Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 10, Issue 4, November 2019: 747-758
DOI: 10.53555/tojqi.v10i4.10595

Research Article

Integrated Renewable Energy with Energy Storage: Electronic Driving Efficiency and Stability

Mohd.Murtaja[1*] Priyanka Singh[2], Vijai Kumar[3], Kapil Kumar[4], John Robins Bentham[5], Rakesh Kumar Pandey[6]

ABSTRACT The incorporation of renewable energy sources with energy storage solutions in electronic drive systems(EDS) offers a promising technique to progress the performance, proficiency, and stability of these systems. The goal of this research is to determine the feasibility of using renewable energy and energy storage technologies to enhance the functionality of EDS by reducing the variation in power and improving energy utilization. This study is important because of the growing essential for sustainable energy resolutions that address the increasing demand for sustainable energy solutions where EDS are critical and the industries requiring these include automotive and industrial automation. The methodology consists of a thorough review of the literature, case studies, and technological developments of renewable energy sources (solar, wind, etc.) and energy storage solutions (batteries, supercapacitors, etc.) integrated into EDS. Also provided are performance metrics, barriers during integration, and challenges. Key findings show that non-conventional energy and energy storage increase the efficiency, stability, and reliability of EDS by improving power quality, decreasing operational costs, and increasing sustainability. Together these technologies can enable effective load management and improved response to power fluctuations. These findings have important implications for future EDS design and procedure, especially in the framework of future smart grids and the overall transition to renewable energy. This work advances the growth of more resourceful and supportable EDS and provides insights for academia and industry practitioners in energy management and electronics.

Keywords: Electronic Drive Systems, Renewable Energy, Energy Storage, Performance Enhancement, Sustainability

1. Introduction

2. 1.1 Overview of Electronic Drive Systems (EDS)

Modern industrial and automotive applications are dependent on Electronic Drive Systems (EDS). They are electrical and electronic combinations of electrical components used to manage and change electrical energy to mechanical motion to drive machinery or vehicles. Motors, inverters, controllers, and sensors are the typical components of an EDS, which cooperatively control the speed, torque, and direction of motion. These systems are indispensable in automotive (electric vehicles), robotics, industrial automation, and HVAC systems due to their flexibility and efficiency (Molina, 2017).

An EDS core function is to control the motor operation with great precision, to make sure that performance is within the requirements. The advantages of these systems are speed regulation, lower energy consumption, and lower maintenance compared to traditional mechanical drive systems. EDS will make progress as industries

---

[1] [1]Department of Electronics and Instrumentation Engineering, Sir Chhotu Ram Institute of Engineering and Technology, Chaudhary Charan Singh University Campus, Meerut-250004 UP, India, murtazaccsu@gmail.com, rakesh18.pnd@gmail.com

[2] [2]Department of Electronics and Communication Engineering, Sir Chhotu Ram Institute of Engineering and Technology, Chaudhary Charan Singh University Campus, Meerut-250004 UP, India, singhprii@gmail.com,

[3],[4],[5]Department of Agricultural Engineering, Sir Chhotu Ram Institute of Engineering and Technology, Chaudhary Charan Singh University Campus, Meerut-250004 UP, India, vijayboby143@gmail.com, kapil.raj.02@gmail.com, johnbentham2004@gmail.com

continue to evolve, as the product is integrated into advanced technologies that can adapt to new requirements, such as renewable energy sources (Moseley and Garche, 2014).

Electronic drive systems, however, may have difficulties in achieving a stable operation and an efficient use of energy, when the energy source is variable or uncertain. Here, we discuss how the incorporation of renewable energy sources as well as energy storage systems can be important.

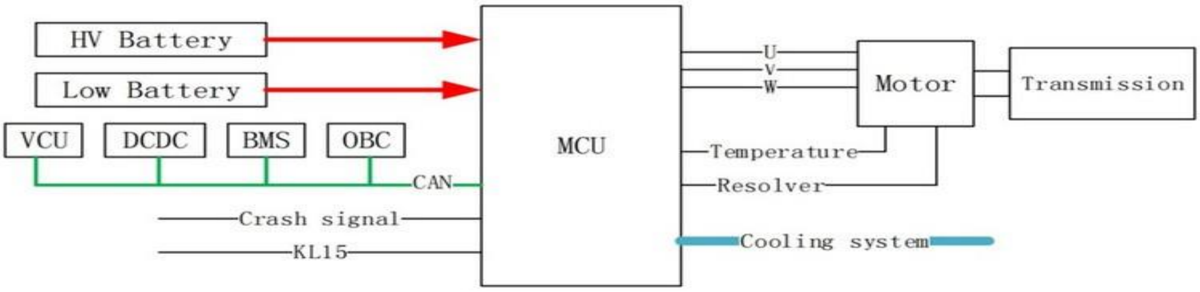

Fig 1:
Working principle of EDS

2.2 Importance of Integrating Renewable Energy & Energy Storage for Improved System Performance and Stability As the world leans toward sustainability and less carbon emission, sources of renewable energy like solar, wind, or hydropower are becoming increasingly popular. Although these energy sources are environmentally friendly, they are intrinsically variable as weather circumstances and time of day vary, and are therefore less reliable than conventional power sources. In electronic drive systems, such variability can result in fluctuating power supply, with the consequent detriment to performance, instability, and even system failures.

These problems can be solved if renewable energy is united with energy storage solutions. Energy storage systems, including batteries, supercapacitors, and flywheels, can stockpile excess energy when abundant from renewable sources and expel that energy when renewable sources falter. This integration guarantees that EDS will have a stable and dependable power source, irrespective of external fluctuations, and thus improve performance, efficiency, and operational lifespan. The advantage of integrating renewable energy and energy storage is that, both are useful in system improvement of load control, peak shifting, and energy regulation for sustainable and profitable system functioning (Nadeem et al., 2018).

