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Modeling and Control of a Mini Hybrid Hydro Matrix / Wind in Micro Grid Applications

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ABSTRACT The performance of controlled hybrid renewable hydro matrix wheels/ wind in micro grid application during the variations of water speed and load is described and investigated. This hybrid contained three wheels and three wind turbines modeled in MATLAB Simulink. This presented hybrid model consists of a water wheel and a generator in the main channel, wind turbine drives an induction generator, battery, variable static load, DC link, and control unit. Appropriate controllers are used to maintain the DC-link voltage constant at its desired value with variations of load, water and wind speed. The obtained simulated result shows that the studied hybrid system with the proposed controller and the storage system have a better performance of load voltage and current waveform compared with the case of not using an energy storage unit and the case of without a controller under the water, wind speed and load variations.

INDEX TERMS DC link, hydro matrix, SEIG, water wheel, wind turbine.

I. INTRODUCTION

The world electricity demand is increasing rabidly because of the rapid increasing in the world's economy and population. On the other side, resources of fossil fuel are decreasing rapidly. Therefore, a seriously and urgently search for alternative environmentally friendly power energy sources to meet the expected required energy became very important.

The intensive use of the amounts of traditional energy, which depend on fossil fuels as petroleum, coal and natural gas cause extremely serious damage to human beings, environment, and all living organisms [1]. This reason led researchers to search for resources of renewable and clean energy, which achieve sustainable development and practical advancement.

Nowadays, many power generation approaches [2]–[7] have been developed such as solar, wind, biomass, hydro, ocean wave and fuel cells as a clean energy sources, especially in micro grid applications.

Any micro grid needs some renewable sources and/or storage energy units [8]–[10]. Hydromatrix power generation is one of renewable energy sources. However in this case, it is generated naturally by water wheel [11] in a sustainable manner and without resulting in any kind of harmful waste.

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In [11], it is used hydromartix wheels, where it consists of three cascaded wheels for generating electricity from moving nature water in main cannels of revers. This way is preferred hydromatrix using outlet moving water from the first stage and to rotate the next wheel stage. Also in this study, it is used under shot water wheel to produce energy from very low moving water in main channels.

In this paper, the stand-alone hybrid wind/hydro/storage power generation unit is presented. Where, a hybrid of three wind turbine and three water wheels in wind/hydromatrix/ storage energy system is considered and investigated.

The proposed system is modeled and controlled in micro grid mode. It is proposed to reuse water wheel in the main channel using natural speed of very low head water to move wheels [11]. But for the reason of variable water speed, it is proposed to use an induction generator (IG) driven by wind turbine [12] to model hybrid renewable power systems [13]. This model combined three-wheels and three induction generator to provide higher reliability and deliver more overall electricity than either source individually [14]. As in wind turbine, it is proposed to use an individual converter for each generator and combined them on DC bus [15], while sharing AC to the other side of the grid or stand-alone loads [16]. Variable water speed can be presented by the wheel speed.

Generally, in distributed generation units, most inverters are considered as current and voltage source [17]. Where,

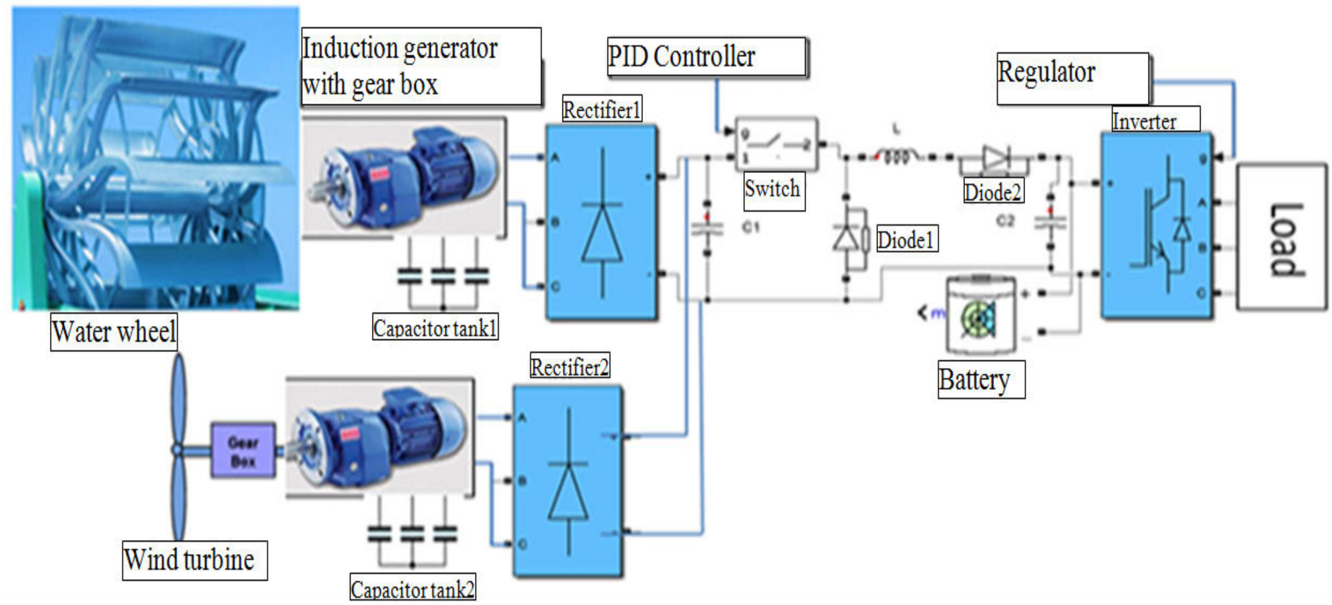

FIGURE 1. Schematic circuit of the proposed hybrid hydro matrix/ wind model with the controller and supplying isolated load.

it is the PWM strategy applied to control the direct current feeding grid [18]. Predictive current control, hysteresis, and ramp comparison are considered as the three major algorithms used to regulate the voltage source inverters output current [6], [19], However, it is important to guarantee high precise of low current harmonic based on predictive current control [20]. This may lead to computationally intensive performance, a bad result and not acceptable performance, especially in case of system parameter variations.

