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Critical Review on Synchronization Methods and Fault Ride through Capability in Grid Connected PV

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***Abstract*—Solar photovoltaic (PV) technology's relevance to the electricity generating sector is continuously growing. Problems with synchronization arise when solar PV is integrated into the grid. Because of ongoing research, the small stand-alone system has been replaced by a grid-tied PV system. Since there is no shortage of solar power, grid-tied PV systems are becoming more and more common. As a starting point, you can create a more efficient grid-tied system. Study of grid-tied inverter operation and control reveals that the most critical properties to measure and regulate for grid-tied application are frequency, phase, and voltage amplitude. three-phase and single-phase synchronization methods are covered in this research. Due of its susceptibility to power system disruptions, a phase-locked loop (PLL) is a common grid synchronization technique. In less-than-ideal grid settings, traditional PLLs use a feedback loop filter (LF) to enhance steady-state performance. When it comes to designing power stages for PV-fed grid synchronization, the review study compares and contrasts various PLL and non PLL solutions. Researchers working on solar-powered grids will gain from this work. When the external grid is weak or catastrophic faults occur, grid-connected converters are at danger of losing synchronization with the external grid and other grid- connected converters. In light of this situation, there is a rising focus on synchronization mechanisms and developing techniques to predict grid-connected converter transient stability. In this paper, grid-connected converters can exhibit synchronization instability in the face of severe symmetrical grid faults, which are examined in depth. An in-depth analysis of each option is carried out so that an educated conclusion may be made.**

***Index Terms*— Grid synchronization, Fault ride through, SRF-PLL, Virtual synchronous machine, Loss of synchronism.**

I. INTRODUCTION

The use of fossil fuels has intensified the greenhouse effect and global warming. RES-based distributed generation (DG) systems are now entering a new phase, ushering in a new era. Distributed generating systems that employ renewable energy sources are becoming increasingly popular in order to improve the utility grid's resilience, stability, and reliability. For the current system to be decarbonized, we must rely largely on clean, renewable energy. As one of a number of alternative energy sources, solar power is supported by the government. In most cases, the distribution generator is linked to the main utility grid and runs in tandem with the main utility generator. Contingency DGs can serve as a backup for the main grid in the event of a power outage [1]-[5].

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The PV system is becoming increasingly vital as technology advances. Controlling solar PV is tough because of its intermittent nature. As a result, PV systems mustfunction within the constraints of grid connection. Because of the uncertainty of renewable production, RES utilization is constrained. A new and advanced scheduling approach basedon chance-constrained programming is suggested for a smallintegrated energy system in order to optimise the operationalflexibility of renewable energy resources and reduce low production cost. Both islanding and grid-integrated functioning of PV systems is possible due to the systems' operational and technical characteristics. As a result of the islanding mode's (IM's) advantages and disadvantages, power generation is restricted. It is not possible for IM to continuously extract the full amount of power required by theload since its power output is limited. For maximum power extraction, the battery is required despite its high cost and size. To generate dc power, grid-tied systems are 99 percent better than stand-alone systems in terms of efficiency. An experimental stand-alone PV system was developed into a grid-tied PV system thanks to the diligent efforts of theresearcher [6]-[10].
DERs (distributed generation, storage, and transmission) that are connected to the grid via IEEE standards operate in grid-tied mode. PV systems may be synchronized with the grid to distribute the load, which is referred to as synchronization. A new pooling parameter has been added totemporary exchanges in the electricity market to accommodate for this new feature. Grid-tied PV systems, onthe other hand, raise a variety of questions and problems. A power electronics converter interface connects the PV systemto the main utility at the PCC (point of common connection). Grid-tied PVs are shown in schematic form in Figure 1. Synchronizing your PV system with your utility is essential for meeting consumer demand. In recent decades, grid synchronization has evolved tremendously [11]-[15].
Grid-enabled solar power is creating new management challenges. Some of the problems connected with widespread use of solar power generation can be alleviated by using inverters that have stronger control qualities. In order to achieve synchronization, there must be a singlesource of electricity. A utility-synchronized voltage/current reference may be created using this technique by supplying data on grid voltage, frequency, and phase. PVs and the grid must be synchronized at all times. When the PV system is controlled in the present manner, it is capable of supplying electricity to the grid. When it comes to grid-connected PVs,a lot depends on the present control strategy and synchronization method. [16]-[20].
A variety of power electronics converters are used to link the PV system to the grid, each with a distinct architecture. PV output may be converted into AC electricity and sent to a utility grid using these converters. These converters are oftenused in grid linked photovoltaic (PV). The maximum power point tracking (MPPT) technique is used to maximize powerextraction from DC–DC converters. When used as a grid- side converter, a DC–AC inverter is capable of providing power to loads and synchronizing a system with the grid.

