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Integration Of Renewable Energy Sources: Analysis Of Ancillary Service Parameters, Power Market, And Response Effects

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Abstract-- In contrast to various sectors involved in producing, distributing, and transmitting electricity, there has been a noticeable increase in competition in recent times. This rise in competition has resulted in challenges when it comes to maintaining the safety, security, reliability, and dependability of the electrical system. To ensure a high level of safety and quality, the system operator is generally held responsible, particularly when considering ancillary services in a market that has been liberalized. The integration of competition has made the electricity market more complex, necessitating the separation of ancillary services (or the liberalized market) from generation services. These services should be subject to penalties and compensation within the market process. To maintain a stable and reliable voltage profile throughout the electrical system, the system operator adjusts and manages the active power to regulate frequency and reactive power. The system operator defines, procures, and implements such services.

In this discussion, we will analyze the comparison between emerging economies and developed economies regarding various techno-economic aspects of ancillary services.

Index Terms—Load Frequency Control, High-RES Penetration, Inertia, Power System Stability.

I. INTRODUCTION

AS technology continues to advance, renewable energy sources are becoming more readily available, cost-effective, and efficient. As a result, there is a significant increase in the integration of renewable energy into the power system. However, this rapid concentration of renewable energy is causing a concerning issue: the deterioration of frequency response.

Due to the increased penetration of renewable energy sources, the power system's ability to maintain stable frequency levels is being negatively affected [1] Renewable energy sources come with their own set of challenges. One major issue is their dependency on extreme weather conditions, which makes them unreliable and intermittent. Additionally, the integration of renewable energy sources in a liberalized market, coupled with the significant growth in electricity market transactions, has complicated the task of ensuring the security and dependability of the electrical system. To ensure a reliable power supply, it is crucial to maintain a proper balance that effectively manages the equilibrium between supply and demand [2]. To address these challenges, certain ancillary services are essential. In the past, these services were integrated within the generation systems, forming a vertical utility system. However, with the rise in competition and increasing complexity, it has become necessary to separate and analyze these services independently. These services can be broadly categorized into frequency control services, voltage control services, and emergency services, all of which hold significant importance globally. With the significant increase in the concerns regarding energy crisis in the world, the extensive use of electrical drive vehicles in electricity markets, for base load, peak force as well as storage for RES. It is to be noted that these electric vehicles could serve to provide regulation in ancillary services market. As these services have a comparatively quicker reaction in real time to the SO requests. In a particular powers system various concerns such as load following, surplus power absorption, peaking power and as a stand by reserve Energy Storage Systems are being used. These systems are also used to neutralize the variability of RES systems in comparison to CER, by storing the energy for the later use. Since with the increasing demand for energy has caused increase in GHG emissions overall the world. Because of this it is inevitable that we move towards integrating RES in the country's mix which would help in increasing energy security [3]. But since increasing RES in the mix pose threat to security and reliability of the power system, ES system proves to be a promising solution for improving energy security and ancillary services [4]. The European market has established a separate auction market specifically for operating reserves, which operates under well-defined regulations. This setup has created opportunities for Battery-based Energy Storage Systems (ESS) to participate in the ancillary service market [5].

In contrast, Germany utilizes Battery Energy Storage Systems (BESS) as a viable alternative to conventional energy resources (CERs) to deliver a range of ancillary services within its grid infrastructure. The system operator offers frequency-based ancillary services in multiple electricity markets, employing optimal scheduling techniques in microgrids to effectively manage local-level operations and mitigate fluctuations in net load. There are numerous definitions of ancillary services, and these variations arise due to the evolution of diverse electricity market structures. Consequently, it has become challenging to comprehensively understand and define specific services accurately. However, through recent investigations into different markets, establishing relevant context can help alleviate the ambiguity associated with defining ancillary services [4].

II. ANCILLARY SERVICES: FUNDAMENTAL DESCRIPTION

The definition of ancillary services is contingent upon the market structure and regulatory framework in place. In essence, resource-based ancillary services can be categorized into frequency control services (such as Regulation, Load Following, and operating reserves), voltage control services (achieved through Reactive Power Support), and emergency services (facilitated by black start services), as illustrated in Figure 1 [7].

