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3D Sustainable Renewable Micro Power Station for Smart Grid Industrial Applications

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***Abstract*—**The supply of clean energy and its security is becoming a global issue for all countries across the world, due to the limitations of fossil fuels resources usages for energy generations, the relative high dependency on imported fuels, their ever climbing prices and its environmental impacts. Power supply must increase as rapidly as demand to ensure sustained growth. This is the rationale upon which Governments, international organizations, researchers are accelerating investments in expanding the power system, its generation and transmission. This paper presents the preliminary research undertaken to design and develop a 3Dimentional (3D) sustainable renewable micro power station model for smart grid industrial applications. It introduces a solution to challenges in the energy generation sector which do not only refrain only to the safe supply of clean Energy. A major importance for the theoretical study of hybrid systems, based on renewable energy (photovoltaic, wind, hydro system) is the availability of the models that can be utilized to study the behavior of hybrid systems and most important, computer aided design simulation tools. As the available tools are quite limited, this paper would present the most current and up to date model which can be used for the simulation purposes of the 3D sustainable renewable micro power station for smart grid applications as well as for educational purposes.

***Keywords*—**3 dimentional (3D), hybrid, smart grid, fossil fuels, hybrid systems.

I. Introduction

IT is believed that the development of sustainable energy systems using renewable energy resources is one of the solutions to successfully reduce global carbon emissions and promote the usage of Green technology. Development of power infrastructure is capital intensive and can also have significant risks, social and environmental impacts [1].

There is always a need for a sound strategies and potential planning for the power sector. Shortcomings in good strategies and plans will result in inadequate supply or costly over investment. Good strategies and plans are critical for developing countries. This is due to their limited access to power which constrains their growth, scarce capital, fragile social and environment conditions. These developing countries challenges are transnational in nature and must be trans-institutional in solutions.

Vulnerability of the power system and its potential environmental and social impacts can be mitigated through diversification of the hybrid power generation. Diversity is attained when the hybrid generation has variety in the number of options that can utilised, disparity among the options (different generation sources and technologies), and balance in the contribution of the options. The importance of hybrid systems has grown as they appeared to be the right solution for a clean distributed energy production. It has to be mentioned that new implementations such as the hybrid system, require special attention on analysis and modelling. Basic components of Regen-Sim library are: Wind generators, PV generators, Hydro generators and Storage devices. Each of these components was basically modelled on studies of mathematical models. Except for Storage device component, each of the other three components has, their individual input parameters, specific primary source of energy and, through interconnection with different types of measurement and display blocks of MATLAB, voltages, currents. The Storage device component was designed with the primary function of serving as a buffer to store the energy produced by renewable sources, from its terminals being directly supplied the DC consumers and the AC through the inverter blocks.

The main aim of this ongoing research presented in this paper is to develop and optimise the possible business and technical model of 3D sustainable renewable micro power station for smart grid industrial applications. The 3D model is to include but not limited to thermal (solar), wind and hydro power systems. Each 1D i.e. source of the power resources has been evaluated considering, availability, system efficiency, performance, cost, social and environmental impacts factors.

II. Technical Approach to the Development of the 3D Sustainable Renewable Micro Power Station

A MATLAB Simulink system would be used in order to evaluate each of the 3D elements of the design; this includes the solar, wind and hydro system.

A. PV System

Evaluation of the Solar System:

The conditions for Photovoltaic (PV) cell measurement are standardized for comparison purposes but may not reflect actual operating conditions. Considering a review of few literatures, the best PV cell efficiencies are estimated at 24.2 % [2] and the highest efficiencies devices demonstrate few

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practical limits without regards to cost or manufacturing considerations hence a simulation of the PV cells at average testing conditions were carried out and presented with an average output voltage of 22.5 volts at a temperature ranging from 0◦ to 25◦C.

