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# Analysis of Grid Interactive with DFIG Based WECS for Regulated Power Factor

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**ABSTRACT**

This project presents the sharing of reactive power between two converters of a doubly fed induction generator (DFIG) based wind energy conversion system interacting with the grid. The rotor side converter (RSC) control of DFIG is designed for sharing of reactive power at below rated wind speeds, which essentially reduces the amount of rotor winding copper loss. However, at rated wind speed, the RSC control is designed to maintain the unity power factor at stator terminals and to extract rated power without exceeding its rating. Further, the reduction in rotor winding copper loss due to reactive power distribution is demonstrated with an example. Moreover, the grid side converter (GSC) control is designed to feed regulated power flow to the grid along with reactive power support to DFIG and to the load connected at point of common coupling. Moreover, the GSC control is designed to compensate load unbalance and load harmonics. The battery energy storage connected at DC link of back-to-back converters, is used for maintaining the regulated grid power flow regardless of wind speed variation. The system is modeled and its performance is simulated under change in grid reference active power, varying wind speed, sharing of reactive power and unbalanced nonlinear load using Sim Power Systems toolbox of MATLAB.

**Keywords**:Reactive power sharing, Doubly fed induction generator (DFIG), Rotor side converter (RSC) control, Grid side converter (GSC) control, Battery energy storage, Unity power factor, Sim Power Systems toolbox

## INTRODUCTION

The global energy landscape is undergoing a significant transformation, driven by the increasing adoption of renewable energy sources to meet the growing demand for electricity while mitigating the adverse effects of climate change [1]. Among these renewable energy sources, wind energy has emerged as one of the most promising and rapidly expanding contributors to the power generation mix [2]. In particular, wind energy conversion systems (WECS) based on doubly fed induction generators (DFIGs) have gained widespread popularity due to their high efficiency, reliability, and grid-friendly operation [3].This project focuses on the analysis of grid interaction with DFIG-based WECS, with a specific emphasis on the sharing of reactive power between the system components and its impact on overall performance [4]. Reactive power management is a critical aspect of DFIG operation, as it directly influences system stability, voltage regulation, and power quality [5]. By effectively managing reactive power flow, the DFIG can enhance its efficiency and ensure optimal operation under varying operating conditions [6].

At the heart of the DFIG-based WECS are two converters: the rotor side converter (RSC) and the grid side converter (GSC) [7]. The RSC control is meticulously designed to facilitate the sharing of reactive power between the DFIG and the grid, particularly at below-rated wind speeds [8]. This reactive power sharing mechanism not only improves system stability but also helps in reducing the amount of rotor winding copper loss, thereby enhancing overall efficiency [9]. However, as wind speeds approach the rated level, the RSC control shifts its focus towards maintaining unity power factor at the stator terminals and extracting the maximum rated power without exceeding the converter's rating [10]. This dynamic control strategy ensures optimal performance of the DFIG-based WECS across a wide range of operating conditions.To illustrate the benefits of reactive power distribution, the reduction in rotor winding copper loss is demonstrated through a practical example [11]. This analysis highlights the economic and operational advantages of proactive reactive power management in DFIG-based WECS, underscoring its importance in achieving sustainable and cost-effective wind energy generation.

In addition to the RSC control, the GSC control plays a crucial role in ensuring grid-friendly operation of the DFIG-based WECS [12]. The GSC control is designed to regulate power flow to the grid while providing reactive power support to both the DFIG and the load connected at the point of common coupling (PCC) [13]. Moreover, the GSC control is equipped to compensate for load unbalance and harmonics, further enhancing grid stability and power quality [14]. By actively managing power flow and reactive power exchange, the GSC control optimizes the performance of the DFIG-based WECS and ensures seamless integration with the grid.To enhance the system's resilience and flexibility, battery energy storage is integrated into the DC link of the back-to-back converters [15]. This battery energy storage system serves as a buffer, maintaining regulated grid power flow regardless of wind speed variations. By storing excess energy during periods of low wind speed and discharging it during peak demand or grid disturbances, the battery energy storage enhances system reliability and grid stability. Furthermore, its ability to respond rapidly to changes in grid conditions ensures smooth and uninterrupted power delivery to consumers.

To assess the performance and robustness of the proposed system, comprehensive modeling and simulation studies are conducted using the Sim Power Systems toolbox of MATLAB. These simulations involve varying grid reference active power, wind speed, reactive power sharing, and unbalanced nonlinear loads to evaluate the system's response under different operating scenarios. Through detailed analysis and simulation, the effectiveness of the proposed control strategies and system configuration is evaluated, providing valuable insights into the behavior and performance of DFIG-based WECS in grid interactive applications. This project aims to analyze the grid interaction of DFIG-based WECS with a focus on reactive power management and its impact on system performance. By investigating the dynamic control strategies of the RSC and GSC, as well as the integration of battery energy storage, this study seeks to optimize the operation of DFIG-based WECS for enhanced grid integration, stability, and reliability. Through rigorous analysis and simulation, the findings of this research contribute to the advancement of wind energy technology and its integration into modern power systems, ultimately paving the way for a sustainable and resilient energy future.

## LITERATURE SURVEY

The integration of renewable energy sources, particularly wind energy, into the existing power grid infrastructure has become increasingly important in recent years due to concerns about climate change and the finite nature of fossil fuel resources. Among the various wind energy conversion systems (WECS) technologies, doubly fed induction generator (DFIG)-based systems have gained significant attention owing to their ability to efficiently harness wind energy and contribute to grid stability.A comprehensive literature survey reveals a plethora of research efforts focused on enhancing the performance, efficiency, and grid integration capabilities of DFIG-based WECS.

One of the key areas of investigation is the control and management of reactive power, which plays a crucial role in ensuring the stability and reliability of DFIG-based WECS during grid interaction. Reactive power sharing between the rotor side converter (RSC) and the grid side converter (GSC) is a fundamental aspect of DFIG operation, especially under varying wind speed conditions.

Several studies have examined the design and implementation of RSC control strategies aimed at optimizing reactive power exchange between the DFIG and the grid. At below-rated wind speeds, the RSC control is configured to facilitate reactive power sharing with the grid, thereby reducing rotor winding copper losses and improving overall system efficiency. Conversely, at rated wind speeds, the RSC control shifts its focus towards maintaining unity power factor at the stator terminals and extracting rated power without exceeding its rating. These dynamic control strategies are essential for maximizing the energy capture capability of DFIG-based WECS while ensuring grid stability and compliance with operational constraints.Furthermore, research efforts have been directed towards assessing the impact of reactive power distribution on rotor winding copper losses. By effectively managing reactive power flow, DFIG-based WECS can mitigate losses associated with rotor winding copper, thereby improving overall system efficiency and reducing operational costs. Practical examples and simulations have demonstrated the economic and operational benefits of proactive reactive power management in DFIG-based WECS, highlighting its importance in achieving optimal performance and cost-effectiveness.