To achieve the required output of AC voltage, a scheme of inverter current control based on the prediction approach is needed to produce the inverter PWM pulses as discussed in [21].

Official information discharged by the service of oil and mineral assets uncovered that Egypt nation has an all-out utilization of oil and its subsidiaries, which is around 25 billion liters every year. Over 70% of them for power age, which the nation imports about 42% causes a huge efficiency in the state spending plan, particularly after the high costs of oil. The proposed model can gauge about 20% of the asset as a sustainable power source asset from the proposed hybrid model equal to around 4 MTOE/year.

II. MATERIALS AND METHODS

The Hybrid renewable hydro matrix/ wind model is shown in Figure 1. Comprises a moving water wheel utilized as sustainable and wind power energy, coupling with IG through the gearbox. The AC generated voltage is converted to the AC voltage via an uncontrolled rectifier. It is used as a buck DC/DC converter with the proposed controller and the energy storage battery to convert the inconstant DC voltage to constant DC voltage, and then it is used as a regulator with a three-phase inverter to convert the constant DC voltage to the desired AC voltage to the load. In this paper, the generated power from each induction generator mainly depending on water wheel velocity and it's torque, Hence, if the water velocity changes due to water shortage in the main stream, the terminal load currents and voltage will be changed. In this study, it is suggested that the proposed hybrid hydro matrix generation unit consists of one part dissimilar in size and speed as indicated in Figure 4.

So, the variations in amplitude and frequency of the output voltage of a hybrid hydro matrix/ wind model can be overcome using the DC-link.

A. WATER WHEELS

Water wheels have truly been seen in catching the vitality of moving stream water for electrical generation [13]. Conventional undershot waterwheels that include flat blades extruding radially from the center of the rotating shaft and fixed to the edge of the wheel [13]. In spite of the fact that the water wheel is not as effective as other turbines, they are as yet a practical choice for generating electrical power from the very low head difference. There are three fundamental kinds; the undershot wheel, the breast shot and the overshot shot. In this study, it is proposed to utilize the undershot water wheel because of the reality inside the undershot water wheel, water flows under the wheel and hits blades or paddles calmly subtle throughout the outer edge of the wheel. They are moved through the impulsion of the particles of water. In comparison with different types, this wheel is much less efficient as though it relies on basic phrases at the kinetic power of the water. This water wheel basically plunges into hydromartix wheels unit which rotates by the nature moving water in the main stream. The generated electricity from this model is depending on the diameter of the water wheel and the water speed in the main stream.

The mechanical torque delivered by the water wheel can vary as in wind farms [22] depends on the water flow rate in the main stream and the connected isolated load. Using a load controller is a better alternative, which feeds a sell offload, permitting the total strength furnished by the generator to the shape of the sum among the client's loads and no load. Because the lively energy balance is finished, the frequency is quality regulated [23]. Additional space is required for a new section or subsection.

B. SPECIFICATION DATA OF WATER WHEELS

Mainly, conventional undershot waterwheels consist of a series of six blades fixed to the end of a wheel. The blades have been typically installed in order that they are faced immediately out along the radius of the wheel. However, the water from the slots goes depends on the water flow to push the wheel. Where, it hits the blades and a number of its momentum is changed into torque which is then transferred to the wheel. However, the efficacy of a typical straight blade undershot wheels were around 30%.

$$\text{Working Diameter (W)} \quad W = (D - H) \times \pi \tag{1}$$

$$\text{Blades no (nb)} \quad nb = W/H \tag{2}$$

$$\text{Aspect Ratio} = B/D \tag{3}$$

This ratio is fulfilled inside the range (B/D = 0.2 to 4.5) [24]

Water force (F) against one wheel vane

$$F = QAv^2(1 - c)^2 \tag{4}$$

Water mass (m) for blade per unit time, $m = QA(v_{in} - v_{out})$.

C. WATER TORQUE

The articulation of the torque of one wheel can be evaluated depending and shown in Figure 2. There are n basins each possessing a point $\Delta\theta$ around the edge, so that n $\Delta\theta = 2\pi$. So it can obtain this form $\omega'\ \Delta t = \Delta\theta$.

The load torque equation can be written as following:

$$T1 = \frac{\rho g Q R}{n\omega'} \int_0^{\theta 1} sin(\theta)\, d\theta) \tag{5}$$

Therefore, result of the integration load torque can be as follows:

$$T1 = \frac{\rho g Q R}{n\omega'}[1 - cos\theta 1] \tag{6}$$

where,

ϱ: water density, kg/m3

g: acceleration of gravitational, m/s2

R: waterwheel radius, m

ω': angular speed of the wheel in, rad/sec

θ: one blade angular position

$\theta 1$: occupied angular position inside water wheel by the blade

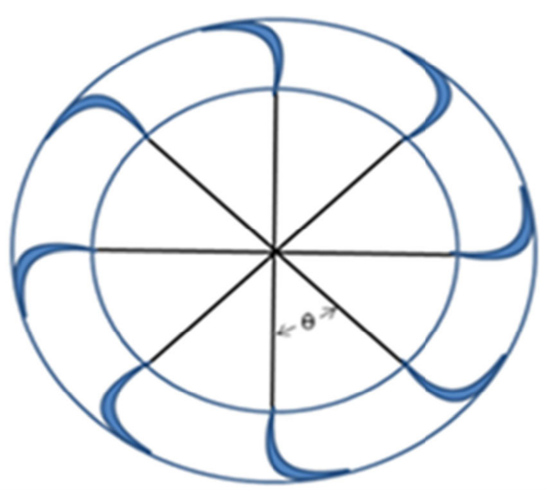

FIGURE 2. Occupied angular position inside water by the blade.

