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A High-Performance Microgrid with a Mechanical Sensorless SynRG Operated Wind Energy Generating System

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Abstract

The article describes the implementation of a new control methodology for a microgrid that incorporates a wind-battery and grid system, capable of operating in both grid-connected and standalone modes. The wind energy generation system (WEGS) employs a synchronous reluctance generator (SynRG) with a novel mechanical sensorless field-oriented control. To overcome issues related to conventional integrator or low-pass filter use during flux estimation in SynRG sensorless control, a fourth-order flux estimator is implemented in this article.

A bidirectional dc-dc converter is used to ensure battery longevity and controlled operation. To achieve complete decoupling between the grid and WEGS, voltage source converters (VSCs) are used in a back-to-back configuration with a common dc-link. In order to mitigate the negative effects of imbalance and harmonic content in grid voltages, grid-side VSC (GSC) regulation is used to enhance power quality at the point of common coupling by using observers to extract positive sequence components of grid voltages.

The MATLAB/SIMULINK platform is implemented for the system's design, modelling, and simulation. A lab model is built to verify the system as it occurs.. This article offers a comprehensive approach to addressing the challenges associated with controlling a microgrid comprising wind-battery and grid systems. It presents novel control methodologies and energy storage solutions to enhance microgrid reliability and efficiency.

Keywords: Renewable energy sources include wind energy generation systems (WEGS), synchronous reluctance generator, & battery grid systems.

I. Introduction

"A global attention on alternative renewable energy sources has resulted from the need to satisfy rising energy consumption rates and limitations on growing conventional energy generation (RES). Wind energy generation systems (WEGS), one of these RES, have grown significantly in recent years. In 2018, there were 51.3 GW of WEGS installations worldwide, totaling 591 GW of WEGS electrical energy producing capacity

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worldwide The utilisation of specialised electrical equipment as generators and developments in power electronics technology are both responsible for the expansion of WEGS.

Variable speed wind turbines (VSWT) utilise synchronous generators (SG), and the permanent magnet SG (PMSG) is the most widely used member of the SG family. Unfortunately, its usage is constrained by the prohibitive cost of permanent magnets and operational problems. Moreover, due to competing magnetic fields and elevated operating temperatures, PMSGs may become demagnetized. SynRGs with enhanced rotor designs are appropriate for VSWT applications in order to solve these problems. Without mechanical sensors, synchronous reluctance generators are more effective, and one can estimate the rotor speed using the flux-linkage vectors' angular velocity. Nevertheless, integrators may encounter drift during low-speed operation, which will reduce performance. In order to overcome this, some applications use an indirect flux detection via online reactance measurement, although extra filtering is needed to eradicate disturbances imposed on the signals. The high-frequency injection method, a cutting-edge technology, has been put out in the literature for low-speed operation. However, it requires accurate understanding of the discrepancy between the average worth and the real rotor position. Sadly, there is currently no reliable flux estimation method for speed regulation of synchronous reluctance machines in the literature, especially for low- and high-speed operations. However, the literature lacks an effective flux estimation method for control scheme of synchronous reluctance machines, especially for low- and high-speed operations. Nonetheless, when regulating synchronous reluctance machines, researchers encounter numerous flux estimation problems. These errors decrease the precision of conventional methods for estimating flux, such as low-pass filters (LPF) and pure integrators. These errors come from a variety of sources, including dc offset, oscillations, phase difference, and amplitude attenuation. The suggested microgrid is only intended to function when connected to the grid. Unfortunately, the system cannot function if there is no grid electricity or if the grid voltages are distorted or exceed their limits. The drawbacks of traditional flux estimators are resolved by using this technique. In light of this, a variant of this fourth-order integrator may be employed to estimate the flux elements in synchronous reluctance generators.

Grid voltages at remote locations may have harmonic content and be prone to imbalance, both of which can damage system performance. Positive sequence elements (PSCs) of grid voltages have indeed been employed for control to solve this problem. A grid synchronisation method based on mixed 2nd and 3rd-order generalised integrators (MSTOGI) has also been developed by researchers. By adding an additional branch to the standard SOGI block, this solution can resolve problems with the quadrature signal that are brought on by the presence of DC offset in the input signal. The filtered signal, however, is susceptible to interharmonics and subharmonics in the input signal because it was extracted using the same SOGI block. The precision of the extracted components is impacted by the presence of close-range harmonics in the input signal. Researchers have suggested a Kalman filtering method that performs better than MSTOGI to make up for these problems. Unfortunately, the Kalman filtering technique's practical application is constrained by its complexity. The proposed solution hasn't yet been used to switch the freestanding to grid synchronization mode.