Fig. 1: Resource Based Ancillary Services

A. Frequency Regulation:

When examining both isolated and interconnected power systems, it is widely recognized that ensuring reliable and secure operation is crucial. To achieve this, the implementation of frequency response ancillary service becomes indispensable. A fundamental requirement for maintaining a secure power system operation is to ensure a balance between supply and demand. Additionally, it is vital to operate the power system within the designated frequency limits. Deviating from these prescribed limits can lead to a deterioration in the performance of grid-connected equipment and, in severe cases, result in substantial damage to the entire generating system [6].

The frequency response ancillary service plays a crucial role in achieving generation-to-load matching, and it is typically procured by the system operator. In deregulated power systems, this service is often recognized as one of the most costly components [8]. Regulation, which involves achieving stability in power systems, can be accomplished through various methods such as Primary, Secondary, or Load Frequency Control (LFC) and Tertiary Generator Governor Response. These approaches are commonly employed to ensure effective control and management [8].

B. Control Action

Governor action plays a vital role in the automatic and decentralized execution of primary control. Whenever there is an imbalance between generation and load, the governor swiftly responds within a few seconds, ensuring that the compensated power remains stable for at least 15 minutes. Load frequency control is employed across different control areas to maintain tie-line interchanges and system frequency [9]. This control mechanism can be achieved by configuring generating units and providing feedback to achieve the desired nominal frequency. It can be done through manual adjustments or automatic generation control. Load frequency control, also known as secondary control, is designed to react within seconds to minutes [9].

Tertiary frequency control relies on system operator dispatch control. Although its response time is relatively slower compared to primary and secondary control, it still responds within several minutes after the occurrence of an event. Operating reserves are also employed by the system operator to address disturbances such as contingencies and frequency deviations [10].

C. Load Following

Resources are anticipated to adjust their output to address imbalances between supply and demand throughout the day. Within a control area, the interconnection frequency is upheld by ensuring a match between supply and demand [11]. Nuclear power plants play a significant role in meeting the base load demand, while renewable energy sources (RES) assist in providing ancillary services like load following and regulation [12]. It is important to highlight that load following (LF) and regulation have distinct differences across three key aspects, which are summarized in the table provided below.

Service Type	**Time Frame**	**Pattern**	**Procurement**
Regulation	Momentarily	Uncorrelated	Self Provided
LF	Long Time Frame	Correlated	Self Provided or Competitive Spot Market

The procurement of load following (LF) services under market mechanisms is commonly associated with competitive spot markets or bilateral contracts. These contracts, established between generating units and customers, should be carefully designed to ensure they are neither trivial nor cost-free [13]. Additionally, they facilitate transparency by providing information about which utility is supplying power to the customer and determining the appropriate pricing for each service [14].

D. Operating Reserves:

In order to ensure the secure and reliable operation of a power system, maintaining a balance between generation and load is crucial. While services like regulation and load following (LF) are available for this purpose, they may not be suitable for handling unexpected or sudden changes in load and generation [15]. Therefore, in such events, the system operator (SO) needs to procure additional operating services. These services assist in restoring the system from sudden frequency outages and typically involve unloaded capability in conjunction with generation services [16].

Load forecasting is performed by statistically analyzing historical data, usually under ideal conditions. However, it is essential to maintain sufficient reserves to prevent unforeseen outages and errors resulting from inaccurate load forecasting [17]. Utility companies typically require a fixed percentage of operating reserves (OR) within specified timeframes, although the exact percentage may vary across markets. Wind and photovoltaic (PV) resources are commonly used as operating reserves by various electrical utilities. However, the increased penetration of wind and PV power presents additional challenges due to their variability and intermittent nature [18]. Therefore, it becomes necessary to explore new approaches and types of obtaining OR capacity to effectively manage wind power variability [19].

NERC's Policy 1 on Generation Control and Performance classifies two categories of operating reserves based on the time required for their usage and the physical process involved. These categories are as follows:

1. Ten-Minute Reserves: (a) Ten-Minute Synchronized (Spinning Reserve) (TMSR) (b) Ten-Minute Non-Synchronous (Non-Spinning) Reserve (TMNSR)

2. Thirty-Minute Replacement Reserve (TMRR).

Further details regarding these reserves are provided in the following table.

