrogen storage path and accumulator bank. Simulation results over one year, based on real wind harvest and load data, proved that the chosen rating of components in connection with the implemented operation strategy for the plant leads to efficient, continuous and independent supply with an amount of used diesel fuel below 15% of that needed for conventional independent electricity supply purely based on diesel generation.

Further work will aim in additionally investigating re-use of the waste heat of the combustion engine. Regarding the hospital example, surgical demands, air conditioning (by absorption coolers) as well as hot water supply are vigorous heat absorbents. In this way, the overall efficiency of the system can further be enhanced.

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