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Design of an Electric Drive System Powered by Renewable Sources

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Abstract — **The most serious disturbances to occur in electric vehicles (EVs) are the management of electric energy sources, which can affect the performance and efficiency of the EV. In this paper, various renewable sources are proposed for an electric drive system, equipped with a double stator induction motor (DSIM) connected to the EV. Overall, this study is centered on the application of multisource energy storage systems in EV drive system, mainly photovoltaic power generation system (PV), battery source (BS), and fuel cell (FC). A Maximum Power Point Tracking (MPPT) controller for a PV system connected to BS which ensures an uninterrupted power supply of the EV, during the steady-state response as well as the temporary behavior. Simulation results are given to demonstrate the benefits of the use of various renewable sources in EVs drive.**

Keywords— Renewable energy sources (RES); DC/DC Converter; Direct torque control (DTC); Electric vehicle (EV); Double stator induction motor (DSIM).

NOMENCLATURE

$i_{S\alpha1,2}$, $i_{S\beta1,2}$ Stator currents (A)

$V_{S\alpha1,2}$, $V_{S\beta1,2}$ Stator currents (A)

$R_{S1,2}$, R_r Stator/Rotor resistances (Ω)

w_r Rotor angular speed (*rad/s*)

L_m, L_s, L_r Mutual, Stator, and Rotor inductance (H)

J_t, k_f Inertia moment ($kg.m^2$) and viscous friction (*N.m.s/rad*)

T_e, T_l Electromagnetic/Load torque (N.m)

C_{FC}, R_{ohm}, R_{con}, R_{act} Equivalent electrical capacitance (F), Ohmic, concentration, and activation resistance (Ω)

I. INTRODUCTION

The production technology of renewable energy devices is near maturity with high system efficiency being the central issue for manufacturers and consumers. The solar panel manufacturers are creating highly efficient panels, whereas power converter and semiconductor manufacturers are creating faster and low-loss switch devices. Similarly, fuel cells (FCs) manufacturers are creating long life optimized designs. The development of electrical storage demands energy storage devices of high reliability to complement renewable sources [1]-[3].

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However, renewable energy sources (RES) are dependent on climatic conditions and hence cannot be used for continuous operations. To avoid this disadvantage, a hybrid configuration of RES can ensure continuous power supply. Through the blending systems, which complement each other, an uninterrupted energy supply can be ensured. Thus, the hybrid systems and their control strategies have been the subject of extensive research in the area of renewable energy. Wind, solar, and hydrogen-based power generation are a few of the most encouraging technologies of renewable energy. While photovoltaic (PV) and wind energy have achieved great advances, FCs are emerging as a prospective green energy source because they have the advantages of zero noise, high efficiency, and low emission pollutants. These received worldwide hybrid power systems (HS) are seeking for interest in recent years. Moreover, it is easier to optimize each renewable energy source's control process within an HS for enhanced energy efficiency. Depending on optimal harvesting power from every source, HS can effectively enhance energy use and reliability [4, 5].

Currently, the increased demand for environmentally friendly transport means it has catalyzed development and research in hybrid electric vehicles (HEVs) to intensify their energy efficiency and environmental sustainability. One of the approaches utilized in curbing the use of fossil fuels and decreasing carbon imprints is adding RES into the powertrain of HEVs, reflecting the automotive sector's progression toward more sustainable and environmentally means [6].

A DC-DC Converter and a Voltage Source Inverter are two essential elements used by the PV system to operate the motor drive. The output voltage of the PV system could be regulated utilizing the Boost Converter before its entry into the inverter.