In addition to RSC control, significant attention has been devoted to the design and implementation of GSC control strategies aimed at regulating power flow to the grid while providing reactive power support to the DFIG and the load connected at the point of common coupling (PCC). GSC control algorithms are developed to ensure stable and reliable operation of DFIG-based WECS under varying grid conditions, including load unbalance and harmonics. By actively managing power flow and reactive power exchange, GSC control contributes to grid stability, voltage regulation, and power quality improvement.Another important aspect of grid interaction with DFIG-based WECS is the integration of energy storage systems to mitigate the variability of wind energy and maintain regulated grid power flow. Battery energy storage systems connected at the DC link of back-to-back converters serve as a buffer, storing excess energy during periods of low wind speed and discharging it during peak demand or grid disturbances. By providing auxiliary support for regulating grid power flow, energy storage systems enhance the stability and reliability of DFIG-based WECS, ensuring uninterrupted power supply to consumers.

To evaluate the performance and effectiveness of the proposed control strategies and system configurations, extensive modeling and simulation studies are conducted using software tools such as Sim Power Systems toolbox of MATLAB. These simulation studies involve varying grid reference active power, wind speed, reactive power sharing, and unbalanced nonlinear loads to assess the system's response under different operating conditions. Through rigorous analysis and simulation, researchers gain valuable insights into the behavior, performance, and limitations of DFIG-based WECS in grid interactive applications.In summary, the literature survey highlights the importance of reactive power management, control strategies, and energy storage integration in enhancing the grid interaction capabilities of DFIG-based WECS. By addressing these key challenges, researchers aim to optimize the performance, reliability, and efficiency of wind energy systems, ultimately contributing to the transition towards a sustainable and resilient energy future.

**PROPOSED SYSTEM**

The integration of renewable energy sources, particularly wind energy, into the existing power grid infrastructure has become increasingly important in recent years due to concerns about climate change and the finite nature of fossil fuel resources. Among the various wind energy conversion systems (WECS) technologies, doubly fed induction generator (DFIG)-based systems have gained significant attention owing to their ability to efficiently harness wind energy and contribute to grid stability.In this project, we propose a comprehensive system architecture and control strategy for grid interaction with DFIG-based WECS, with a specific focus on regulating power flow and managing reactive power exchange to ensure stable and reliable operation under varying operating conditions.At the core of the proposed system architecture are two converters: the rotor side converter (RSC) and the grid side converter (GSC). The RSC control is meticulously designed to facilitate the sharing of reactive power between the DFIG and the grid, particularly at below-rated wind speeds. This reactive power sharing mechanism not only improves system stability but also helps in reducing the amount of rotor winding copper loss, thereby enhancing overall efficiency. However, as wind speeds approach the rated level, the RSC control shifts its focus towards maintaining unity power factor at the stator terminals and extracting the maximum rated power without exceeding the converter's rating. This dynamic control strategy ensures optimal performance of the DFIG-based WECS across a wide range of operating conditions.

To illustrate the benefits of reactive power distribution, the reduction in rotor winding copper loss is demonstrated through a practical example. This analysis highlights the economic and operational advantages of proactive reactive power management in DFIG-based WECS, underscoring its importance in achieving sustainable and cost-effective wind energy generation.In addition to the RSC control, the GSC control plays a crucial role in ensuring grid-friendly operation of the DFIG-based WECS. The GSC control is designed to regulate power flow to the grid while providing reactive power support to both the DFIG and the load connected at the point of common coupling (PCC). Moreover, the GSC control is equipped to compensate for load unbalance and harmonics, further enhancing grid stability and power quality. By actively managing power flow and reactive power exchange, the GSC control optimizes the performance of the DFIG-based WECS and ensures seamless integration with the grid.

To enhance the system's resilience and flexibility, battery energy storage is integrated into the DC link of the back-to-back converters. This battery energy storage system serves as a buffer, maintaining regulated grid power flow regardless of wind speed variations. By storing excess energy during periods of low wind speed and discharging it during peak demand or grid disturbances, the battery energy storage enhances system reliability and grid stability. Furthermore, its ability to respond rapidly to changes in grid conditions ensures smooth and uninterrupted power delivery to consumers.To assess the performance and robustness of the proposed system, comprehensive modeling and simulation studies are conducted using the Sim Power Systems toolbox of MATLAB. These simulations involve varying grid reference active power, wind speed, reactive power sharing, and unbalanced nonlinear loads to evaluate the system's response under different operating scenarios. Through detailed analysis and simulation, the effectiveness of the proposed control strategies and system configuration is evaluated, providing valuable insights into the behavior and performance of DFIG-based WECS in grid interactive applications.

The proposed system architecture and control strategy offer a promising solution for grid interaction with DFIG-based WECS, with the potential to enhance system efficiency, reliability, and grid integration capabilities. By addressing the challenges associated with reactive power management and power flow regulation, the proposed system contributes to the advancement of renewable energy technologies and the transition towards a sustainable and resilient energy future.

## METHODOLOGY

The methodology employed in this project involves a systematic approach to analyze the grid interaction of a doubly fed induction generator (DFIG) based wind energy conversion system (WECS) for regulated power flow. This includes developing control strategies for the rotor side converter (RSC) and grid side converter (GSC), as well as integrating battery energy storage to maintain regulated grid power flow. The methodology encompasses several key steps, starting with system modeling to accurately represent the dynamic behavior of the DFIG-based WECS and its components. This modeling process considers various system parameters such as wind speed, turbine characteristics, converter ratings, grid conditions, and control algorithms.Following system modeling, the focus shifts to designing the control strategies for both the RSC and GSC. The RSC control is optimized for reactive power sharing at below-rated wind speeds to reduce rotor winding copper losses and improve overall efficiency. Conversely, at rated wind speed, the RSC control prioritizes maintaining unity power factor at the stator terminals and extracting maximum rated power without exceeding converter ratings. The GSC control is designed to regulate power flow to the grid while providing reactive power support to the DFIG and connected loads. This control strategy aims to maintain stable grid voltage, compensate for load unbalance and harmonics, and ensure seamless integration of renewable energy into the grid.