PV Temperature & Output Voltage Analysis

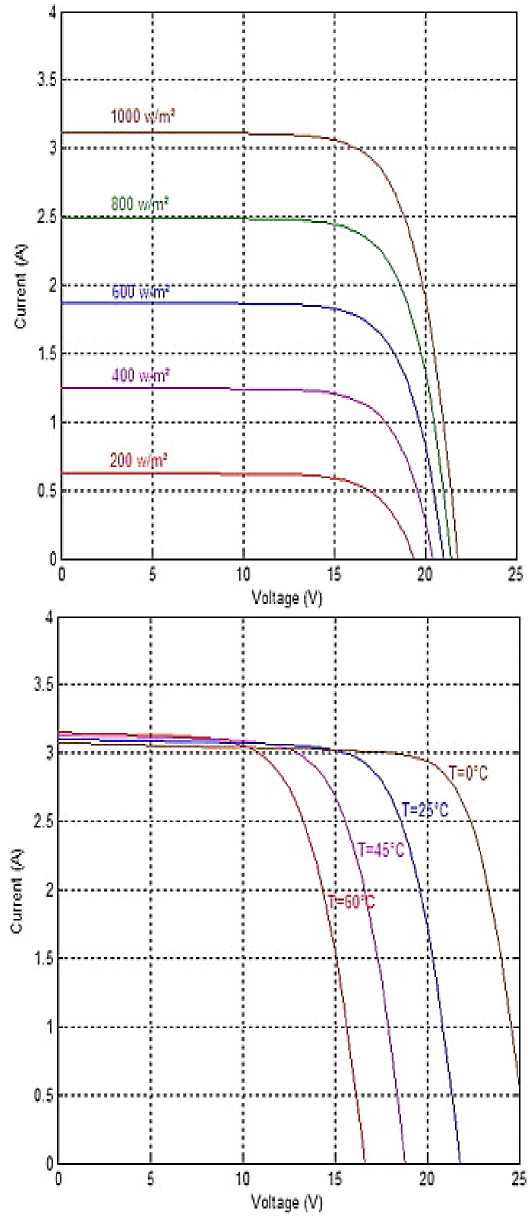


Figure 1 PV cell temperature and irradiance variance test

Figure 1 shows the evaluation of the solar panel under ideal testing conditions, considering the voltage output and the power generated. It can define a single PV cell to produce approximately 3.15 Amps which is quite ideal for a micro power generation system.

1D Solar System

Photovoltaic systems are systems made up of solar panel which converts light emitted from the sun to electrical energy. Each panels used is rated by its own unique DC output power. Currently the best commercial solar panel efficiency is around 17.4%. PV system output for micro scale power system can be expected to be around 24 V and upwards depending on cell sizes and irradiance. Considering our intended 3D design, a sample panel was chosen for which the technical details would be used to define its efficiency and a MATLAB/ Simulink simulation would be carried out to evaluate its output. These data would be used for the Practical design of the 3D unit.

TABLE I PV CELL TECHNICAL DATA

Technical details		
Cell Material		Mono Crystalline
Maximum power		20 watts
Nominal voltage		12 volts
Maximum voltage		17.6 volts
Open circuit voltage		21.8 volts
Maximum current		1.14 Amps
Short circuit current		1.25A
Maximum system voltage		600 volt
Dimensions	length	24 ½ inch
	Width	10 ¾ inch
	Thickness	1 inch
Glass thickness		3.2 mm
Maximum wind resistance		65 m/s -145 MPH

The technical details of the solar panel provided are ideal for micro power generation considering the maximum power output and the current magnitude. In order to define the system efficiency, it would assume that the power supply needed is for 2 x 20 watt bulbs and a fan of 20 watts.

System Setup

Considering a 4 hour backup time,

$$Total\ Load\ =\ 44\ h \times 40\ watts$$
$$=160WH^{-1}\ (watts\ per\ hour)$$

Measure battery Ampere needed for the load

$$Current\ (I) = \frac{160}{12} = I = 13.33\ AH$$

This means that the battery needed is a 12 volts / 14 AH

Generally a battery charging current = 10% of its AH therefore:

$$The\ charging\ current\ (I) = \frac{13.33}{10} = 1.4\ Amps$$

$$Solar\ panel\ needed\ =\ 1.4\ A\ \times 12\ volts$$

$$Therefore\ Power\ =\ 16.8\ watts$$

From these data it can assumed that the charge controller is 12 v/ 1.4 Amps.

System loss is not added to these measurements, so as recommended a 25% system loss will be added

Solar panel = 20 watts

Battery= 12 volts, 15 AH

Charge controller = 12 volts / 2Amps

The efficiency of the solar panel can then be calculated Light from sun to earth surface is estimated at $1M^2 = 1KW$

Therefore:

$$Efficiency = \frac{Output\ power}{Input\ power} \times 100\%\ ; \frac{16.8}{1000} = 16.9\% \approx 17\%$$

Figure 2 The PV arrays and technical details [3]

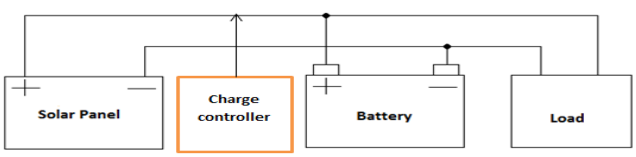
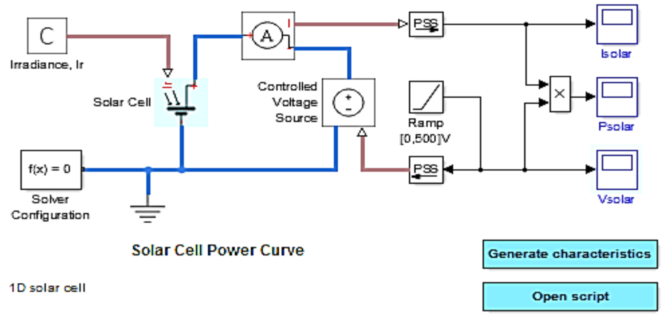


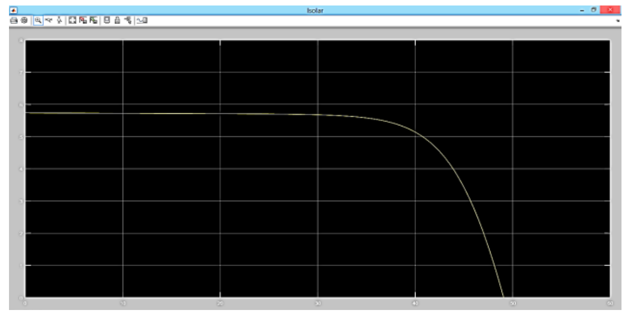
Figure 3 PV system setup, main components and connection mapping

