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Review on Stability and Power Quality Problem and Mitigation on Renewable Energy Penetration in Grid System

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Abstract: An increase in the production and integration of renewable energy sources to the power grid system have begun to have an impact on the stability and security of the power grid. As renewable energy sources (RESs) like solar PV array plant and wind plant begin to displace traditional power plants, grid integration requirements have become an important issue. To ensure grid stability, additional criteria and technological constraints have been implemented. An updated assessment of current integration criteria and compliance control techniques for renewable power plant integration into the electric grid is being conducted as part of this study to close the knowledge gap. There is a comparison of the most important criterion for grid stability, including frequency stability and voltage stability, quality of power, voltage ride-through (VRT), reactive and active power controls. To meet these standards, a variety of control techniques have recently been proposed. As a result, cutting-edge options for compliance technologies and control techniques are analysed and evaluated in this paper. Additionally, a thorough examination of the benefits, challenges, and drawbacks of global harmonisation of integration requirements is included. Even though current incorporation necessities may enhance grid security, stability, operation, and dependability, a thorough assessment concludes that further improvements to shielding legislation, optimization of control system and international harmonisation are still required. There are a number of recommendations for further research into the integration and technical limitations of RESs that follow this. This study's findings could help to create a seamless and stable grid integration of RESs, as well as aid researchers in the development of new design methods and control systems based on current requirements. Educate and support operators in power system for creating or cultivating their individual standards that differ from the international norms that remain in place.
Keywords: fault ride-through, Current limitation, grid forming control, grid connection, voltage-source converter

I. INTRODUCTION

There must be a shift from fossil fuels to sustainable energy due to rising global power consumption and a desire to reduce CO2 emissions [1]. As a result, grid-connected renewables like wind and photovoltaics (PV) have seen significant increases in their installed capacity in modern electricity networks. Dispersed power generation will be forced to centralise in the coming decades due to advances in Renewable Energy Sources (RES) [2]. Because of their enormous rotating inertia, today's centralised power plants produce most of the world's electrical energy with excellent transient stability and resilient performance [3]. When using a power electronic converter, the rotational inertia needed to react instantly to grid frequency disturbances will be lost over time [3], [4]. Inertia is not naturally supplied by power electronic converters, so this is the case. The degree of Distributed Generation (DG) penetration has a significant impact on the network's ability to remain operational in the event of disruptions or faults. A converter's transient behaviour is almost entirely controlled by the control scheme used, in contrast to synchronous machines [5]. Wind turbines (WTs) and photovoltaic (PV) systems, for example, used to be designed to disconnect from the utility grid when things went wrong. This was fine because the small reduction in power output was barely noticeable. Renewable energy's rise will have a significant impact on the grid, causing unstable frequency of operation that could lead to uncontrol of power interruptions and unfluctuating blackouts [5]. TSOs and DSOs have been forced to demand specific behaviour from DGs during disruptions and breakdowns because of the aforementioned circumstances. TSOs: To ensure maximum supply security, Low-Voltage Ride-Through (LVRT) capabilities should include with DGs. RES like PV and WTs can be connected to the macro grid by means of Voltage-Source Converter (VSC) architecture [6].

A third order LCL filter is commonly used because of its compactness and high attenuation capacity when compared to a bulky single reactor at output end [7–9]. Line filtering is required to reduce the converter's high frequency switching harmonics. In the present, most grid-connected converters are grid following /feeding current regulated VSC that intention to supply maximum power into the grid in the nature of harmonic free currents in wind power systems and PV applications. Grid-feeding converters dominate grid-connected RES control today, and because they must support the network in accordance with required grid code, such systems must be evaluated for LVRT capability and supporting functionalities to determine their performance. The regulation of PV power plant and WTs power plant during outages of grid, with LVRT capabilities, has been extensively studied [11–19]. Most research only looks at voltage drops of 10-50 percent, despite the fact that many grid regulations require LVRT capabilities all the way to no grid power. Transition control under near-zero-voltage conditions is no longer perceived in the same way. As soon as a grid-supporting converter fails, the converter's operating current is typically limited by converting it to a grid-feeding structure [20]. Consequently, grid feeding research, such as the use of a current-controlled converter, can be applied to virtually any type of control system. It is possible, however, that a grid-feeding strategy will fail to synchronise with the grid when a power system fault occurs; additionally, unstable current controllers have been investigated [21]-[22], since the Phase-Locked Loop (PLL) cannot maintain grid synchronisation. Synchronization Loss is the technical term for this (LOS). [23] discusses various PLL methods that have been evaluated under varying voltage sag patterns. Despite the fact that the voltage drop caused by the three-phase symmetrical fault is not severe, it could lead to PLL instability in the event of a solid fault. To ride through a near-zero-voltage situation, a grid-feeding converter must be able to simulate PLL instability and decide whether any actions or changes are required to improve the PLL structure or tuning technique during a failure. Multiple research projects have looked at the instability of PLL in weak grids and found that the fundamental process that defines PLL LOS in severely degraded grids remains poorly understood. A few studies have attempted despite this, in low-voltage conditions to model and analyse PLL instability [21], [24]-[30]. In low and zero-voltage grid events, there are other ways to avoid LOS besides modelling. Research suggests a variety of ways to reduce controller noise, including freezing/blocking of the PLL, zero or limited injection, voltage-dependent active injection, network impedance X/R characteristics, and injection based on the PLL frequency error [21]-[24], calculate the limit on current injection that causes LOS in a steady-state network. a static – quasi signal large model is built that adds the PLL dynamics and discovers a destabilising component of feedback on positive side to the Injection current and grid voltage are coupled in the PLL model [25–27]. the Equal Area Criterion (EAC) is established as another method of evaluating the LOS mechanism. The EAC is commonly used for synchronous machines' rotor-angle transient stability testing [28–30]. Finally, in [28], the momentary stability of the intrinsic system with nonlinearity is examined using nonlinear techniques. Even though, as previously stated, there are some studies on the evaluation of various grid codes, as the number and scale of RESs increase, some countries have started to impose additional and advanced criteria, while others have started to create their own requirements. Thus, this study provides a current comparison of standards, grid codes (GC), regulations and rules that have been officially recognised by operators of power grid in various countries for the integration of RESs up to this point in time. A comparison of grid stability requirements such as voltage stability, frequency stability, variable resistance technology (VRT), problems with power quality at the power control centre (PCC), active and reactive power regulations are therefore prioritised first. An in-depth look at the compliance technologies, methods and controllers in use today to meet these criteria is then highlighted and summarised. Power system operators must verify compliance with the new rules to ensure that new power sources do not adversely affect the utility grid's operation and stability. To make things even better, new power system operators can use a comparison of recent integration criteria to develop technical rules that adhere to local laws in countries where RES penetration is high. To help RES developers and manufacturers, this research compares current international legislation. Last but not least, suggestions and ideas for future research are offered from the perspectives of both technical applications and academic research.