S. No	Type of Reserve	Resource Status	Time for Procurement and Sustainment
1.	a. TMSR	Online, Partly Loaded	10 min
	b. TMNSR	Not necessary online	10 min, 2 hrs
2.	TMRR	Online as well as Offline	30 or 60 min, 2-4 hrs

The Thirty-Minute Replacement Reserve (TMRR), also known as the Thirty-Minute Operating Reserve (TMOR) in ISO NE, serves as a supplemental or backup reserve. Its primary purpose is to replace costly reserves, offering a faster response time and helping to reduce regulating costs [20]. Figure 2 demonstrates that energy and reserve requirements are derived from the same generating capacity. The calculation of spinning reserve requirements in various systems worldwide, such as Belgium, France, the Netherlands, Spain, California, PJM, UCTE, and others, is provided in the table below.

Country/ Region	Calculation of the amount of SR
UCTE	$\sqrt{10\mathrm{L}_{\mathrm{maxzone}} + 150^2} - 150$
Belgium	Minimum 460 MW by Generators (UCTE Rules)
France	Minimum 500 MW by Generators (UCTE Rules)
The Netherlands	Minimum 300 MW by Generators (UCTE Rules)

Spain	Between $3\sqrt{L_{max}}$ and $6\sqrt{L_{max}}$
California	50%* Max (5% P_{hydro} + 7%$P_{other\ generation}$; $P_{largest\ contigency}$) +$P_{non-firm\ import}$
PJM	1.1% of the peak+ Probabilistic calculation on typical days and hours

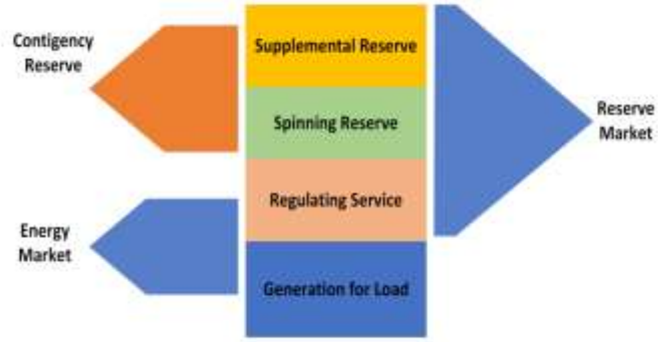


Fig. 2: Operating Reserve from Generation Capacity

E. Voltage Control (or Reactive Power) Support Services (VCSS/RPSS)

To ensure the security and reliability of a power system, the implementation of ancillary services (AS) becomes essential. These services primarily focus on voltage control, managing the bus voltages within the network of an electrical power system [21]. The provision of reactive power control is a significant aspect of these ancillary services. They are typically associated with steady-state problems, and various reactive devices such as FACTs devices, load tap-changing transformers, synchronous motors, capacitor banks, distributed generation (DG), and microgrids are utilized to compensate for these services [22].

F. Black Start Services (BSS) or Power System Restoration (PSR)

When a system blackout occurs, it results in significant social and economic losses, making it crucial to restore the system promptly. System operators have the responsibility to ensure the availability of services that can restore the system to a state of equilibrium after a blackout [25]. It is important to note that improper controller design can propagate disturbances to other control areas, potentially leading to severe system blackouts. This is a complex and challenging task that varies depending on the specific system [26].

During a blackout, Non-Black Start Units are provided with energizing power by units that possess black start capability. Typically, hydropower units or diesel/gas turbine engines with smaller capacities are employed to restore power system stability. Fast Cut Back (FCB) is utilized in conjunction with traditional conventional generators, such as thermal units, to accomplish Black Start Services [27]. This function allows thermal units to disconnect from the grid during a blackout and serve as an auxiliary source of power. It is an essential control mechanism that improves restoration time and increases black start (BS) capacity, offering advantages over traditional BS units [27].

These services are procured through bilateral contracts in the ERCOT market, following the fulfillment of specific performance criteria. The procurement process takes place annually within the competitive market framework [28].