The technology described in the article combines a SynRG-based wind energy generating system (WEGS) with a bidirectional converter-controlled battery bank to create an effective hybrid microgrid. his microgrid topology combines the advantages of both grid-connected and freestanding operation to run efficiently. By connecting VSCs back-to-back, it is possible to achieve decoupled functioning of the WEGS and the grid. The speed that matches the highest power generation from SynRG is calculated using a max power extracting (MPE) algorithm which is based upon that tip speed ratio (TSR). The SynRG is controlled using a position/speed sensorless field-oriented control (FOC) based on an FFE-FLL algorithm. This eliminates the limitations of the normal integrator and LPF while estimating the stator flux components. The system features include:

1. Using a SynRG-based wind power generation network with back-to-back coupled VSCs allows for connection to the grid and controlled charging and discharging of a battery backup.
2. the microgrid's capacity to function both in isolated and grid-connected environments without harming nearby essential loads.
3. switch between grid-connected and freestanding modes without interruption.
4. It is the first for SynRG to use an FFE-FLL-based position/speed sensorless FOC in wind energy conversion applications.
5. The MPE from wind turbine with variable speeds is achieved through effective regulation of the SynRG's shaft speed, doing away with the need for expensive mechanical sensors.

II. Proposed System

As per Figure 1, the system configuration looks to have a number of parts, including a SynRG-based WEGS, a BDC-controlled ES, local non - linear loads, and the power grid. Power is generated by the SynRG-based WEGS and distributed to the grid, ES, and nearby loads. T The BDC either charges or discharges the ES according to the load demand and power availability. The system uses interface inductors, resistor-capacitor (RC) ripple filters, and resistor-capacitor (RC) switching to reduce the switching impacts of both the GSC on the voltages and currents.

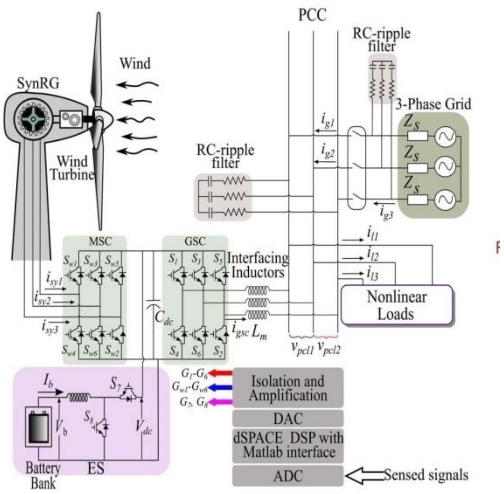

Fig 1. Proposed system

An RL load attached at the PCC that is fed by a diode bridge rectifier is used to validate the GSC control. Machine side converters (MSC) and grid side converters (GSC) are frequently employed in the field of wind turbines for control purposes. In order to accomplish Maximum Power Extraction (MPE) without any of the expense of expensive mechanical sensors, one method employed in MSC control is to estimate the parameters of speed and position. Using this method may be more cost-effective and effective than using conventional sensors. The GSC control can act individually in islanded mode to preserve system stability during grid interruptions.

III. Methodology

To effectively manage a wind/battery microgrid, various control schemes are employed to regulate its different components, including the MSC (Main Supply Controller), BDC (Battery DC-DC Converter), and GSC (Grid Side Converter). The following are the typical control schemes used in a wind/battery microgrid:

- **MSC Control Scheme**

The MSC is responsible for managing the power flow between the wind turbine and the battery bank. Its control scheme involves using power electronics to optimize the power flow from the wind turbine to the battery bank. The MSC control scheme usually integrates maximum power point tracking (MPPT) algorithms to extract maximum power from the wind turbine. The MPPT algorithm ensures that the wind turbine operates at its maximum power point, thereby maximizing the power output. The MSC control scheme also includes a battery charge controller to regulate the charging and discharging of the battery.

Estimation of f ω^{ref}_{r}:

The mechanical power produced by a wind turbine with blade length r_b and operating at a wind speed (V_{wi}) can be calculated using the following formula:

$$P_{wi} = (1/2) * \rho * A * V_{wi}\hat{}3 * C_p$$

To obtain maximum power generation from a wind turbine, it is necessary to operate at the maximum value of the coefficient of performance (Cp), denoted as C_{mp}. Consequently, we can estimate the speed (ω_{ref}) that corresponds to the maximum power generation from the wind energy generation system (WEGS)

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for any wind speed (within the cut-in and rated speed range) of V_{wi} as follows:

$$\omega^{ref}_{r} = \lambda_m r_b V_{wi}.$$

The reference speed determined using Equation (3) is used as the rated speed for the Peak Power Point Tracking (MPPT) control when a wind power system (WEGS) is operating in the Peak Power Extraction (MPE) mode.