II. STATUS OF RENEWABLE ENERGY GENERATION IN WORLD

When comparing 2018 to 2017, the global RES power generation grew relatively steadily, by 181 GW (GW), according to the most recent global status report on sustainable energy (REN21). Additionally, the various countries that have installed significant number of RESs to their macro power grid was increased [31]. RESs were predicted to account for 26% of global power production by the end of 2018, with a capacity of approximately 2378 GW. 28 percent of Wind energy and 11 percent of hydropower followed PV power in terms of new connected renewable energy sources, with a combined rise about 100 Giga Watts (11 percent). Fig. 1 depicts an overview of the most widely used for generating electricity by renewable energy sources (RESs) around the world. A 25 percent of world's total generating electricity capacity is now supplied by renewable power plants (RPPs). In 2017, around 90 countries had renewable energy production capacity of at least 1 GW, with 30 countries having more than 10 GW.

Some regions saw an increase in the portion of wind power and solar PV, and an increasing number of countries used around 20% of flexible RESs in their generation of electricity mechanisms. This chart (Fig. 3) shows how much renewable energy will make up of the world's total power generation by the year 2020. In spite of hydropower being the most important source of energy, solar photovoltaics grew at the fastest rate between 2013 and 2018. When it came to renewable energy capacity in 2013, hydropower was more than twice as large as all other sources combined. However, by the end of 2018, hydropower's share of renewable energy had dropped to just 48%. As can be seen in Fig. 4, the 2018 capacity of renewable energy production, excluding hydropower, can be summarised as follows: Renewable energy sources include wind (591 GW), solar PV (505 GW), biopower (130 GW), geothermal (13.33 GW), and other sources (6 GW) [32]. As shown in Fig. 4, the top ten nations in 2020 will have the most installed renewable energy production capacity. About 30% of all RESs have been installed in China, with the United States, Brazil, and Germany following close behind with the remaining 20%.