The advantages of combining renewable energy and energy storage with EDS are significant:

1. Enhanced Efficiency: In other words, EDS can use renewable energy to work more effectively, and hence, consume less non-renewable energy.
2. Stability and Reliability: Energy storage systems are applied to ensure a stable power supply to EDS while renewable energy supply may be varying.
3. Sustainability: This integration assists in the change of direction to green energy, thus making industries relying on energy distribution system less reliant on carbon.

As industries shift towards more sustainable practices, the role of renewable energy integration with EDS would be critical towards the attainment of environmental objectives, with operational reliability and performance.

2.3 Objectives of the Review

This review paper focuses on the detailed analysis of integration of renewable energy sources and energy storage systems with electronic drives. By evaluating existing technologies, case revisions, and developing trends, the review aims to:

The influence of renewable energy sources on electronic drive system performance and stability is analyzed. The purpose of this work is to understand how the different forms of non- conventional energy (solar, wind etc.) can be incorporated into EDS and what influence they will have on the stability and efficiency indices of the system.

1. Evaluate the energy storage technologies such as batteries and supercapacitors to improve the dependability and effectiveness of energy distribution systems (EDS).
2. Identify the technological, economic and policy challenges to the integration of renewable energy and energy storage with EDS.
3. Identify constraints that influence reliable function of EDS operations and ways to resolve these problems.

These goals are reviewed here to provide a clear understanding of the relationship between renewable power, energy storage, and electronic drive systems and the opportunities as well as challenges that industries are facing in transition to sustainable energy solutions.

2. Renewable Energy Sources for Electronic Drive Systems

2.1 Types of Renewable Energy and Their Integration with Electronic Drive Systems (EDS)

Incorporation of renewable energy sources into Electronic Drive Systems (EDS) is an important strategy to further sustainability, decrease requirement on fossil fuels and improve energy efficiency of industrial applications. Solar, wind and hydropower are becoming popular because they are eco friendly and do not deplete natural resources when generating power. These renewable sources when combined with energy storage systems provide remarkable stability to EDS, compensating to the impacts of power fluctuations (Ribeiro et al., 2001).

1. **Solar Energy:** Solar energy is one of the most used renewable energy sources that we use by using photovoltaic (PV) panels that convert sunlight into electrical power. In particular, solar energy works well with electric vehicles (EVs) and industrial systems that must be operated continuously during daylight hours. EDS can be integrated with solar panels to provide power directly to the drive system, or to charge energy storage units for the system to draw from the stored energy when there is low sunlight. However, EDS that are solar-powered are especially useful in regions where there is abundant sunlight, and the integration can substantially lower operational costs and decrease dependence on grid electricity.
2. **Wind Energy:** Another important renewable source is wind energy, which is made available using wind turbines: they convert the kinetic energy of wind into electric power. In favorable wind patterns such as offshore wind farms or wind farms with consistent wind speeds wind energy is often used to supplement EDS. Wind is much like solar power when it can be integrated into EDS, or charge energy storage arrangements to provide a consistent and supportable power source. In automotive applications, wind energy is particularly suitable for use in the support of electric vehicle charging and for improving the general sustainability of electric mobility (Vazquez *et al.*, 2010).

3. **Hydropower:** For many years, hydropower — the utilization of flowing water (usually through dams or rivers) — has been one of the most lucrative and reliable kinds of renewable energy. For EDS, the application of hydropower is to provide electricity to the grid or micro-hydro for local use in remote areas. EDS integration with hydropower contributes to achieving voltage regulation, increase the rating, and ensure the reliability of the supply. Hydropower is mostly used in large scale application like industrial production and mining where constant power supply is required.
4. **Biomass Energy:** Source of biomass energy, which includes such organic materials as wood, agricultural residues, and waste. In regions where other types of renewable energy might be unavailable, this renewable energy kind may be valuable. When integrated with energy storage systems, biomass energy can be utilized to provide a continuous electricity supply to EDS despite the low levels of energy generation. EDS usually employ biomass fired systems in remote regions where connection to the grid is limited since the resource is reliable.

In order to integrate these renewable energy sources to EDS, inverters, controllers and energy management system (EMS) are employed to manage the generation, conversion and distribution of power. This paper shows that renewable energy is variable and therefore EDSs must be developed to accommodate this characteristic without impacting the system. This is typically done through energy storage systems: that has the ability to store and dissipate energy when the load is beyond the energy store.

2.2 Benefits of RE in Enhancing System Efficiency and Sustainability

The integration of renewable energy into EDS has numerous advantages in relation to energy efficiency and sustainable performance. Wind energy has many advantages for industries that need to switch to cleaner energy sources, and these advantages help make EDS more practical.