G. Energy and Ancillary Service Market Structure

An auction is a process of allocating resources based on specific rules, regulations, and evaluation criteria set by a designated authority. It enables a transparent and structured allocation process. To gain a comprehensive understanding of the market structure, it is essential to comprehend how electricity markets are organized and the inclusion of submarkets. The market clearing mechanism plays a crucial role in delineating the relationships among different market structures, providing clarity and coherence [29].

H. Market Structures:

Electricity markets are established to ensure the security, reliability, and cost-effective operation of the power system. These markets vary globally based on factors such as the duration of operation, the information provided by individual participants to the system operator (SO), and the SO's role in control and facilitation. Different market structures have traditionally existed worldwide to cater to these diverse considerations [30].

I. Forward Markets

In order to link up future delivery based on the forecasted demand, the market for which the suppliers seem to be committed and scheduled is forward market [31]. On the basis of time of operation these can be broadly classified as shown in the table.

On the basis of Time of Operation	
Day Ahead Market (DAM)	Intra Day Market (IDM)
24 Hour Ahead of Actual Delivery	Used in order to adjust deviation in DAM.
Biding of retailers based on load forecasted	Allows everyone to adjust the day ahead schedule at pre determined times
AS depend upon load forecasting	This is normally referred to as gate closure.

J. Real Time Balancing or Real Time Market

The real-time balancing market, also known as the real-time market, focuses on addressing the imbalance between supply and demand. When a specific mismatch occurs, the necessary services are procured, thereby improving the system's consistency [32]. This is achieved through deviation settlement, which involves day-ahead and long-term contracts. When these services are procured, the service operator must act quickly to rectify the deviation in real-time. In practice, the real-time balancing market operates approximately 5-10 minutes before the actual deviation occurs [33]. Real-time estimates are used to determine ex-ante and ex-post pricing, based on the actual prices of the marginal units that clear the market in real-time [34].

K. Market Clearing or Settlement Mechanism:

To accurately assess the quantities produced and consumed within the system, market clearing and settlement mechanisms are established. These mechanisms facilitate the determination of payments between participants. The system operator (SO) provides multiproduct markets encompassing services such as energy, ancillary services, and transmission products. In a simplified form, separate merit order stacks are used for energy and ancillary services during the dispatching of the multi-product energy and ancillary service market. The stack represents the quantity and price associated with each product offered by participants. This mechanism operates by eliminating higher-cost offers in favor of lower-cost offers, resulting in a more transparent and easily understandable process.

However, the viability and optimality of the dispatch results cannot be guaranteed in the case of market-oriented dispatch (MOD), where products are coupled. This approach is commonly utilized in India for procuring Frequency Responsive Ancillary Services (FRAS) through a market clearing mechanism where energy and ancillary services compete using the same resources. A similar approach is employed by entities like CAISO and ERCOT, where product clearing occurs based on a predetermined priority sequence, considering potential substitute uses for the same generator. However, MOD fails to optimally procure energy, leading to underutilization of resources and ancillary services, resulting in elevated prices or system-level infeasibility.

Due to challenges encountered during the initial stages, CAISO transitioned to a non-sequential-based Rational Buyers Approach (RBA). In cases requiring multi-commodity dispatch, Joint Optimization Dispatch (JOD) is used, aiming to minimize net costs when considering capacity, ancillary services, and other services by assigning inseparable commodities to bidders. The implementation of Time-of-Day (TOD) markets, where some products are substitutes and their prices are difficult to separate, can be observed across various electricity markets worldwide, as depicted in the accompanying table.

II. FREQUENCY CONTROL SERVICES

Maintaining a constant frequency at its target value requires effective control of the active power produced, ensuring a balance between load and generation. To achieve this, a specific amount of active power is mandated, referred to as frequency control reserve [10]. In the event of an imbalance or fault in the system leading to a drop in frequency, a designated amount of active power is allocated to compensate for the frequency deviation. This compensatory measure is known as Positive Frequency Control. On the other hand, Negative Frequency Control is employed when the system frequency exceeds a threshold value, aiming to reduce the frequency. The frequency control services can be categorized as follows [10]:

a. Primary Frequency Control: The calibration of active power generation from generating units and the utilization of controllable loads serve two important purposes: facilitating the swift restoration of load and generation and countering frequency variations. Within the synchronous zone, generators equipped with speed governors automatically contribute to this control process. Additionally, frequency-sensitive loads, such as induction motors, participate in control through the demand side, exerting a self-regulating effect. However, it is worth noting that the contribution of the demand side in primary frequency control response is not always considered.