The motivation behind this work is that hybrid energy sources are supplying electric vehicles (EVs). These energy sources have a vital goal concerning electric drive systems. Hence, it is important to highlight the use of hybrid sources that improve the system's efficiency. In addition, these sources have a lot of advantages, such as: optimizing power efficiency for industrial operations, reducing energy costs and enhancing sustainability. On the other hand, direct torque control (DTC) is an alternative control methodology that has a significant interest in the process field due to its simplicity and superior dynamics, despite its drawbacks of variable switching frequency, torque ripples, and high flux [7]. This strategy is used, as a nominal control for double stator induction motor (DSIM) propulsion EV. Recently, the DSIM drives have been proposed for EV applications due to their advantages, such as: reduce torque pulsations, higher system reliability, and good power delivery per phase.

This study aims at investigating the usage of various renewable sources in EV applications.

The suggested research is structured into five sections: Section 2 presents the dynamic model of overall system from source to load, while Section 3 introduces the DTC strategy. Section 4 illustrates the simulation results, which demonstrate the suggested study. At last, Section 5 addresses the conclusion.

II. MODELING OF THE OVERALL SYSTEM

A. DSIM Modeling

The DSIM mathematical model in the αβ stationary reference frame may be expressed as follows:

$$\begin{cases} \dot{X}_{\alpha\beta S_{1,2}} = f_i\left(X_{\alpha\beta S_{1,2}}\right) + GU_{\alpha\beta S_{1,2}} \\ Y_{\alpha\beta S_{1,2}} = CX_{\alpha\beta S_{1,2}} \end{cases} \quad (1)$$

With $X_{\alpha\beta S1,2}$, $U_{\alpha\beta S1,2}$, and $Y_{\alpha\beta S1,2}$ are the state vector, input vector, and the output vector, respectively.

The mechanical drive is given by [8]:

$$\begin{cases} J_t\dot{\omega}_r = T_e - T_L - B_r\omega_r \\ T_e = p\left(\left(\varphi_{S\alpha 1}i_{S\beta 1} - \varphi_{S\beta 1}i_{S\alpha 1}\right) + \left(\varphi_{S\alpha 2}i_{S\beta 2} - \varphi_{S\beta 2}i_{S\alpha 2}\right)\right) \end{cases} \quad (2)$$

Where J_t , T_e, T_l and B_r are the total coefficient inertia, motor torque, load torque, and friction coefficient, respectively, w_r, $\varphi_{r\alpha}$, and $\varphi_{r\beta}$ are the rotor speed and rotor flux, respectively.

B. Mathematical Modeling of a Vehicle

The EV dynamics model is given by the following equation [9]-[10]:

$$F_t = \frac{1}{2}\rho C_a A\left(V \pm V_w\right)^2 \pm M_v g\sin\left(\alpha_p\right) + C_r M_v g + M_v\dot{V} \quad (3)$$

Where F_t is the total force exerted on the vehicle, ρ is air density, C_a, C_r are aerodynamic and rolling coefficient, A and M_v are frontal area and mass of the vehicle, V and V_w are the velocity of the vehicle and wind speed, respectively.

C. Modeling of PV System

The PV panel model includes single diode, a series and parallel resistance. The characteristic of this model is given as follows [10]-12]:

$$\begin{cases} I_{pv} = I_{ph} - I_d - I_{sh} \\ I_{pv} = I_{ph} - I_o\left(e^{\left(q\frac{\left(R_s I_{pv} + V_{pv}\right)}{AKT}\right)} - 1\right) - \frac{R_s I_{pv} + V_{pv}}{R_{sh}} \end{cases} \quad (4)$$

Where I_{pv}, I_{ph}, I_d, and I_{sh} are the output current, photo-current, diode current, and shunt current, respectively.
q, A, K, and T are the electron charge, ideality factor of the diode, Boltzmann's constant, and the operating temperature, respectively.

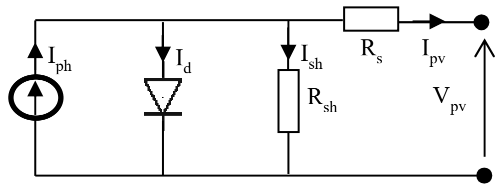

Fig.1. PV cell equivalent circuit

The electrical parameters of the module used in this study are listed in Table 1.