1. **Reduced Dependence on Fossil Fuels:** The greatest benefit of renewable energy sources is that they reduce the utilization of fossil energy resources. Coal natural gas, and fossil fuels are scarce resources and are causes of environmental pollution and climate change. EDS can integrate solar, wind and other forms of renewable energy to assist industries cut on their carbon intensity and emissions of greenhouse gases. This is particularly important as climate change battles intensify globally, with many countries setting ambitious emission reduction targets (Zhao et al., 2015).
2. **Improved Efficiency:** Renewable energy sources such as those paired with energy storage systems can greatly improve EDS efficiency. For instance, solar and wind power are clean power sources that can directly power the system, or that can be stored for later use. This efficiency of energy use is optimized by reducing the need to draw grid electricity and instead tapping into locally available renewable resources.
Moreover, renewable energy sources make it possible for EDS to run at peak efficiency without having to worry about grid fluctuations or power outages and to operate smoothly, and continuously in critical applications like electric vehicles and industrial automation.
3. **Cost Savings:** While you will have to spend money to install renewable energy systems (solar panels or wind turbines) in your home, their long-term savings in terms of lower energy bills and greater system efficiency can eventually compensate for their high initial cost. Renewable energy systems have low operating costs once installed, particularly so in locations where there is strong sunlight or wind. Further, the utilization of renewable energy with energy storage solutions enables peak shaving to lower electricity costs in periods of peak demand. Renewable energy is a financially viable solution for industries that are looking to reduce operational costs over time, due to these cost savings.
4. **Sustainability and Environmental Benefits:** Incorporating renewable energy with EDS contributes to sustainability by utilizing less non-renewable resources. Renewable energy sources unlike fossil fuels are replenishable and have zero or minimal impact on the environment when in operation. For example, neither harm emissions nor hydropower is harmful in the right amounts. It will help clean up the energy that powers industries as they make the switch to cleaner energy solutions.
5. **Enhanced Stability and Reliability:** With the combination of renewable energy and energy storage solutions, EDS improves in stability and reliability. EDS can make use of excess energy formed during high availability stages, storing that energy so that it remains stable during periods of low energy production. This capability to buffer helps minimize power fluctuations and to reduce the chance of system downtime. In addition, the versatility of renewable energy sources enables EDS to better adapt to the energy demands and thereby improve system reliability (Bajpai and Dash, 2012).

3. Energy Storage Solutions for EDS

3.1 Overview of Energy Storage Technologies

ESS are critical components of EDS in terms of stability, reliability and efficiency of the system. Such systems store energy during low demand or high renewable energy generation and release during high demand or low generation of renewable energy. Energy storage technology requires careful selection in terms of energy capacity, charge rates, energy storage life, costs, and application (Carrasco et al., 2006). The major techniques of energy storage include battery, supercapacitor, flywheel, and pumped storage hydropower.

1. **Batteries:** Energy storage technology most commonly employed in EDS is batteries especially in electric vehicles and renewable power systems. There are three common types of batteries: Lithium-ion referred to as Li-ion, lead acid and nickel metal hydride referred to as NiMH. The most preferred type of battery for EDS use is lithium-ion batteries because of their high energy density and long cycle life, and low maintenance needs. They have a high capacity for stored energy which can be released at a constant rate, and they are suitable

for use in electric vehicles, industries and renewable energy (Chauhan and Saini, 2014). The EDS power source that is commonly used is lead acid batteries, although older and less efficient than lithium-ion batteries; however, they are used in some EDS applications because the initial cost is less. While a shorter lifespan, and lower energy density, may have given lead acid batteries a poor reputation, they are still practical and suitable for certain kinds of applications – especially for storing energy in the context of the backup. The common NiMH battery used in hybrid vehicles and smaller EDS applications are often used. Despite their better performance, the energy density of these batteries is still lower than the lithium-ion batteries and as such are less efficient for large-scale applications.

2. **Supercapacitors:** Energy storage devices called supercapacitors, or ultracapacitors, can quickly store and release electrical energy. That's why supercapacitors differ from batteries that store energy chemically. They are thus well suited for use in applications that require short bursts of energy for example electric vehicles regenerative braking system and industrial load profiles where power peaks are observed. The benefit of supercapacitors is that they have better cycle life than batteries and have capability to deliver high power in a short time. For this reason, they can operate at a broad temperature and are therefore often employable in a broad climatic condition (Chemali et al., 2016). Super capacitors are not as energy dense as batteries, that is, they can store a lot less energy than batteries in a given time. Consequently, they are not suitable for long term energy storage but are best suited for applications that require a fast discharge of energy.

3. **Flywheels:** A flywheel is an object that stores mechanical energy in the form of a spinning rotor at its overall high speed. The kinetic energy is then again converted back to electrical energy when energy is required in the rotor. Flywheel has benefits in EDS for delivering high power for a short period, and also, it comes out as very useful for regulating power and maintaining voltage levels in the system. Advantages include high efficiency, extremely long life span, and relatively short response time, making them appropriate for use in applications that demand swift energy supply. For example, in hybrid vehicles and uninterruptible power supply (UPS) systems; the capability of providing power instantly is crucial and hence flywheels are employed (Chemali et al., 2016). However, flywheels have a limited energy storage capacity and therefore are not well suited for storing large amounts of energy over long periods, making them less effective for applications where long long-duration energy supply is needed.

Pumped-storage Hydropower: A pumped-storage hydropower (PSH) type of energy storage relies on gravitational potential energy. At times of peak energy demand, water is released to rush through the plant and generate electricity, and at other times water is pumped up to a high level. PSH is generally most popular in large grid applications, but the principles have been adapted for use in some industrial electronic drive systems to stabilize power. The conversion efficiency rates are so high for PSH at up to 90% that

it is one of the most efficient methods of energy storage. But it has limited use because it requires specific geographic conditions, like water and the right sort of terrain. Moreover, PSH is normally not feasible in smaller scale systems as it requires infrastructure, and therefore would not be practical for such applications, but only for large systems or industrial applications.

3.2 Role of Energy Storage in Stabilizing Power and Optimizing EDS Performance

Stabilizing the power supply and enhancing the performance of electronic drive systems is critical, especially when they are integrated with renewable energy sources, which necessitates energy storage. Renewable energy generation, such as solar and wind power generation, suffers from an intermittent attractiveness and tends to pose nontrivial issues with ensuring a consistent and reliable power supply to EDS (Dubal *et al*., 2015). These challenges are addressed by energy storage solutions, which allow EDS to continue to operate efficiently even where renewable energy production is variable.