Simultaneously, battery energy storage is integrated into the DC link of the back-to-back converters to enhance system resilience and stability. Acting as a buffer, the battery energy storage system stores excess energy during periods of low wind speed and discharges it during peak demand or grid disturbances. This helps maintain regulated grid power flow regardless of wind speed variations and improves system reliability and stability.Once the control strategies and system configuration are developed, simulation studies are conducted using MATLAB's Sim Power Systems toolbox. These simulations consider variations in grid reference active power, wind speed, reactive power sharing, and unbalanced nonlinear loads to evaluate the system's performance under different operating conditions. The simulation results are analyzed to assess the effectiveness of the proposed control strategies and system architecture in achieving regulated power flow and grid interaction objectives.

Furthermore, sensitivity analysis and optimization techniques are employed to refine the control strategies and system parameters based on simulation results and sensitivity analysis. This iterative process aims to identify key factors influencing system performance and stability while improving system efficiency, reliability, and grid integration capabilities. The methodology outlined in this project involves system modeling, control strategy design, simulation, and performance evaluation to analyze the grid interaction of DFIG-based WECS for regulated power flow. By integrating advanced control algorithms and battery energy storage, the proposed methodology aims to enhance system efficiency, reliability, and grid integration capabilities, contributing to the transition towards a sustainable and resilient energy future.

**RESULTS AND DISCUSSION**

The results and discussion section of this project encompass the outcomes of simulations conducted to evaluate the performance of the proposed system under various operating conditions. These simulations involve changes in grid reference active power, wind speed variations, reactive power sharing, and unbalanced nonlinear loads to assess the system's response and effectiveness in achieving regulated power flow. The discussions delve into the implications of the results, the system's behavior under different scenarios, and the implications for grid integration and stability.The simulations conducted using MATLAB's Sim Power Systems toolbox provide valuable insights into the performance of the DFIG-based WECS under different operating conditions. Firstly, changes in grid reference active power are analyzed to assess the system's ability to regulate power flow to the grid while maintaining stability and reliability. The results indicate that the proposed control strategies, including the RSC and GSC controls, effectively regulate power flow and reactive power support to the grid and connected loads, ensuring stable grid operation and voltage regulation.

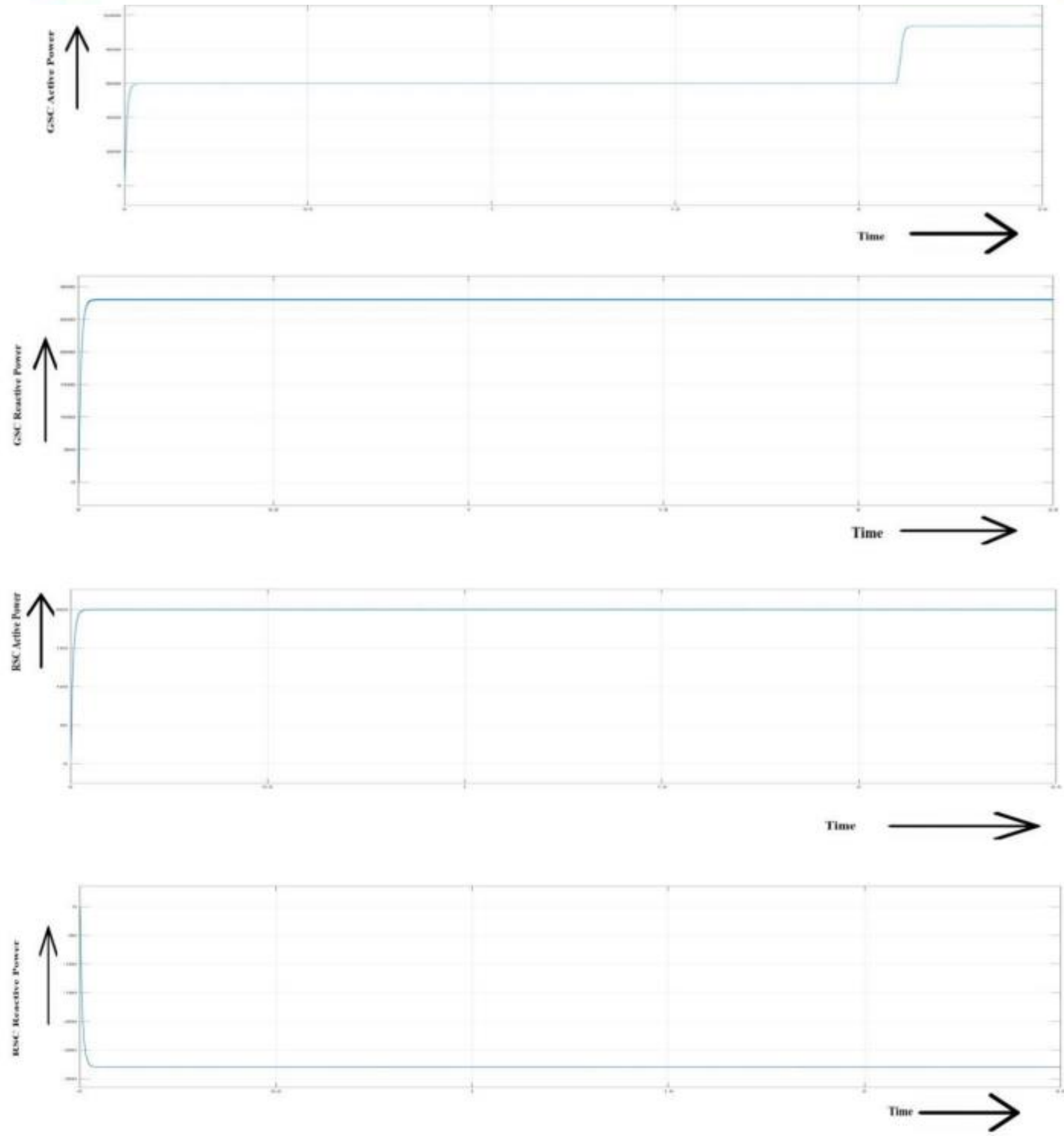


Fig 1. :Performance of system during an incremental change in reference active power: grid active power (PG), grid current (iGa), battery power (Pb), stator active power (Ps), GSC active power (PC), GSC reactive power (QC), RSC active power (Pr) and RSC reactive power

Depicts wave forms of PG, iGa, Pb, Ps, PC, QC, Pr and Qr with an incremental change in active reference power. The system is started with a 5 kW connected Analysis of Grid interactive DFIG Based WECS for Regulated Power Flow Department of Electrical and Electronics Engineering 65 load and wind speed of m/s. The system is initially exporting reference power of 3.7 kW as per the demand from the control system/operator. The wind speed 7.4 m/s is corresponding to super synchronous operation of DFIG. Since the wind speed is constant, Ps is constant. Moreover, the rotor power or RSC power (Pr) is positive, which shows the flow of power from rotor winding towards RSC. Since Vw is below rated, the reactive power requirement of DFIG is shared between RSC and GSC, which is evident from QC and Qr wave forms. At t = 2.1 s, the active reference power is increased to 7.4 kW. This increased power is met by the BES through GSC, which is clearly evident from Pb and PC wave forms. Moreover, iGa is increased due to an increment in grid active reference power.