D. WATER WHEELTORQUE

The torque generated (Tw) by the flow on the wheel can be calculated as:

$$T_w = \rho AR(v_{in} - v_{out})^2 = \rho AR(v_{in} - \omega R)^2$$

$$\text{Angular speed at steady state, } \omega R = 1/3 \text{ vin} \tag{7}$$

where,

Tw: Generated torque by water N.m,

Vin: input water velocity on blade, m/s

Vout: output velocity leaving the blade, m/s

A: blade area m^2

E. WHEELS OUTPUT TORQUE AND POWER

Water wheel output power (Pout) is resulting from its force, where Pout = Fv this is the applied force multiplied by the distance moved by the blade per unit time [24]. Thus:

$$P_{out} = \rho A v^3 c(1 - c)^2$$

$$\text{For a wheel number one, } c = 1/3,\ v = 1.5 \text{ m/s,} \tag{8}$$

The author compute the torque (T) from one wheel by divided its power on angular velocity as following:

$$T = p \times 60/(1800 \times 2 \times \pi) = 29\text{Nm}.$$

F. DC-DC CONVERTER

In this paper, the DC/DC converter is considered based on a buck converter. The unidirectional buck converter achieves an interface between the DC/AC inverter and the uncontrolled rectifier to regulate the transfer of electrical power. The circuit of the used buck converter and its considered PID controller are shown in Figure.3a and Figure.3b respectively.

The voltage and current relationships between the primary and secondary sides are given by:

$$\frac{V_{rect}}{V_{dc}} = D \tag{9}$$

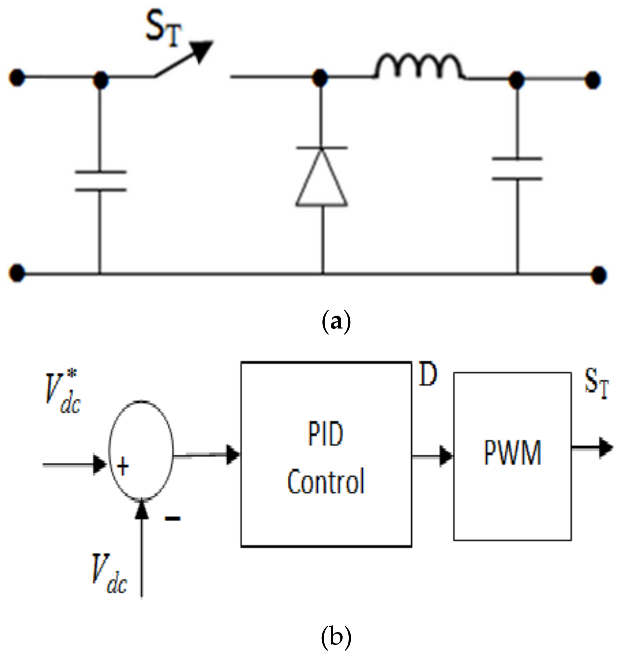

FIGURE 3. (a) Buck-converter circuit diagram, (b):: Buck- converter controller block diagram.

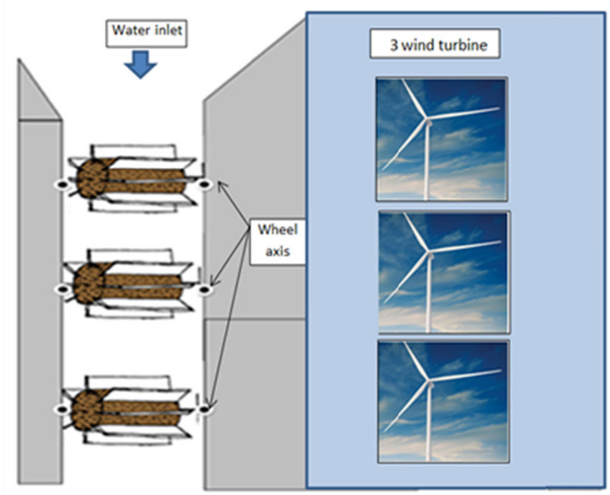

FIGURE 4. Elevation view for hybrid model with 3 wheel and 3 winds.

$$\frac{I_{rect}}{I_{dc}} = \frac{1}{D} \tag{10}$$

D is the duty cycle ratio of the converter.

Where the parameters of the PID controller shown in Figure4 are tuned based on tuning Heuristics using Zeigler-Nichols algorism via MATLAB software package. Then those given PID parameters values are tuned manually until best performance is obtained. The above PID control parameters are given as following:

$$K_p = 0.005, \quad K_i = 100 \quad K_d = 1.08$$

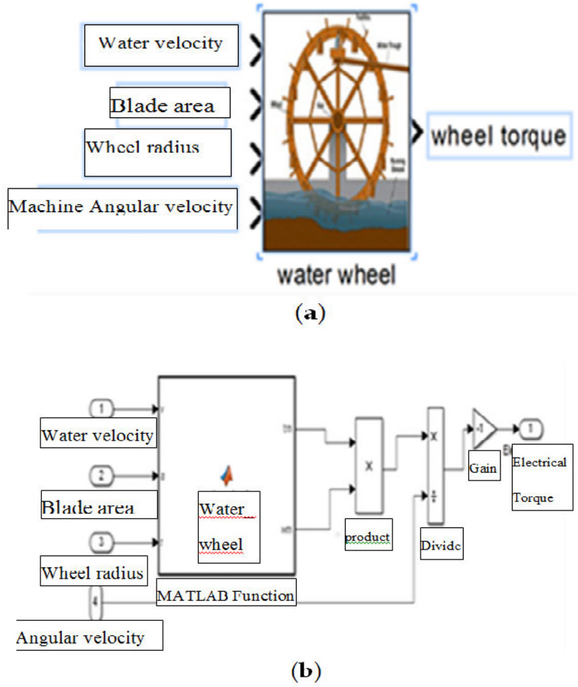

FIGURE 5. (a) MATLAB/SIMULINK developed water wheel model, (b) Water wheel model block diagram based on MATLAB function.