1. **Power Stabilization:** Energy storage plays one of the key roles in stabilizing power stream by 'smoothing' out fluctuations in renewable energy formation. For instance, you can store excess energy in batteries or supercapacitors for example when there is high solar or wind production. As the generation from non-conventional energy sources drops, the stored energy can be put back onto the grid to keep a steady power output to the EDS. EDS are thus protected from power-limited or degraded operations that impact user's

utilization of services. EDS enabled by energy storage makes the system more resilient, supplying backup power in case of a grid failure or other disruption. Using energy storage, systems can run autonomously, without experiencing downtime and with less chance of system failure.

2. **Peak Shaving and Load Management:** Peak shaving refers to reducing the demand on the power grid while stages of high energy demand, and Energy storage systems are vital to peak shaving. Energy storage solutions store energy when demand is low and

discharge it when demand is high, therefore balancing the load on the grid and reducing strain and cost. For EDS this means that the system can operate at high efficiency without oversizing the power supply infrastructure. Energy storage applications, like electric vehicles (EVs) for example, achieve improved charging and discharge

efficiency when energy storage is integrated, and improve smooth operation. Control of charging and discharging rates through load management strategies can be used to enhance energy consumption and prolong the lifetime of the energy storage system.

3. Enhancing System Efficiency: Energy storage increases EDS's overall efficiency because it allows the energy to be stored for when it is most needed. When it comes to electric vehicles, for instance, those kinds of energy can be stored in a battery or supercapacitor and used to power the motor and support features such as regenerative braking which uses the vehicle's energy to capture energy as the vehicle slows then stores it and can release it later (Faisal *et al.*, 2018). This allows for higher utilization of energy and reduced wasted power, which extends the time spent operational and reduces energy costs. Moreover, coupling energy storage with EDS enables the better exploitation of renewable energy. The stored renewable energy can be used to reduce carbon emission, enhance the sustainability of the system and reduce operational costs as compared to use of grid electricity which might be generated from non-renewable resources.

4. Supporting Efficient Charging and Discharging Cycles: Energy storage solutions also underpin electronic drive systems and also enhance efficient charging and discharging cycles. Batteries and supercapacitors or flywheels can be charged and

discharged rapidly and deliver (instantaneous) power when required. That is especially significant in the power-train applications such as EVs and industrial machineries that requires power immediately to meet fluctuating power requirements. Of such, the supercapacitors are most appropriate in instances where energy can be fast charged

and

discharged such as during regenerative braking or load leveling. Batteries, in contrast, can supply continuous, steady power, and are therefore well suited to long-term storage and use of energy (Dubal *et al.*, 2015).

4. Performance and Stability Enhancement

4.1 How RE and Energy Storage Improve the Performance and Stability of EDS

Electronic drive systems (EDS) require renewable energy sources as well as energy storage solutions that can improve their performance and stability. As electric vehicles (EVs), industrial automation systems, and renewable energy storage systems are dependent on a reliable and consistent power supply, EDS is equally dependent on a reliable and consistent power supply to function optimally. On the other hand, renewable energy like solar as well as wind are recurrent, bringing back and forth supplies of power. In much of the same way, the surge in demand for power in most applications, if not handled carefully, can cause instability or raise operational costs and inefficiencies (Gür, 2018). However, mitigation of these issues via potential integration of renewable energy sources, along with energy storage systems leads to smoother operation as well as greater performance.

1. **Improved Power Supply and System Efficiency:** The occurrence of renewable energy sources in EDS decreases the need for conventional power grids and fossil fuels. Take solar and wind power, for example these can supply clean energy to (for example) operate electric motors, bringing down operational costs and emissions in the process. Although renewable energy generation is not predictable, these sources must be combined with energy storage systems to supply a stable energy supply. For example, lithium-ion batteries and supercapacitors act as storage technology that helps absorb the variability of energy generation from renewable sources (Hadjipaschalis, Poullikkas, and Efthimiou, 2009). Energy storage enables

energy stored during periods of higher- than-usual renewable generation to be discharged during periods of low renewable generation, providing a constant and reliable power supply to the EDS reducing downtime, and enabling more efficient operation.

2. **Peak Load Management and Reduced Grid Dependency:** Fundamental to applications, like electric vehicles or industrial systems, that require consistent and uninterrupted power, renewable energy with energy storage can be used to manage peak loads. Under conditions of peak energy demand, the load can be met by dispatching stored energy from batteries or supercapacitors, thereby reducing the dependence on the grid and decreasing energy costs. For example, in electric vehicle applications, energy storage systems might optimize the use of power by managing the charging cycles. This includes EVs with renewable energy sources (for example solar panels) and energy storage solutions that will be able to keep a high charge when grid electricity is not available or expensive. In addition, these systems can be integrated to charge vehicles during off-peak hours to help balance the grid load and provide a more stable system overall (Ibrahim, Ilinca, and Perron, 2008).

3. **Enhanced Voltage and Frequency Stability:** In EDS, in particular, industrial systems, voltage and frequency need to be stable to avoid damage to sensitive equipment. The power produced by renewable energy generation fluctuates and can affect system performance. This paper shows that by quickly supplying or absorbing energy, energy storage systems can smooth out these fluctuations by helping to maintain a stable voltage and frequency. Of these, supercapacitors are especially good in helping to keep the voltage stable because they can quickly charge and discharge energy. Voltage spikes can be absorbed or a quick burst of energy can be provided during power dips, keeping the system in all round good shape (Kaldellis, 2010). Rapid response to demand fluctuations greatly improves the reliability and life of EDS.