TABLE I. ELECTRICAL PARAMETER

Parameter	Value
Maximum power	459.9 W
Optimum voltage	30 V
Optimum current	15.33 A
Open-circuit voltage	37.5 V
Short-circuit current	17.63 A
Parallel strings	1
Series-linked modules per string	10
Temp coefficient of Voc	-0.40 %/deg.C
Temp coefficient of Isc	0.087005 %/deg.C

D. Modeling of Fuel Cell System

The dynamic model of a proton exchange membrane fuel cell (PEMFC) is based on a chemical reaction between oxygen and hydrogen. As Fig. 2, depicts the electrical model of the PEMFC [13]. The two electrochemical reaction results can be expressed as follows:

$$H_2 \Rightarrow 2H^+ + 2O^- \quad (5)$$

$$\frac{1}{2}O_2 + 2H^+ + 2O^- \Rightarrow H_2O \quad (6)$$

The static model is given as follows:

$$V_{FC} = E_n - V_{con} - V_{act} - V_{ohm} \quad (7)$$

Where: V_{FC}, E_n, V_{con}, V_{act}, V_{ohm} are the output voltage, the open circuit voltage, the concentration polarization voltage, the activation losses voltage, and the ohmic losses voltage, respectively.

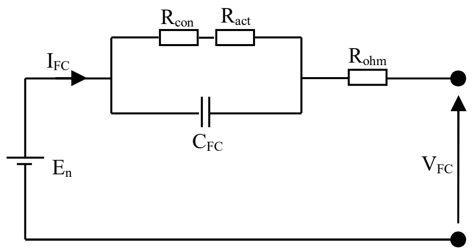

Fig.2. Fuel cell equivalent circuit

E. Modeling of the Battery Source

An accurate Li-ion battery model is crucial for predicting battery behavior under diverse operating situations and for assessing battery states, involving state of charge (SOC) and state of health. The electrical model is illustrated in Fig. 3 [14]-[15].

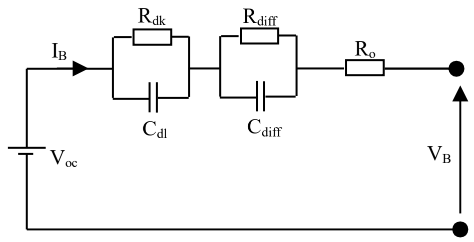

Fig.3. Battery equivalent circuit

The output voltage is given by [16]:

$$V_B = V_{oc} - V_{dl} - V_{diff} - V_o \quad (8)$$

Where: V_B, V_{oc}, V_{dl}, V_{diff}, V_o are the output voltage, open circuit voltage, voltage across R_{dl}-C_{dl}, voltage across R_{diff}-C_{diff}, and instantaneous voltage, respectively.
The SOC of the battery is obtained using the integral equation as follows [17]:

$$SOC(t) = SOC_i - \frac{1}{3600}\int_{t0}^{t} i_B(t)dt \quad (9)$$

With: SOC_i ,i_B are the initial SOC and the battery cell current, respectively.

F. DC/DC Step-up converter

A parallel chopper is used as a source-load adapter, ensuring that the power is supplied by the PV system. Thus, it is used to increase the generated DC voltage of the module [18], as shown in Fig. 4.

To optimize the PV system operation in various weather conditions, we use the MPPT method based on Perturb and Observe (P&O) technique, which generates a duty cycle for controlling boost converter.

