Available online at https://sej.journals.ekb.eg/
FACULTY OF ENGINEERING – SOHAG UNIVERSITY

Sohag Engineering Journal (SEJ) Vol. 05, No. 1, March 2025

Hybrid Multi-Stage Hydro-Matrix and PV Solar Cell in a Real Grid for Minimizing Electricity Consumption and Avoiding Voltage Issues

Medhat E. M. Ali [a]*, Mohamed Ebeed [a,b], Mohamed Khamies [a]

[a,]Electrical Engineering Department Faculty of Engineering, Sohag University, Sohag 82524, Egypt,
[b]Department of Electrical Engineering, University of Jaén, 23700 EPS Linares, Jaén, Spain
E-mail addresses: [1]en.med_kad@eng.sohag.edu.eg.(Corresponding author)
[2] mebeed@eng.sohag.edu.eg (M. Ebeed).
[3] mohamed.khamies@eng.sohag.edu.eg.*t*

Abstract

This study presents an innovative approach to addressing the persistent issue of voltage minimization in dynamic load feeding within real-world grids, particularly in Egypt. The proposed method leverages a hybrid multi-stage renewable energy system, designed to enhance voltage stability and efficiency in isolated or utility grid-connected scenarios via a DC bus. The hybrid system integrates multi-stage hydro-matrix power water wheels and a multi-stage PV solar system, creating a sustainable energy solution tailored for regions reliant on the River Nile's channels. The hydro-matrix component comprises three undershot water wheels coupled with an induction generator, collectively producing approximately 20 kW of output power. Simultaneously, the PV solar system consists of eight parallel strings, each with fourteen series modules, delivering a total output of 28 kW. The energy outputs from these two subsystems are converted into DC voltage and integrated via the DC bus. To further enhance system reliability, a controlled battery system is incorporated, effectively mitigating performance fluctuations caused by variations in water speed, PV cell temperature, and solar irradiance. This hybrid multi-stage renewable energy system demonstrates its potential to feed diverse load types in rural and semi-urban areas near the Nile, addressing challenges such as low power factors and voltage minimization. The findings underscore the system's significance in advancing renewable energy utilization and improving grid stability in regions with fluctuating renewable energy resources.

 DOI: 10.21608/sej.2024.324616.1066

Keywords: Multi Stage, SEIG, DC link, Under Shot Water Wheel, Hydro Matrix, PV Solar cell.

1. INTRODUCTION

The increasing demand for reliable and sustainable energy has driven significant advancements in renewable energy technologies. With the depletion of conventional fossil fuel resources and their adverse environmental impacts, the adoption of renewable energy systems has become a critical component of global energy strategies. Hybrid renewable energy systems, which combine multiple energy resources [1], offer a robust solution to the intermittent and reliability challenges associated with standalone renewable sources [2,3].

Photovoltaic (PV) solar energy and wind energy [4] are among the most prominent renewable energy sources due to their availability and scalability. Hybrid systems integrating these resources, along with appropriate energy storage technologies, can provide consistent power output and improve the overall efficiency of energy systems [5,6]. However, the integration of hydropower, particularly through innovative hydro-matrix systems, into hybrid configurations has gained attention for its potential to harness low-head water resources efficiently. Studies demonstrate that hydro-matrix systems, such as those implemented in the Nile River, can generate substantial energy output by leveraging natural flow characteristics with minimal ecological disruption [7,8].

The development of robust control and energy management strategies is essential to ensure the reliability and efficiency of hybrid systems. Advanced inverter designs and control algorithms, such as multi-input inverters and voltage-controlled voltage source inverters, play a pivotal role in stabilizing power supply and mitigating the adverse effects of variable renewable energy inputs [9-11]. Moreover, predictive current control techniques have demonstrated significant improvements in harmonic reduction and voltage regulation in hybrid systems [12].

* Corresponding author: en.med_kad@eng.sohag.edu.eg.

In regions like Egypt, where fossil fuels dominate the energy mix, the adoption of hybrid renewable systems integrating PV solar, wind, and hydro-matrix technologies presents a sustainable alternative [13]. These systems not only reduce dependency on imported energy but also address environmental challenges and promote energy independence [7], [14]. The incorporation of energy storage units further enhances the system's capability to handle fluctuations in energy supply and demand, ensuring stability under varying operational conditions.

This study proposes a hybrid renewable energy system combining hydro-matrix power wheels, PV solar systems, and battery energy storage. The system is designed to operate efficiently in low-head hydropower environments and aims to optimize energy output and system stability under diverse environmental and operational conditions. By leveraging advanced control strategies and energy storage solutions [15], the proposed system demonstrates significant potential to address energy sustainability and reliability challenges in renewable energy applications.

TABLE1: LITERATURE REVIEW AND IDENTIFIED RESEARCH GAP

Reference	Energy System	Focus Area	Methodology/Approach	Identified Gap
[1]	Hybrid Solar-Wind	Optimum sizing for stand-alone systems	Mathematical optimization of hybrid systems	Lacked consideration of control strategies for reliability in dynamic environmental conditions.
[2]	Geothermal	Future potential of geothermal energy	Reservoir engineering methods	Geothermal integration with hybrid renewable systems not addressed.
[3]	Hybrid PV-Wind	Power generation forecasting	Hybrid system forecasting using machine learning-based models	Limited exploration of energy storage optimization in hybrid systems.
[4]	Hydro Matrix	Hydropower generation from Nile canals	Hydro-matrix system modeling and energy calculation	Did not integrate PV or wind resources for hybrid setups.
[5]	Wind Energy	Controller design for variable-speed wind turbine	Proportional-Integral-Derivative (PID) controllers	Focused only on wind systems; hybrid configurations and control challenges omitted.
[6]	Hydro Matrix	Hydro-matrix design for power generation	Nine-wheel hydro-matrix system simulation using MATLAB/Simulink	Lacked exploration of hybrid energy system performance under dynamic loads.
[7]	Hybrid PV-Wind	Multi-input inverter design for hybrid systems	Developed a multi-input inverter for grid integration	Did not focus on isolated or off-grid hybrid systems.
[9]	Hybrid AC/DC Microgrid	Power management strategies for hybrid grids	Overview of hybrid AC/DC power management strategies	Limited focus on low-head hydropower integration.
[10]	Distributed Energy Systems	Voltage/current-controlled inverters	Applied voltage and current-controlled inverters	Focused on distributed systems, not hybrid or isolated systems.
[11]	Wind-Based Energy Storage	Robust control of standalone wind-based energy storage	Robust control and modelling for variable-displacement pump-driven energy storage system	Focused on standalone wind systems; hybrid configurations not addressed.
[12]	Distributed Generation Systems	Voltage and current control of distributed systems	Voltage and current control strategies for distributed systems	Omitted focus on hybrid renewable energy systems.
[13]	Inverters	Output feedback control of voltage source inverters	Developed feedback control algorithms for voltage source inverters	Limited exploration of inverter roles in hybrid energy systems.
[14]	Renewable Energy Applications	Review of digital control techniques for voltage source inverters	Comprehensive review of control techniques for voltage source inverters	Lacked specific focus on hybrid energy systems' dynamic stability and performance.
Current Research (Proposed Study)	Hybrid Hydro-PV	Efficient and reliable power generation with low-head hydropower integration	Development of a hybrid system combining hydro-matrix power wheels, PV, and energy storage with advanced control methods	Addresses energy storage, control strategy optimization, and dynamic environmental condition effects.