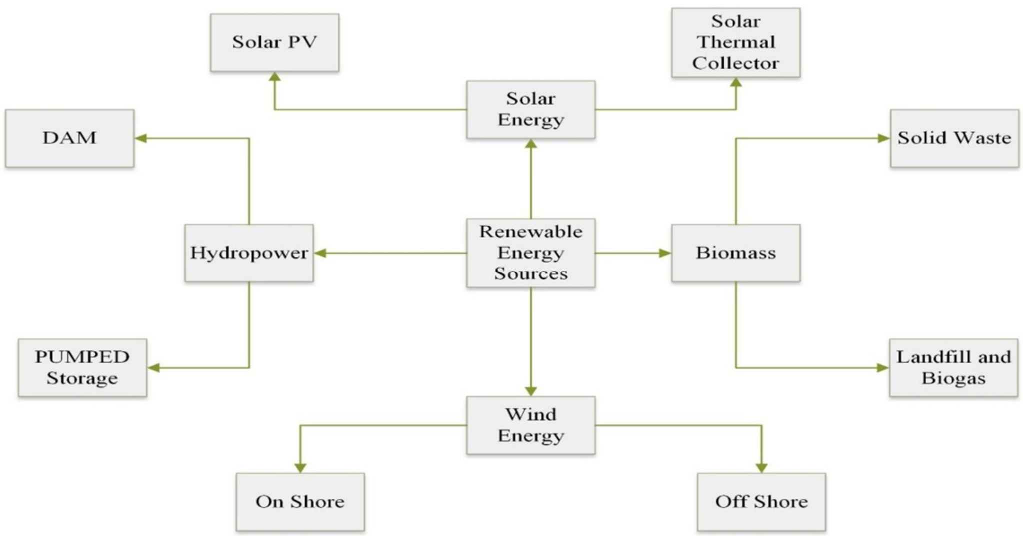

Fig 1. Different types of Renewable energy sources

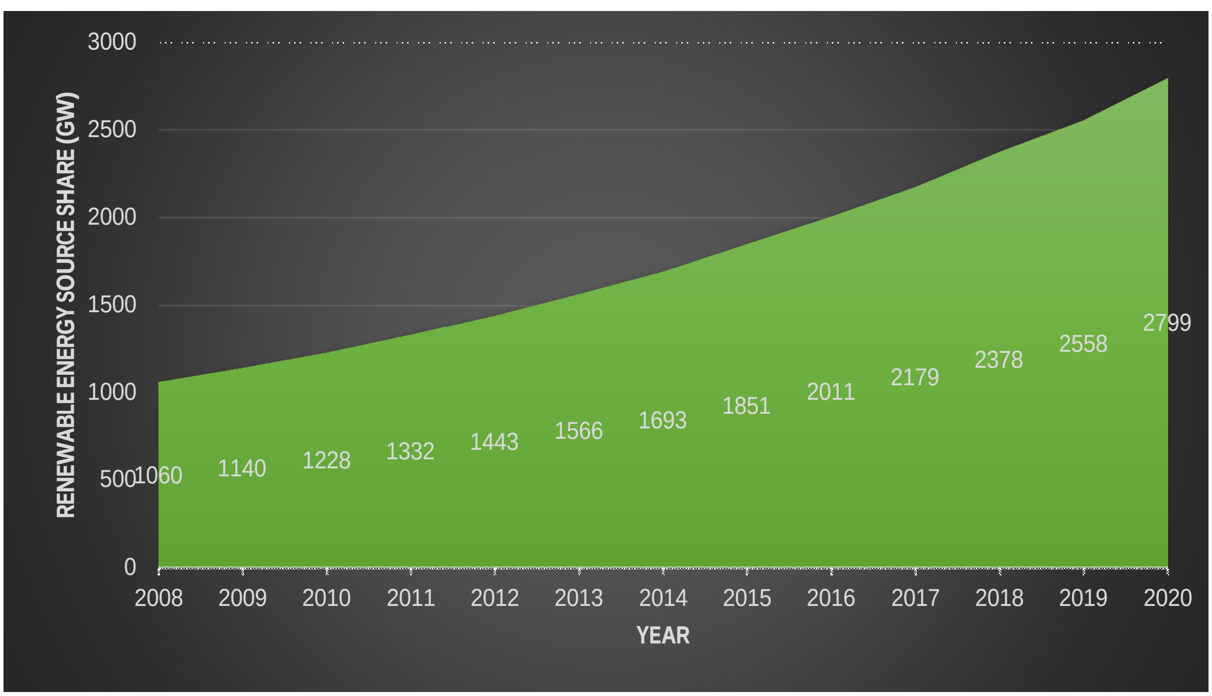

Fig 2. Energy generation by renewable energy in global from 2008-2020

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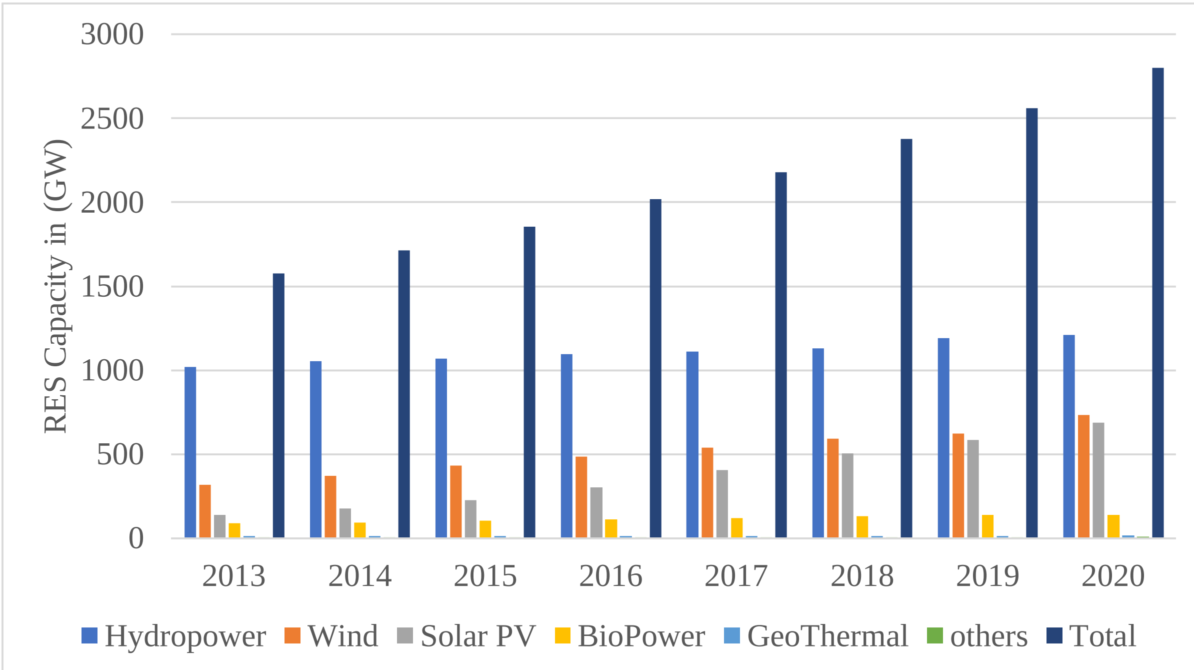

Fig 3. Capacity of different renewable energy sources in global from 2013 to 2020