4.2 Case Studies and Real-World Applications Demonstrating Improvement

Last but not least, several practical applications and examples are provided to discuss the effectiveness of integrating renewable energy power and energy storage systems on EDS. These case studies show the efficiency of the above technologies as applied in electric vehicles, industrial applications and grid uses.

1. **Electric Vehicles (EVs):** A study in the electric vehicle sector has revealed that integration of solar energy and energy storage system enhances the efficiency of electric vehicles. For example, Tesla's solar roof, together with their power wall, allows the batteries in electric cars to be charged using solar energy. To avoid this and make eVs as cost effective and efficient transportation means, this integration ensures that eVs always stay charged even when there are no external sources of power and subsequently stretches the limelight on eV batteries while avoiding dependence on charging stations. Furthermore, the preliminary research by Lukic et al. (2008) stated that fast charge capable vehicle with ESS had better energy efficiency and operational range than traditional EVs of the University of California. The vehicles were able to perform short bursts of acceleration and deceleration by using supercapacitors in conjunction with batteries, harvest more energy from regenerative braking and also prolong the battery lifespan because the supercapacitors would handle more frequent usage instead of the primary battery system.

2. **Wind Power Integration in Industrial Systems:** The application of wind energy systems coupled with energy storage in industrial applications was examined in a case of Denmark. In particular, the authors established that when wind turbines were integrated with energy storage systems, including lithium-ion batteries, the energy system became more effective and coherent (Mamun et al., 2022). Surplus wind energy was stored during the generated time and supplied when the generation was low, thus eliminating the dependency on the grid to power the industrial processes. For this case, the energy storage system ensured that voltage and frequency were constant to prevent disruption of industrial equipment. Load leveling was also possible with the storage system, which meant new power plants were not needed and the energy system would be more efficient and less costly.

3. **Solar Energy and Storage in Commercial Buildings:** On the other hand, solar energy and energy storage systems have been applied in commercial building sector for energy management and system stabilization. A study done in a large commercial establishment in California showed that the combined application of rooftop solar PVs with energy storage systems significantly reduced energy costs and consumption. Energy storage systems deployed in the building held energy produced during the day by the

solar panels and employed the stored energy during nighttime periods when conditions were cloudy. On the other hand, this reduced the building's reliance on the grid and also minimized the building's carbon footprint (Molina, 2017). Furthermore, with the energy storage system, the power supply was stabilized to guarantee that critical systems such as HVAC and lighting functioned throughout power/energy fluctuation.

4. **Grid-Scale Energy Storage for Renewable Integration:** Energy storage in grid applications, such as the Hornsdale Power Reserve in South Australia, are important examples of large-scale energy storage. The facility, which comprises lithium-ion battery storage systems, was intended to support the integration of renewable energy into the power grid. By storing excess wind and solar energy generated during off-peak hours and releasing it during peak demand periods, the system greatly improved grid stability and cut the need for fossil fuel-based peaking power plants. In this case, energy storage was integrated and shown to enable the more effective use of renewable energy in grid systems, decreasing operational costs and environmental impacts (Keyhani, Marwali, and Dai, 2009). It has been a major stabilizer for the frequency of the grid, to ensure consistency and reliability of power.

5. Challenges and Barriers

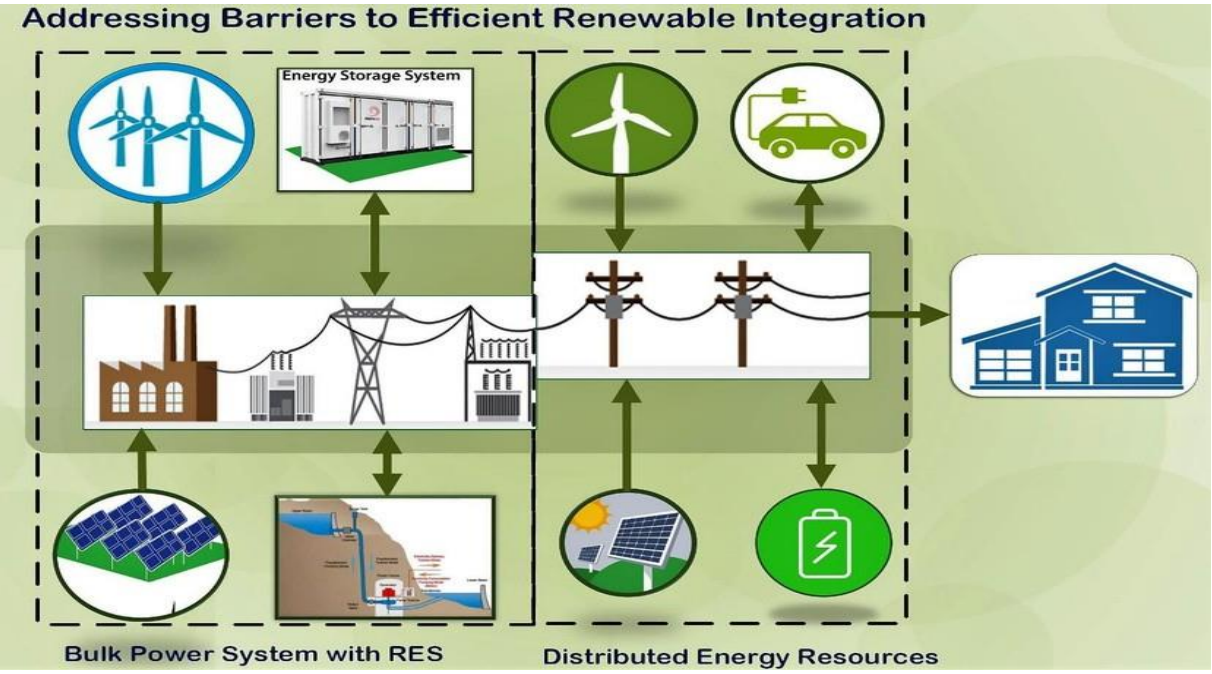

Fig 2:
Addressing barriers to efficient renewable integration (*Addressing Barriers to Efficient Renewable Integration*)