   Demerits of Primary Frequency Control: The generating units play a crucial role in adjusting the frequency by increasing their output in response to a frequency drop. To minimize unplanned power transients, it is important to ensure that primary control is distributed throughout the interconnected network. In the case of an islanded system, maintaining stability requires a uniform redistribution of power to support the separated power system.

b. Secondary Frequency Control

   The system incorporates a centralized automatic control mechanism that utilizes generating units to fine-tune active power and restore imbalances in frequency and interchanges to the specified target value. Secondary control plays a vital role in returning the frequency to the target value. Only generating units located in the specific area where the imbalance originated participate in this control, as each control area is responsible for balancing loads and generation.

   In secondary frequency control, load participation is typically not required, and control is essential. As a result, some power systems may not implement this control if they maintain frequency through automatic primary and tertiary control alone. However, in the case of large interconnected loads, secondary frequency control is employed when manual control alone cannot quickly address the load on tie lines.

   Within the UCTE (Union for the Co-ordination of Transmission of Electricity), this frequency control is commonly referred to as Load Frequency Control (LFC). UCTE considers both secondary frequency control and dispatch as part of its control framework.

c. Tertiary Control

   The next type of control encompasses both manual adjustments in dispatching and the commitment of generating units. This form of control is typically utilized to restore primary and secondary responses, or in cases where the secondary control is unable to fulfill the required task. Balancing the system through energy trading is an integral component of tertiary control.

III. VOLTAGE CONTROL SERVICES

For a lucid explanation of voltage control service, a three-level hierarchy may be drawn [23]:

Primary Voltage Control

To maintain the voltage at a specific bus within a power system at a predetermined set point, local automatic control known as primary voltage control is employed. Automatic Voltage Regulators (AVRs) are utilized among the generating units to fulfill the role of this control. Additionally, static voltage compensators are other devices that can participate in primary control.

Secondary Voltage Control:

When it comes to injecting reactive power within a regional voltage zone, a centralized automatic control known as secondary voltage control is employed. This control mechanism is commonly utilized in countries such as France and Italy.

Tertiary Voltage Control:

Tertiary Voltage Control refers to the manual method employed for optimizing reactive power flow across the power system. To ensure a strong correlation between voltage and the transmission network, it is crucial for participating units to have the capability to absorb or generate reactive power. The provision of reactive power is categorized into basic and enhanced reactive power services based on the providers of voltage control services.

IV. TECHNICAL FEATURES OF PRIMARY FREQUENCY CONTROL

In steady-state scenarios, if Δf represents the frequency deviation and fn represents the nominal frequency, the participating generator will adjust its generation by ΔPg accordingly. The measurement of generator frequency is obtained through the rotation speed of the shaft. The droop Dg, which represents the gain of the feedback loop in the primary frequency controller, can be defined as

$$D_g = -\left(\frac{\Delta f}{f^n} / \Delta P_g / P^n\right)$$

Where P^n is the nominal generated output power [10]. On one hand, having a low droop leads to an enhanced system response due to its heightened sensitivity to frequency deviations. On the other hand, during significant disturbances, a lower droop setting increases the likelihood of successfully transitioning to an islanding mode.

We can define λ^{zone} of control area in order to determine the frequency droop characteristics.

$$\lambda^{zone} = -(\rho_{ae} - \rho_{se})/\Delta f$$

Where ρ_{ae} is the actual power exchange from zone to all the neighboring zone, positive value of which represents overall export.

The combined effect of the generator's primary frequency control and the load's self-regulating behavior is represented by the frequency characteristics [10]. Within the controller, there exists a frequency band where the output remains constant, known as the insensitivity range of the primary controller. These insensitivity ranges can be broadly classified into:

a. Non-Intentional Sensitivity: This is present within the controller.

b. Intentional Sensitivity: This sensitivity is added on the purpose.