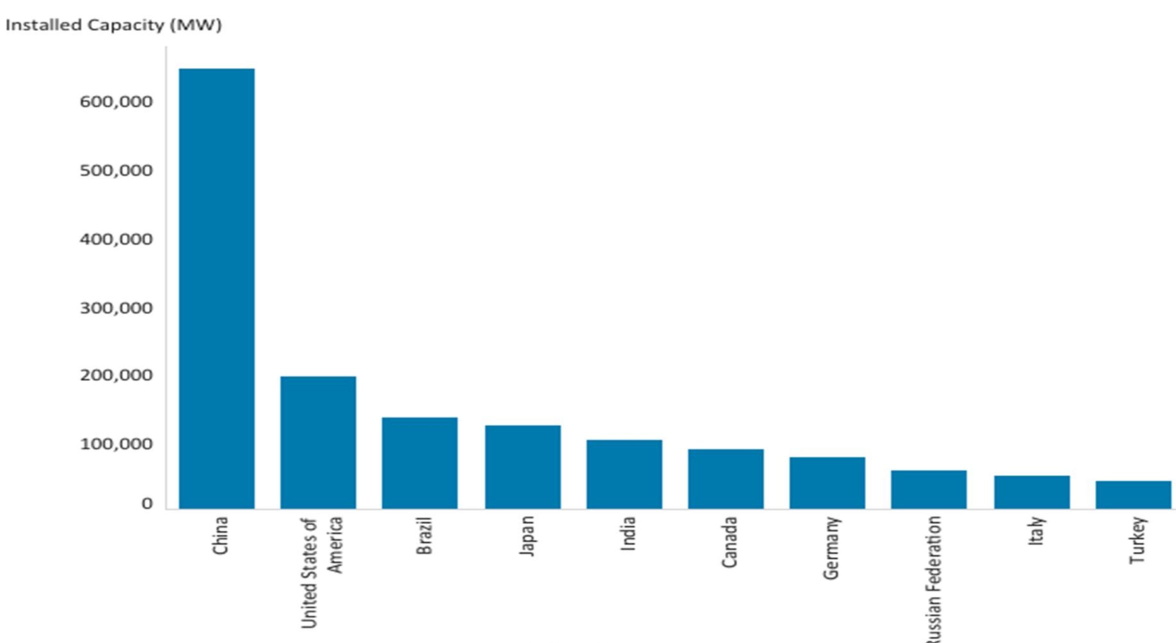

Fig 4. Capacity of renewable energy sources in top ten countries up to 2020

III.REQUIREMENTS FOR INTEGRATION OF RENEWABLE ENERGY SOURCES

Renewable energy sources (RESs) must be seamlessly integrated into the electrical grid in order to maintain a stable power system. When there are disturbances or abnormal circumstances, it is critical to maintain voltage supply by using VRT (HVRT ZVRT and LVRT) and reactive current absorption or injection. The relationship among reactive and active power with regard to voltage stability and frequency requirements are addressed based on current laws since certain nations and organisations have begun implementing rules to main grid stability by guarantee enhanced power quality at the PCC.

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A. Voltage Ride-Through

In light of the increasing penetration of RPPs into the utility grid, such as wind and solar, the VRT has emerged as a critical need. Because of the poor integration of RESs in the past, rules required that in the event of a breakdown, these power sources be immediately disconnected from the grid. Disconnecting RPPs during faults, on the other hand, could exacerbate the problem and lead to instability. VRT has therefore become a standard condition for any RES integrated to the macro grid under current legislation. Due to the need for voltage and grid stability, VRT mandates that RPPs behave like traditional power plants via remaining connected to the macro grid and providing supplementary services (e.g., reactive current absorption/injection).

1) *Low-voltage Ride Through:* Especially in large-scale systems, abruptly disconnecting an RPP could have a negative impact on the stability of the utility grid, this has resulted in rules requiring the RPP to remain operational during a failure that causes a voltage drop of around ninety percent to a specified fraction of the standard voltage (typically fifteen percent) for a specified time period. Reactive and active power production should be quickly restored to pre-fault levels subsequently the fault has been removed by the RPP. There is a comparison in Fig.s 5 and 6 between the LVRT requirements of various countries based on voltage percentage and maximum time (s). After an 80 percent drop in PCC voltage, the Danish GC orders Wind and PV integrated grid installations to remain in continuousness mode for 30 seconds. the PCC voltage returns to 90% of its previous value within 1.5 seconds, the RPP will not trip. Unless something changes, you'll have to disconnect from the system. Other than the voltage levels and time period, the LVRT requirements are the same as the Danish standards. Rules in China, Denmark, and Japan stipulate that if a drops of voltage by more than eighty percent under its standard value, the RPP must resist the failure and continually supply the power to the grid for a specified period of time before being removed. For RPPs in the Romania and United Kingdom, the Puerto Rico Electric Power Authority (PREPA) and the North American Electric Reliability Corporation (NERC) have been required to uphold connection mode even if drop of voltage to 15% of its standard value [39]–[42].

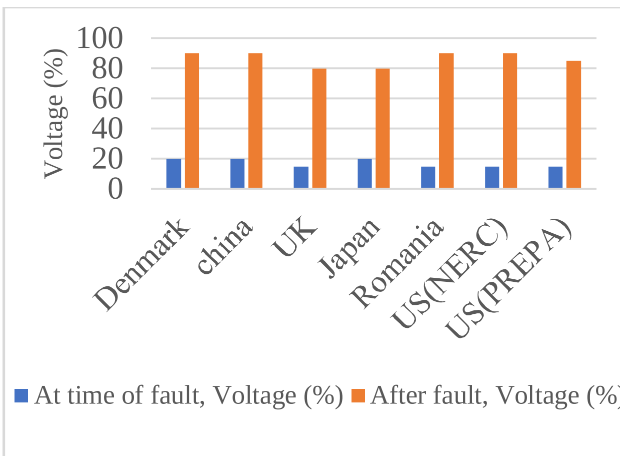

Fig 5. Different nations' LVRT requirements in terms of voltage

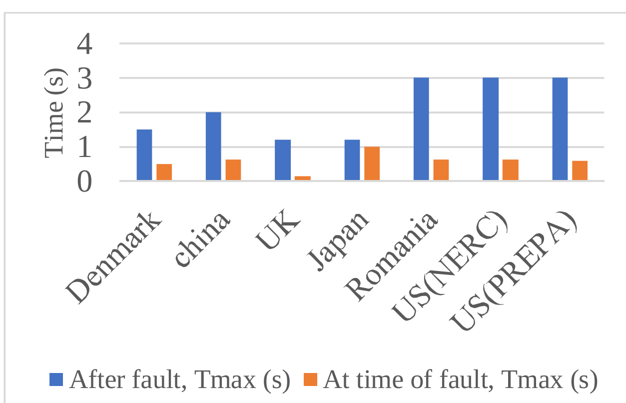

Fig 6. Different nations LVRT requirements in terms of maximum time (s)

2) *Zero-voltage Ride Through:* Since Zero-voltage ride through depicts a zero-voltage situation, it can be considered a subset of LVRT. As a result, the RES can remain in integrated with grid and maintain frequency of grid at constant. In zero-voltage conditions, RESs, like LVRT, should help with grid stability and voltage recovery by reactive current injection. Fig.s 7 and 8 show the international use of ZVRT parameters in terms of percentage of voltage and maximum time (s). Disconnecting of macro grid when voltage sag occurs was illegal under every law examined, even if the voltage was zero. In contrast, the maximum recovery voltages (Vmax) and timeframes vary widely. There should be no exceptions to this rule at the PCC [43]-[47].