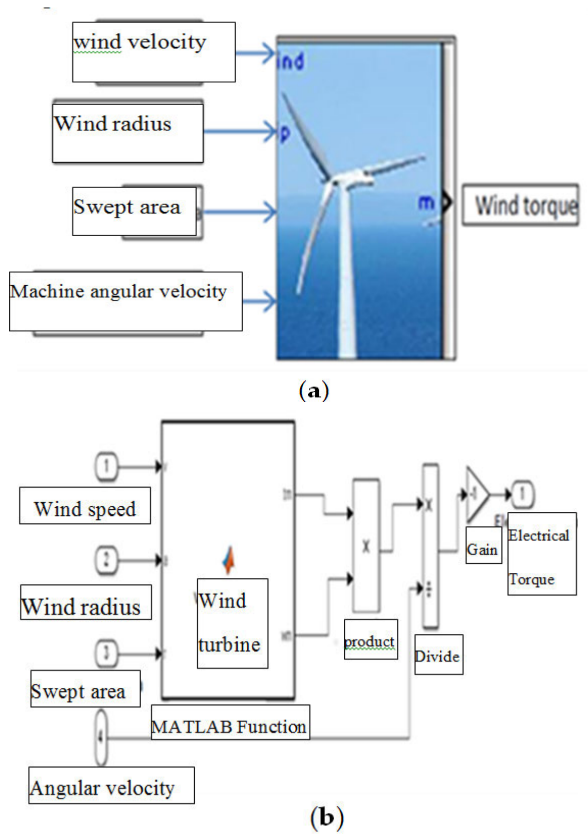

FIGURE 6. (a) MATLAB/SIMULINK developed wind turbine model, (b) wind turbine model block diagram based on MATLAB function.

III. CONSIDERATION OF HYBRID MODEL

In this investigation, it is proposed that the studied model of a hybrid model consists of three water wheels in one slot and the other contained three wind turbines. The main channel is narrowed to one-third of its overall wide. This is proposed

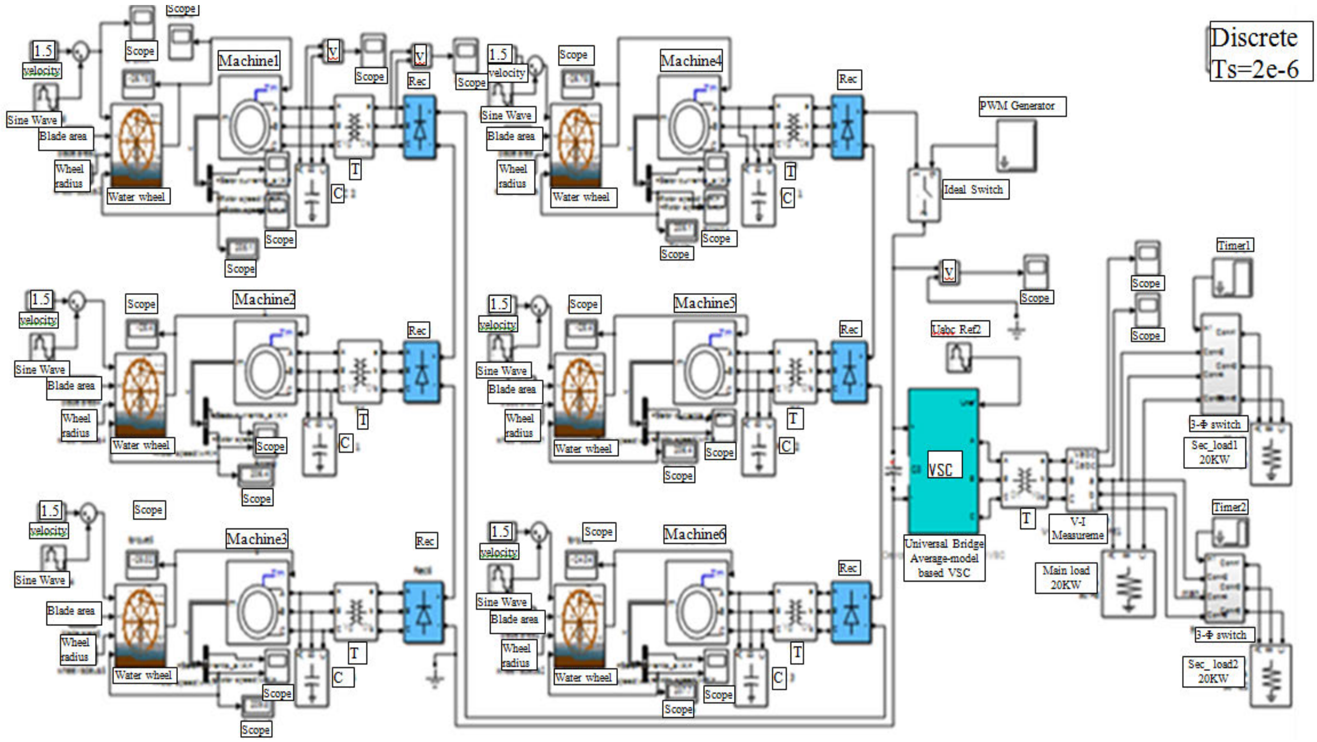

FIGURE 7. Simulation of of hydro matrix wheel without control unit.