MATLAB/ Simulink Design & Simulation

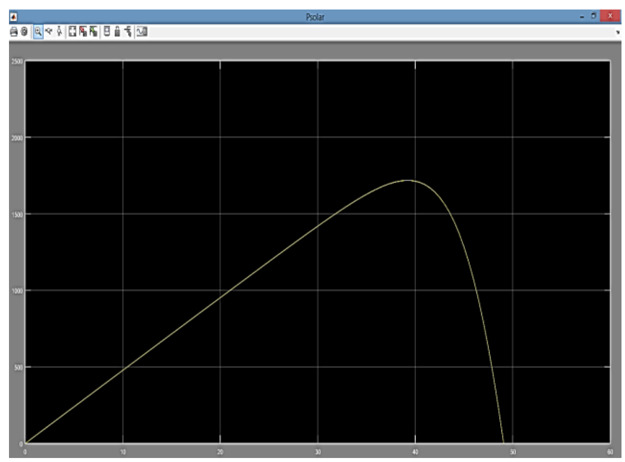
Since the field tests can be expensive and depend primarily on weather conditions it is very convenient to have simulation models to enable work at any time. For this reason the research investigates a simple one-diode solar cell mathematical model, which was implemented applying MATLAB script. The model can be considered as an easy, simple, and fast tool for characterization of different types of solar cells, as well as, determines the environmental conditions effect on the operation of the proposed system. It can conclude that the changes in irradiation mainly affect the output current, while the changes in temperature mainly influence the output voltage.



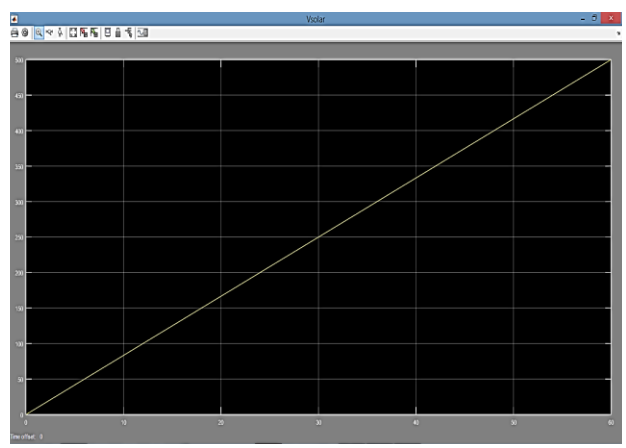
(a) 1D solar system



(b) Output current (I)



(c)Output power (w)



(d) Output Voltage (V)

Figure 4 (a) MATLAB designed PV module, (b) current, (c) power, (d) output voltage characteristics

Solar Converter System:

The controller senses the grid voltage and current and gives the corresponding grid active and reactive power. The power controller senses the inverter output voltage and current and gives the corresponding active, reactive power. The current controller is mainly used for getting a triggering pulse as per the reference value. Using the Proportional Integral (PI) controller as shown in **Figure 4(a)** the reference current (Idref) is obtained with the load voltage, load current which is used to determine the RMS value of the load. By using PI controller we can get quadrature axis reference current which is another input of current controller.

The single stage solar converter model simulates one complete AC cycle for a specified level of solar irradiance and corresponding optimal DC voltage and AC RMS current [4]. Using this model, the optimal values have been determined as 230V DC and 3.15A AC for an irradiance of 1000W/m^2 and panel temperature of 33 degrees Celsius. Efficiency is determined in two independent ways. The first compares the ratio of AC power out to DC power in. The second calculates losses by component by making use of Simscape logging. The small difference in calculated efficiency value is due to differences between trapezoidal integration used by the script and the greater accuracy achieved by the Simulink variable-step solver.

The characteristics of Solar PV system behavior have been developed. The results of the solar PV system provide the current and the inverter tracks the reference current from the solar PV and supplies to the grid. The simulation of the power converter shown in Figure 4 shows the representation of the PV system. The simulation shows the DC voltage being the first simulation, the Demanded AC RMS current, the AC voltage and AC current. The simulated PV module circuit helps in understanding the PV characteristics, DC to DC converter topologies, component calculation & circuit design. A step by step procedure of modelling the PV module is shown. In the simulation model, the curve between P-V & V-I is shown in **Figure 5** for varying temperature & varying irradiance. It was then interfaced with a buck-boost converter. The results obtained from the model show close correspondence to manufacturer's curve. The results as it can be seen provides a clear and concise understanding of the I-V and P-V characteristics of PV module which will serve as the model for the 3D design modelling.

B. Hydro System

Evaluation of the Hydro System

This section focuses on the analysis of the power generation feasibility of both a pump as turbine (PAT) and an experimental propeller turbine, when applied to water supply systems. This is completed through an analysis of the electrical generation aspects of the PAT's induction motor and of a permanent magnet DC motor, which was connected to the propeller turbine. The collected data allows for parameter optimization, adequate generator choice and computational modelling. These tests constitute a good sample of the range of applicability of small scale turbines as valid solutions for micro-hydro systems. It is also possible to consider multiple scenarios, such as rescaling/resizing, for larger turbines and systems, and the use of power electronics for further efficiency enhancing.