1.1 Research gap

Despite the increasing global focus on renewable energy integration [16,17], existing renewable energy systems often struggle with maintaining voltage stability and power quality when supplying dynamic loads [18]. Conventional systems typically rely on single-source renewables, which are susceptible to performance degradation due to environmental variations such as fluctuating water flow rates, inconsistent solar irradiance, and temperature changes. In Egypt, where many rural and semi-urban regions depend on decentralized energy systems along the River Nile, these limitations are particularly pronounced. Previous studies have focused on individual renewable technologies [19] or simple hybrid systems, but there remains a significant gap in developing robust, multi-stage hybrid systems capable of addressing the combined challenges of voltage minimization, power factor degradation, and dynamic load variability in such regions. Moreover, the application of advanced energy management solutions, like controlled battery systems [20], in hybrid setups remains underexplored in these contexts.

- Limited studies explore the integration of hydro-matrix systems with PV and wind energy for hybrid setups.
- Lack of focus on advanced control strategies tailored for hybrid renewable systems to handle dynamic environmental conditions.
- Minimal attention to low-head hydropower as a viable resource in hybrid energy configurations.
- Few studies integrate energy storage technologies effectively within hybrid systems for enhanced reliability.

1.2 Motivation of the Study

Egypt's geographical and environmental conditions [21,22], particularly the availability of the River Nile and abundant solar resources, present an immense opportunity for renewable energy development. However, the dynamic nature of loads in these regions, coupled with fluctuating renewable resource availability, often leads to power quality issues, including voltage dips and low power factors. These challenges hinder reliable energy access and grid stability for communities along the Nile. Motivated by the need for sustainable, high-performance energy systems, this study aims to develop an innovative hybrid energy solution that combines hydro-matrix power wheels and multi-stage PV solar systems [23]. This system is further supported by a controlled battery storage mechanism to ensure consistent performance. Addressing these challenges not only improves energy reliability for underserved regions but also contributes to Egypt's broader renewable energy goals and global sustainability efforts.

1.3 Main Contribution of the Study

This study introduces a novel hybrid multi-stage renewable energy system designed to mitigate voltage minimization and enhance power quality for dynamic loads in real-world grid scenarios. The main contributions of this work are as follows:

- Development of a hybrid system that combines multi-stage hydro-matrix power water wheels (producing 20 kW) with multi-stage PV solar arrays (producing 28 kW) integrated through a DC bus, ensuring efficient energy conversion and distribution.
- Implementation of a controlled battery storage system to stabilize energy output during fluctuations in water flow, solar irradiance, and temperature conditions.
- Addressing critical issues such as low power factor and voltage dips, the system is tailored for feeding diverse load types around the River Nile's main channels.
- Providing a scalable and sustainable energy solution for rural and semi-urban communities in Egypt, contributing to renewable energy research and advancing the adoption of hybrid systems in similar geographic and environmental contexts.

2. THE CONSIDERED SYSTEM MODELLING

The proposed hybrid multi-stage hydro matrix and PV solar cell model is illustrated in Figure 1. It incorporates a kinetic undershot water wheel designed for sustainable energy generation alongside PV solar cells. Each hydraulic undershot water wheel in the multi-stage system is connected to an induction generator via a large gearbox. The alternating current (AC) power generated by each water wheel is converted into direct current (DC) power using a three-phase uncontrolled rectifier [24]. To ensure a stable DC voltage, the system includes a buck DC/DC converter integrated with the proposed controller and an energy storage battery. A regulator, coupled with a three-phase inverter [25], is utilized to convert the stable DC power back into AC power, enabling it to supply the load reliably.

The study investigates the power output of each induction generator, which is primarily determined by water velocity and the torque of the undershot water wheels. Variations in water velocity, caused by changes in the main channel stream, directly affect the output power and, subsequently, the terminal load currents and voltage. To counteract these fluctuations, the implementation of a control unit is proposed to stabilize the load voltage, ensuring consistent performance regardless of changes in water velocity or load conditions. The hybrid multi-stage hydro matrix and PV solar cell system is designed with channels of varying depth and width, as well as water wheels of different sizes, as depicted in Figure 2. The use of a DC-link [26] is proposed to mitigate fluctuations in frequency and output voltage amplitude within the hybrid system. This design leverages traditional undershot water wheels, which have proven effective in harnessing low-head, low-speed moving streams for electricity generation. The efficiency of these wheels is enhanced with bucket-shaped blades, and their operational equations and parameters are detailed in [14].

