The role of WES and BESS in the provision of operating electricity reserves-a review

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***Abstract*—Active power reserves are required for an electrical system to work effectively. These reserves are modified regularly to meet system generation and demand to maintain a constant electrical frequency. Regulation reserves, spinning reserves, and non-spinning reserves are the three main forms of operating reserves. Reserves can be used in both normal and extraordinary conditions to maintain supply and demand balance. There have been various attempts to do research into how renewable generation might contribute to the provision of reserves now that large-scale wind energy has been integrated into the grid, but these efforts have been hampered by the stochastic and intermittent character of renewable generation. When proper control techniques are put in place, wind turbines can participate in the provision of operating reserves. This paper discusses the role of wind energy systems and battery energy storage systems in the provision of operating reserves. This research also looks at South Africa's operating reserve margin and storage capacity.**

Keywords—Operating reserve margin, wind energy systems, energy storage, load demand, battery energy storage systems, generation.

I. Introduction

An electrical system must have active power reserves to function properly. To maintain a consistent electrical frequency, these reserves are regularly adjusted to meet system generation and demand [1]. They are often supplied by synchronized traditional producing units like thermal or hydroelectric power facilities. The amount of power reserves provided by conventional generators decreases as these producing facilities are being replaced with non-synchronized renewable-based power plants (such as wind and solar). Therefore, just like traditional producing units, wind power plants must also supply power reserves [2]. Even though the generator set does not offer a passive instantaneous power reserve and the amount of power produced by wind plants heavily relies on the fluctuating and challenging to predict wind speed, research shows that with the right techniques, it is possible for wind energy systems to supply power reserves and therefore play a role in grid frequency control [3]. For wind energy systems to be successfully integrated into the grid, these abilities will be essential [1].

A viable alternative for wind energy producers competing in the power market, medium to large-scale battery energy storage systems (BESS) have recently seen cost reductions and technological advancement [4]. Integrating wind farms with battery energy storage systems provides power utilities with a viable solution to turn fluctuating wind power generation into a dispatchable technology that can also help supply ancillary services which normally cannot be provided by non-dispatchable technologies [5].

Over the past few years, battery energy storage technologies have become very popular in power systems. Utility-scale BESS are a suitable resource to participate in competitive energy and ancillary service markets because of their great operational flexibility, as seen by their instantaneous ramping, bidirectional movement capability, and quick response time [6].

The main objective of this work is to review the literature on the topic of providing operating reserves by combining wind energy systems and battery energy storage systems. The format of this essay is as follows: Section II gives an overview of operating reserves that are required for the reliable operation of the power grid. Section III explores the use of wind energy systems as operating reserves focusing on the control methods that must be put in place in order for wind turbines to do this successfully. Section IV discusses the integration of battery energy storage systems with wind energy systems for the provision of operating reserves. Section V describes the state of operating reserves in South Africa. Finally, Section VI draws conclusions and summarizes the paper.

II. Overview of Operating Reserves

It is impossible to accurately estimate future demand, loads and generator outputs can vary significantly across a wide variety of timeframes, and critical parts of the power system are prone to unplanned breakdown at any time. To properly address these issues, service demand, and maintain system frequency, power utilities secure various quantities and types of operating reserves.

Whenever the available generating capacity cannot keep up with the load demand, which can occur for a variety of reasons such as wrongly projected power consumption or unplanned generator failures, reserve margin is defined as the amount of energy that is saved somewhere to help meet the load demand. Depending on how it will be used and how much energy is held, the reserve margin can be further divided into operational, supply, and facility categories [7].

The three primary types of operating reserves are regulation reserves, spinning reserves, and non-spinning reserves. Reserves can be employed in both normal and abnormal conditions to ensure a balance between power generated and energy demanded. Because a variety of

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resources can be used to supply reserve ancillary services, distributed generation is now used more frequently. Reserves should be dispersed as the load develops to guarantee that there is enough energy generated to meet demand. When the generation is insufficient to satisfy the demand, immediate action is required [8].

Normal Conditions (Non-event): Both quick random fluctuations and consistent periodic variations are common, yet neither one ever causes the system to lose its secure state.

Abnormal Conditions (Event): Rare, abrupt shifts in the power balance pose a hazard to the grid's security. Despite the rarity of these occurrences, they can significantly harm the system's economy.

Operating reserves are subject to numerous definitions and regulations.