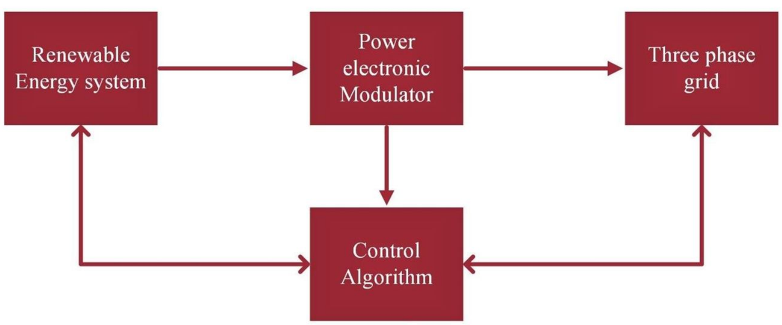

Figure.1. Grid tied Renewable Energy System

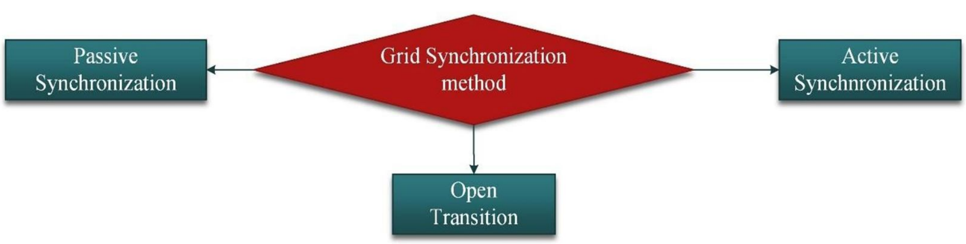

Figure.2. Different Synchronization method for Grid tied Renewable Energy System

There are times when synchronization between an inverter and the grid voltage is critical to guarantee that the inverter is able to transmit maximum power. Development of grid-tied PV systems has as its ultimate goal the transmission of the greatest quantity of power. Grid-connected PV systems may be made more efficient and intelligent by tailoring the characteristics of each component, according to PV researchers (Hariri et al., 2020). Maintaining a steady supply of power is essential for reliable, secure, and uninterrupted functioning of an inverter. [21]-[25] identify three main synchronization approaches (Fig. 2) in the literature.

During the grid synchronization of a PV system, it is critical that frequency and phase angle be assessed fast and precisely. As a result of non-linear loads in the electrical network, the problem is exacerbated by transients such as phase shift and harmonics. The grid's frequency is frequently influenced by shifts in demand. Due to high cycling current, the system may become unstable if the frequency is incorrectly set. A lack of supply and demand causes network frequency to fluctuate. Frequency estimation is crucial for the safety of power systems, the preservation of power quality, and grid synchronization [26]-[30].

Multiple approaches for tracking grid frequency and phase are provided by Arul Kumar, K [31] for converter-based resources. Existing on-grid synchronization methods literature splits them into two types based on how they are controlled: single-phase and three-phase systems. Here, many methods for determining the phase angle and grid frequency are explained in detail. Grid synchronization has advanced over the last few decades, and this page provides asummary of current developments in the field. ZCD is one of the open-loop grid synchronization algorithms. However, theabsence of PLL restricts the possibilities of an open-loop method. When dealing with steady state defects, open-loop techniques lose their appeal when real-time frequency monitoring is not available. Grid synchronization employs PLL the most frequently because to its simplicity, dependability, and efficiency. On the basis of their benefits and disadvantages, as well as their potential for future improvement, we want to evaluate the performance of several single-phase and three-phase PLL synchronization systems [32]-[37].

The following is a breakdown of the paper's structure: Section 2 explores a cutting-edge grid-tied PV system synchronization technique. basics of grid synchronization arecovered in detail in Section 3 and also three phase PLL techniques are contrasted and discussed in depth PV system synchronization issues and future research opportunities are discussed in the report's concluding parts. In Section 4, fault ride through capability in grid connected PV and scope and challenges are discussed. Researchers who are interested in the PV-fed grid may find all they need in this document. An effective method for their utilization may have beendiscovered via this research.

II. GRID-TIED PV SYSTEM SYNCHRONIZATIONTECHNIQUE

More and more applications are turning to Grid Synchronization for their needs. A brief history of grid-tied photovoltaic systems is provided in this section. Most people utilize solar power since it's easy to get and inexpensive to produce (RES). Electricity providers and the federal government both favor grid-connected solar power installations. In the end, the simple stand-alone system has been replaced by grid-tied PVs owing to continual study. In the electrical grid, grid-connected photovoltaics (PVs) are becoming more common. System synchronization is critical for the integration of renewable energy sources into theelectric grid. RES (renewable energy sources), as well as other energy sources, are increasing in production, transmission, and consumption in an integrated system. The Stackelberg game optimization for a perfect integrated energy system is available for