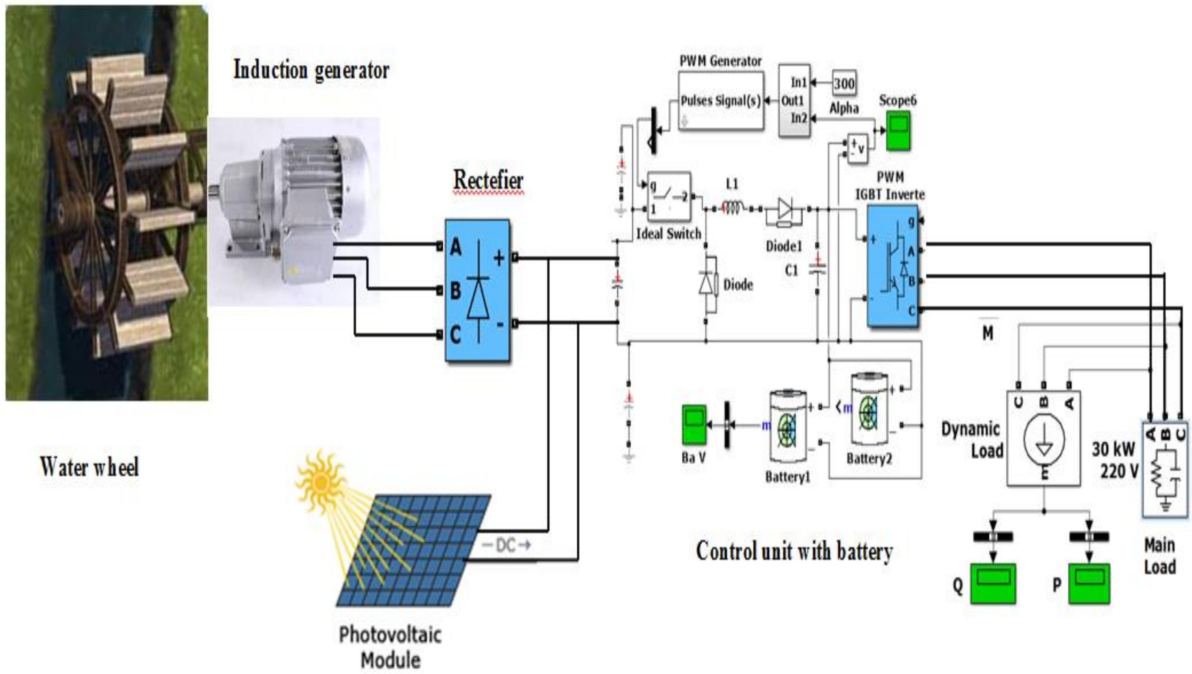


FIGURE.1 Schematic circuit of the proposed multistage hybrid hydro matrix/ PV solar cell model with the controlled circuit and feeding an isolated load.

In this investigation, it is proposed that the studied hybrid model consists of multistage underwater wheels in one main channel for the first kind as shown in Figure 2. The second source contained multi stage PV solar cell via DC bus. The proposed model of an under-shot water wheel is developed and designed with a MATLAB/SIMULINK condition as [14].

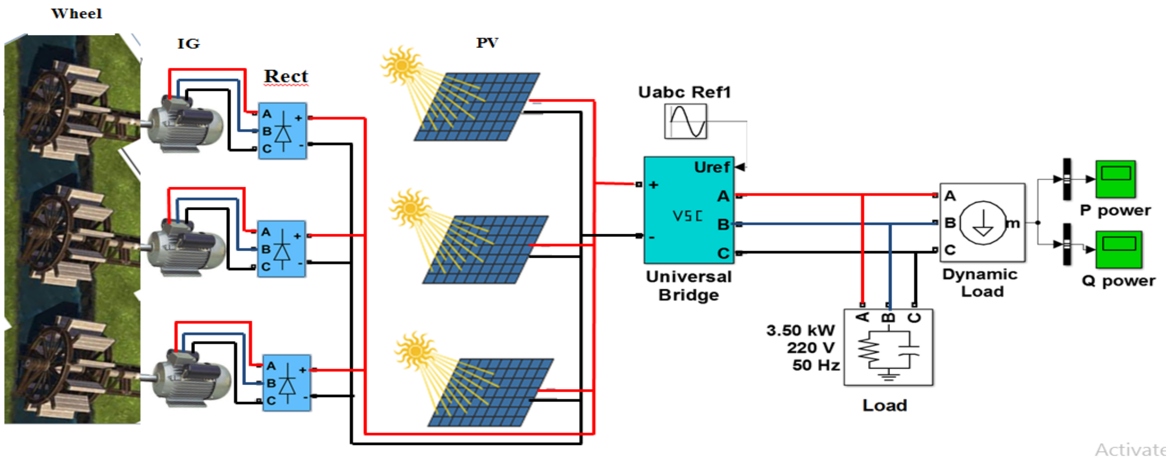
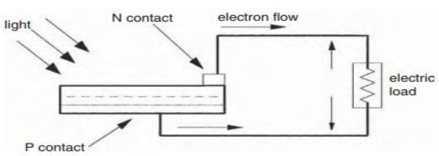
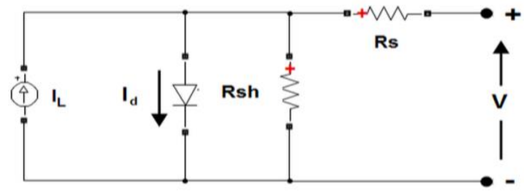


FIGURE. 2. Elevation view for hybrid model (hydro matrix / PV solar cell) with three multi-stage water wheels and three multi-stage PV solar cell.

2.1 The model of PV solar cell

The physics of the PV [27] cell is look like pn junction which light, the absorbed light energy photons is transferred to the electrons–holes system of the junction. The charged carrier in the pn junction region will create potential energy and circulate current through the load. This potential drives the photocurrent in the PV circuit. In equivalent circuit, the current supplied to the external load is equal to the current produced by the illumination power, minus the leakage current to the shunt diode. The open-circuit voltage V_{oc} of the photovoltaic cell is measured when there is no current load.