The purpose of these insensitivity ranges can be comprehended by considering two generators with differing insensitivity characteristics. The generator with the smaller insensitivity range will participate in primary frequency control earlier and more frequently compared to the other generator.

V. TECHNICAL FEATURES OF SECONDARY FREQUENCY CONTROL

While the secondary frequency control is considered it can be structured in the following manner [23].

1. Centralized
2. Pluralistic
3. Hierarchical

When a single control is used for an entire control area, it is referred to as a Centralized Organization. Conversely, if the system is divided into multiple independent zones, each with its own controller and regulating capacity, it is termed as a Pluralistic approach. However, a Hierarchical Organization is similar to the pluralistic approach, with the distinction that the main controller coordinates the actions of all the individual controllers.

According to UCTE and NERC (North American Electric Reliability Corporation), the Area Control Error (ACE) can be calculated as:

$$\mathrm{ACE}^{\mathrm{UCTE}} = \rho^{\mathrm{me}} - \rho^{\mathrm{se}} + \mathrm{K}^{\mathrm{ri}}(\mathrm{f}^{\mathrm{m}} - \mathrm{f}^{\mathrm{t}})$$

$$\mathrm{ACE}^{\mathrm{NERC}} = \rho^{\mathrm{me}} - \rho^{\mathrm{se}} - 10\mathrm{B}(\mathrm{f}^{\mathrm{m}} - \mathrm{f}^{\mathrm{t}}) - \mathrm{I}_{\mathrm{me}}$$

Where K^{ri} is the K factor of control area (in MW/Hz) and B is the frequency bias setting (in MW/Hz and –ve).

Overestimation or underestimation of these factors can result in conflicts between primary and secondary frequency control. Here, ρ^{me} represents the measured value of total power exchanged between zones (positive value denotes exports). f^{m} represents the measured network frequency, while f^{t} represents the target frequency, which may deviate from the nominal frequency when synchronous time is controlled. I_{me} is a small correction factor used to mitigate discrepancies between demand's energy management and instantaneous power exchange. This type of controller relies on a proportional-integral (PI) controller.

VI. TECHNICAL FEATURES OF VOLTAGE CONTROL

The reactive power at specific terminals is converted from Q(stator) to Q(POD), which represents the reactive power at the point of delivery. Q(POD) is typically located near the transmission network and is owned by the producer. It is observed that until the reactive power at Q(POD) reaches approximately 15% of the nominal apparent power Sn, the auxiliaries, step-up transformer, and transmission line absorb the reactive power. Therefore, the power supplied by the generation to the network can be estimated using the following equation:

$$\mathrm{Q}_{\mathrm{POD}} \approx \mathrm{Q}_{\mathrm{stator}} - 0.15\mathrm{S}_{\mathrm{n}}$$

Where,

$$\mathrm{S}_{\mathrm{n}} = \frac{\mathrm{P}_{\mathrm{n}}}{\mathrm{P}_{\mathrm{f}}}$$

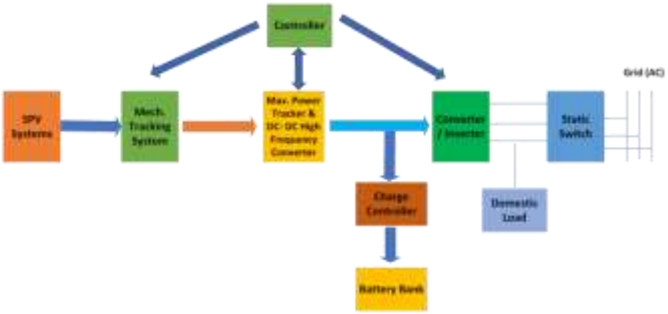
VII. SOLAR AND WIND POWER

In order to integrate renewable energy sources on to grid, while considering power system reliability, it is neccasary that we first understand its working and obtain respective characteristics.