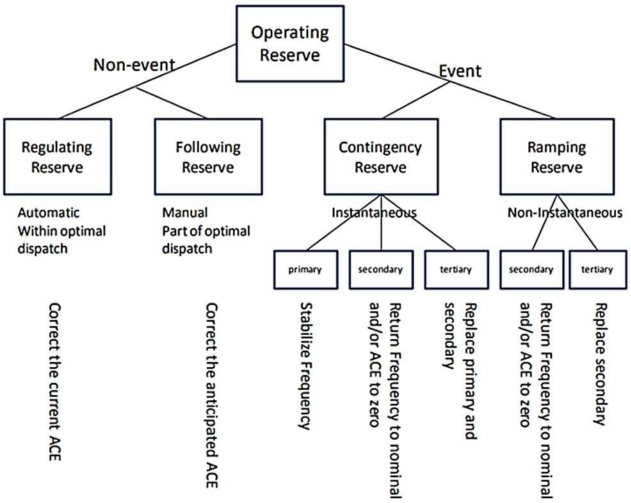

Fig. 1. An illustration of operational reserve types and their uses [9].

According to [10], as indicated in the equation below, the amount of reserve margin can be deterministically determined in the percentage of peak demand:

$$RM = \frac{IC - Peak\ Load}{Peak\ Load} \cdot 100 \quad (1)$$

where RM is the percentage reserve margin and IC is the total installed capacity.

In a paper authored by [11], the percent reserve margin (PRM) is determined as follows:

$$PRM = \frac{Power\ Supply - Power\ Demand}{Power\ Demand} \cdot 100\% \quad (2)$$

In a paper that was published [12], the planning reserve margin is calculated as follows:

$$PRM = \frac{G-P}{P} \quad (3)$$

The equations used by the three different authors mentioned above are very similar. The key aspect when determining seems to be the peak load/demand. An interesting thing to notice is that [10] uses installed capacity to determine the reserve margin whereas [12] uses available generating capacity

III. WIND ENERGY SYSTEMS AS OPERATING RESERVES

There have been some attempts at conducting research into how renewable generation can contribute to the provision of reserves now that large-scale wind energy has been integrated into the grid, but these efforts have been constrained by the stochastic and intermittent nature of renewable generation [13].

Wind used to be viewed as a non-dispatchable "must-take" resource without the capacity to offer reserves, however, it is now understood that a wind turbine's production may be precisely controlled (up to the amount allowed by instantaneous wind speed). As a result, wind can offer various reserve services. Of course, there are significant distinctions between wind and more conventional resources that offer both relative benefits and drawbacks [14].

A. Wind Energy On The Grid

Due to its special characteristics, wind energy presents both new opportunities and challenges for the operation and design of power networks. Ongoing research is being done to determine standards and the best methods for conducting wind integration studies. Below is a discussion of the main problems and benefits of power system operation brought on by the use of significant volumes of wind energy.

1) Increase in operating reserves

Due to both the short-term (between 1-6 h) unpredictability of wind energy, which can be large, and its low predictability, system operators have the responsibility to increase the level of operating reserves [15].

2) Effect on strategic planning

A key part of long-term (or strategic) planning for the power system is the assessment of the generation fleet's capacity to consistently fulfil the anticipated load demand over an extended period. One method of measuring wind energy's contribution to the future power system's ability to operate dependably is by looking at its capacity factor, which can be thought of as the amount of wind energy that will undoubtedly always be available. This is far more challenging to research than non-intermittent conventional generation systems since wind is so unpredictable. Therefore, there is no universally accepted solution, with the most cautious options giving wind energy a capacity factor of 0 [15].

B. Challenges of Wind Integration

Generating electricity from wind energy systems is fast becoming more popular and important in the modern electricity grid as it contributes dearly to reducing emissions and producing environmentally friendly energy. The peculiarities of wind energy systems, such as their sporadic nature, turbine technology, and safety considerations, increase the difficulties of effective and financially feasible grid integration [16]. The following are some of the factors that are complicating wind integration:

1) Voltage Support

Some wind energy systems use induction generators, which are known to be reactive power consumers by nature, to transform the kinetic energy from the rotating wind turbines into electrical energy. An induction generator needs a specific amount of capacitance across the stator terminals to be excited, and in this situation, that capacitance is provided by the grid's reactive power. As a result, these systems cannot supply reactive power to the grid because they themselves need reactive power to operate [17].

2) Frequency

When wind power is added to the electrical grid, the overall inertia is decreased, and this effect is especially significant for smaller, isolated systems [18]. In the event of any disruption, the majority of wind power plants' control systems frequently segregate the mechanical system from the electrical system, which reduces the contribution of wind power plants to network inertia [19].

The greatest affordable strategy to lessen the possibility of frequency occurrences that correspond with low wind speed situations, according to published literature, is to use energy storage devices for frequency management. Energy storage systems are able to make up for the active power lost during periods of low wind speed by increasing wind power production. The primary reserve should primarily come from wind farms. Improvements in wind speed monitoring and forecasting techniques may also improve the effectiveness of regulatory algorithms and reduce the amount of wind energy squandered [20].