(a) (b)

FIGURE. 3. (a) PV effect converts the photon energy into voltage across the pn junction (b) the equivalent circuit

Each photovoltaic solar cell block has five-parameter model, current source IL (light-generated current), along with the diode parameters (I0 and nI), as well as the series resistance R_s, and shunt resistance R_{sh} are utilized to illustrate dependent I-V characteristics of the modules, which are influenced by irradiance and temperature and is given by the equation:

$$V_{oc} = V + IR_s \tag{1}$$

and the current through the diode is expressed as

$$I_d = I_D[e^{\frac{QV_{oc}}{AkT}} - 1] \tag{2}$$

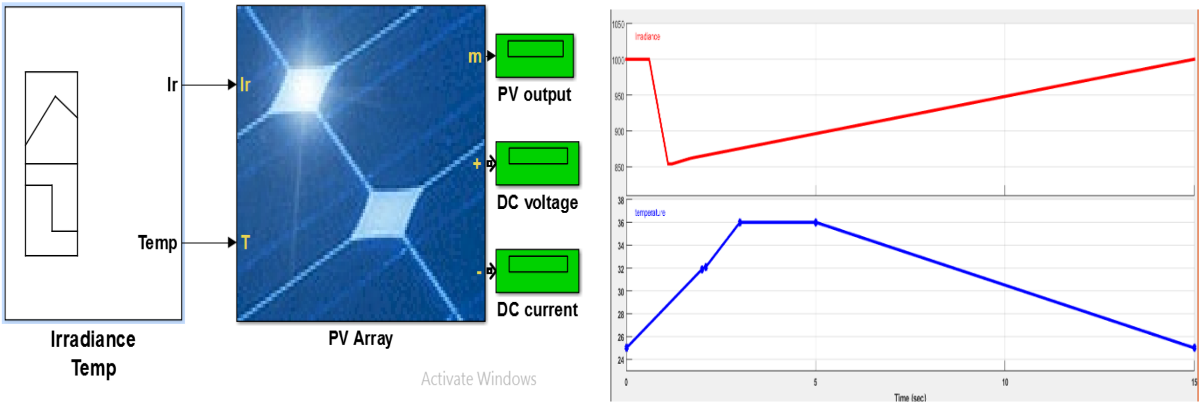
where
ID = the saturated diode current
Q = the electron charge = 1.6×10^{-19} C
A = constant of curve-fitting
k = constant of Boltzmann = 1.38×10^{-23} J/°K
T = absolute temperature on °K scale
Consequently, the load current can be expressed by this following equation:

$$I = I_L - I_D\left[e^{\frac{QV_{oc}}{AkT}} - 1\right] - \frac{V_{oc}}{R_{sh}} \tag{3}$$

the open-circuit voltage is obtained from

$$V_{oc} = \frac{AkT}{Q} Log_n\left(\frac{I_L}{I_D} + 1\right) \tag{4}$$

Using a MAT LAB-SIMULINK environment The proposed hybrid model was developed and designed in some condition to present a six multistage PV solar cell [28] with adding to three multi stage hydro matrix model, as shown in in Fig 3a. By using a nonlinear equation to modulate the PV solar cell using MATLAB function is obtained, which block diagram is shown in Fig.3b.



(a) (b)

FIGURE 4. MATLAB/SIMULINK developed a PV solar cell model for temperature and irradiation day applied to PV solar.

The nonlinear function of the photovoltaic solar cell Array block implements a module as shown in Fig 4. The array is built of strings and each string consists of modules whi'/;ch some of them are connected in parallel, and the other modules are connected in series.

TABLE 2. GENERATED POWER PARAMETER FOR ALL WHEELS AND PV SOLAR CELL IN OUR HYBRID MODEL AND THE VALUE OF INVERTER AND BATTERY CAPACITIES, STATIC AND DYNAMIC LOAD.

S N	Generation type	Number of items	Power of each item	Total power	inverter capacities	battery capacities	Total static load	Total of dynamic load
1	Water wheel	three	18 Kw	54 Kw	50 Kw	500 Ah	30 Kw	4 KVA
2	PV solar cell	sex	3.4 Kw	20.4				

3. THE CONSIDERED ARRANGEMENT FOR THE CONCIDERED MODEL

The simulation results of the proposed hybrid hydro matrix/PV solar cell model were analyzed to evaluate its performance under varying conditions, including water velocity changes, solar irradiation variations, temperature fluctuations, and load variations. The study considers two cases, and the outcomes for both cases are depicted in Figures 5 and 6, respectively. In the first case, the hybrid model includes three large undershot water wheels, each coupled with a large induction generator. Each undershot water wheel stage comprises three wheels, and all water wheel stages are connected to six multistage PV solar cell modules. This configuration operates without any control mechanisms, such as energy storage or advanced controllers. In the second case, the model is enhanced by introducing a control unit equipped with a PID controller [29]. Additionally, an energy storage system in the form of a battery tank is incorporated. This configuration is designed to mitigate the impact of parameter fluctuations, such as changes in water velocity, solar irradiation, temperature, and both dynamic and static load variations. The output results, specifically the load AC current and load AC voltage, for both cases are shown in Figures 7 and 8. These figures highlight the effectiveness of the control unit and energy storage system in maintaining stable load conditions, even under varying system parameters. Comparisons between the two cases demonstrate the improved stability and reliability of the hybrid system when equipped with the proposed control mechanisms.

Case 1: Hybrid Hydro Matrix/PV Solar Cell Model with Variable Load and Environmental Conditions In this case, the design model of a hybrid system consisting of a hydro matrix and PV solar cells is developed using the MATLAB/SIMULINK environment. This system is connected to a variable load, which includes both dynamic and static components. The water speed fluctuates between 1.45 m/s and 1.65 m/s, while the irradiation of the PV solar cells changes from 1000 W/m² to 850 W/m². Additionally, the temperature varies between 25°C and 37°C, as illustrated in Figure 5. The static load increases by 3 kW after three seconds and further increases by 3 kW after five seconds. The simulation results demonstrate that both load current, and voltage fluctuate in response to changes in dynamic or static load conditions, as shown in Figure 7.

Case 2: Hybrid Hydro Matrix/PV Solar Cell Model with Control Unit and Energy Storage In this case, the hybrid system consists of three multi-stage water wheels connected to six multi-stage PV solar cells. A control unit is employed in conjunction with a battery bank storage system to regulate the output of the DC/DC converter from the hydro matrix and the PV solar cell model. The DC/AC inverter is also utilized to maintain stable AC load voltage under varying conditions. All conditions for varieties (dynamic and static) load applied as previse case no 1 except the adding of control unit with connecting a battery bank storage system as shown in Fig. 6.