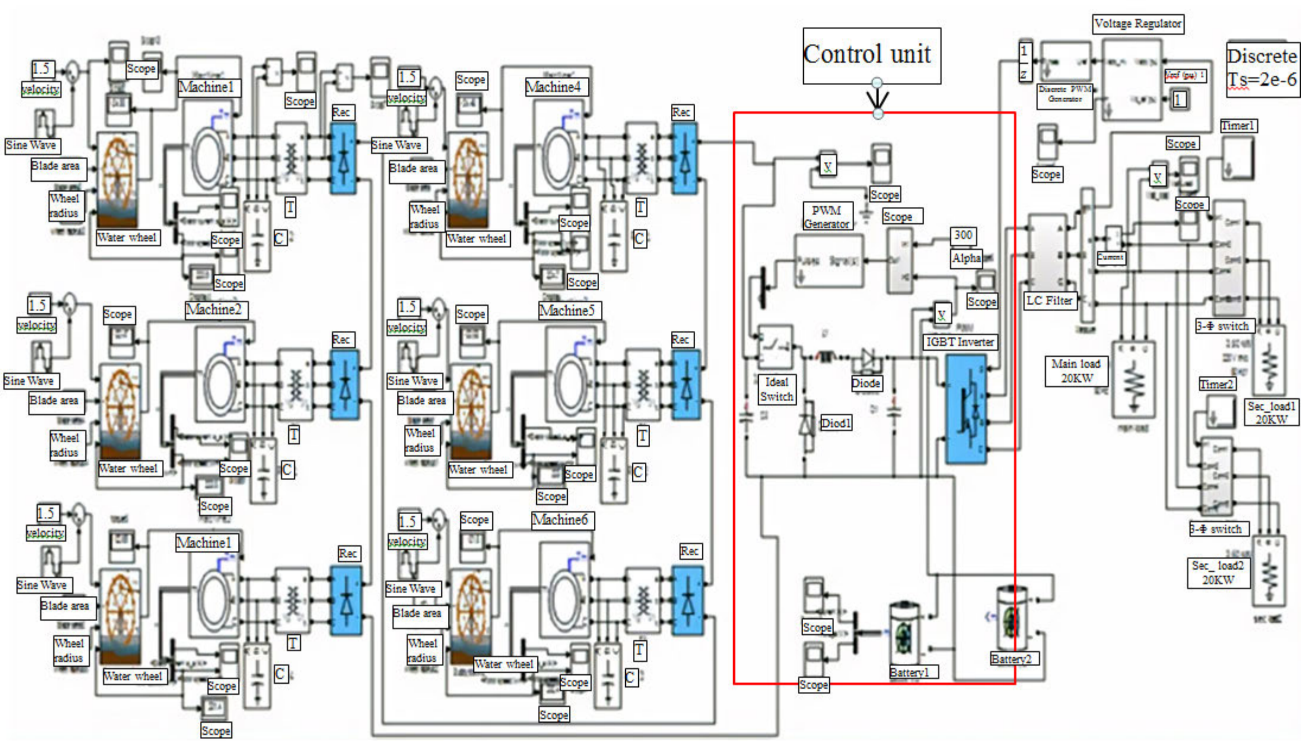

FIGURE 8. Hydro matrix wheels with control unit and battery.

to increase the water velocity to triple as shown in Figure 4. Likewise, it is considered that the depth of this slot is about 2 m and with width about 4 m.

A. MODEL AND BLOCK DIAGRAM OF WATER WHEEL

The author developed a MATLAB/SIMULINK condition to represent and control the proposed under shot water wheel

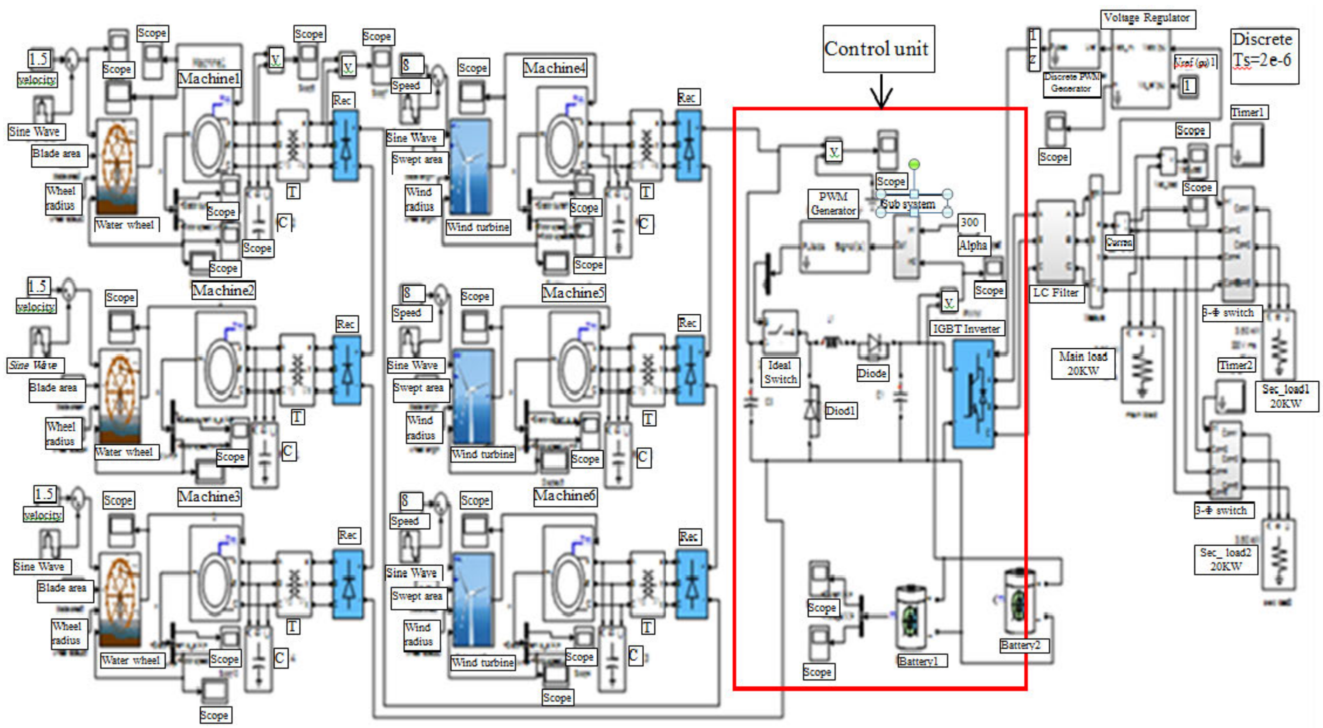

FIGURE 9. **Hybrid hydro matrix/ wind included both control unit and battery.**

model as shown in Figure 5a, and the nonlinear model of the wheel turbine using MATLAB function is obtained as shown in Figure. 5b.