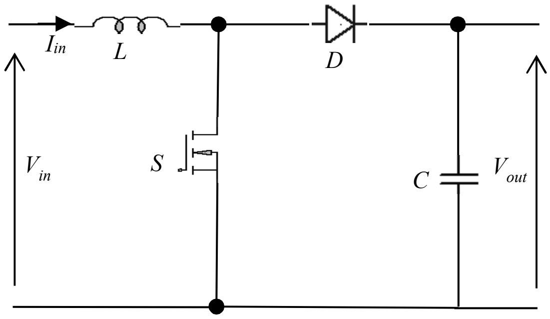

Fig.4. DC/DC Step-up converter structure

The output voltage and current equations based on the ON/OFF switch can be written as follows:

$$\begin{cases} I_{out} = I_{in}(1 - D) \\ V_{out} = V_{in}\left(\dfrac{1}{1 - D}\right) \end{cases} \quad (10)$$

Where: I_{in}, I_{out}, V_{in}, V_{out}, and D, are the input/output current, input/output voltage, and duty cycle, respectively.

III. DTC STRATEGY

The DTC approach is a reliable control solution for guaranteeing an induction motor's quick dynamic response. Its principle operation is based on an instantaneous space vector theory. It can also be explained by analyzing the stator voltage equations in the stator flux reference frame [19]. In this section, to apply the DTC technique, we have used two switching tables, each one for an inverter. As a result, the analysis of DTC for the DSIM is similar to that of DTC for an induction motor, with a modified switching table, as shown in Fig. 6.

The DTC strategy is based on an extended algorithm:

$$\begin{cases} \varphi_{S\alpha1,2} = \int_0^t \left(V_{S\alpha1,2} - R_{S1,2} i_{S\alpha1,2}\right)dt \\ \varphi_{S\beta1,2} = \int_0^t \left(V_{S\beta1,2} - R_{S1,2} i_{S\beta1,2}\right)dt \end{cases} \quad (11)$$

Where: $V_{S\alpha1,2}$ and $V_{S\beta1,2}$ are the stator vectors voltages.

Thus, the stator flux magnitude and its angle are given by:

$$\begin{cases} |\phi_S| = \sqrt{\varphi_{S\alpha1,2}{}^2 + \varphi_{S\beta1,2}{}^2} \\ \theta_S = a\tan\left(\varphi_{S\beta1,2} / \varphi_{S\alpha1,2}\right) \end{cases} \quad (12)$$

The voltage vectors of this strategy are shown in Fig.5.

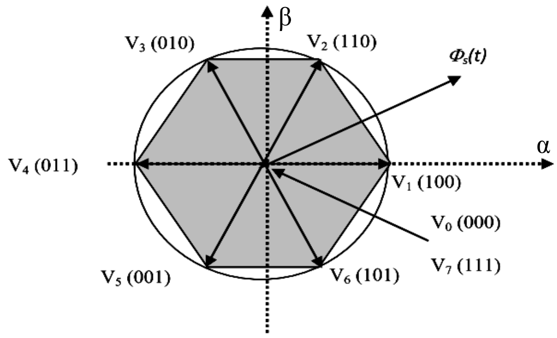

Fig.5. Trajectory of stator flux using the selection of suitable voltage vectors

With: P_L, P_B, P_{PV}, P_{FC} are the required power, battery power, photovoltaic power, and fuel power, respectively.

In this study, two scenarios are possible. Firstly: the PV generator is used to charge the battery and power the load. Secondly: the load is supplied by the whole energy sources with integrate FC, if the power of the PV is not sufficient and SOC < 30%. In both scenarios, the system was operated under a constant temperature of 25°C and an irradiance of 1000 W/m². Table 1 illustrates the electrical characteristics of the PV module used in the specified scenario. To assess the effectiveness of the suggested study, various simulations are shown in Figs. 7-10.

The DC bus voltage is kept steady at 400 V, even when using hybrid power sources, as illustrated in Fig. 7

Fig. 8 depicts the power results of hybrid energy sources that fed the drive system. In Figs. 8a and b, the evolution of the fuel cell power and PV power throughout the DC/DC boost converter fill the need of required power during steep changes in desired velocity. In Fig. 8c, the progression of the power supplied onto the battery is clarified as well.