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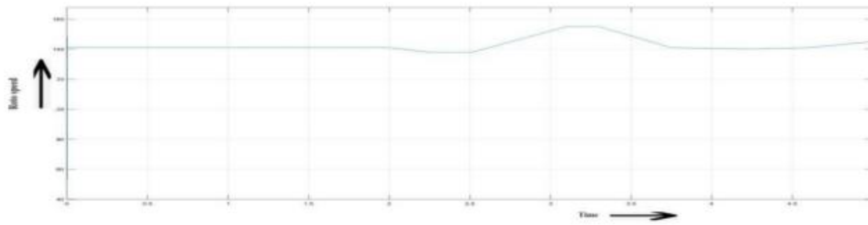
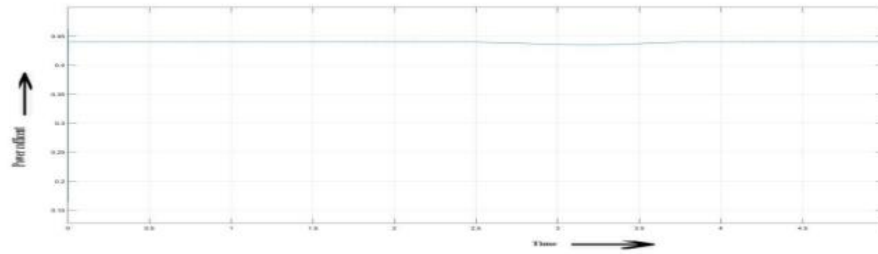
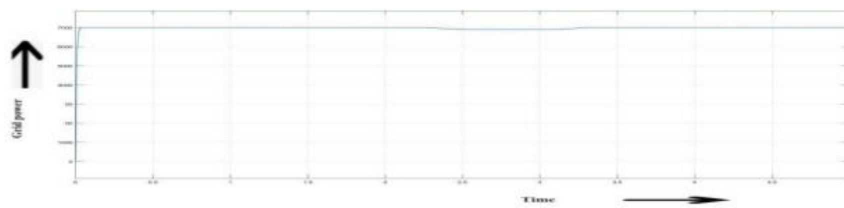
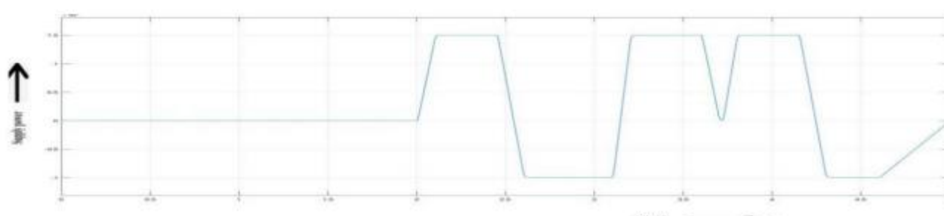
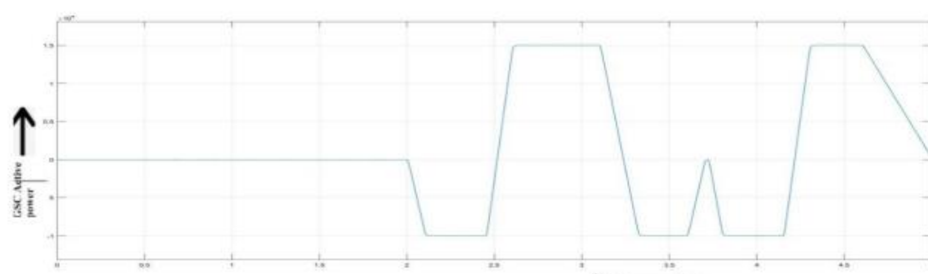
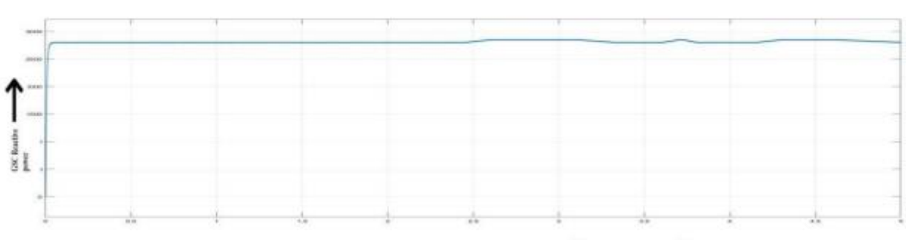