The nonlinear function of the water wheel can be obtained using the following based on MATLAB function as following

function [tm, wm] = water_wheel(v, A, R)

where the mechanical angular speed and the turbine output torque can be given as

$$w_m = (c \times v)/R \tag{11}$$

$$t_m = \rho \times A \times R \times (1-c)^2 v^2 \tag{12}$$

where

$V = 1.5$	velocity of the water (m/s)
$A = 11$	blade area (m^2)
$R = 6$	radius of one water wheel (m)
$C = 1/3$	power coefficient
$\rho = 1000$	density of the water (kg/m^3)
Wm	turbine angular speed (rad/s)
Tm	The turbine output torque (Nm)

B. MODEL AND BLOCK DIAGRAM OF WIND TURBINE

The author developed a MATLAB/SIMULINK condition to represent and control the proposed wind model [25] to adding it with hydromatrix model as shown in in Figure 6a. The nonlinear model of the wind turbine using MATLAB function is obtained as shown in Figure.6b.

The nonlinear function of the wind turbine can be obtained using the following based on MATLAB function:

function [tm, wm] = water_wheel(v, A, R)

where the mechanical angular speed and the turbine output torque can be given as [26]

$$w_w = (c \times v)/R \tag{13}$$

$$t_w = \frac{1}{2}\rho \times A \times R \times c_T \times v^2 \tag{14}$$

where

$v = 8$	wind speed (m/s)
A = 113	swept area (πR^2) (m2)
$R = 6$	radius of one water wheel (m)
$c = 1/3$	air power coefficient
$\rho = 1.2$	density of the air (kg/m^3)
Ww	wind angular speed (rad/s)
tw	wind output torque (Nm)

IV. SYSTEM CONFIGURATION

Results we have obtained from the Digital simulation to study the performance of a hybrid hydro matrix/ wind model under load variations and change water velocity. The proposed hybrid isolated hydro matrix power system configuration in cases of without control, with control and hybrid hydro matrix/ wind model with control unit and at the same time are shown in Figures 7, 8 and 9 respectively The proposed system is simulated and tested using MATLAB/SIMULINK software package at different operating conditions of water speed and load parameters variations in the three above cases. In the first case, six generators are driven by six water wheel turbines without control. While in the second case, a PID control system is considered while the battery is not included. Finally, it is proposed to include an energy storage unit in addition to the control system.

In these three cases, it is proposed to vary the system parameters of water velocity, load parameters, water speed, water wheel toque, IG rotor speed, AC load voltage, and AC load current as shown in Figure. 10, Figure. 11 and Figure. 12.

A. CASE 1: HYDROMATRIX WITHOUT CONTROL

In this case, a model of a hybrid stand-alone hydro matrix model using the environment of MATLAB/SIMULINK software is implemented and simulated under the variations of load parameters and water speed. However, six generators are driven by water wheel turbines and connected to the variable load. Also, the water speed is varied between 1.4m/s to 1.6m/s, the load is increased to be 5 kW after 3 sec., and then the load is increased again by 5kW extra after 5 sec. As shown in Figure. 7.

In the shown model, the author used the capacitor bank for each IG to compensate for its reactive power and then to regulate the rotor speed higher than the synchronous speed by slip (from 2% to 5% above synchronous peed).

B. CASE 2: HYDROMATRIX WITH CONTROL

In this case, a control unit based on a proportional-integral-derivative algorithm is considered to regulate both DC/DC converter and DC/AC inverter for load voltage regulation as shown in Figure.8.

C. CASE 3: HYBRID MODEL WITH CONTROL

In this case, a hybrid model consists of three water wheels in one slot and the other contained three wind turbines. The main channel is narrowed to one-third of its overall wide. This is proposed to increase the water velocity to triple. the control unit and battery storage are considered to regulate both DC/DC converter from hybrid hydro matrix/ wind model and DC/AC inverter for load voltage regulation as shown in Figure. 9.

V. RESUTLS AND DISCUSSION

Digital simulation results using MATLAB-SIMULINK are obtained to study the performance of the hybrid hydro matrix/ wind model under the condition of water speed and load parameter variations. The obtained results are water speed, water wheel torque, IG rotor speed, load voltage and load current. The three mentioned cases of operation are considered.

In the first case, each IG is driven by a water wheel. The water speed is varied from 1.4m/s to 1.6m/s and supplied an isolated variable static load as shown in Figure 7. The obtained results based on this case are shown in Figure. 10. The obtained results of this case show that when the water velocity varies from a minimum value of 1.4m/sec to a maximum value of 1.6m/sec, the obtained torque from a water wheel is varied too from 25N/m to 35N/m depending on the water velocity and flow rate. The steady-state value of the IG