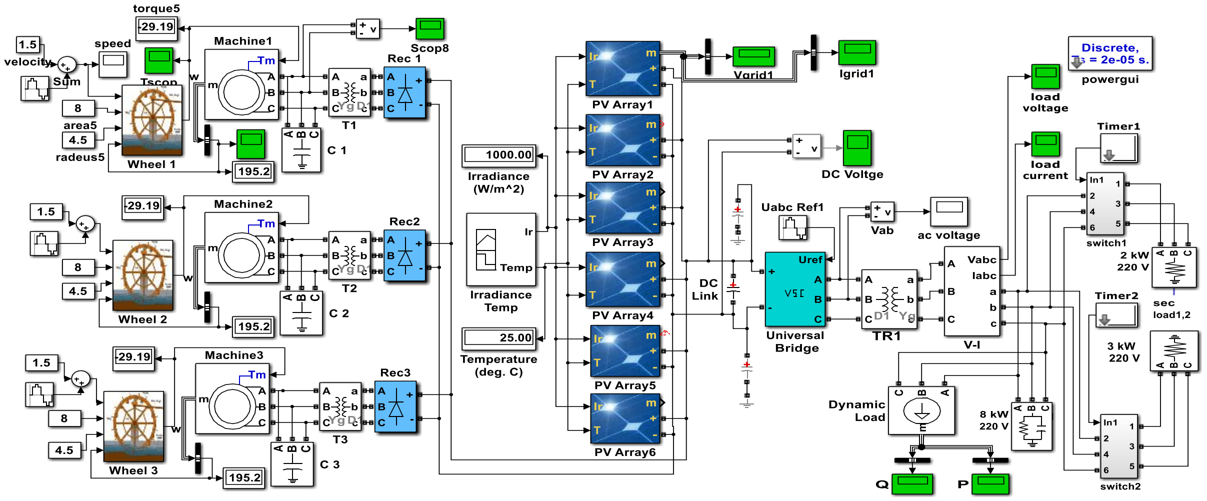


FIGURE.5. Hybrid hydro matrix wheel/ PV solar system included both dynamic load and variable static load without control unit.

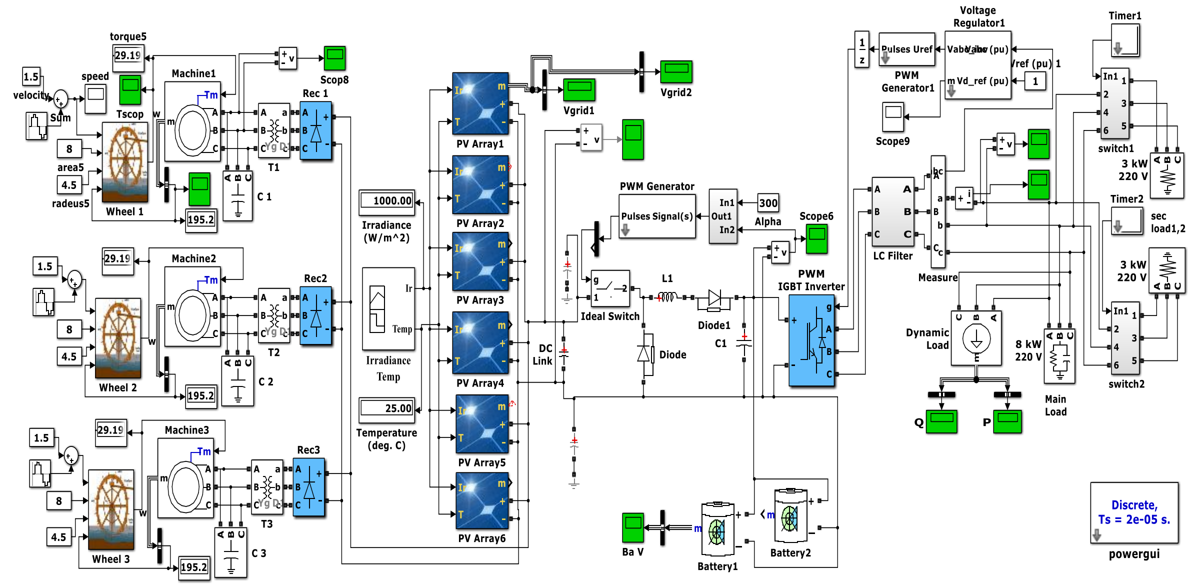


FIGURE. 6. Hybrid hydro matrix/ PV solar system included both control unit and battery bank

4. RESUTLS AND DISCUSSION

The performance of the multi-stage hybrid hydro matrix combined with multi-stage PV solar cells under various conditions was evaluated through simulations using MATLAB/SIMULINK. In the first scenario, each induction generator (IG) is driven by an undershot water wheel, with water velocity fluctuating between 1.45 m/s and 1.65 m/s within the hydro stream system. This variation represents the operating conditions for the hydro matrix system. Solar irradiation ranges from 1000 W/m² to 850 W/m² throughout the day, and temperatures vary between 25°C and 37°C, applying to the multi-stage PV solar cell system. This hybrid hydro-PV system is used to power an isolated load, which is both static and dynamic, as shown in Fig. 5. The load increases by 3 kW every three seconds. The results for this scenario are shown in Fig. 7. The water velocity fluctuates between 1.45 m/s (minimum) and 1.65 m/s (maximum), causing the torque generated by the water wheel to fluctuate between 25

N·m and 35 N·m, influenced by the water velocity and flow rate. In steady-state conditions, the rotor speed of the induction generator reaches 190 rad/sec, which is approximately 4% higher than its synchronous speed of 183.16 rad/sec. As for the load variations (dynamic and static), the load increases by 3 kW every three seconds. As a result, the load voltage drops from 240 V to approximately 160 V, while the load current rises from 25 A to 28 A, as shown in Figs. 7a and 7b. After five seconds, the load increases by an additional 3 kW, causing the load voltage to drop from 160 V to 130 V, and the current rises from 28 A to 30 A, as depicted in Figs. 7a and 7b. The results for this model, considering the variations in water velocity and other parameters, are presented in Fig. 7. It is evident that without a control unit, significant fluctuations in both load current and voltage occur, as shown in Figs. 7a and 7b.