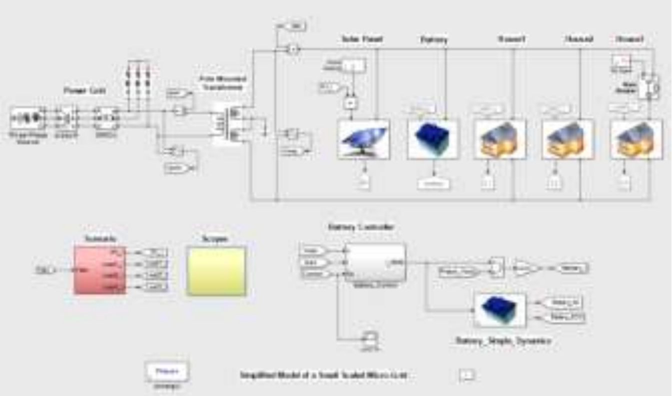
A. Grid Connected Photovoltaic System

Grid-connected photovoltaic power systems are designed to harness solar energy through photovoltaic panels and seamlessly integrate with the utility grid. These systems comprise various components, including photovoltaic panels, Maximum Power Point Tracking (MPPT), solar inverters, power conditioning units, and grid connection equipment. Figure 18 [**([67], 2011)**] illustrates a conceptual representation of a grid interactive SPV system for domestic use.

To ensure compatibility with the grid, the direct current (DC) output from the solar panels needs to be converted to alternating current (AC) since the grid operates at a standard voltage (such as 400V for distribution loads). This conversion is achieved by raising the DC voltage through a high-frequency chopping process utilizing a DC/DC converter. By employing a converter-inverter, the system enables bidirectional power flow, allowing electricity to be exchanged between the solar power system and the grid based on the availability of solar energy. To address grid outages that may occur during the night, a battery is incorporated into the system to provide backup power. This ensures continuous electricity supply and enhances the reliability of the system even in the absence of grid connectivity.



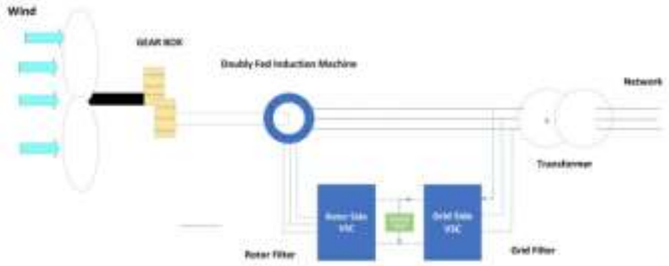
The Simulink diagram for the following diagram is given by



B. Wind Power

As we harness energy from a different renewable source, we employ the power of wind to rotate turbine blades resembling a propeller. This rotational motion drives a generator, resulting in the production of electricity. The generation of wind energy is primarily influenced by three simultaneous factors: the constant and uniform heating of the atmosphere by the sun, the rotation of the earth, and various irregularities on the earth's surface.

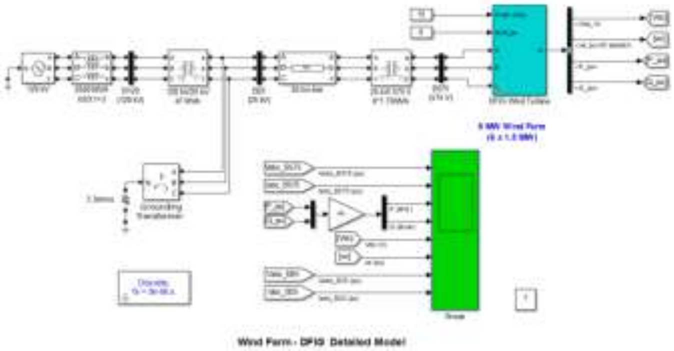
Wind turbines harness the power of aerodynamic force exerted on rotor blades to convert wind energy into electrical energy. When the wind passes over the blades, a difference in air pressure occurs between the two sides. As a result, lift and drag forces are generated due to this pressure disparity. To initiate the rotation of the rotor, the force of lift must exceed the force of drag. The rotor is then directly connected to a generator or, alternatively, coupled with a gearbox to enhance rotational speed. This transformation of aerodynamic force into the rotation of the generator facilitates the generation of electricity. In order to understand the working characteristics of the wind power following block diagram is considered.