C. Control Methods for Wind Turbines

In [21], a preliminary taxonomy of RES frequency control approaches is offered. Variable-speed wind turbines (VSWT) have been subject to this categorization, as seen in Figure 3. There are two sorts of frequency control techniques: those that use energy storage systems (ESSs), like flywheels, batteries, pumped hydropower, or supercapacitors [22], and those that don't.

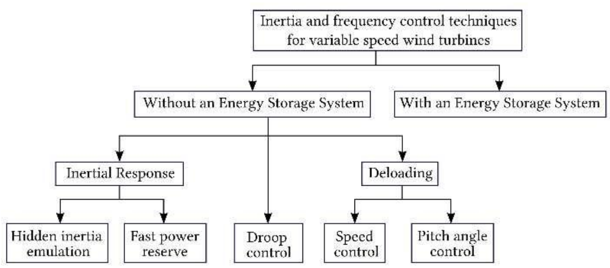

Fig. 2. Different techniques that can be used to control inertia and frequency in variable-speed wind turbines [23].

For wind turbines to be able to participate in reserve provision, they can be controlled in two methods namely rotor speed control and pitch angle control [24]. How reserve can be achieved in each of these scenarios is covered in the following subsections. In the event that there is an energy storage system, reserve provisions will also be included in this section.

1) Power Reserve Control

The system's primary regulating mechanism is intended to make up for any mismatch between supply and demand. A linear change in generated power with grid frequency constitutes the primary regulation. The generated power should therefore drop as the grid frequency increases and vice versa. As a result, a power reserve is necessary to enable primary regulation to be applied in both directions [25].

The mechanical output power that the wind turbine will be able to capture will be determined by its aerodynamic behaviour and will be:

$$P_m = \frac{1}{2}\rho \cdot A.C_p.(\lambda,\beta)v^3 \quad (4)$$

where ρ denotes air density, A denotes rotor sweep area, v denotes wind speed, Cp denotes power coefficient, β denotes pitch angle, and λ denotes tip speed ratio, which is denoted by:

$$\lambda = \frac{\omega_r R}{v} \quad (5)$$

Equation (5) above makes it clear that the tip speed ratio and pitch angle have an impact on the wind turbine's output power. The two primary types of control systems utilized throughout the deloading process are speed control and pitch angle control [21].

a) Control of Turbine Speed

The main flaw in rotor speed control reserve provision is that even small reserves need significant overspeeding. This suggests that the maximum feasible reserve is minimal. If the wind turbine's reserves are larger, it will be able to operate at its rated operating speed in light to moderate winds, engaging the blade pitching mechanism. Rotor speed control is more suitable to offer primary operating reserve and reserve for quick frequency response systems than secondary operating reserve because of the operating speed limitations of wind turbines. If more reserves are needed, it is preferable to change the blade pitch angle [24].

b) Pitch control

Pitch angle, the second controller for the wind turbine, raises the blades' angle to lessen stress. It is optimal to activate the over-speed controller if the wind turbine generator cannot be turned on when it reaches its rated speed [21].

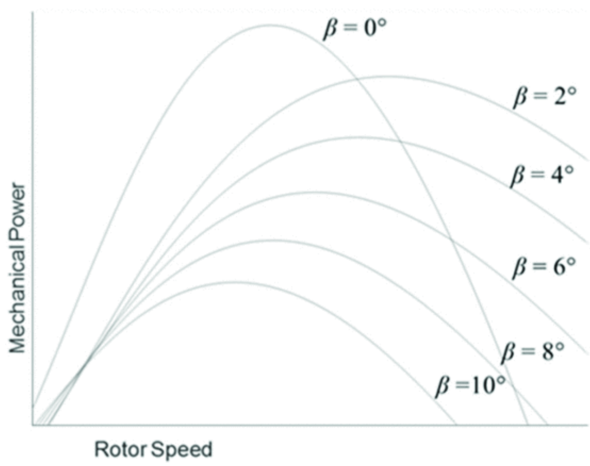

Fig. 3. The wind turbine's power curve illustrating the impact of the blade pitch angle [24].

The graph shows that as the blade pitch angle increases, the maximum power is reduced. When the blades are pitched

($\beta > 0°$), the wind turbine cannot fully utilize the power of the incident wind. Thus, operating reserves are produced. During grid imbalances, this reserve could be used to supply power for frequency regulation.

IV. BESS INTEGRATION WITH WIND FOR OPERATING RESERVES

Although there are many benefits to using wind energy, there can also be technical issues with grid connections, power quality, dependability, protection, generation dispatch, and control. Serious difficulties can arise when integrating a power source with such high intermittency, particularly when doing so in a vulnerable area of the grid [26]. This paper focuses on the power supply side usage of battery energy storage devices. The following are the services that can be provided by BESS on the generation side.