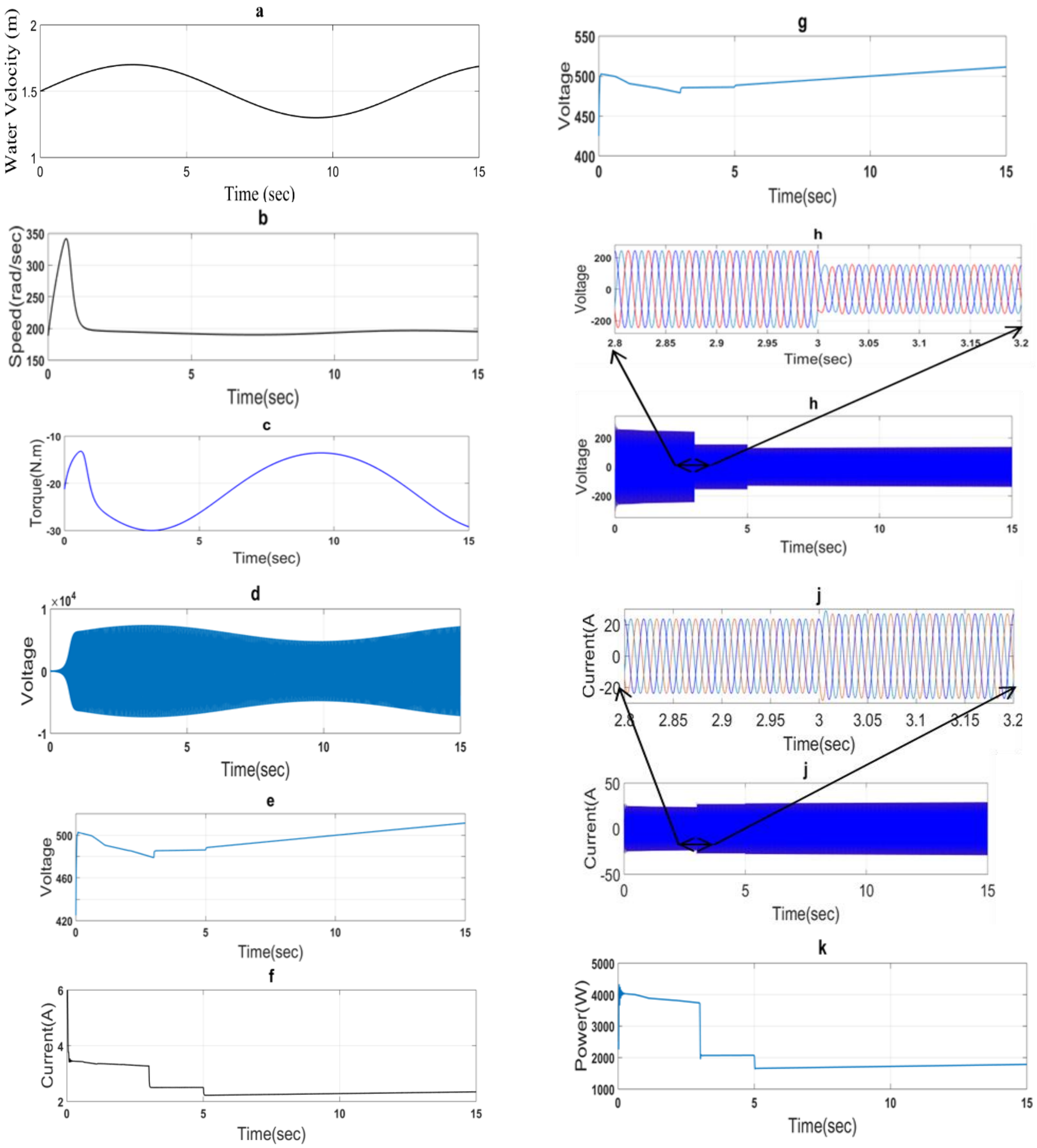


FIGURE 7. The results obtained from hybrid hydro matrix wheel/ PV solar system simulation without control (case number one) (a) water velocity. (b) IG rotor speed. (c) Water wheel torque. (d) IG ac voltage. (e) PV array voltage. (f) PV array current. (g) DC bus voltage. (h) load voltage(j) load currents. (k) active power(W).

In the second case, the proposed system, which consists of a hybrid hydro matrix and photovoltaic solar cell model, incorporates a controller that utilizes a control unit connected to a battery bank storage system, as illustrated in Fig. 6. During The velocity of the water fluctuates between 1.45 m/s and 1.65 m/s within the hydro stream system this condition for hydro matrix system. The sun irradiation variety between 1000 W/m^2 to 850 W/m2 during the day, and its temperature variety between 25o to 37o will apply to the multistage PV solar cell system. This hybrid hydro with PV system will feed an isolated variable (static and dynamic) load, as shown in Fig 6. The load connected to the hybrid model will be increased by 3 kW after each three sec. The results derived from this case are illustrated in Fig. 8. The load voltage, in this case, has a very minimal variation due to connected with control unit with battery storage system, as shown in Fig 8b.