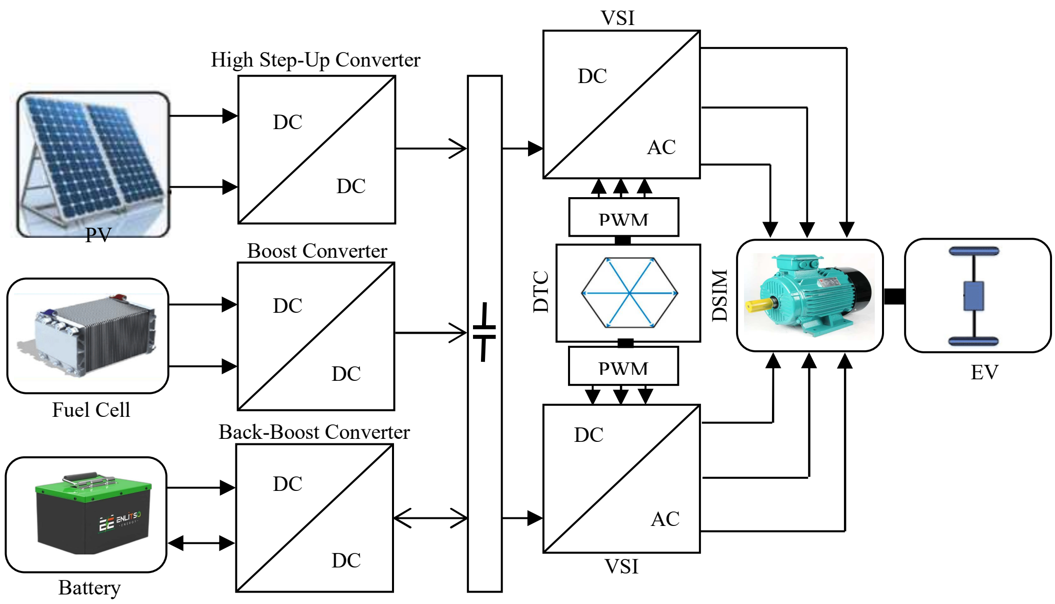

Fig.6. Schematic diagram of hybrid energy sources supplied an electric drive system

IV. Simulation Results

This section demonstrates the overall performance of the suggested scheme applied to the electric drive system based on DTC of DSIM powered by various RES. These simulation results have used nominal parameters of DSIM (see Appendix). This later is powered by two PWM voltage inverters. On the other hand, the power management control is mandatory to make coordination between the various energy sources. All these sources work to provide DC bus (Fig. 7), where the total power is calculated as follows:

$$P_L = P_B + P_{PV} + P_{FC} \quad (13)$$

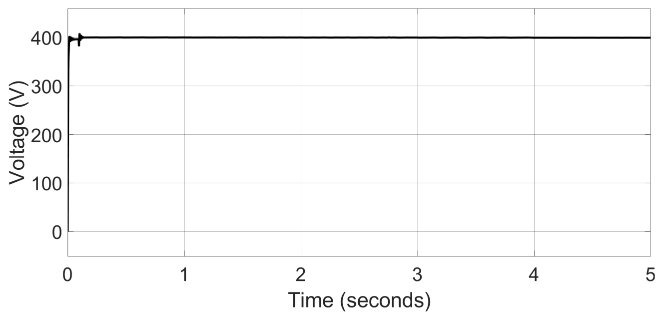

Fig.7. DC bus voltage source

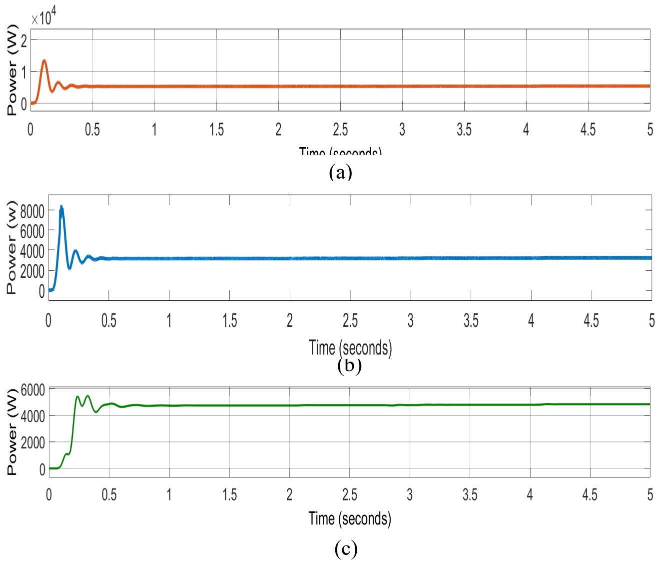

Fig.8. Power evolution: (a) PV power, (b) Fuel power, (c) Battery power

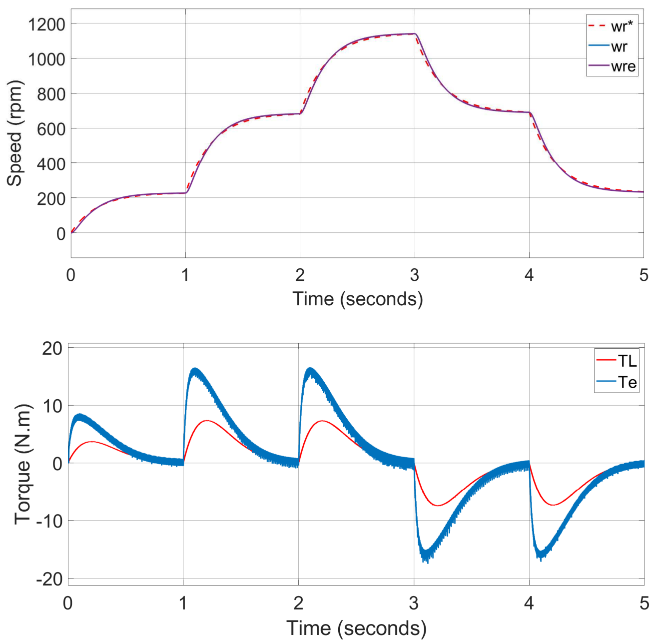

Fig.9. Reference, rotor speed, and emulated speed (upper plot), electromagnetic torque and load torque (lower plot)

The obtained results indicate that precise estimations of power transfers inside the EV powertrain are attained.

Thus, we have focused on the simulation outcomes of the electric drive system. However, Fig. 9 shows the results of the speed, electromagnetic torque, and load torque of the DSIM and load, respectively. This illustrates that the motor accelerates with trajectories of the reference speed (rpm) [222, 680, 1140, 700, 235] and for variable values of the load torque. The rotor speeds follow perfectly the reference value. The values of the electromagnetic torque depend on the reference trajectory of motor speed and values of the load torque.

It is evident, from Fig. 10, that even the rotation speed of the DSIM changes, the flux kept constant and follows its reference value stator current. The stator current remains sinusoidal and assumes the required value.

The obtained results demonstrate that the suggested method performs efficiency under the specified test conditions, and the mean square error (MSE) in the rotor speed is 1.68 rpm.