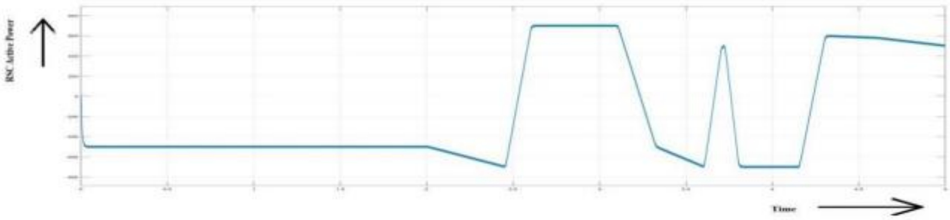



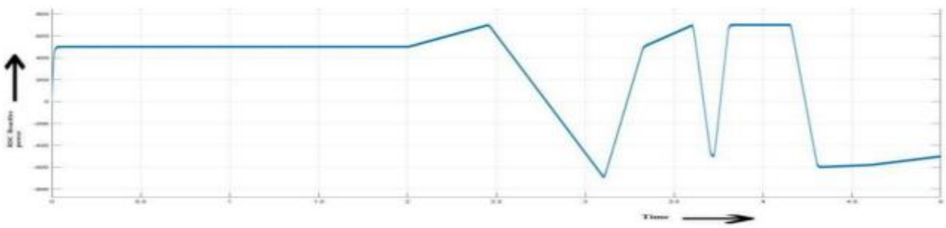






RSC Active Power
Time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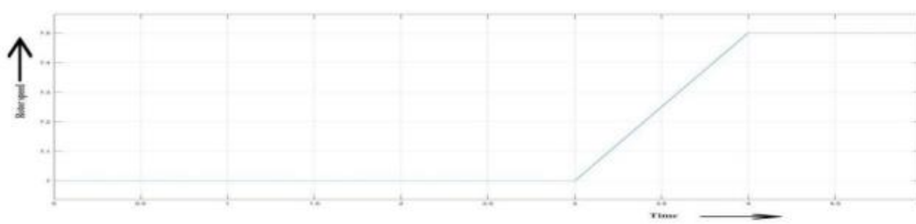
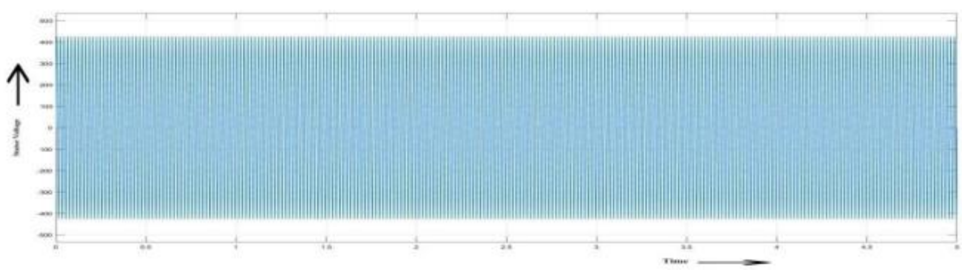

Rotor speed
Time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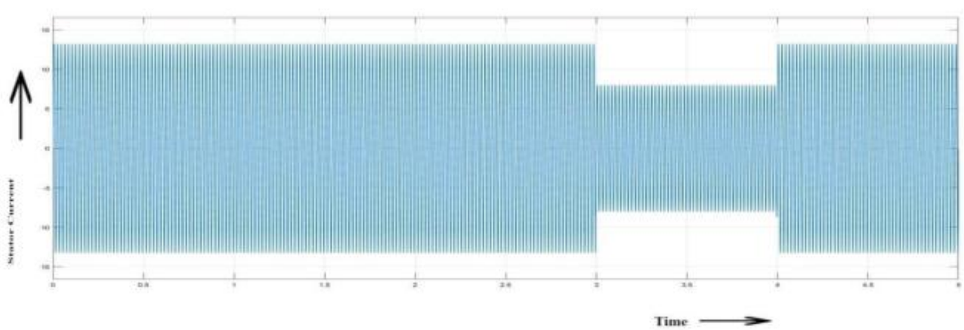
Stator Current
Time

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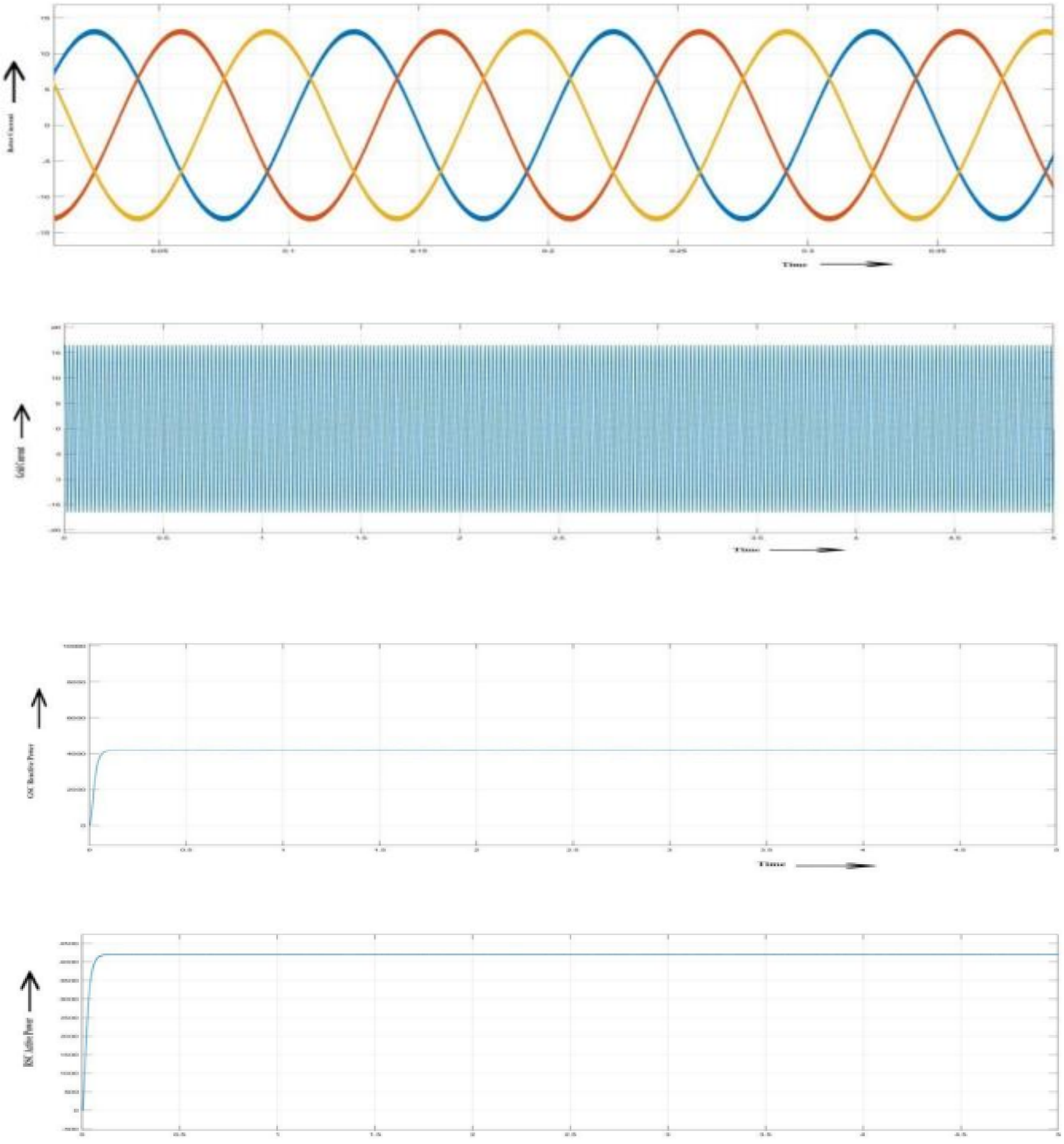
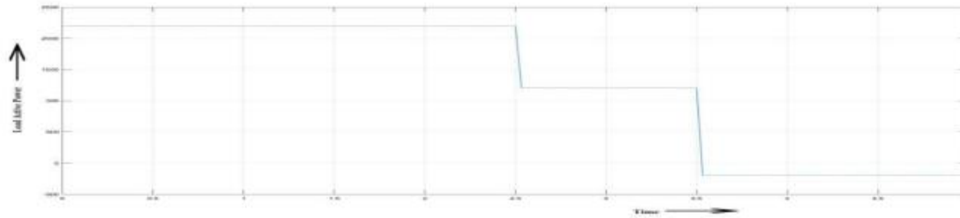