- **BDC control scheme:**

The BDC is responsible for managing the charging and discharging of the battery system in the microgrid. The BDC control scheme involves monitoring the battery state of charge, forecasting load demand, and implementing appropriate control strategies to ensure the battery system operates within safe operating limits while maximizing its operational lifetime.

- **GSC Control scheme:**

The GSC is in charge of overseeing how the microgrid is connected to the larger grid. To secure the stability and dependability of the microgrid while managing the flow of power between both the grid and the utility grid, the GSC control method requires monitoring the grid's voltage and frequency**.** The control strategies for Grid-Side Converter (GSC) in grid-connected and islanded operation modes are covered in this section. The GSC control is depicted in block diagram form in Figure 6.

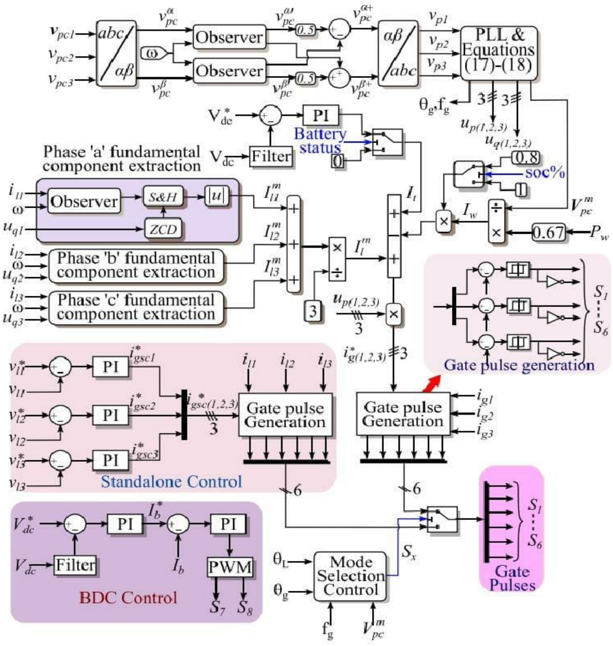

Fig 4. main control

1) Mode 1-Normal Operating Mode (With Grid):

The localized loads, the storage, and the grid all receive a portion of the electricity that is generated by the wind energy production system (WEGS) under normal operating circumstances. The grid currents in this case follow the baseline grid currents generated by the control method. The optimum value of the system currents are decided by the WEGS power generated and the total value of the basic element of load currents. The component active voltage patterns made from PCC voltages determine both the frequency and amplitude of the grid currents. The changing pulse for the Grid-Side Converter are created using hysteresis current controllers (GSC).

2) Mode 2-Standalone Mode:

The system is advertised as operating in a grid-connected state, although it has

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the ability to switch to a standalone mode in the event of a grid loss or when grid parameters are exceeded. The major goal of the GSC management in standalone mode is to keep the load voltage at the correct level. The system does this by comparing the reference values (vl(1,2,3)) with the measured load voltages (vl(1,2,3)).

3) Mode Selection Control:

The block requires four inputs: the grid voltage's frequency (fg), its magnitude (V m pc), the phase angle of the voltage level (g), and the load voltages (L).

Using these inputs, the block generates a synchronization signal (Sx) that determines whether the microgrid should operate in grid-connected mode or standalone mode. However, the passage does not provide details on how the synchronization signal is calculated.

In terms of the microgrid's control scheme as a whole, this block is crucial since it makes sure that the system runs in the appropriate mode based on the grid's present conditions.

For Mode 1: Grid-connected mode, Sx = 1.

Mode 2: Standalone mode: 0

IV. Implementation

The control system converts (vpc1, vpc2, and vpc3) the imbalanced PCC voltages into PSCs (vp1, vp2, and vp3) In spite of uneven PCC voltages and irregular load currents, the control system can still create sinusoidal grid currents since the standard grid currents are derived from the unit effective templates. The study covers the il (1,2,3) and igsc (1,2,3) waveforms to demonstrate the efficiency of the control scheme.

Additionally, the study assesses the efficiency of the control system during the switch from grid-connected state to islanded and vice versa. Under typical circumstances, the system is evaluated using a grid voltage level of 220 V and a rate of 50 Hz. As all three requirements in formula (25) are met in these circumstances, Sx = 1, suggesting that its microgrid is functioning in grid-connected state (Mode 1). In order to validate the synchronisation control and verify the efficiency of the control system, the study displays experimental morphologies of vp, vl, ig, il, igsc, g, and L in Fig. 8.