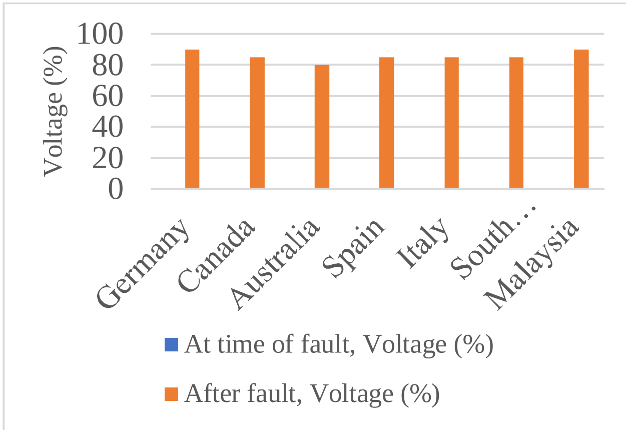

Fig 7. Different nations' ZVRT requirements in terms of voltage

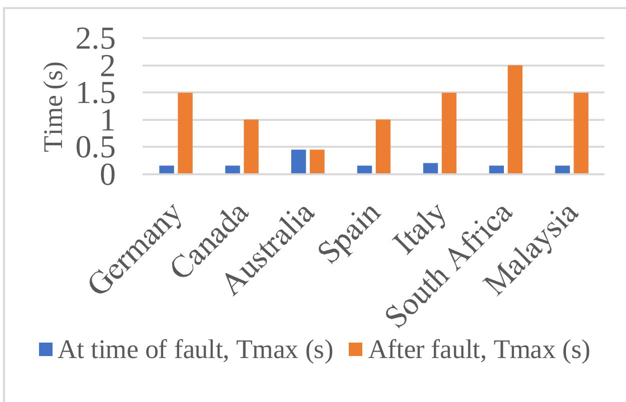

Fig 8. Different nations' ZVRT requirements in terms of maximum time

3) *High-voltage ride through:* The recent integration requirements require that RPPs remain connected to the utility grid for a specific period of time once the voltage increases in order to sustain the stability in voltage and avoid serious events caused by overvoltage. HVRT necessities are defined as the percentage of voltage and maximum time shown in the Fig.s (9 and 10), which compare the criteria (s). Graphs 9 and 10 show how different countries' HVRT regulations compare to GC requirements. The frequency of voltage swell events (over-voltage) is lower than that of voltage sag incidents, but the methods used to manage them are the same (i.e., under-voltage). Although several nations (such as Canada, Japan, Romania, and China) require LVRT capability in renewable energy sources, comparable HVRT regulations have yet to be implemented in those countries. As shown in Fig. 8, Germany, Denmark, Spain, the United States, Italy, Australia, and South Africa all have HVRT mandates that are at the cutting edge of the technology. According to US regulations set by PREPA, renewable energy generators must be connected and capable of withstanding an overvoltage of 140% of their original value within one second in order to comply with the most stringent requirements for overvoltage tolerance. Overvoltage up to 130% of nominal are allowed before disconnecting from the grid in Spain and Australia. On the basis of the comparison presented above, it is difficult to determine global VRT needs for various reasons, including different levels of renewable energy integration with macro grid and varying national network operating methods [48]-[52].

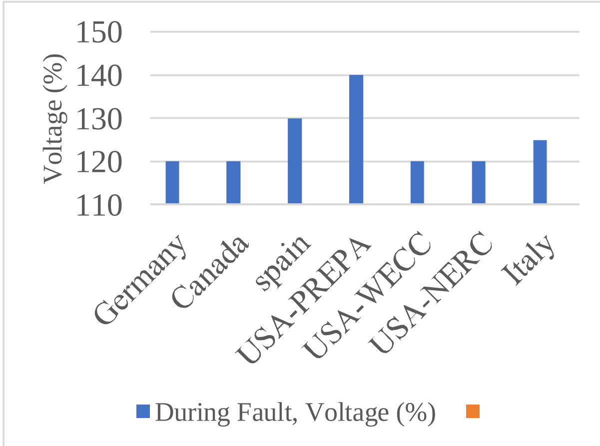

Fig 9. Different nations' ZVRT requirements in terms of voltage

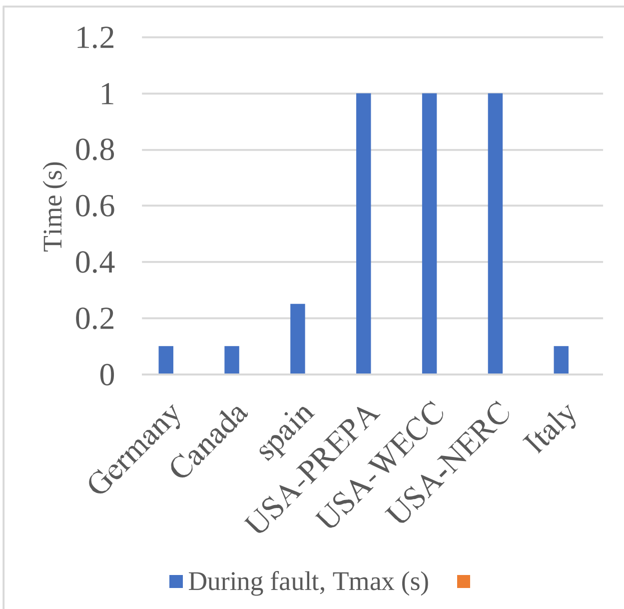

Fig 10. Different nations' ZVRT requirements in terms of maximum time (s)

4) *Reactive Current Injection/Absorption:* RPPs are required by the majority of GCs in order for them to function like conventional synchronous generators in the event of a fault, remain connected, and remain connected. Reactive currents must be added to the macro power grid to help with recovery of voltage and keep the stability of the power system. In order to recover the voltage quickly during and after a fault and minimise drop voltage, this injection of reactive current should be provided simultaneously with ZVRT/LVRT during under-voltage occurrence (inductive loads). During HVRT, renewable generators must absorb reactive current in order to keep voltage stable in the event of an overvoltage. The quantity of injected or absorbed reactive current must be assessed in relation to the drop voltage or rise, according to German GC standards. As long as the voltage remains within the dead-band (10%), the RPPs must continue to function normally and no injection of reactive current needed. To meet the slope of droop characteristics, RESs must inject reactive current into the grid when voltage rises or falls above the dead-band. Reactive current must be injected at 100 percent of its rated value if the voltage drops under 50% of its standard value. If the voltage exceeds the 15 percent dead band, the USA-ePREPA regulations need RESs, particularly PV and wind facilities, to absorb/inject one percent to ten percent of reactive current. If the voltage falls below 1% of its standard value, the RES is required by Australian regulations to inject reactive current at 4% of its standard value. [53]-[54].