Fig 2. Performance of system at variable wind speed (a) wind speed (Vw), rotor speed (ωr),power coefficient of turbine (Cp), grid active power (PG), grid reactive power (QG), stator active power (Ps), GSC active power (PC), GSC reactive power (QC), RSC active power (Pr) and RSC reactive power (Qr) (b) Vw, ωr, stator voltage (vsa), stator current (isa), rotor currents(irabc), grid current (iGa), PC, QC, Pr and Qr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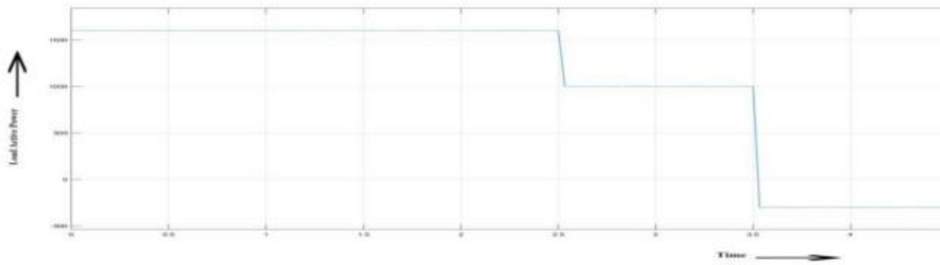
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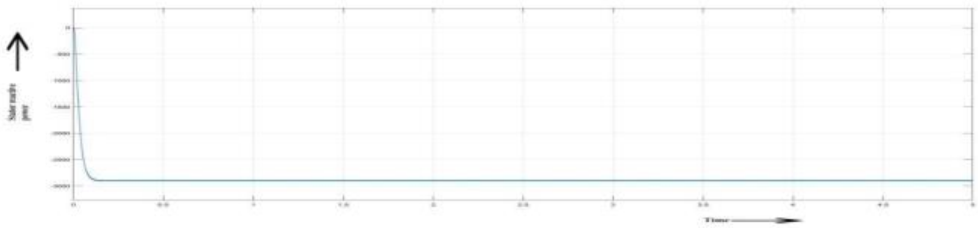
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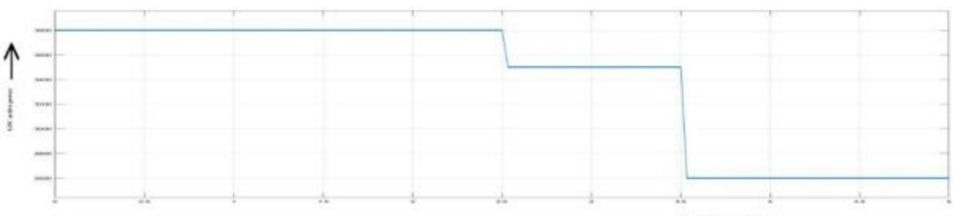
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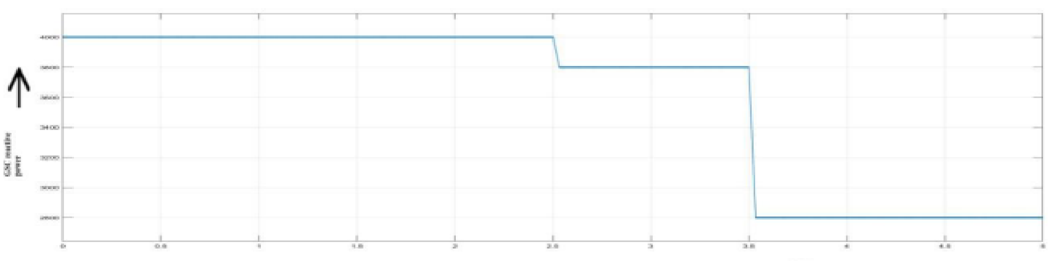
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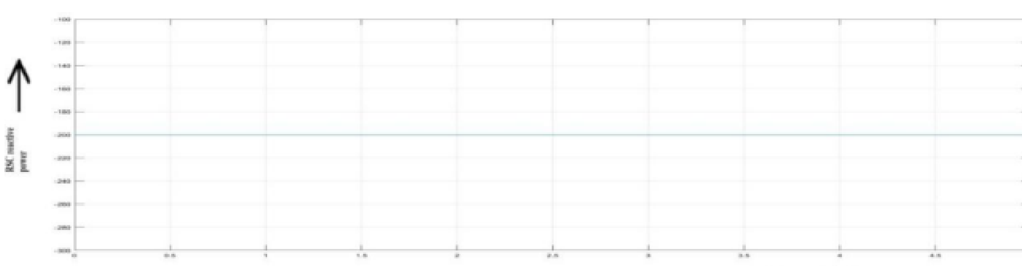
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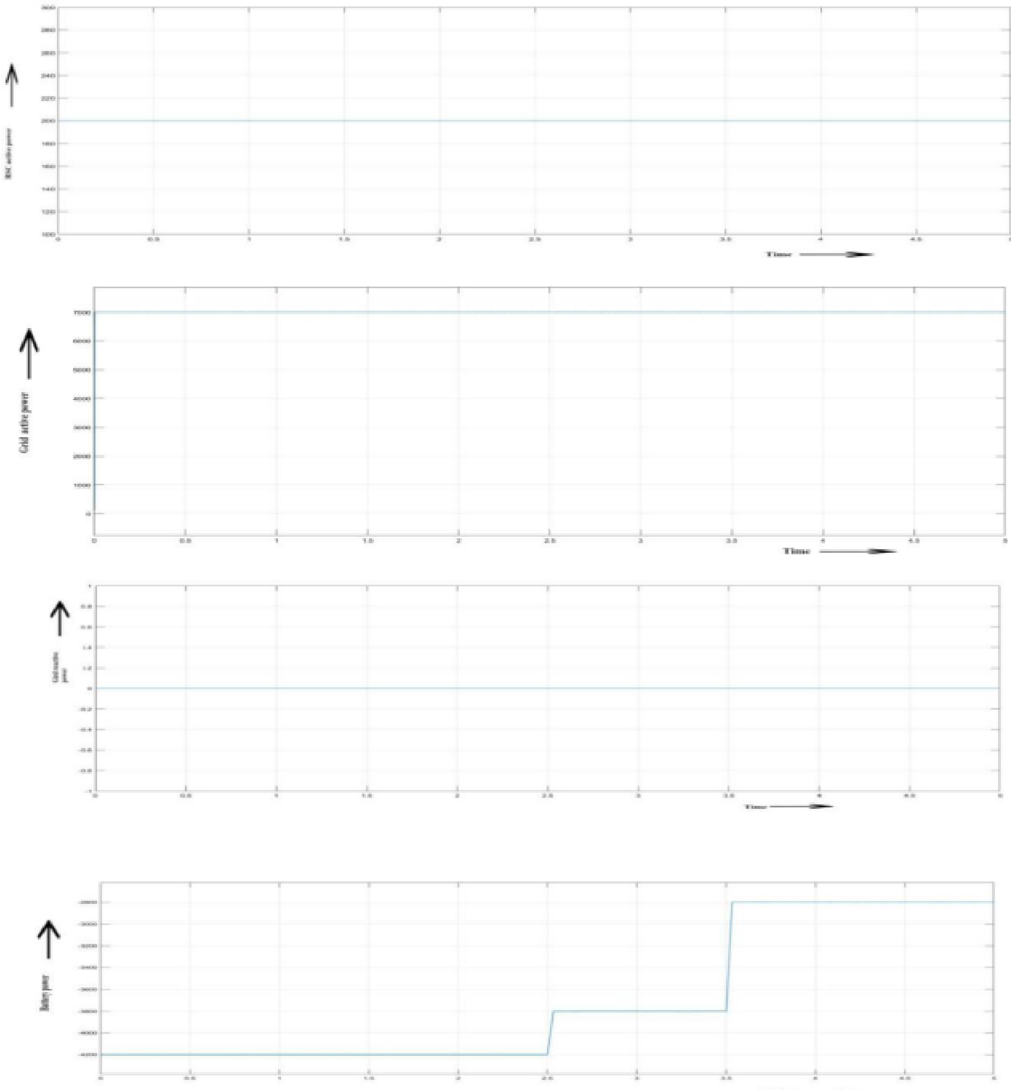
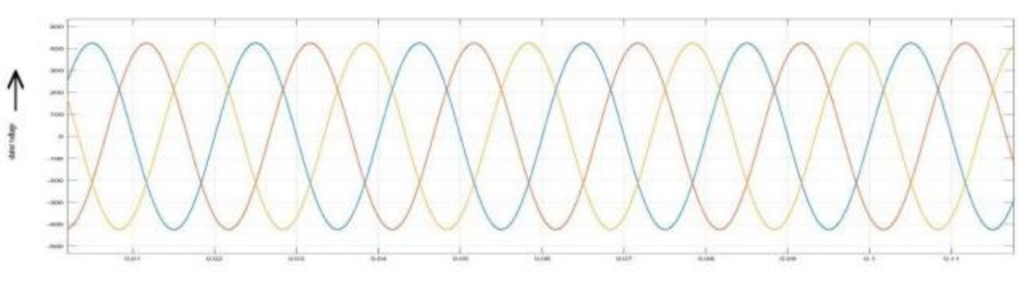