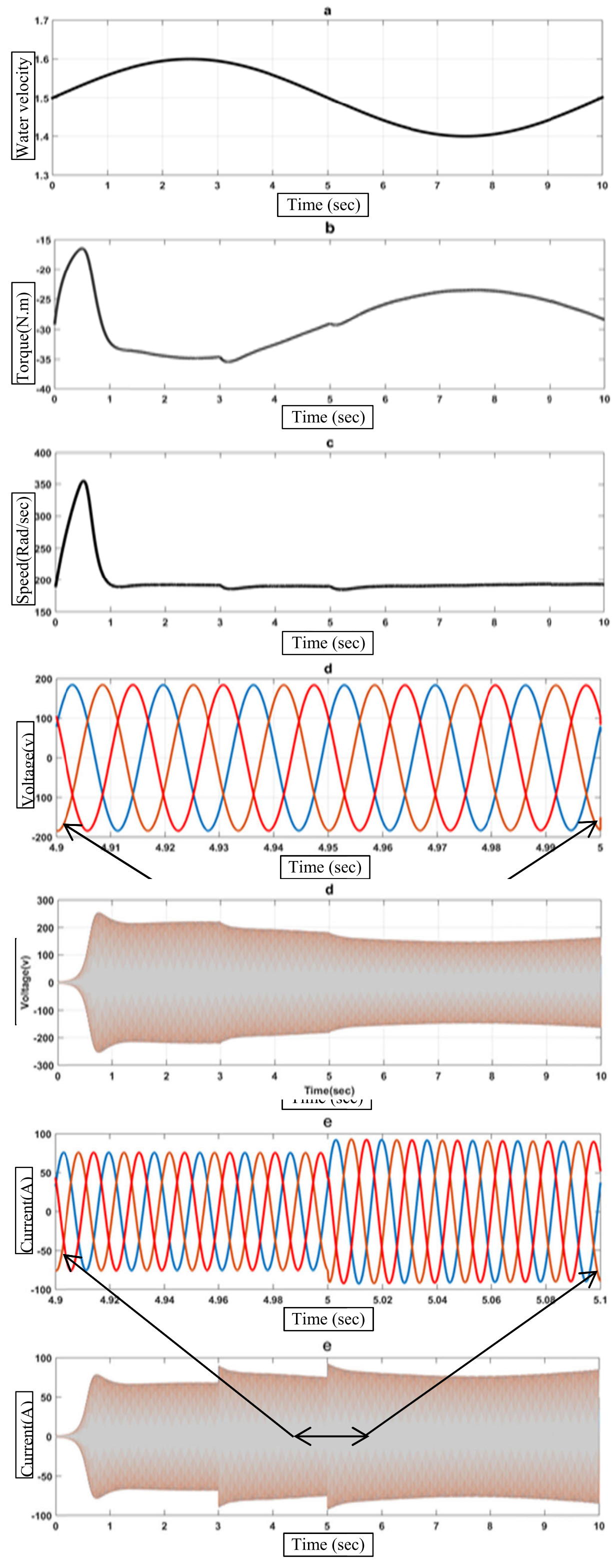

FIGURE 10. The obtained simulation results of the proposed HMPW without control (case one) (a) water speed. (b) water wheel torque. (c) IG rotor speed. (d) load voltage. (e) load currents.

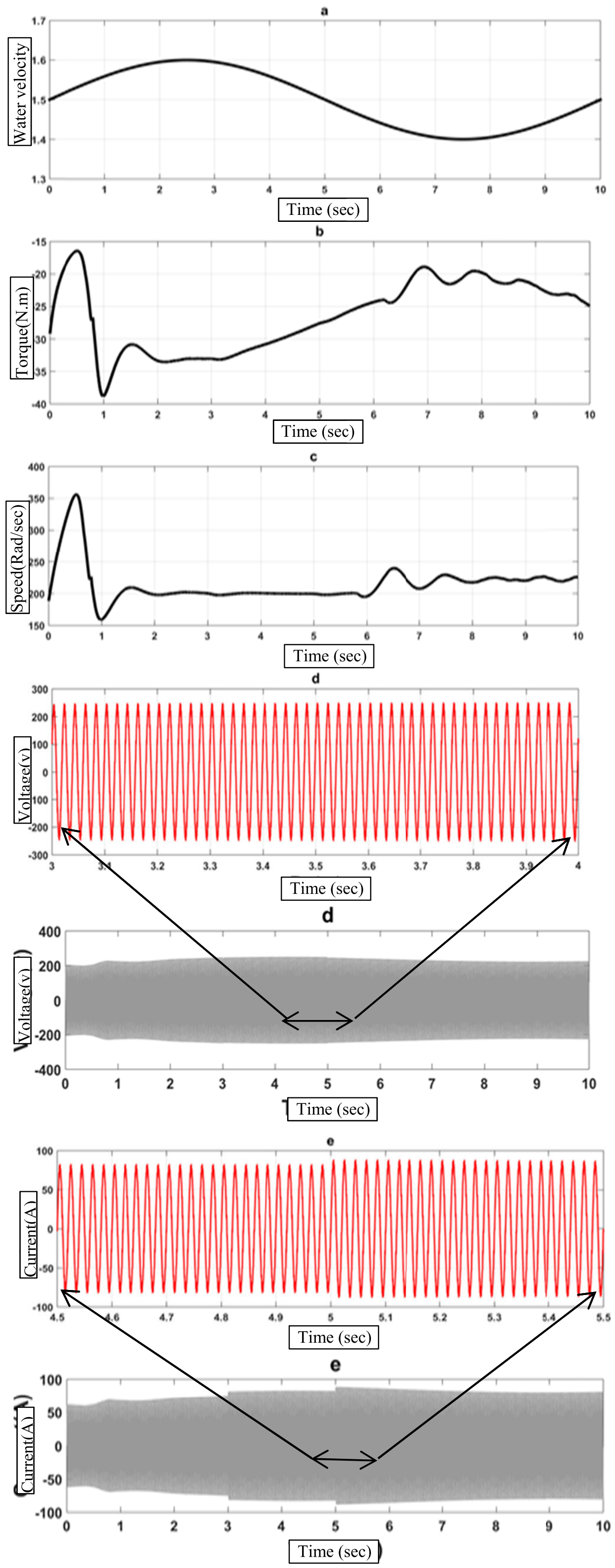

FIGURE 11. The obtained simulation results of the proposed HMPW with control (case two) (a) water speed. (b) water wheel torque. (c) IG rotor speed. (d) load voltage. (e) load currents.