5.1 Technical Challenges

The integration of renewable energy and energy storage solutions into electronic drive systems (EDS) is a technical challenge that must be addressed to provide efficient, reliable, and scalable systems. Renewable energy sources, including solar and wind power, create one of the main challenges, being intermittent and variable. These sources are much less predictable than traditional fossil fuel-based energy generation because they rely so heavily on weather and time of day. For example, renewable power resources such as wind and solar lose (or lack) power during periods of calm weather or the absence of sunlight (Kouchachvili, Yaïci, and Entchev, 2018).

To overcome such challenges, it is common to incorporate energy storage systems to store surplus energy during a period of high production and to release it at a period when the supply falls short of the demand. But, the storage and retrieval of energy need to be done efficiently and reliably to have a steady output. Energy storage devices including batteries and supercapacitors have to be designed to meet high power load, long life and low energy conversion efficiency during charging and discharging processes. Moreover, the energy storage systems must respond quickly to the power demand variation, which is challenging given the nature of the storage technologies.

Another big technical challenge is to seamlessly integrate renewable energy sources and energy storage systems into the current electronic drive infrastructure. In general, EDS is designed to operate with utility power that usually has different voltage, frequency and stability compared to those of renewable energy sources. To achieve these systems' integration, high-level power management systems are required to address the variability of renewable energy and the EDS. However, with many energy sources and storage devices, controlling can be numerously difficult and lead to synchronization issues that affect system performance and stability (Lukic et al., 2008).

5.2 Economic Challenges

The incorporation of renewable energy and energy storage systems into EDS faces severable economic challenges. This has issued, especially with respect to the cost of investment in reformation within renewable energy systems such as photovoltaic panels in solar power systems, the returns from wind turbine and systems of energy storage comprising lithium-ion batteries are one of the leading factors (Zhao et al., 2015). These technologies were relatively expensive in the last few years, however, they are still very capital-intensive for commercial and residential uses. The major constraint to the increased use of renewable energy in different subsectors of EDS is the high capital costs that make it difficult for small and medium enterprises to integrate these systems.

Energy storage and its inability to break even in the first years present economic challenges in the integration of renewable energy systems. Batteries and other related technologies are improving, but they are still rather costly than conventional methods of generating power.

Besides, other costs associated with energy storage technologies, including maintenance, replacement, or degradation of the technology over time, may be incorporated into a system's cost. This means that the economics of energy storage entails the ability to recover costs of capital investment and operational costs besides providing for the value of investment.

A second economic issue is the market characteristics of renewable energy and energy storage. Conventional methods of power generation are still in use to a large extent in many areas and are subsidized in those areas by government policies. In contrast, renewable energy systems may experience few incentives and subsidies and thus have an economic problem. Due to challenges that arise when integration is not accompanied by direct financial incentives or subsidies for the usage of renewable energy, integration may not be easy because adoption is not financially competitive with traditional sources of energy in some regions where these renewable energy technologies are still in their embryonic stages before grid parity is achieved.

5.3 Regulatory and Policy Challenges

Currently, there are several challenges that inhibit the integration of renewable energy and energy storage solutions to EDS and the regulatory and policy environment is still being established. The biggest challenge can be traced down to the lack of standard rules and policies in different regions. However, energy policies grid regulations, and technical standards are different in different countries or regions, rendering integration of renewable energy sources and energy storage systems into existing infrastructures difficult.

For example, in most areas, there is not a clear regulatory framework for interconnecting renewable energy systems and storage devices with the grid. There are areas where grid operators are very heavily regulated around how DERs can be integrated, rooftop solar, battery storage things like that. However, these regulations can involve complicated approval procedures sometimes that can inhibit or stymie the adoption of renewable energy systems in EDS applications. In some areas, the local grid will not be able to handle the variable and distributed characteristics of renewable energy, causing power quality and reliability issues (Bajpai and Dash, 2012).

The lack of incentives for businesses and consumers to adopt renewable energy and energy storage systems is another regulatory challenge. Although some governments provide tax credits, subsidies, or feed-in tariffs to promote renewable energy, these incentives are often insufficient to compensate for the high upfront costs of these systems. Furthermore, the legal and institutional conditions prevailing in many parts of the world remain unfavourable to distributed renewable power generation and supply (Carrasco et al., 2006).

However, due to the high potential of the renewable energy sources to benefit from integration with EDS, the economic and regulatory hurdles to the use of renewable energy sources remain high.

6. Future Trends and Innovations

6.1 Emerging Technologies in Energy Storage and Renewable Integration

Several emerging technologies that have the ability to address the challenges and enhance system performance will define the future of renewable energy integration and energy storage in electronic drive systems (EDS). Another excellent realisation is the solid-state batteries, which claim to provide higher energy densities, charging times and safety compared to today's widely known lithium-ion batteries. The energy storage industry is set for a revolution as solid state batteries offer more efficient and longer life solutions for renewable energy storage.