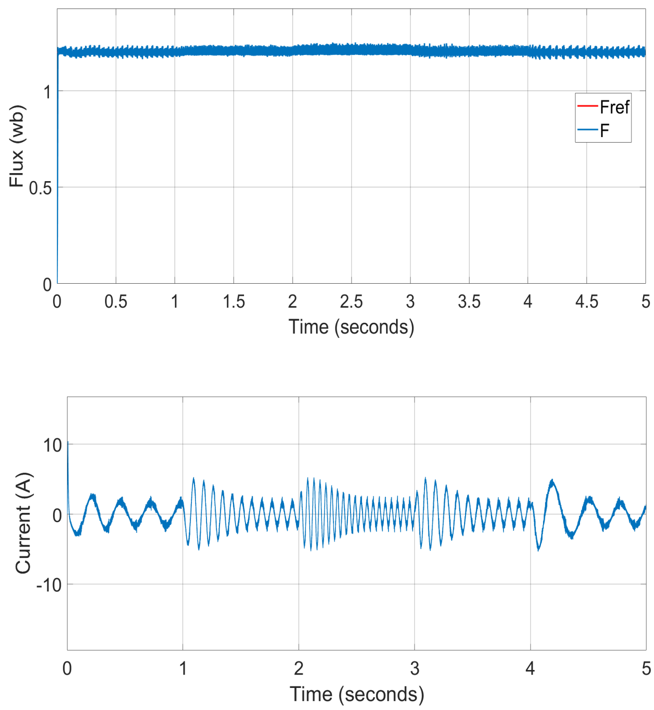

Fig.10. Stator flux (upper plot), and stator current (lower plot)

V. Conclusion

In this paper, an affective hybrid energy sources method is suggested for EV applications. This method possesses the capacity to enhance the sustainability and environmental cleanliness of transportation network, while simultaneously encouraging the utilization of RES. Additionally, the drive system with DTC of DSIM fed by hybrid sources can be used in industrial applications that require accurate regulation and reliable operation. The obtained results substantiate the efficacy of the proposed hybridization strategy in improving the performance, reliability, and energy efficiency of RES electric vehicles.

Furthermore, this study provides a foundation for the future investigations, which could concentrate on advancing the suggested hybrid RES methodology through the optimization of testing procedures, the enhancement of measurement reliability, and the evaluation of dynamic performance across diverse environmental conditions.

APPENDIX

TABLE II. DSIM PARAMETER

Parameter	Value
P_n	4.5 kw
R_s, R_r	3.72 Ω
L_m	0.367 H
L_r	0.006 H
$L_{s1,2}$	0.022 H
J	0.062 kg.m²

REFERENCES

[1] Z. Qin, J. Ma, M. Zhu, T. Khan, "Advancements in energy storage technologies: Implications for sustainable energy strategy and electricity supply towards sustainable development goals," *Energy Strategy Reviews*, vol. 59, P. 101710, 2025, https://doi.org/10.1016/j.esr.2025.101710

[2] Njema, George G., Ouma, Russel Ben O., Kibet, K. Joshua, "A Review on the Recent Advances in Battery Development and Energy Storage Technologies," *Journal of Renewable Energy*, p. 2329261, 2024, https://doi.org/10.1155/2024/2329261

[3] F. Jiang *et al.*, "A comprehensive review of energy storage technology development and application for pure electric vehicles," *Journal of Energy Storage*, vol. 86, p. 111159, 2024, https://doi.org/10.1016/j.est.2024.111159

[4] O.E. Olabode, T.O. Ajewole, I.K. Okakwu, A.S. Alayande, D.O. Akinyele, "Hybrid power systems for off-grid locations: A comprehensive review of design technologies, applications and future trends," *Scientific African*, vol. 13, e00884, 2021, https://doi.org/10.1016/j.sciaf.2021.e00884

[5] K. Boutaghane *et al.,* "Using new control strategies to improve the effectiveness and efficiency of the hybrid power system based on the battery storage system," *Scientific Reports,* vol. 15, p. 4730, 2025. https://doi.org/10.1038/s41598-025-88804-9

[6] D. Mignogna, P. Ceci, C. Cafaro, G. Corazzi, and P. Avino, "Production of Biogas and Biomethane as Renewable Energy Sources: A Review," *Applied Sciences*, vol. 13, no. 18, p. 10219, 2023, https://doi.org/10.3390/app131810219

[7] V. S. Reddy Chagam and S. Devabhaktuni, "An Isolation Transformer-less Single DC Source fed Dual 5-leg Inverter Controlled 5-Phase Induction Motor with Modified Direct Torque Control," *IEEE Latin America Transactions*, vol. 22, no. 3, pp. 229-239, 2024, https://doi.org/10.1109/TLA.2024.10431418

[8] R. Belal, M. Flitti, and M. Lamine Zegai, "Tuning of PI speed controller in direct torque control of dual star induction motor based on genetic algorithms and neuro-fuzzy schemes", *RRST-EE*, vol. 69, no. 1, pp. 9–14, 2024, doi: 10.59277/RRST-EE.2024.1.2.