Fig.3 depicts wave forms of PL, QL, Ps, Qs, PC, QC, Pr, Qr, PG, QG, and Pb with reactive power sharing between converters at a wind speed of 7.5 m/s



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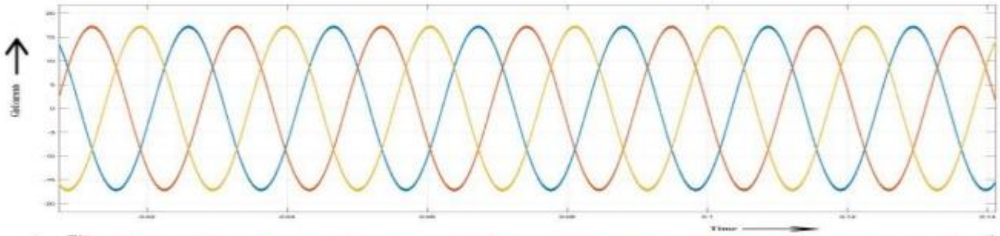


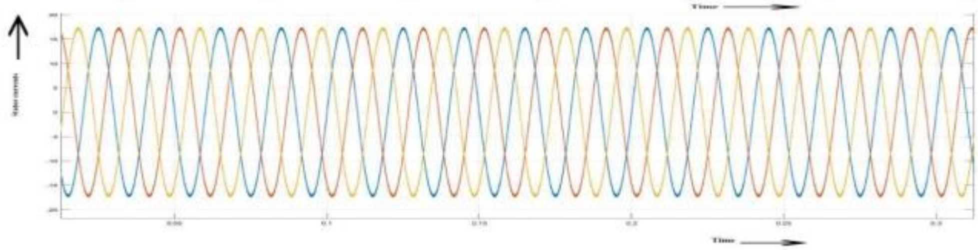


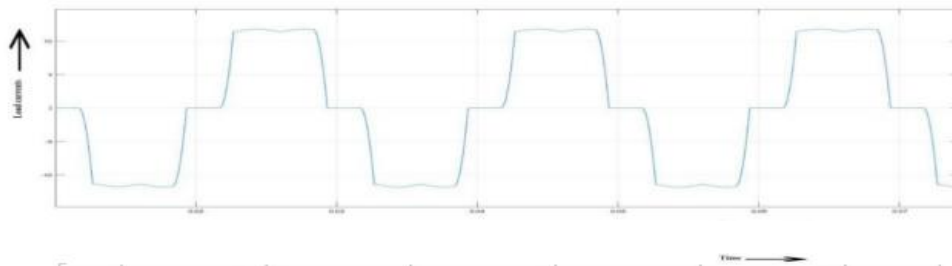


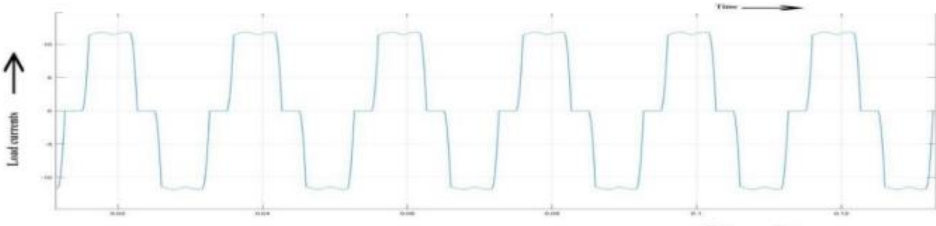


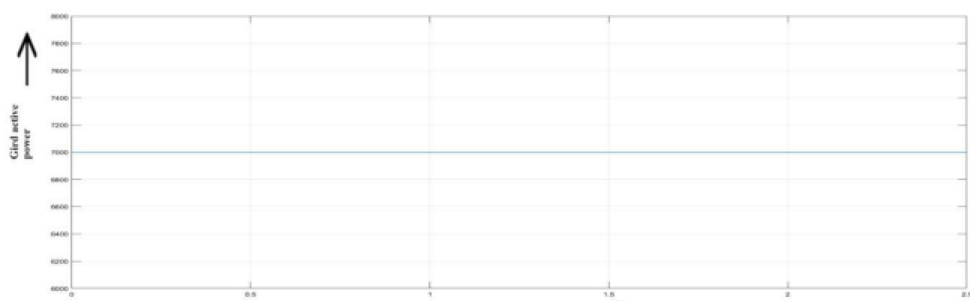


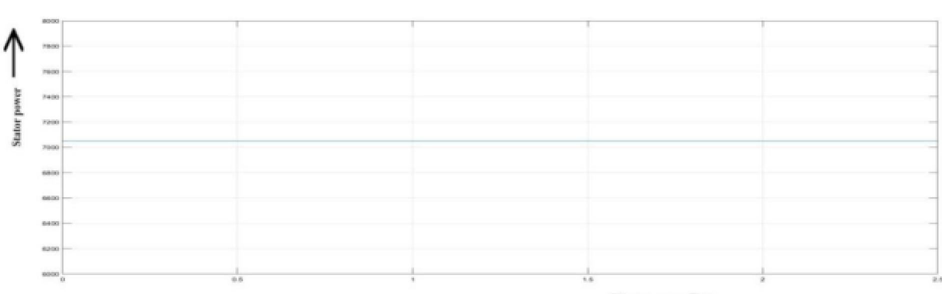

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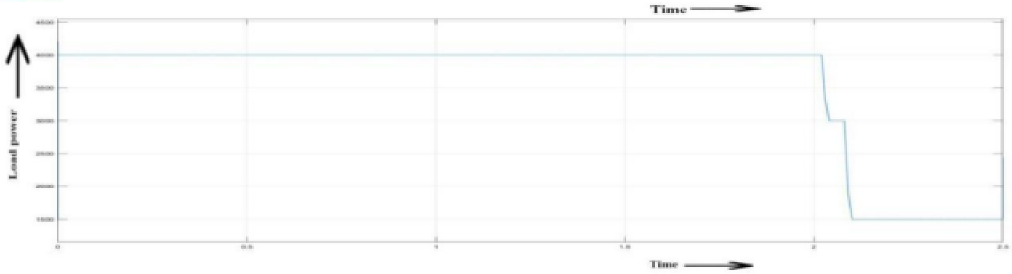


Fig. 9.4 System performance at unbalanced nonlinear loads: stator voltages (vsabc),grid currents (iGabc), stator currents (isabc), load currents (iLa , iLb, iLc),grid active power (PG), stator power (Ps), and load power (PL).

Furthermore, wind speed variations are considered to evaluate the system's response to dynamic changes in wind conditions. The simulations demonstrate the system's capability to adapt to varying wind speeds and maintain regulated grid power flow. By dynamically adjusting the RSC control to share reactive power and optimize energy capture, the DFIG-based WECS maximizes energy output while ensuring grid stability and compliance with operational constraints.

Reactive power sharing between the RSC and GSC is analyzed to assess its impact on system efficiency and stability. The simulations confirm that reactive power sharing at below-rated wind speeds reduces rotor winding copper losses and improves overall system efficiency. Additionally, maintaining unity power factor at rated wind speeds ensures optimal power extraction without exceeding converter ratings. These findings underscore the importance of proactive reactive power management in enhancing the performance and reliability of DFIG-based WECS during grid interaction.Moreover, the simulations consider the effects of unbalanced nonlinear loads on system operation and stability. The results indicate that the proposed GSC control successfully compensates for load unbalance and harmonics, maintaining stable grid voltage and power quality. By providing reactive power support to the DFIG and connected loads, the GSC control mitigates the adverse effects of load unbalance and harmonics, ensuring smooth and reliable operation of the grid-connected system.