Hydro Turbine Modelling

The free flows of water caused due to gravity from higher to lower geodesic points have various yet specific kinetic and potential energies. For a stationary hydro system, lossless and friction- free flow with incompressibility are mostly experienced [5], the difference of energy between the two geodesic points can be calculated using Bernoulli pressure equation:

$$p + \rho_{water} gh + \ +\rho_{water} v_{water}^2 = constant \qquad (1)$$

Bernoulli's equation can be transformed so that the first, second and third term expresses the pressure level, the level of the site and the water velocity level respectively.

$$\frac{p}{\rho_{water} g} + h + \frac{1}{2}\frac{v_{water}^2}{g} = constant$$

The practical difference in head measurement (h_r) can be defined through a gradient definition of the difference in pressure, in height and in velocity of the water flow:

$$h_r = \frac{p_2 - p_1}{\rho_{water} g} + (h_2 + h_1) + \frac{v_{water1}^2 - v_{water2}^2}{2g} \qquad (2)$$

Considering Bernoulli's pressure equation, the power generated by the water could be expressed as P_{water} which magnitude can actually be determined by using:

$$P_{water} = \rho_{water}\, g q_{water} h_r \qquad (3)$$

"q_{water}" is considered as the volumetric related flow rate, one can then use the Bernoulli's equation to determine the power generated considering the volume of flow and the practical head. One must then consider on a more practical approach two different heads of the river in order to define the power by doing:

$$P_{water} = \rho_{water}\, g q_{water} \,(h_2 - h_1)$$

Considering the Micro hydro turbine, the energy generated through the rotational movement of the turbines is converted into a mechanical power with some micro losses during conversion described by the turbine efficiency $n_{turbine}$ where the power available at the turbine shaft is given as:

$$p_{turbine} = n_{turbine}\, \rho_{water}\, g q_{water} h_r$$

Where the torque of the turbine can be found by:

$$T_{turbine=} \frac{p_{water}}{\omega r} \qquad (4)$$

where: ωr represents the rotor angle speed.

In micro hydro power generation system such as the one presented in this design, the height is kept constant by the use of a fore bay tank, while the volume- related water flow can be adjusted manually using an upstream guide vane. To avoid the repercussions of load variation on the generator dummy load, load controller or ballast load are used for power balancing when the system is used as stand-alone.

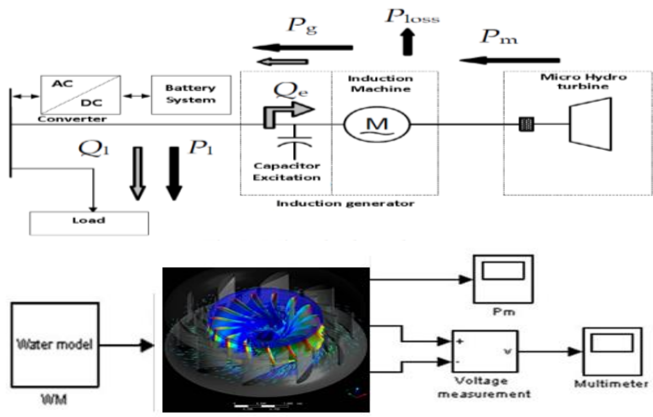
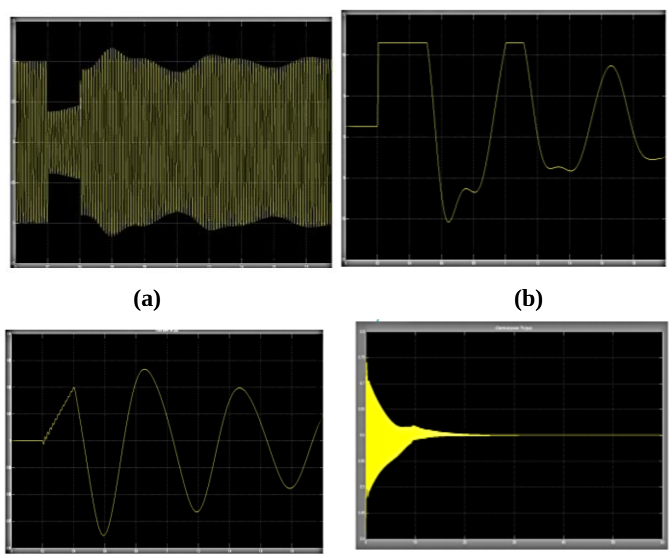


Figure 5 Micro hydro power induction generator/ turbine (Simulink)



(a) **(b)**

(c) **(d)**

Figure 6 Output waveforms (a) Output voltage of generator (va); (b) Excitation voltage (vf), (c) Speed characteristics vs time; (d) Active power

The modelling and simulation of the micro hydro turbine was carried out done in this paper using MALAB/Simulink tools. The simulation results as shown in figure 6 shows that with proper choice of governing system, the micro hydropower system leads to proper load sharing, constant voltage output and constant speed with variation of load values. This leads to an economical operation of the system. The modelling of this system can be made more accurate and attractive by introducing a voltage regulator block, a battery for storage system, a reactive power control block, etc. The introduction of a control device block to control the power quality of the system may be incorporated in the modelling. Given the results obtained in laboratorial testing and due to the nature of water supply systems, the chosen (and simulated) control method was the one resorting to flow control valves. The objective of these simulations was to control and avoid a runaway situation, which results from a load withdrawal on the generator. MATLAB/Simulink was used. The control scheme is described below and the simulation results are presented.