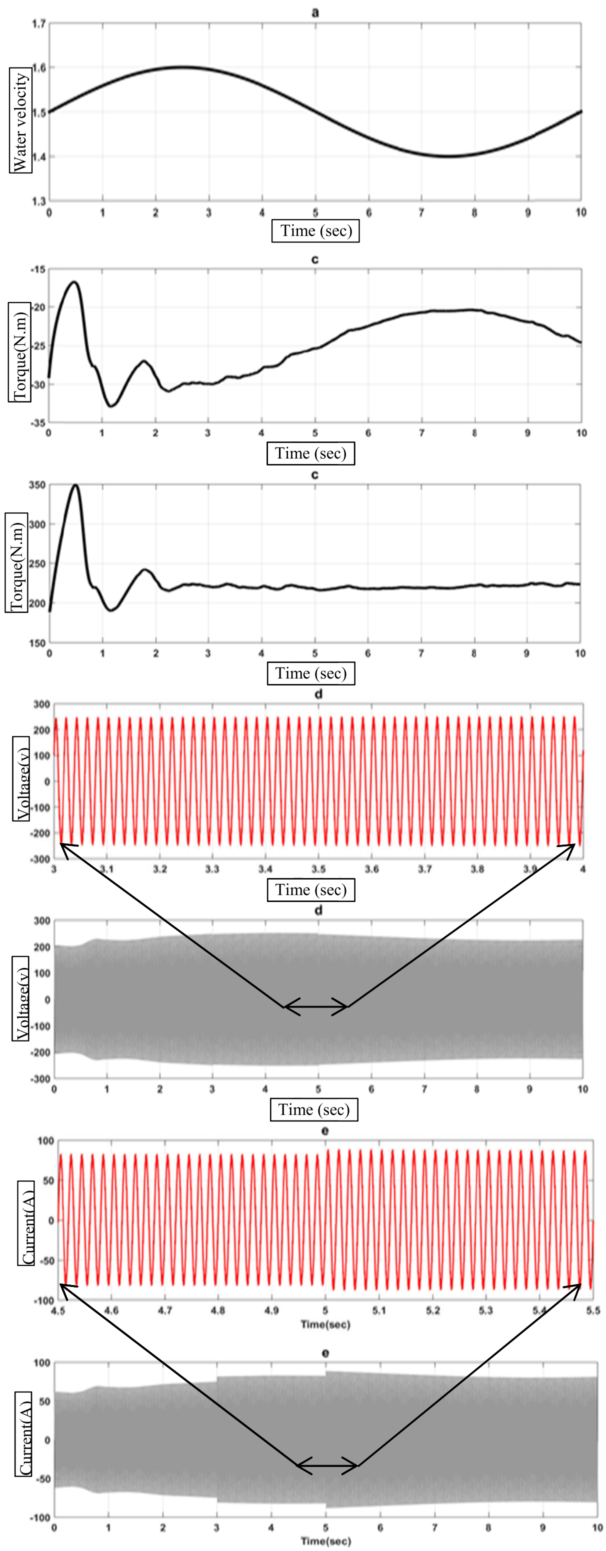

FIGURE 12. Simulation results of the proposed hybrid hydromatrix wheel/wind turbine with control and with battery case no three (a) water speed. (b) Water wheel torque. (c) IG rotor speed. (d) load voltage. (e) load currents.

rotor speed is 190 rad/sec., this angular velocity is exceeded by about 5% of its synchronous speed which was equal to about 183.16 rad/sec. The load voltage is 220 V.

After three seconds, the load is increased by 5 kW. So, the load voltage decreased to about 180 V and the load current increased from about 60 A to about 70 A as shown in Figure.10d and 10e respectively. Again after five seconds, the load is increased by 5 kW. Then, the load voltage decreased again to 140 V and the current increased to 80A as shown in Figures 10d and 10e respectively.

In case two, the proposed system is controlled with a control unit as shown in Figure. 8. The obtained results of water speed, wheel torque, IG rotor speed, load voltage and load current are shown in Figure. 11. Also, it is proposed to vary water speed and load parameters. From Figure.11 we can notice that the load voltage has small variation as shown in Figure. 11d and 11e.

In the last case no three, the proposed system (hybrid hydro matrix/ wind model) includes the controller as shown in Figure. 9. Also, the obtained results are water speed, wheel torque, IG rotor speed, load voltage and load current as shown in Figure. 12. The load voltage in this case, has a very small variation as shown in Figure 12d.

VI. CONCULUSION

This study proposed to investigate the way to generate electrical power depending on the water movement in the main channels of the River Nile in Egypt based on hydro matrix wheels. Where this study aims to use hydro matrix wheels as a power generation unit, This proposed hybrid generation unit is composed of six IG connected with six water wheels as turbines, an uncontrolled rectifier, a buck DC/DC converter, DC/AC inverter, storage system and the loads. It is proposed to divide the main channel into two or more separate slots, and the overall width of these slots equals one-third of the main channel, which leads to an increase in water speed. Suitable controllers based on PID algorithms are designed and applied to guarantee to generate the required load voltage level.

A battery storage unit in the control unit is used to compensate for any reduction in hydropower generation and also to smoothing the DC-link voltage. This study also investigated the proposed system performance based on the controlled hydro matrix wheels in conditions of load and water speed variations.

Digital simulations have been carried out to evaluate the effectiveness of the studied performance of a hybrid hydro matrix/ wind model. The hybrid hydro matrix/ wind model with the suggested controller has been tested based on load and water speed variations. The results prove that the proposed controllers are successful in maintaining the load voltage of a performance hybrid hydro matrix/ wind model against water flow rate and load variations constant at its desired values of magnitude and frequency. Moreover, the system with the proposed controller performance is compared with the case of not using the battery, which shows that the system is superior to the proposed system where it has a good prediction of the electrical parameter waveforms'' chapter, so there is compatibility. Moreover, the authors can elaborate the prospect of the development of research results and inspire further studies (based on the result and discussion).

To guarantee continuous supplying electrical power in case of electrical power reduction of both hydro and wind at the same time, the hybrid hydro/wind/diesel generation unit will considered based on suitable control system in the future.

CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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