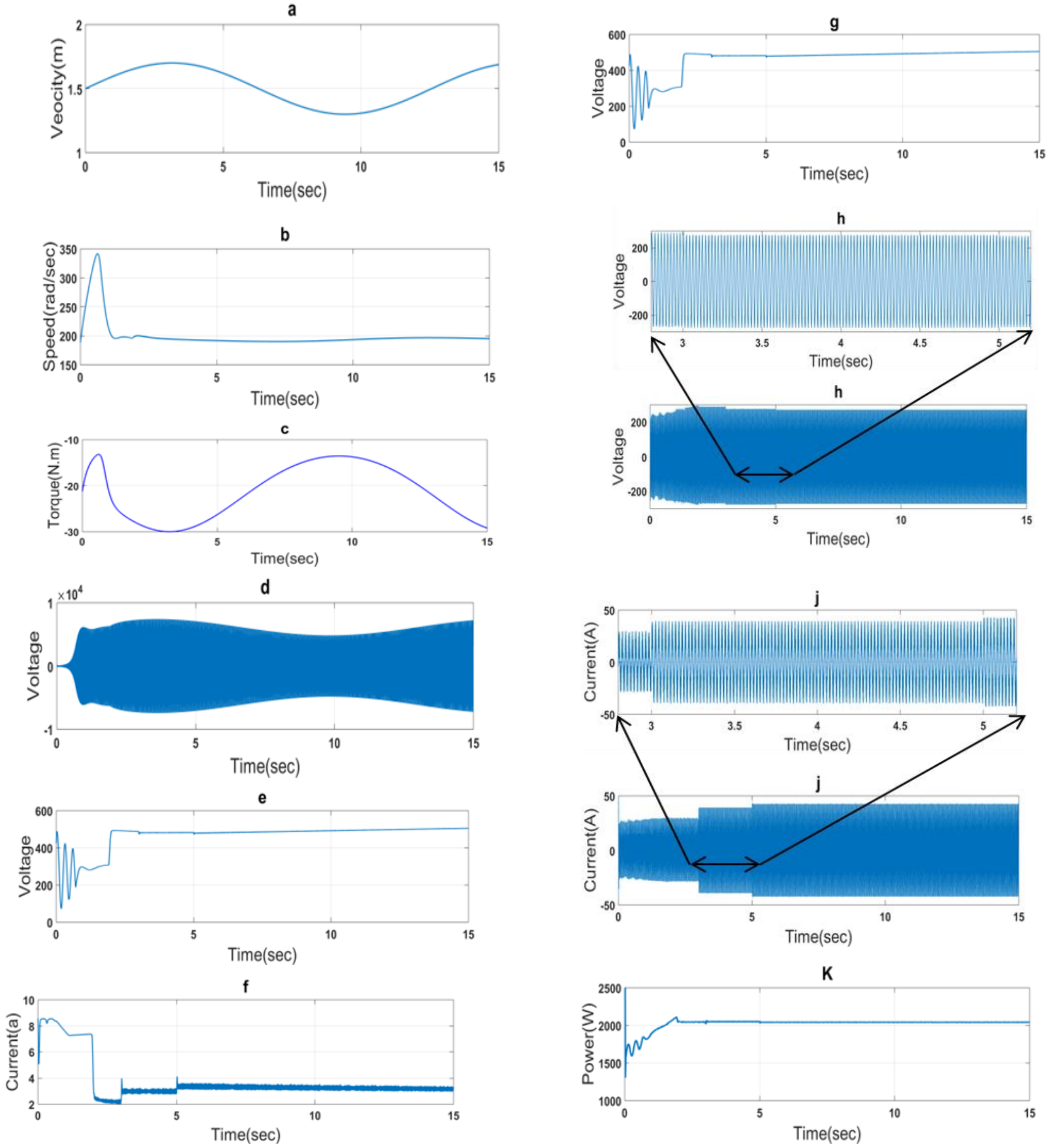


FIGURE.8. The obtained results from hybrid hydro matrix wheel/ PV solar system simulation without control (case number one) (a) water velocity. (b) IG rotor speed. (c) Water wheel torque. (d) IG ac voltage. (e) PV array voltage. (f) PV array current. (g) DC bus voltage. (h) load voltage. (j) load currents. (k) active power(W).

5. CONCULUSION

This study proposed to investigate how to generate a sustainable energy from a new hybrid system to feed variable loads besides the main channels of the Nile in Egypt. Based on multi stage hydro-matrix under shot wheels combined with multi stage PV solar cells. The proposed combined multi-hydro-matrix wheels as a first-stage of power generation unit and the multi-PV solar cell system as a second-stage Furthermore, the first stage of this hybrid model generation unit is composed of three multi-stage IG connected with three multi-stage undershot water wheels as turbines. Including an uncontrolled rectifier, a buck DC/DC converter, a DC/AC inverter, a battery storage system, and the associated variable (dynamic and static) loads. The subsequent phase of this hybrid system consists of six multistage PV solar cell systems, which are linked to the initial system via a DC bus. It is suggested to constrict the primary channel into smaller, broader, or more distinct slots, with the total width of these slots approximating one-third of the main channel, resulting in an enhancement of water velocity. Controllers that utilize PID algorithms are appropriately designed, and A battery storage bank is connected to guarantee a fixed voltage level during any reduction in hydropower generation or any reduction in sun irradiation. The simulations model in MATLAB have been conducted to assess the efficacy of the performance analyzed for a hybrid multi-hydro matrix combined with multi-PV solar cells. The results demonstrate that the suggested controller unit, when connected to a battery, effectively sustains the load voltage of a hybrid hydro-matrix/PV solar model across all variations, maintaining its desired values of both magnitude and frequency consistently.

Conflict of Interest

The author(s) have stated that there are no potential conflicts of interest related to the research, authorship, or publication of this article.

Acknowledgment

It is important to highlight that there is no financial support associated with the research, authorship, or publication of this article.

References

[1] Mohammad Ali Bagherian, Kamyar Mehranzamir,"A comprehensive review on renewable energy integration for combined heat and power production" Energy Conversion and Management, Volume 224, 2020, 113454, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2020.113454.

[2] W. Zhou, C. Lou, Z. Li, L. Lu, and H. Yang, "Current status of research on optimum sizing of stand-alone hybrid solar-wind power generation systems," Applied Energy, vol. 87, no. 2, pp. 380–389, Feb. 2010.

[3] S. K. Sanyal, "Future of geothermal energy," in Proc. 35th Workshop, Geothermal Reservoir Engineering, Stanford University, California, Feb. 2010, pp. 1–3.

[4] Chen, G.; Ji, Z. A Review of Solar and Wind Energy Resource Projection Based on the Earth System Model. Sustainability 2024, 16, 3339. https://doi.org/10.3390/su16083339.

[5] M. J. Sanjari, H. B. Gooi, and N.-K. C. Nair, "Power generation forecast of hybrid PV–wind system," IEEE Transactions on Sustainable Energy, vol. 11, pp. 703–712, 2020.

[6] Y. Chen, Y. Liu, S. Hung, and C. Cheng, "Multi-input inverter for grid-connected hybrid PV/Wind power system," IEEE Transactions on Power Electronics, vol. 22, no. 3, pp. 1070–1077, 2007.

[7] H. Hesham, A. Kassem, and M. Ali, "Hydro matrix power wheels generate more than 5 GW/h from main branch canals (River Nile) in Egypt," Journal of Power and Energy Engineering, vol. 4, pp. 71–78, 2016, doi: 10.4236/jpee.2016.43007.

[8] W.-L. Chen and Y.-Y. Hsu, "Controller design for an induction generator driven by a variable-speed wind turbine," IEEE Transactions on Energy Conversion, vol. 21, no. 3, pp. 625–635, Sep. 2006, doi: 10.1109/TEC.2006.875478.

[9] S.-H. Ko, S. R. Lee, H. Dehbonei, and C. V. Nayar, "Application of voltage- and current-controlled voltage source inverters for distributed generation systems," IEEE Transactions on Energy Conversion, vol. 21, no. 3, pp. 782–792, Sep. 2006, doi: 10.1109/TEC.2006.877371.