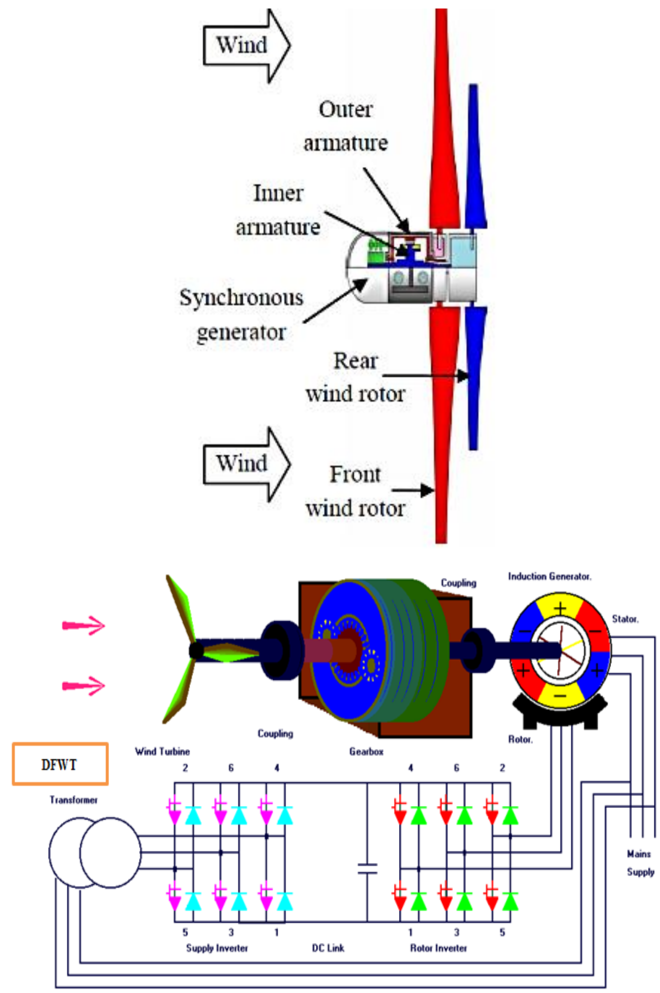


Figure 7 Contra rotation double rotor wind turbine

The system capacity may be enhanced up to 100kW (maximum limit of micro power generation) and other option for connecting other renewable energy sources may be exercised. This may be tested for some realistic load patterns of some chosen areas. As it can be noted from the output waveforms, active power characteristics **Figure 6(d)** of the synchronous generator, shows a steady state value of 0.6 pu i.e. 1800 W which is nothing but the actual load connected to the hydro system. It is observed that the steady state is obtained around 27 sec. To reach the stable operating point on power - angle characteristics, few oscillations around this point occurs. This leads to initial overshoots of the power characteristics of the micro hydro turbine system.

C. Wind Turbine System

The most used and conventional type of wind turbine are made up of large sized wind rotors that are known for spawning high outputs even in the presence of moderately strong winds [6]. Considering this theory, the relative output of a smaller wind size turbine is micro generated as the blades respond mostly to weaker winds. The theory then suggests that the application or decision of wind size blades is a direct result of the wind presence and its studies in different areas. The conformity of wind turbine size to potential wind circumstances are equipped with brakes or pitch control mechanism strategies enabling them to exercise control of turbine speeds and protect the generator when in abnormal rotation due to wind speed.

The contra rotation double wind turbine however is made up of a double rotor wind turbine that initially rotates at low wind speed namely but one of the rotors mostly the smaller turbine, rotates against the front wind turbine. As wind speed increases, both rotors speed increases but the smaller turbines are the rear is even faster due to its smaller size and also due to the direction of winds hitting the blade.

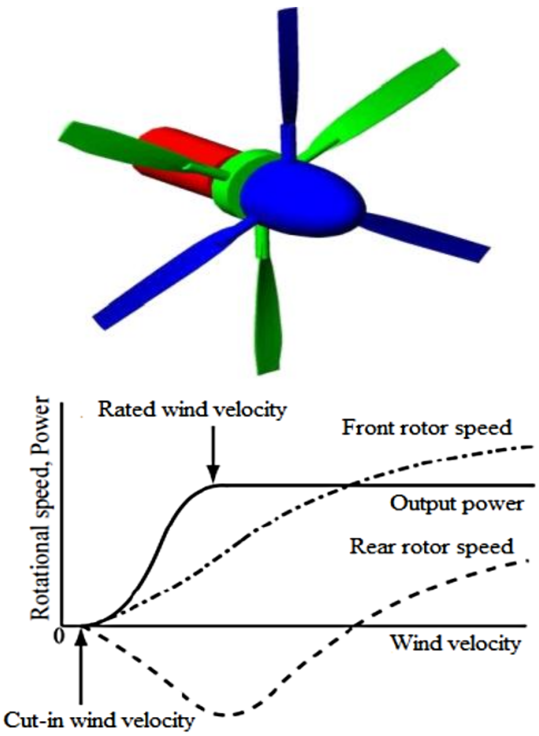


Figure 8 Contra rotation double rotor wind turbine front & rear blades isometric and front view with operational mode