Other energy storage technologies are also emerging such as flow batteries, hydrogen fuel cells apart from solid-state batteries (Faisal et al., 2018). Appropriate real-life examples include long-duration, scalable energy storage that can be done using flow batteries that actually store energy in electrolytes. Consequently, they are suitable for large-scale renewable energy storage applications especially in the context of the grid. Another way renewable energy is being stored and used is in hydrogen fuel cells, where the electricity produced by the electrochemical process is used to split hydrogen into electricity. These technologies could potentially have a large part to play in the decarbonisation of sectors such as transport where hydrogen vehicles could complement battery electric vehicles. Modern power electronics and smart inverters are being designed to enhance the effectiveness of conversion between renewable resources, storage devices and EDS in the aspects of renewable energy integration (Chemali et al., 2016). These innovations simplify the control of power and the integration of systems so that systems can respond faster to fluctuations in availability of renewable energy and decrease energy usage. Smart grids technologies are also emerging to form new smart, distributed, and efficient energy distribution systems.

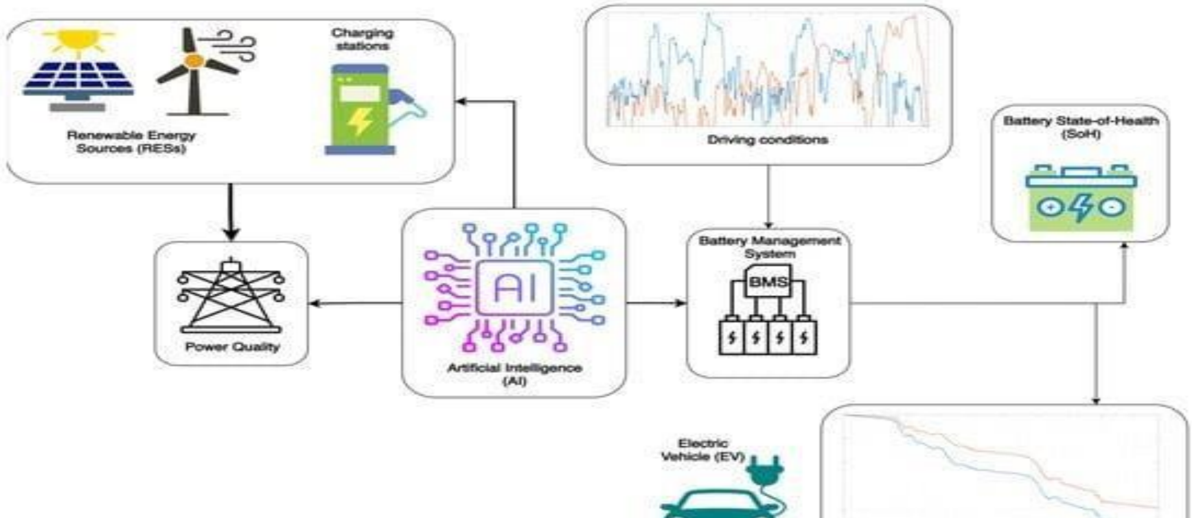

Fig 3:
The implementation of artificial intelligence (AI) in energy storage systems for electric vehicles.

6.2 Role of AI and Smart Grid Systems in Optimizing EDS

The future performance of EDS is expected to be optimized with the help of artificial intelligence (AI) and smart grid technologies. With AI, it is possible to analyze huge amounts of data related to renewable energy sources, energy storage systems as well as EDS components and predict power demand and supply fluctuations. They (these insights) can then be leveraged to optimize the charging and discharging cycles of energy storage systems to ensure that the supply and demand of energy is always in balance. In addition, AI can assist with predictive maintenance, recognizing potential problems before they cause system failure, and lowering downtime with the consequent improvement of system reliability (Molina, 2017).

Then the integration of renewable energy and storage systems is enhanced by the use of smart grids using advanced communication and automation technologies. Smart grids allow real-time monitoring and control of energy flow thereby enabling efficient distribution of energy from renewable sources to EDS with minimum loss and delivering power to where it is most required. Moreover, the cost structure of EDS can be further reduced by employing DSM measures by smart grids that enable consumer response to price signals and grid conditions.

The integration of AI and smart grid will enable efficient integrated renewable energy systems, optimal energy storage and EDS systems management. These advancements will allow EDS to operate more effectively and more consistently, and offer a roadmap to future, more efficient, more affordable energy solutions (Nadeem et al., 2018).

7. Conclusion

The combination of renewable energy sources and energy storage solutions into electronic drive systems (EDS) could significantly enhance the performance, robustness and sustainability of EDS. However, with the integration of clean energy technologies such as solar and wind energy and advanced energy storage such as batteries and supercapacitors, some dependence on conventionally energy grids can be reduced, operation cost can be reduced and this transition to more environmentally friendly power systems can be supported. This enables us to accumulate excess renewable energy and use it when required, maintaining the continuity of power changes and avoiding disruption and keeping us going even with an intermittent supplyof energy.

But there is still a long road to go before EDS can be fully optimized using renewable energy and storage. Energy intermittency, system integration complexities, and efficient power management systems are required to address technical issues. In addition, high upfront costs, and lack of standardization of policies across regions present huge economic and regulatory barriers. However, the challenging transition away from fossil fuel energy systems can still be managed with current technologies. Furthermore, emerging technologies including solid state batteries, hydrogen fuel cells, and smart grids provide new solutions to overcome these challenges and integrate renewable energy in EDS.

Future EDS will become even more dependent on new energy storage and renewable energy integration, artificial intelligence, and smart grid technologies that enable adaptive, predictive, and more optimized systems. As such, electronic drive technologies are leading this path towards a more sustainable, resilient and efficient energy landscape, and enable that electronic drive systems can meet the growing requirements of modern energy consumption, whilst contributing to global environmental goals.