5) *Frequency Stability Regulations And Active Power Control:* As long as there is a balance between electricity supply and demand, the electrical grid's frequency (usually 50 or 60 Hz) will remain constant. If there is an imbalance, the frequency will deviate from its normal value. To avoid a significant frequency deviation, Traditional thermal and fossil-fuelled plants frequently have a governor control system that kicks in when there is an imbalance. RPP generating units, on the other hand, are unable to deal with frequency fluctuations because they lack direct governor control. As RPPs have taken the place of conventional plants, researchers have become interested in alternate frequency stability techniques. As a result, RPPs all over the world must be equipped with mechanisms for controlling their real power output in response to frequency variations. Affording to a standard frequency and real power variation curve, the generated active power should decrease as the frequency increases. When the frequency changes from 50.2 Hz to 51.5 Hz, the German GC mandates a 40% reduction in active power output. If the frequency falls below 50.2 Hz, the generating units must restore their rated active power. If the frequency rises above 51.5 Hz or falls below 47.5 Hz, immediate disconnection is required. Because of this, the Irish grid code requires RESs when the frequency varies outside of the standard range (49.7 f 50.3 Hz). The Malaysian GC mandates that if the frequency exceeds 50.5 Hz, the output power of PV power plants must be reduced by 40% per Hz. While some countries, such as South Africa, do not have any formal frequency support legislation, others, such as the TSO or DSO, have been given this responsibility. There is no requirement for active power reduction in China's GC as frequency rises; There is a frequency fluctuation between 50,2 and 50,5 Hertz that RPPs must tolerate, or they will be disconnected from the grid [55].
6) *Voltage Regulation and Reactive Power Control:* Transmission and distribution voltage deviations are frequently overcome by synchronous generators and distribution substations, respectively. RES penetration, on the other hand, may have a significant impact on voltage stability and make these activities more difficult. Consequently, under various operating conditions, power system operators have been confronted with the problem of maintaining steady voltages within acceptable limits. Active power or terminal voltage can be used to control the power factor at the PCC; typical power factor control requirements rely on terminal voltage and active power to retain stable macro grid. Low voltage PV and wind power plants in Germany must comply with German regulations and have reactive power greater than 0.95 lagging/leading power factor. South Africa, China, and Italy, all have the same expectations. The leading/lagging power factor for wind energy facilities in Ireland is 0.835. In order to receive reactive power assistance under Malaysian regulations, PV systems at the PCC must have a power factor of less than 0.9 lagging/leading (Energy Commission Malaysia). PV systems must have a 0.85 lagging/leading power factor, and wind farms must have a 0.91 lagging/leading power factor of, according to the Spanish Grid code (GC). As a result, certain networks must retain the voltage constant in satisfactory bounds while using reactive power support via power factor control (often between 0.9 and 1.1 p.u.).
7) *Power Quality Requirements:* RES integration on a large scale may lead to power quality issues. Nations have implemented laws and regulations to ensure the quality of renewable energy sources (RESs) electricity. The main problems with RES integration have to do with voltage transients, harmonics, flickering, and voltage imbalance. RES integration is known to cause harmonics, flickers, and voltage imbalances, so this section focuses on how to stabilise them.

a) *Harmonics:* It's a serious power quality issue called harmonic distortion, and it's caused by a non-sinusoidal nature of distortion of the voltage and current waveform, which changes its standard properties or form significantly. Because RESs use so many power electronic devices, the generation process is distorted, and this distortion is compounded over time. As a result, the PCC's harmonic distortion from RESs has been reduced to an absolute minimum using strict guidelines. Electricity quality is frequently assessed using total harmonic distortion (THD) of current and voltage. In order to keep voltage and current waveforms in sync with the grid, renewable energy sources connected to it have some THD restrictions imposed on them. It is required that current and voltage THD be below 5 percent at the Point of common coupling in accordance with IEC standard, IEEE 154 and IEEE Std 519-201Stds, for example technical rules in Malaysia and Brazil, for example, mandate a 5 percent THD limit at the distribution or transmission point of common coupling. Renewable energy sources such as wind and solar must meet THD limits of no more than 3% under Romanian regulations. While EREC G83 is known for its strictness [57], most countries adhere to IEEE or IEC standards.
b) *Voltage unbalance:* As a result of these variations or nominal phase shifts (120°), there is a voltage imbalance, which can be expressed as a positive to negative sequence voltage component ratio. The voltage imbalance factor is used by a number of standards to assess the severity of voltage imbalance (VUF). Consequently, certain GCs and standards restrict voltage imbalance factor at point of common coupling and confirm that a well-balanced three-phase voltage is injected into the grid when there is a voltage imbalance. As an illustration, IEEE standards mandate a voltage imbalance of no more than 3%, while IEC standards mandate a VUF of no more than 2% for all distribution generators. Regulations in Romania required a 1%

voltage imbalance at the PV and wind plant connection points. Specifically, the voltage imbalance of the grid should not be more than 2% at the PCC, or 1.3 percent at the load, as specified by the UK guideline (P29), which Malaysia also adopted. Voltage imbalances of no more than 2% are allowed according to Canadian standards (CAN/CSA-C61000-2-2). Voltage unbalance should be kept to a maximum of 1% to 2%, according to international standards [58].

c) *Flicker:* The intermittent nature of RES power generation has recently been a source of concern, as evidenced by the massive voltage swings and flickering on distribution networks that have resulted. Changing loads can cause voltage fluctuations in a customer's system, which is known as voltage flicker and can be seen as abrupt changes in lighting. If Pst = 0, there is no voltage flicker, and Pst = 1, there is flicker pollution. If Pst = 0, there is no voltage flicker, and Pst = 1, there is flicker pollution. According to IEC standard 61000-4-15, Pst and Plt must be measured for a minimum of 10 minutes and a maximum of 2 hours. For small and medium-sized renewable generators, the acceptable flicker level has been widely accepted as 1.0 and 0.25 for Pst and Plt [45].