Operation of contra rotation double rotor wind turbine

In order to understand the operation of the contra rotation double rotor wind turbine, a simulation using computational fluid dynamics and a 3D Inventor modeling program (Inventor 2008) version was used for the two and three dimension wind turbine. It then used FLUENT DDP in CFD to define the lift, drag and pressure coefficient. The same tool was used to define force components which show the impact of velocity increase, wake and wind energy turbulence. Considering the aerodynamic analysis conducted, a flow determinant issue was found around the distribution of velocity, and pressure variance in axial direction. Initial simulation made considered 60cm diameter for the front rotor placed in a wind tunnel of a 150×300. Initial results showed that flow conditions were steady and front rotor speed reached 600 rpm and 3.14 tip speed ratio for the rear rotor. Testing conditions shows that wind directions are of a uniform velocity prior to hitting both rotors hence the boundary conditions for the rear blade are initial velocity vectors for the front rotor. The pickup boundary Three dimension wind turbine rotor is produced using.

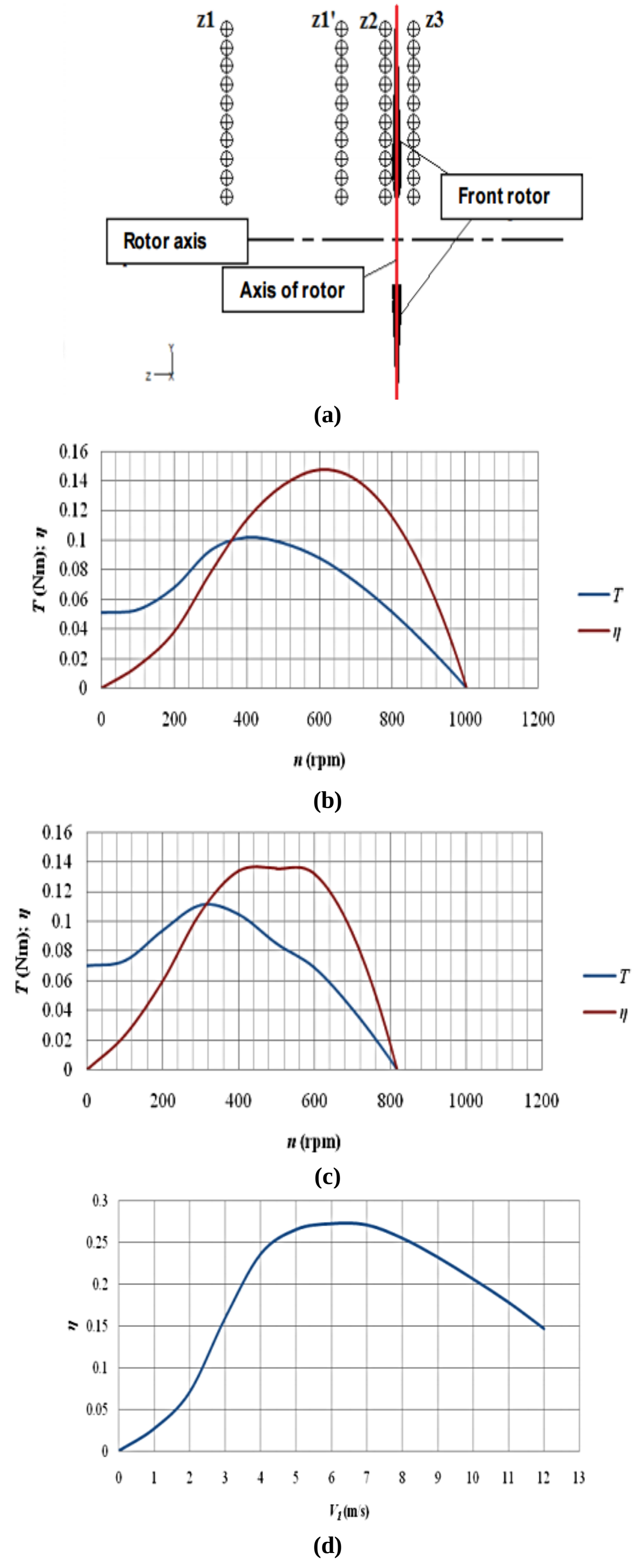


Figure 9 (a) Position of pick up velocities & (b; c) torque/efficiency vs rotational speed (front & rear) (d) efficiency vs wind velocity [Inventor, 2014]

Simulation Results

Using the 3D FLUENT DDP, the two/three dimension rotors were tested and simulated using optimum blade designs methods showing excellent results and similitude. The analysis carried out and compared by fluent shows that there is a slight difference between the resultant velocities which is indeed normal as the velocity at the rear turbine would essentially be different from the front turbine. The calculation result of velocity resultant distribution along the blades as well show similar differences where the torque is 15 Nm and the efficiency is about 34% at 500 rpm. Using numerical simulation Fluent, the torque obtained is approx. 13 Nm and the efficiency is about 29% at 500 rpm. Similarly both efficiencies for the contra rotation double rotor wind turbine calculated using calculations and fluent shows similar results and trend. As one can deduct from **Figure 10**, both rear and front rotor have similar order of torque which is an ideal performance for this wind system. Considering all, it could say that the methodology used for this design analysis and testing is a perfect tool for optimum blade profile where the numerical simulation is perfection for preliminary design in order to have estimated design and testing characteristic of contra rotation blade span.