In Fig. 20 we have doubly fed induction generator (DFIG) which is utilized in various variable speed drives. In the given system, the stator is directly linked to the power grid, while the rotor is supplied power by a bidirectional converter that is also connected to the grid. The primary purpose of the converter here is to compensate for the speed difference between the rotor and the synchronous speed by employing slip control. The characteristics of the DFIG can be briefly summarized as follows:

1. Limited operating speed range: It operates within a specific range, typically ranging from 30% below to 20% above the synchronous speed.
2. Small scale power electronic converter: The converter used in the system is relatively small, resulting in reduced power losses and cost.
3. Complete control of active and reactive power exchange: The DFIG allows precise control over both active and reactive power exchanged with the grid.
    a. Requires slip rings: The system requires the use of slip rings for transferring power between the rotor and converter.
    b. Requires a gear box: Typically, a three- stage gearbox is employed in the system to achieve the desired speed ratio.

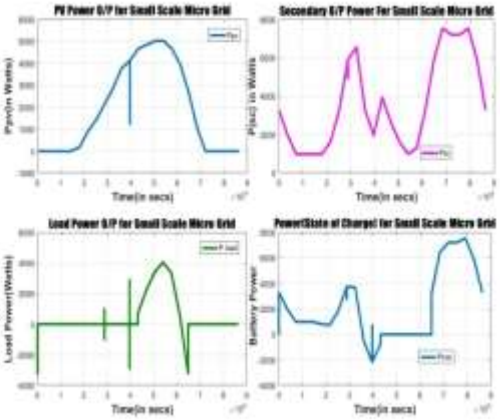
In a DFIG configuration where the rotor side is equipped with a back-to-back converter and the stator is directly connected to the grid, an SFOC (stator flux-oriented control) system is employed. This control system allows separate control of the active and reactive power on the stator side. In order to understand the characteristics of the given DFIG based model following Simulink diagram is considered in Fig. 21.

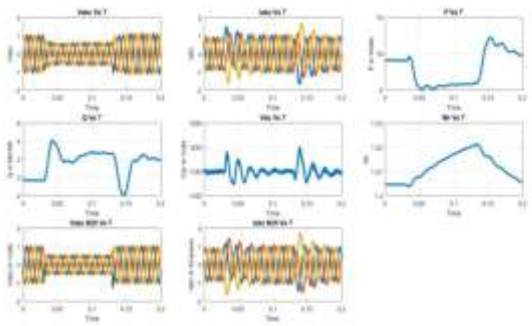


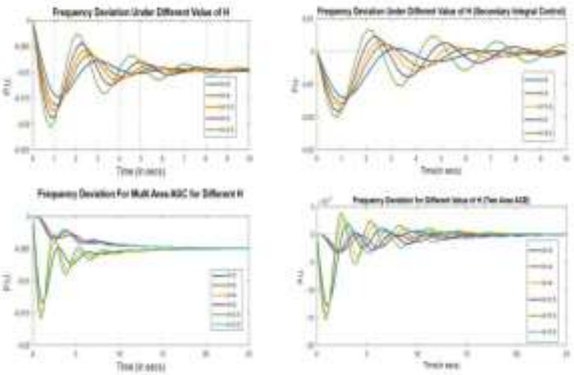
Whenever the integration of renewable energy is concerned up to 50% it doesn’t cause any major problems. However increased integration of renewable energy causes reduction in inertia and hence causing ancillary services response to be sluggish as shown in conclusion section.

VIII. CONCLUSION

This study involves a concise examination of different market structures, enabling the authors to gain insights into various ancillary services, their terminologies, and their variations across countries. The paper extensively analyzes diverse ancillary parameters, including frequency control, voltage and reactive power support, and the maintenance of transmission and generation reserves. Furthermore, technical aspects related to frequency control and voltage control are thoroughly explored. These services play a crucial role in understanding how to effectively integrate renewable energy sources into grid interactive systems. Also basic characteristics of renewable energy from the energy source is studied and is as shown in fig. and fig. Now with the integration of renewable there is considerable decrease in the inertia of the system, hence it is shown in Fig. that how system deteriorates when inertia is varied.







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