References

1. Bajpai, P. and Dash, V., 2012. Hybrid renewable energy systems for power generation in stand-alone applications: A review. *Renewable and Sustainable Energy Reviews,* 16(5), pp.2926-2939. DOI: 10.1016/j.rser.2012.02.009.
2. Carrasco, J. M., Franquelo, L. G., Bialasiewicz, J. T., Galván, E., PortilloGuisado, R. C., Prats, M. M. and Moreno-Alfonso, N., 2006. Power-electronic systems for the grid integration of renewable energy sources: A survey. *IEEE Transactions on Industrial Electronics,* 53(4), pp.1002-1016. DOI: 10.1109/TIE.2006.878356.
3. Chauhan, A. and Saini, R. P., 2014. A review on integrated renewable energy system- based power generation for stand-alone applications: Configurations, storage options, sizing methodologies, and control. *Renewable and Sustainable Energy Reviews,* 38, pp.99-120. DOI: 10.1016/j.rser.2014.06.006.
4. Chemali, E., Preindl, M., Malysz, P. and Emadi, A., 2016. Electrochemical and electrostatic energy storage and management systems for electric drive vehicles: State- of-the-art review and future trends. *IEEE Journal of Emerging and Selected Topics in Power Electronics,* 4(3), pp.1117-1134. DOI: 10.1109/JESTPE.2016.2587381.
5. Dubal, D. P., Ayyad, O., Ruiz, V. and Gomez-Romero, P., 2015. Hybrid energy storage: The merging of

battery and supercapacitor chemistries. *Chemical Society Reviews,* 44(7), pp.1777-1790. DOI: 10.1039/C4CS00266K.

6. Faisal, M., Hannan, M. A., Ker, P. J., Hussain, A., Mansor, M. B. and Blaabjerg, F., 2018. Review of energy storage system technologies in microgrid applications: Issues and challenges.*IEEE Access*, 6,pp.35143-35164. 10.1109/ACCESS.2018.2831065.
7. Gür, T. M., 2018. Review of electrical energy storage technologies, materials, and systems: Challenges and prospects for large-scale grid storage. *Energy & Environmental Science,* 11(10), pp.2696-2767. DOI: 10.1039/C8EE01419A.
8. Hadjipaschalis, I., Poullikkas, A. and Efthimiou, V., 2009. Overview of current and future energy storage technologies for electric power applications. *Renewable and Sustainable Energy Reviews,* 13(6-7), pp.1513-1522. DOI: 10.1016/j.rser.2008.09.028.
9. Ibrahim, H., Ilinca, A. and Perron, J., 2008. Energy storage systems—Characteristics and comparisons. *Renewable and Sustainable Energy Reviews,* 12(5), pp.1221-1250. DOI: 10.1016/j.rser.2007.01.023.
10. Kaldellis, J. K., ed., 2010. *Stand-alone and hybrid wind energy systems: Technology, energy storage and applications.* Amsterdam: Elsevier.
11. Keyhani, A., Marwali, M. N. and Dai, M., 2009. *Integration of green and renewable energy in electric power systems.* Hoboken, NJ: John Wiley & Sons.
12. Kouchachvili, L., Yaïci, W. and Entchev, E., 2018. Hybrid battery/supercapacitor energy storage system for the electric vehicles. *Journal of Power Sources,* 374, pp.237- 248. DOI: 10.1016/j.jpowsour.2017.11.040.
13. Lukic, S. M., Cao, J., Bansal, R. C., Rodriguez, F. and Emadi, A., 2008. Energy storage systems for automotive applications. *IEEE Transactions on Industrial Electronics,* 55(6), pp.2258-2267. DOI: 10.1109/TIE.2008.922601.
14. Luo, X., Wang, J., Dooner, M. and Clarke, J., 2015. Overview of current development in electrical energy storage technologies and the application potential in power system operation. *Applied Energy,* 137, pp.511-536. DOI: 10.1016/j.apenergy.2014.09.081.
15. Molina, M. G., 2017. Energy storage and power electronics technologies: A strong combination to empower the transformation to the smart grid. *Proceedings of the IEEE,* 105(11), pp.2191-2219. DOI: 10.1109/JPROC.2017.2728720.
16. Moseley, P. T. and Garche, J., eds., 2014. *Electrochemical energy storage for renewable sources and grid balancing.* Oxford: Newnes.
17. Nadeem, F., Hussain, S. S., Tiwari, P. K., Goswami, A. K. and Ustun, T. S., 2018. Comparative review of energy storage systems, their roles, and impacts on future power systems. *IEEE Access,* 7, pp.4555-4585. DOI: 10.1109/ACCESS.2018.2888497.
18. Ribeiro, P. F., Johnson, B. K., Crow, M. L., Arsoy, A. and Liu, Y., 2001. Energy storage systems for advanced power applications. *Proceedings of the IEEE,* 89(12), pp.1744- 1756. DOI: 10.1109/5.975900.
19. Vazquez, S., Lukic, S. M., Galvan, E., Franquelo, L. G. and Carrasco, J. M., 2010. Energy storage systems for transport and grid applications. *IEEE Transactions on Industrial Electronics,* 57(12), pp.3881-3895. DOI: 10.1109/TIE.2010.2076414.
20. Zhao, H., Wu, Q., Hu, S., Xu, H. and Rasmussen, C. N., 2015. Review of energy storage system for wind power integration support. *Applied Energy,* 137, pp.545-553. DOI: 10.1016/j.apenergy.2014.04.103.