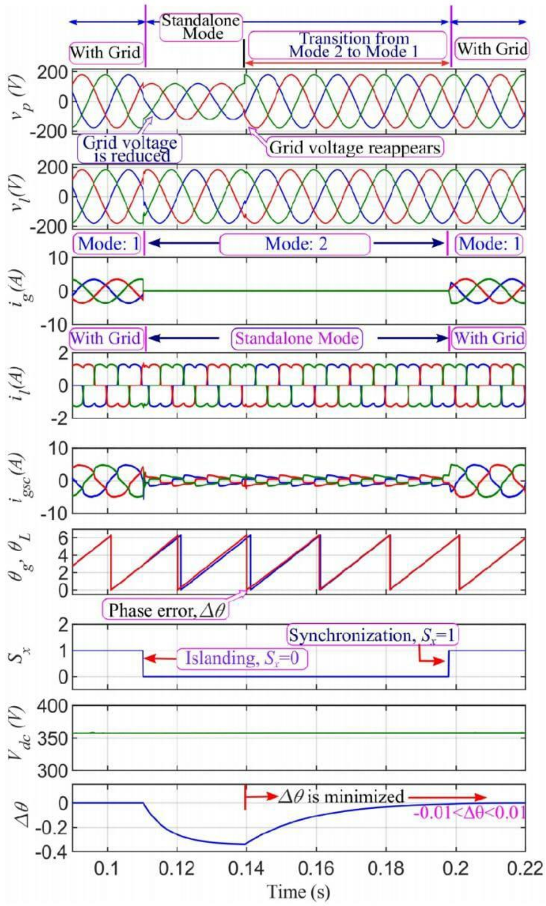

Fig 5. Graphical representation of changes occurs in the system

V. Experimental results

A 3.7 kW SynRG is integrated into the Renewable Renewable Energy Production System (WEGS) with Differential Wind Speed and is connected directly to the rotor of an Induction Machine (IM). A

Variable Frequency Drive (VFD075E43 A) gets instructions from the MATLAB/Simulink platform to drive the IM in order to replicate the wind turbine (WT). With a three-phase autotransformer linked to a 415 V, 50 Hz supply, the necessary voltage level of 220 V for the grid is produced. The MATLAB/Simulink software on a host Computer is used to develop the control algorithms in real-time, and the dSPACE-1103 is interfaced (digital signal processor). For the purpose of amplification and isolation, the dSPACE-1103 creates gating pulses for the GSC and MSC IGBT (Gate Field -effect Bipolar Transistor) switches. These pulses are then given to the semiconductor switches circuits via optocoupler (6N136) circuits. The performance of the system has been assessed in both static and dynamic circumstances.

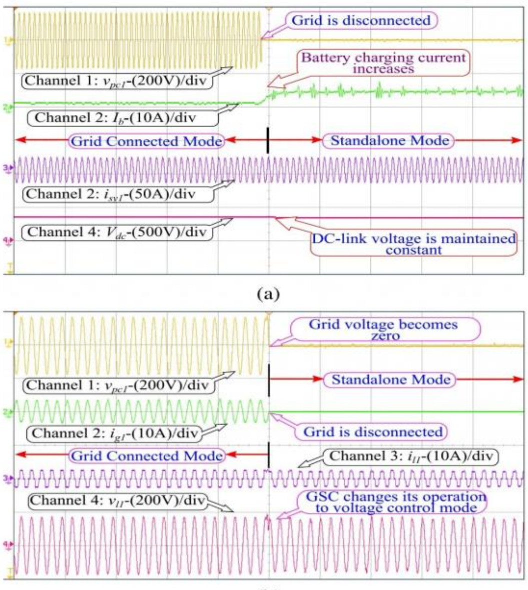

Fig 7. Grid-connected to standalone operation of the system

VI. Conclusion

This article introduced a grid system that combines wind power, battery bank, and grid connection. The system was evaluated under both static and dynamic operation conditions, and observer -based control of SynRG utilising FFE-FLL was experimentally confirmed. During grid disruptions, the BDC-controlled battery storage proved to be helpful in allowing the WEGS to support small demands. Reactive energy compensation and operating with a unity power factor at the PCC were both accomplished by the system while maintaining a constant dc-link voltage. Also, with unbalanced PCC voltages, the GSC control's efficiency was shown. The testing findings verified the additional benefits of the storage system for batteries and supported the precision of the MSC control.

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