IV. COMPLIANCE AND CONTROL METHODS

Due to the increasing use of renewable energy sources (RES), various conditions have been imposed on RPPs that force them to behave like traditional power plants, such as managing and verifying sag, voltage reduction and transience, reactive current injection, swell, and reactive current absorption, and providing support to grid during instabilities. It follows then that developers, producers and researchers need to be able to show compliance with these standards by means of controls. As a result, this section discusses simulation and practical testing, by means of which controls and solutions for compliance with the most recent RPP criteria can be verified.

A. Voltage Ride Through and Reactive Current Support

To provide reactive current and VRT support for various RESs, several control methods have been developed to provide reactive current support during the injection and absorption phases of LVRT/ZVRT. ESSs, for example, have been suggested to examine LVRT standards addressing the incorporation of PV using supercapacitors and batteries for energy storage to examine the use of external systems. LVRT agreement for penetration of wind power plant has also been considered using batteries and super capacitors. ESS controllers have the ability to tolerate faults, absorb excess energy, and inject reactive current to keep the grid stable in case of a failure The stored energy can be used again after the problem is fixed. On the other hand, ESSs come with a hefty price tag both upfront and over time.

Furthermore, ESSs have not yet been able to solve the HVRT requirements. Reactive current support for biomass incorporation by means of peripheral devices such as a series brake resistor (SBR) was examined in some studies and found to meet VRT and reactive current support criteria. It is suggested that wind farms connected to the main power grid use improved control techniques based on German GCs to meet LVRT and HVRT requirements and absorb or inject reactive current throughout swell or sag actions. For grid failure resistance and voltage recovery assistance, the authors followed German regulations and used a fuzzy controller. PV systems that are connected to the grid can also benefit from VRT and reactive current assistance provided by external devices such as STATCOMs, SVCs, and braking chopper circuits (BCC).

STATCOM, SDBR, and SVC have all been investigated for use in wind farm integration in the past. BCC, as an example, can withstand grid failures but is unable to inject current like STATCOM or SVC. A predetermined amount of reactive power is absorbed by the proposed HVRT controller in the event of an overvoltage. To meet the GC criteria (Italian) for single phase single stage PV systems with severe grid failures, a ZVRT control method based on a second-order generalised integrator approach is used. The injected reactive current during ZVRT occurrences was at least 100% of the nominal value. Severe grid failures that bring the nominal voltage down to zero activate ZVRT.

To attain HVRT/LVRT with reactive current absorption/injection for a extensive wind power plant integrated to grid, a new controller-based dynamic voltage support makes use of a hybrid system made up of external devices represented by a dynamic voltage restorer (DVR) and optimization control represented by a multi-objective bee algorithm. It's important to note that in the event of an unbalanced grid failure, effective current restriction management and reactive and active power rule by less fluctuations are critical. In this respect, a reference current generator-based flexible power regulation approach is utilised. The results of this study show that the suggested control is effective in regulating reactive and active power and in reducing fluctuations caused by faults in grid. It is. RPPs can act likewise to traditional power plants thanks to features like VRT and reactive current support, which help keep the grid safe and stable. Most studies show excellent performance. Many researchers have looked into how to meet the new integration requirements, and their findings are summarised in [45],[54],[61].

B. Frequency Stability Regulations and Active Power Control

There has been a lot of investigation into how RESs react to grid frequency changes in recent years. Researchers who conducted a literature review found widespread agreement on the significance of stability in frequency necessities when using RESs and active power management. PV systems and wind turbines both use control of real power methods for stable frequency operation. There are a variety of control methods available for large wind farms, including fuzzy based gain tuned PI controls and pole placement adaptive controls. In response to rising frequency, an load frequency control method was implemented to decrease wind farm real power. A closed-loop active power regulation technique is recommended for creating a active frequency response in a wind farm associated with grid. In order to reduce the generated power, an active power tracking strategy was implemented after that. A frequency variation control technique was proposed for PV systems to alter the amount of active power generation. During frequency increases until a stable state was reached, the researchers found that the suggested controller was effective at storing excess power in the storage batteries. In accordance with US regulations, a second active power control loop was used to examine the effect of extensive PV systems on frequency response when subjected to instabilities. Regenerative energy systems (RESs) are capable of actively contributing to grid stability when they are integrated with active power [59].

C. Voltage Stability Regulation and Reactive Power Control

It is common for huge RPPs to be built on vast returns or in other open areas with low load demand, so all the power they produce is exported elsewhere in the world. Due to RESs' fluctuating power production, the grid's reactive power balance could be upset at the coupling point among the main grid and RPPs, changing the voltage bus-bars. The insufficient reactive power source of the residual RPPs, on the other hand, could lead to voltage instability. As a result, reactive power regulation is managed by PV inverter controllers. For example, an inverter control technique that regulates reactive and active power independently to ensure grid voltage stability is based on current needs. Reactive power management advancements that were well-matched with German GCs were examined in the same way. Researchers claim that PQ control can also be utilized precisely regulate reactive power in accordance with GC rules using PQ control. Voltage stability was improved by implementing reactive power management, which made use of local grid data in real time. When wind and PV plant voltage limitations reach 1.1 per unit, the inverter must absorb reactive power and reduce the likelihood of overvoltage. The use of capacitor banks, STATCOM or SVC to provide voltage capability via reactive power control has been used for reactive power support for PV or wind integration. If you use hydropower, reactive power regulation can be used to keep unstable power systems stable and meet Romanian grid stability requirements. Because energy production is highly stochastic, reactive power management was implemented to improve voltage responsiveness. Reactive power management is critical in a renewable-connected grid for maintaining voltage stability under a variety of operational conditions [60].