A. Smooth Power Output Fluctuation

In the context of an electrical power network, the use of renewable energy has increased the demand for storage. In fact, BESS can aid in coping with fluctuating production of solar and wind energy. One of the most crucial applications of battery energy storage systems in an electrical power system is the support of renewable energy sources [27].

The employment of a BESS for smoothing new energy generation was the subject of numerous theoretical approaches, research, and analysis. The first issue that needs to be solved is creating a new energy power source and a BESS-integrated model [28].

In [29], a BESS is suggested to boost the amount of wind energy used in power systems, which lessens its intermittent nature. The need for a fluctuation mitigation system can be met by a BESS, as has been demonstrated. Additionally, BESS raises power system reliability when RES has an impact on it.

In [30], it has been shown that BESS can increase wind farms' revenue streams when used with the right control technique. BESS has emerged as the most widely used, mature technology to assist wind power systems [31]. The system reserve generation can also be decreased by using BESS extensively in a wind farm [32].

B. Frequency Regulation-Primary Control

A utility-scale BESS's expanding installed capacity offers more workable methods for updating frequency management tactics and enhancing power system reliability. With the integration of a BESS, the system's anomalous frequency profile can be controlled and recovered because it serves as an energy buffer [28]. BESS is the best technical choice for primary control provision because it has the advantage of responding quickly and precisely to frequency fluctuations compared to other storage technologies [33].

A BESS is assessed as an efficient regulation resource in [34] under the control performance standards to react instantly to frequency deviation. Standard optimization approaches can be used to solve the problem of finding cost-effective charge-level management strategies to ensure the BESS operates during primary control supply, as mentioned in [35].

C. BESS as Spinning Reserves

A spinning reserve is an unloaded generation that is coordinated and ready to handle an increase in load demand or to help in an emergency, such as a generator or transmission line breakdown. [27]. To keep the balance between generation and demand, spinning reserves are required, with a response time of between seconds and ten minutes [36]. BESS's rapid time to response enables it to provide a spinning reserve in a power system. When frequency values drop below a certain limit, BESS is discharged in accordance with the power system's frequency, and BESS is charged in accordance with a higher standard limit [36].

V. OPERATING RESERVE MARGIN AND STORAGE CAPACITY IN SOUTH AFRICA

According to estimates, South Africa has the highest electricity production and consumption. According to estimates, South Africa produces more than half of the power used in Africa. Furthermore, it has long been acknowledged that the country is home to one of the largest energy reserves. The reserve margin, however, has recently somewhat shrunk. To give an example, the South African energy reserve margin decreased from 25% in 2002 to 20% in 2004 and then to 16% in 2006. The reserve margin was expected to be between 8 and 10% in 2008, which is significantly below the national goal of at least 15% [37] [38].

A. Power System Reserve Categories in South Africa

According to the South African ancillary services technical criteria [39] [40], there are five separate reserve categories that must be met:

- Instantaneous reserves: are used to halt the frequency following an emergency and maintain it below reasonable limits.
- regulating reserves, which are used to balance supply and demand on a second-by-second basis and through the use of AGC.
- ten-minute reserves, which maintain supply and demand equilibrium in reaction to differences between the day-ahead market and real-time, such as errors in load forecasting and unreliable unit performance.
- emergency reserves, which are used to bring the linked power system back to full functionality while slower reserves are turned on when the system is malfunctioning; and
- Supplemental reserves: are utilized to guarantee a manageable day-ahead risk.

Table 1 provides an overview of the response time requirements (defined as reaction time + rise time) based on the technological requirements for ancillary services [40].

TABLE 1. DIFFERENT TYPES OF RESERVE CATEGORIES, HOW THEY ARE STARTED, HOW QUICK THEY START AND HOW LONG THE RUN.

Reserve category	Activation	Maximum response time	Minimum duration
Instantaneous	Auto start	10s	10m
Regulating	Auto start	10m	1hr
Ten-minute	Manual start	10m	2hrs
Emergency	Manual start	10m	2hrs
Supplemental	Manual start	6m	2hrs

VI. CONCLUSION

This paper's primary goal was to review existing material on the potential contribution of battery energy storage systems and wind energy systems to the provision of operating reserves.

Due to the intermittency nature of wind, the provision of operating reserves from wind energy systems is not a straightforward process but when the correct wind turbine control methods are put in place, wind plants can participate in the provision of operating reserves.

The operating reserve margin in South Africa is in a dire state. The goal is for Eskom to keep a reserve margin of 15% but currently, there are close to no reserves available. This is an ongoing research study and its main purpose is to investigate the possible contribution of wind energy systems and battery energy storage systems in the provision of operating reserves in a deregulated electricity market.

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