The integration of battery energy storage into the DC link of the back-to-back converters is evaluated to assess its effectiveness in maintaining regulated grid power flow regardless of wind speed variation. The simulations demonstrate that the battery energy storage system serves as a buffer, storing excess energy during periods of low wind speed and discharging it during peak demand or grid disturbances. This helps stabilize grid voltage and frequency, enhance system resilience, and ensure uninterrupted power supply to consumers.Overall, the results of the simulations highlight the effectiveness of the proposed control strategies and system configuration in achieving regulated power flow and grid interaction objectives. The discussions emphasize the implications of these findings for grid integration, stability, and reliability, as well as the potential for future research and development in the field of renewable energy systems. By optimizing control algorithms, integrating energy storage, and improving grid interaction capabilities, DFIG-based WECS can play a crucial role in transitioning towards a sustainable and resilient energy future.

## CONCLUSION

The grid interactive DFIG based WECS with proposed control systems, has been implemented for reactive power sharing capability and regulated grid power flow. The significant reduction in rotor winding copper loss, has been found due to reactive power distribution between converters at below rated wind speeds. Moreover, there is minimal effect on decrease/increase in the converter’s losses with reactive power sharing. Moreover, satisfactory performance of RSC control has been found in sharing the reactive power at below rated wind speeds, maintaining UPF at rated wind speed and extraction of maximum power from the wind turbine. In addition, the performance of GSC control has been found satisfactory in achieving regulated power flow, reactive power compensation of DFIG stater and load, compensation of load harmonics and load unbalance. Furthermore, the acceptable performance of BES has been found in maintaining the constant power flow through the grid irrespective of wind speed variation. Simulated results have shown that the system gives reasonably good performance under change in grid reference active power, varying wind speed, reactive power sharing and unbalanced nonlinear loads. Grid currents, stater currents and voltages have been found balanced and sinusoidal and their Thuds are well below the permissible limits of the IEEE 418 standard.

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