III. 3D System Software Unit

The 3D system architecture is shown in **Figure 10** and its software unit is presented in **Figure 11**. The system architecture was modelled as such that the one or various types of primary energy sources with different parameters, and onverters could easily be integrated making the system an innovative sustainable and smart hybrid system with different topologies of the local distribution system and last but not least different types of consumers with linear or nonlinear characteristic. It shows the amalgamation of three renewable energy sources representing a novel adaptive system for efficient sustainable energy production and management.

System Architecture

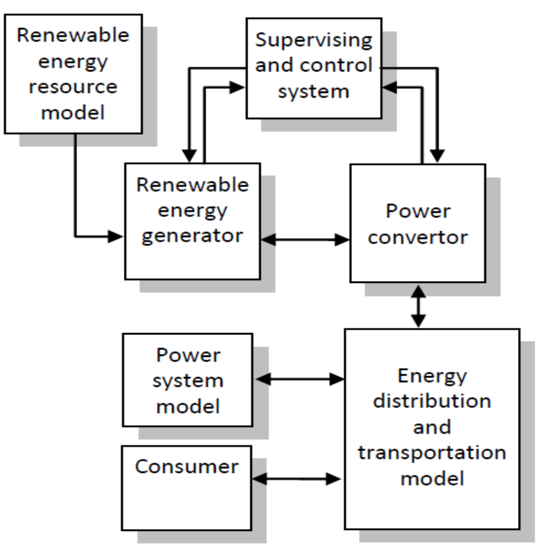


Figure 10 3D System architecture

MATLAB /Simulink Model Implementation

The 3D system CAD model is presented in **Figure 11**. It shows the dynamic behavior of the proposed model which is examined under different operating conditions. Real-time measured parameters are used as inputs for the developed system. The proposed model and its control strategy offers a proper tool for optimizing hybrid power system performance, such that it may be used in smart-house applications. SIMULINK models are developed; using MATLAB simulations software to highlight the characteristics of the output power characteristics. In addition, reactive power compensation of the electric grid is included, operating simultaneously and independently of the active power generation. In order to be able to simulate the system, power generation blocks (PV, wind / hydro, battery blocks) were used together with measurement tools for power, current and voltages. An AC/DC voltage busbar and voltage regulator blocks were also used.

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Simulation Results

The simulation was achieved as a result of the model developed in REGENSIM where the system behavior was studied with the availability of a power network studied under different circumstances where different input parameters led to different configurations and output. Considering the analysis and mathematical assumptions done for the design, a linear and a nonlinear consumer load system (Pi=33kW) was used with the renewable energy sources values ranged between 0.7-3kWh/m2 for the photovoltaic system, a 2 to 23 m/s for the contra rotation double rotor wind turbines and a water flow speed ranging from 30 and 1001/s at 40m level difference from the hydro source.

IV. Results and Discussion

The simulation results show the output of the 3D renewable sustainable micro power station for smart grid, house and industrial applications. Figure 13 shows the active and reactive power produced through Simulink simulation generated form the three renewable energy sources (PV, wind, hydro) as it can be noted from the system software unit. As one can note from the architecture, the energy generated is directly fed into the storage "battery" where load power is driven from. This also is ideal for meeting losses in the network where the surplus power generated is directly injected into LPN (local public network). Active power shows approximately $3 \times 10^4\ W$ generated for both active and reactive power which shows that power compensation within the network is efficiently managed with the capacitive bank within the network. It can then conclude from the simulation analysis that the presence of reactive power is a result of the nonlinear elements used within the simulation model thus the power transformers, converters based on electronic switching elements and the highly nonlinear nature of the consumer loads as seen in **Figure 12**.