[9] J. Liu, Z. Wang, C. Zong, J. Yang, "Research on the simulation model of electric vehicle parameters based on PMSM-AMT," *IEEE Conference and Expo Transportation Electrification Asia-Pacific, ITEC Asia-Pacific, IEEE*, 2014, pp. 1–6. https://doi.org/10.1109/ITEC-AP.2014.6940925

[10] A. Narendra *et al.*, "Solar PV fed FSVSI based Variable Speed IM Drive using ASVM Technique," *Engineering Science and Technology, an International Journal*, vol. 40, p. 101366, 2023, https://doi.org/10.1016/j.jestch.2023.101366

[11] M. Ozcelik, A.Yilmaz, "Modification of the incremental conductance algorithm in grid connected photovoltaic systems," *RRST-EE*, vol. 61, no. 2, pp. 164–168, 2016,

[12] T. Roubache, S. Chaouch, "Sensorless ANFIS-based control of PV-powered double stator induction motors for EVs," *Journal Européen des Systèmes Automatisés*, vol. 57, no. 1, pp. 67-76, 2024, https://doi.org/10.18280/jesa.570107

[13] R. Seyezhai, B. L. Mathur, "Modeling and control of a PEM fuel cell based hybrid multilevel inverter," *International Journal of Hydrogen Energy*, vol. 36, no. 22, pp. 15029–15043, 2011, https://doi.org/10.1016/j.ijhydene.2011.04.019

[14] R. Rotas, P. Iliadis, N. Nikolopoulos, D. Rakopoulos, and A. Tomboulides, "Dynamic Battery Modeling for Electric Vehicle Applications," *Batteries*, vol. 10, no. 6, p. 188, 2024, https://doi.org/10.3390/batteries10060188

[15] Y. Zhao, L. Geng, S. Shan, Z. Du, X. Hu, X. Wei, "Review of sensor fault diagnosis and fault-tolerant control techniques of lithium-ion batteries for electric vehicles," *Journal of Traffic and Transportation Engineering*, vol. 11, no. 6, pp. 1447-1466, 2024, https://doi.org/10.1016/j.jtte.2024.09.003

[16] N.N. Mawuntu, B.-Q. Mu, O. Doukhi, D.-J. Lee, "Modeling of the Battery Pack and Battery Management System towards an Integrated Electric Vehicle Application," *Energies*, vol. 16, p. 7165, 2023, https://doi.org/10.3390/en16207165

[17] A. Bharatee, P. S. Abhishek and P. K. Ray, "Design of a PV-Integrated EV Charging Station with Power Management Schemes," *5th International Conference on Energy, Power and Environment: Towards Flexible Green Energy Technologies (ICEPE)*, Shillong, India, 2023, pp. 1-6, https://doi.org/10.1109/ICEPE57949.2023.10201616

[18] C. Ben Regaya, F. Farhani, H. Hamdi, A. Zaafouri, A. Chaari, "Robust ANFIS Vector Control of Induction Motor Drive for High-Performance Speed Control Supplied by a Photovoltaic Generator," WSEAS Transactions on Systems and Control, vol. 15, pp. 356-365, 2020, https://doi.org/10.37394/23203.2020.15.37

[19] A. Belgacem, Y. Ben Salem and M. N. Abdelkrim, "Modified DTC control using fuzzy logic control for dual three phase induction machine with open phases," *IEEE 12th International Multi-Conference on Systems, Signals & Devices (SSD15)*, Mahdia, Tunisia, 2015, pp. 1-6, https://doi.org/ 10.1109/SSD.2015.7348212.