[10] J. Latham, M. Mohebbi, and M. L. McIntyre, "Output feedback control of a single-phase voltage source inverter utilizing a variable structure observer," in Proc. IEEE American Control Conference, Seattle, WA, USA, May 2017, pp. 24–26.

[11] S. Tahir, J. Wang, M. H. Baloch, and G. S. Kaloi, "Digital control techniques based on voltage source inverters in renewable energy applications: A review," Electronics, vol. 7, no. 2, pp. 1–37, 2018, doi: 10.3390/electronics7020018.

[12] F. Nejabatkhah and Y. W. Li, "Overview of power management strategies of hybrid AC/DC microgrid," IEEE Transactions on Power Electronics, vol. 30, no. 12, pp. 7072–7089, Dec. 2015, doi: 10.1109/TPEL.2014.2384999.

[13] H. F. A. Hamed, A. M. Kassem, and M. E. M. Ali, "Design and modeling of hydro matrix power wheels contain nine wheels by using MATLAB Simulink," 2017 Nineteenth International Middle East Power Systems Conference (MEPCON), Cairo, 2017, pp. 1031–1036, doi: 10.1109/MEPCON.2017.8301308.

[14] M. E. M. Ali, A. M. Kassem, and H. F. A. Hamed, "Modeling and control of a mini hybrid hydro matrix/wind in microgrid applications," IEEE Access, vol. 8, pp. 170843–170852, 2020.

[15] Sara Mahmoudi Rashid, "Employing advanced control, energy storage, and renewable technologies to enhance power system stability", Energy Reports, Volume 11, 2024, Pages 3202-3223, ISSN 2352-4847, https://doi.org/10.1016/j.egyr.2024.03.009.

[16] Qusay Hassan, Patrik Viktor, Tariq J. Al-Musawi, Bashar Mahmood Ali, Sameer Algburi, Haitham M. Alzoubi, Ali Khudhair Al-Jiboory, Aws Zuhair Sameen, Hayder M. Salman, Marek Jaszczur, "The renewable energy role in the global energy Transformations" Renewable Energy Focus, Volume 48, 2024, 100545, ISSN 1755-0084,https://doi.org/10.1016/j.ref.2024.100545.

[17] Mahdi Pouresmaieli, Mohammad Ataei, Ali Nouri Qarahasanlou, Abbas Barabadi, "Integration of renewable energy and sustainable development with strategic planning in the mining industry" Results in Engineering, Volume 20, 2023, 101412, ISSN 2590-1230, https://doi.org/10.1016/j.rineng.2023.101412.

[18] Abdallah Ben Abdelkader, Youssef Mouloudi, Mohammed Amine Soumeur "Integration of renewable energy sources in the dynamic voltage restorer for improving power quality using ANFIS controller"Journal of King Saud University - Engineering Sciences,Volume 35, Issue 8,2023,Pages 539-548,ISSN 1018-3639, https://doi.org/10.1016/j.jksues.2022.11.002.

[19] Zamathula Queen Sikhakhane Nwokediegwu, Kenneth Ifeanyi Ibekwe, Valentine Ikenna Ilojianya, Emmanuel Augustine Etukudoh, & Olushola Babatunde Ayorinde. " RENEWABLE ENERGY TECHNOLOGIES IN ENGINEERING: A REVIEW OF CURRENT DEVELOPMENTS AND FUTURE PROSPECTS. Engineering Science & Technology Journal, 5(2), 367-384. https://doi.org/10.51594/estj.v5i2.800

[20] A. Al-Quraan, B. Al-Mhairat"Sizing and energy management of standalone hybrid renewable energy systems based on economic predictive control" Energy Conversion and Management,Volume 300,2024,117948,ISSN 0196-8904,https://doi.org/10.1016/j.enconman.2023.117948.

[21] Raihan, A., Rahman, J., Tanchangya, T., Ridwan, M., Rahman, M. S., & Islam, S. (2024)." A review of the current situation and challenges facing Egyptian renewable energy technology" Journal of Technology Innovations and Energy ISSN: 2957-8809 Volume 3, 29-52 https://doi.org/10.56556/jtie.v3i3.965.

[22] Tawfik, M., Shehata, A. S., Hassan, A. A., & Kotb, M. A. (2023). Renewable solar and wind energies on buildings for green ports in Egypt. Environmental Science and Pollution Research, Volume 30(16), 47602-47629. https://doi.org/10.1007/s11356-023-25403

[23] Guilong Peng, Swellam W. Sharshir "Progress and performance of multi-stage solar still" A review, Desalination, Volume 565, 2023,116829,ISSN 0011-9164,https://doi.org/10.1016/j.desal.2023.116829.

[24] K. Koev, V. Ruseva and A. Krasteva, "Modelling and Simulation of an Electric Transport High-Power Three-Phase Full-Wave Uncontrolled Rectifier in the MATLAB/Simulink Environment," 2024 9th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE), Ruse, Bulgaria, 2024, pp. 1-5, doi: 10.1109/EEAE60309.2024.10600497.

[25] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A review of single-phase grid-connected inverters for photovoltaic modules," IEEE Transactions on Industry Applications, vol. 41, no. 5, pp. 1292–1306, 2005.

[26] Satyanarayana, P. V. V., Radhika, A., Reddy, C. R., Pangedaiah, B., Martirano, L., Massaccesi, A., ... & Jasiński, M. (2023). Combined DC-link fed parallel-VSI-based DSTATCOM for power quality improvement of a solar DG integrated system. Electronics, 12(3), 505; https://doi.org/10.3390/electronics12030505.

[27] D. Yadav et al., "Analysis of the Factors Influencing the Performance of Single- and Multi-Diode PV Solar Modules," in IEEE Access, vol. 11, pp. 95507-95525, 2023, doi: 10.1109/ACCESS.2023.3306473.

[28] M. Denny, "The efficiency of overshot and undershot waterwheels," Eur. J. Phys., vol. 25, pp. 193–202, 2004, doi: 10.1088/0143-0807/25/2/006.

[29] M. N. Marwali and A. Keyhani, "Control of distributed generation systems-part 1: Voltages and currents control," IEEE Transactions on Power Electronics, vol. 19, no. 6, pp. 1541–1550, 2004.