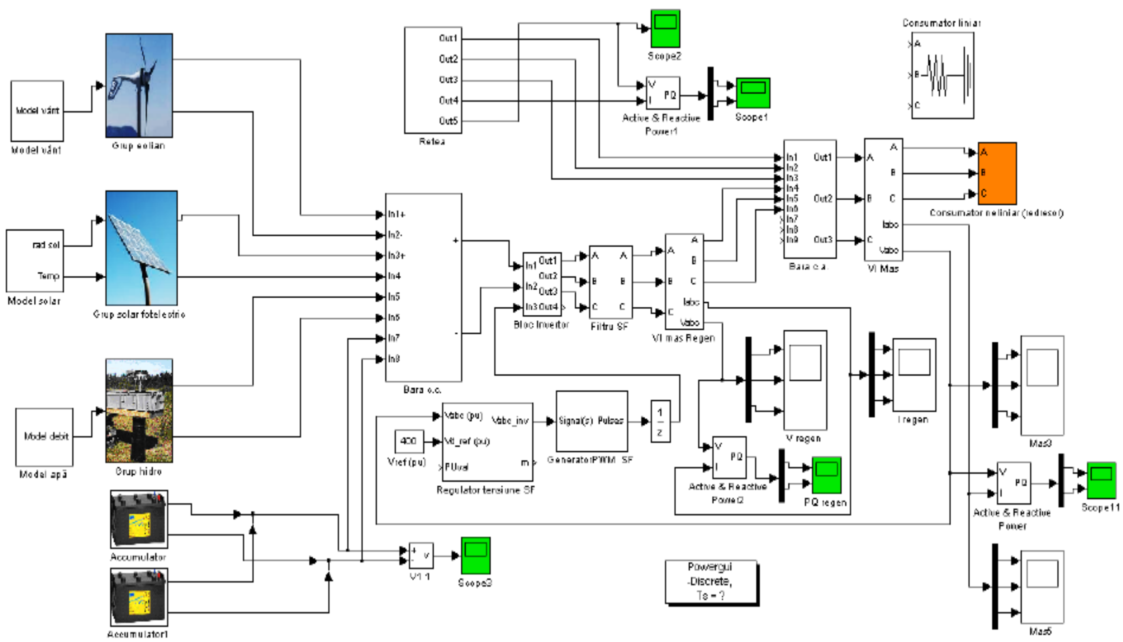

Figure 11 3D system CAD simulation model

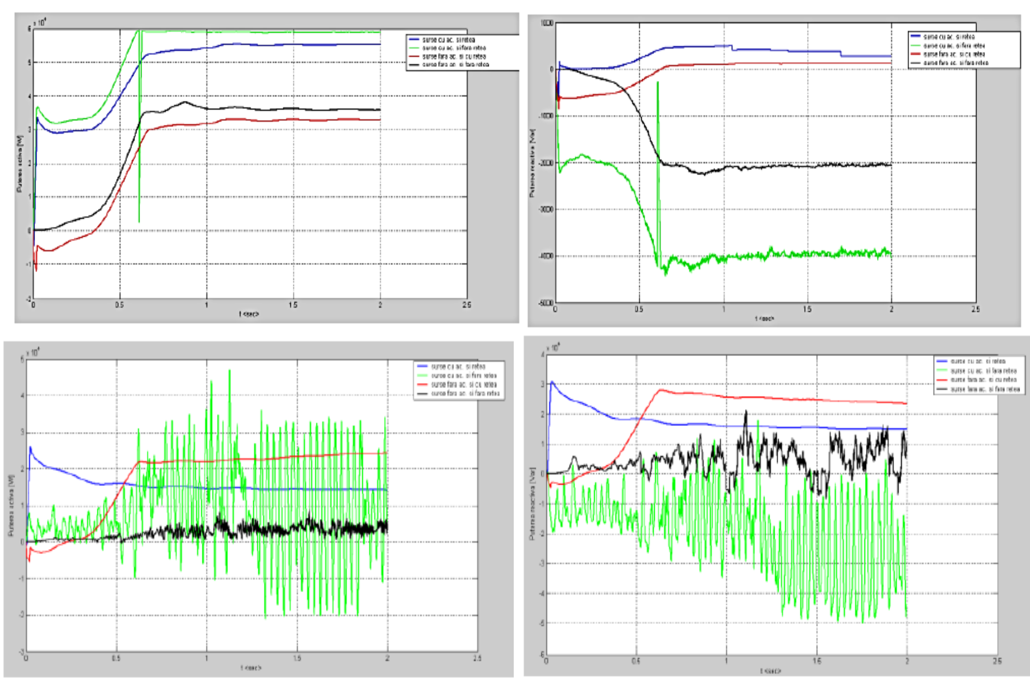

Figure 12 Renewable energy sources: active and reactive power

V. CONCLUSION

The paper presented the preliminary research undertaken to design and develop a 3D sustainable renewable micro power station model for smart grid industrial applications. It introduced a solution to challenges in the energy generation sector which do not only refrain only to the safe supply of clean Energy. A major importance for the theoretical study of hybrid systems, based on renewable energy (photovoltaic, wind, hydro system) is the availability of the models that can be utilized to study the behavior of hybrid systems and most important, computer aided design simulation tools. As the available tools are quite limited, this paper presented the most current and up to date model which used for the simulation purposes of the 3D sustainable renewable micro power station for smart grid applications as well as for educational purposes.

The 3D sustainable renewable micro power system model architecture is presented in this paper. The initial results showed the importance of the approach and its smart grid application advantages. It also demonstrated the challenges that should be considered prior to building the system for reel field test. To typify this feature, the paper considered studies for the suitability of using solar, wind and hydro resources available in Simulink tool allowing the development of the simulation model referred to steady, transient systems, with the possibility of active and reactive power flowing evolution. It is worth noting the importance of the presented model considering its usefulness tool in energy management system domain and its technological advantages for future sustainable, hybrid, and smart applications developments.

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