D. Compliance With the Power Quality Requirements

Studying power quality has become more popular in the last two decades as more and more sensitive electronic equipment has grown in popularity. regulations and standards have been established to improve the quality of output power of RPP to the macro grid and improve the quality of the overall system. Harmonics, voltage imbalance, and voltage flicker are all issues with RES penetration that have recently been studied to meet the standards. The current THD, voltage THD voltage unbalance, and could be reduced to 0.15, 0.2 percent, and 0.74 percent, respectively, by studying extensive solar power plants associated to the Malaysian grid. This met the country's GC requirements. In a weak delivery network with a combined wind power system, a technique for reducing flicker emissions was developed, based on the three-phase fluctuation in the stored shaft inertia of the turbine and changes in generator speed. The ideal grid impedance angle was used to reduce flicker and eliminate voltage oscillations. Likewise, a controller combined into the main grid was proposed to reduce wind turbine voltage flicker to acceptable levels. Voltage imbalance, voltage harmonics and flicker current were measured at the PV station-to-Colombian grid PCC to examine PV power quality when integrated with a distribution system in a tropical region. There was a 3.5% increase in voltage unbalances, while harmonics of current and voltage increased by 22% and 7%, respectively. 0.2 to 0.35 and 0.09 to 0.10 were the required ranges for voltage flicker short term (Pst) and long term (Plt). A number of quality issues may arise if renewable energy sources are connected to old, low-voltage grids. grid-connected photovoltaic (PV) flicker control technique that effectively and quickly reduces flicker at the PCC while eliminating voltage fluctuation It was also presented at the PCC a method for reducing harmonics, voltage flicker, and system imbalance to meet IEEE requirements. A modular multilevel converter controller was coupled with a large-scale wind farm and an active shunt filter to keep THD levels within acceptable limits in wind farms. By injecting negative current sequences into the grid using DVR to reduce the VUF at the PCC, grid-connected wind turbines' voltage imbalance complied with US regulations.

RES-to-main-grid criteria that are met would confirm the injection of good produced electricity into the macro grid, enhancing system stability and security [27],[50],[55].

V. HARMONIZATION OF THE INTERCONNECTION REQUIREMENTS

These rules vary greatly across countries and electricity system operators, as the above-mentioned analysis of interconnection requirements for RES integration has shown We can't give an economic or technical explanation of the current connection requirements because national grids use different operating techniques and RPPs integrate at different levels around the world. According to the Global Capacity Standard (GC), some countries demand that all RES connected to the grid have VRT capability control no matter how high the degree of interconnection is. Other countries like Germany require VRT capability control only for large-scale renewable energy sources. There have been inefficiencies and higher costs for RPP inventors and manufacturers as a result of this difference. By the European Renewable Energy Council's (EREC's) requirements, operators of power system must educate their cutting-edge and current interconnectedness standards in a uniform and standardised manner. EREC As long as integration rules are consistent, all events will be more efficient, and this will allow them to be used whenever it is appropriate. Hardware and/or software changes are constantly being imposed on RES makers to confirm that the necessities of each unit are met. To put it another way, by coming up with a global design that is unique, appropriate, and efficient, manufacturers and operators alike will save money. The following are the primary objectives of global harmonisation: Establishing exclusive and satisfactory guidelines for the integration of huge- or limited RPPs into the macro grid, and developing well-organized practical guidelines based on the experiences and backgrounds of various power system operators will lower overall costs and enable like development and engineering procedures around the world.

Economic efficiency should be guaranteed by the criteria that have been set forth. Only when a stable, secure, and reliable power system operation is required, are high-cost technical requirements necessary. Furthermore, if RPP penetration is kept to a minimum, certain expensive rules may be overlooked. Technical integration requirements must be harmonised to a minimum in regions where the total cost of RES is low. The practical necessities must also deliberate the penetration level, the robustness of the power system, and/or the use of renewable energy generating methods. In the future, the integration requirements of different regions, nations, and organisations may also differ [52].

VI. CONCLUSION AND RECOMMENDATIONS

A renewable energy source (RES) is a technology that produces energy while having as little impact on the environment as possible. In spite of this, many standards, regulations and requirements have been put in place to ensure the power system's smooth operation. For grid stability, this research compared and contrasted various recent criteria and standards for the integration of renewable energy sources (RESs). Some of the problems addressed in this study include reactive current injection, reactive current absorption, VRT, frequency and voltage fluctuation, and power quality. These criteria are also addressed using cutting-edge compliance technologies and control techniques. To provide a complete picture and to propose that laws take into account the techno-economic circumstances, the harmonisation of the integration requirements is also addressed. Because of their high grid integration, renewable energy sources (RESs) require more oversight, regulation, and standardisation than traditional power plants do. Standards and requirements for system operators vary widely, making it difficult to implement a uniform standard across the industry. RESs equipment manufacturers and developers may be hit with additional costs as a result. As a result, harmonising these standards on a global scale would enable manufacturers to create RESs equipment aimed at the market. However, in the event of an unbalanced grid, the RES connected to it would suffer, necessitating additional research. Overvoltage on the RES dc side and sag and swell in grid-connected PV may alter the rate of reactive power flow in the system, affecting the power factor, are the most likely issues. Unbalanced grid voltages and harmonic distortions, which can cause series and parallel resonance, affect power efficiency, overheating, and overcurrent and, are (a) a negative impact on equipment such as power electronic devices, (b) oscillations in dc-link and power signals, (c) harmonic distortions and unbalanced voltages on the grid and (d) loss of synchronisation (e) islanding for grid-connected solar to create safe and dependable utility grids with excellent power quality here are some recommendations for further improving integration requirements, compliance technologies and controllers RPP penetration on a large scale will have an impact on the power system's security, stability, and dependability. For a robust and stable integration of RESs, more research and revision of current regulations are required. To ensure efficient power system operation, coordination and optimization techniques with respect to various integration controls should be investigated. Various control and optimization methods have recently been used to verify RPPs' compliance with technical requirements. To reduce the number of integration requirements, international power system operators should aim to use a constant numerical value for each.

Because most of these approaches rely on computer simulation, they necessitate hands-on testing. Researchers, developers, manufacturers, and operators should form an international task force to harmonise integration requirements based on penetration expansions and the cost-benefit ratio across all sectors. In terms of RES integration management and coordination, there is a lot of unexplored territory that requires more investigation. For this reason, these recommendations may help to ensure that renewable energy production matures and that penetration standards are improved and implemented. As a result, power system operators, renewable energy developers, and manufacturers can use these ideas as a solid foundation for developing rules for connecting renewable energy sources to the electrical grid.

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