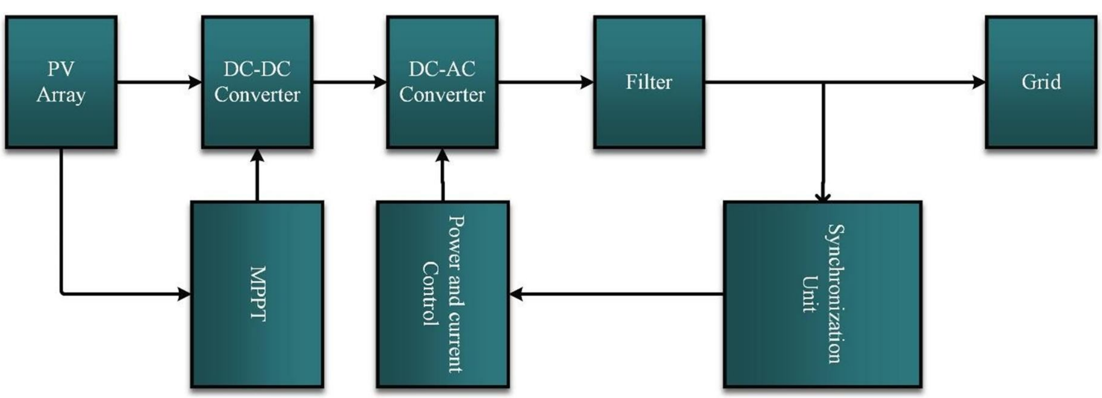

Figure.3. Grid tied solar PV system

RES solar systems. Stackelberg's game-based method of balancing integratedenergy operators and consumers is achieved by coordinatingrenewable generation and demand response. Grid synchronization can only be achieved if utility voltage frequency and phase are properly maintained. Grid synchronization can have a variety of effects, including reactive power compensation, voltage flicker control, voltage synchronization, and losses. Unbalanced settings needfeatures like simplicity, speed, and accuracy in bothfrequency and phase detection, as well as noise immunity and harmonic rejection capability in synchronization algorithms. Grid synchronization rejects many kinds of errors, including phase leaps, frequency aberrations, and voltage harmonics [38]-[42].

The quality and synchronization of the power injected byan inverter linked to the grid can be controlled. Electric car onboard chargers, active power filters, island detection, and dynamic voltage restorer all utilize grid-connected converter technology. An increasing number of people are concerned about the reliability and consistency of the electricity grids. As a result, various control techniques and improved synchronization mechanisms are being researched for various topologies. The smart grid's reliance on grid-tied voltage source inverters (VSIs) is rising. VSI synchronization solutions are becoming increasingly popular as the demand for dependable and quick control grows. As part of the overall performance, considerable consideration must be given the synchronization mechanisms employed. Reactive power is one of the many benefits it may give, along with a reduction in power outages and an increase in service efficiency. Synchronization of the grid is done using a sophisticated control approach. Synchronization of the inverter output voltage waveform with the grid voltage is, in reality, a considerable issue. Because of this, the grid is fraught with problems [43]-[48].

New power converter topologies for PV applications were developed by Pal [49]. Scientists have concentrated on increasing the converter's power density, reliability, and efficiency in order to further boost the performance of PV systems. An understanding of PV grid interconnection systems and current grid synchronization approaches may inspire future researchers to utilize the most recent technology advancements in the field. There have been a number of PLL methods investigated in the past. The dynamic response of the PLL is strongly influenced by its performance under distorted situations. As a result, a grid- tied PV system's proper operation is dependent on the PLL. There is a comparison of several PLL methods, including ones with one or more phases. High-power applications choose the three-phase grid-connected system because of its nearly constant power flow and ability to eliminate undesiredimbalance in utility current. The most modern state-of-the-artPLL and all of its components, including single- and three- phase systems, are thoroughly examined. The advantages and disadvantages of various PLL approaches are compared and contrasted [50].

III. METHODS USED FOR SYNCHRONIZATION OF GRIDWITH SOLAR PV SYSTEM

PV systems that can be linked to the grid and used to generate clean, reliable power are becoming increasingly popular among researchers. Understanding, analyzing and evaluating these smart technologies in normal and abnormal grid operations is critical. The phase sequence, phase, frequency, and voltage must all be met in order for the grid to be synchronized.

Grid-tied PV systems are seen in Figure 3. Sophisticated power electronics converters are useful for grid-tied PV installations. Using an interconnected power converter, electricity is taken from the source and delivered via a utilitygrid. A DC–DC converter is needed because the output voltage (Vpv) of solar PV is low DC and needs to be boostedfor a variety of applications. It is necessary to employ the source-side DC–DC converter in order to keep track of the MPP along the I–V curve. DC voltage (Vdc) is converted to AC power via a grid side converter for grid-tied application usage (Vac). The number of grid-tied PV systems is on the rise as a result of rapid improvements in power electronics. Using an inverter, you may connect your solar power systemto the grid. To achieve harmonic switching frequencies, grid- side inverters must be utilized. Harmonics in the switching frequency can be removed with an inverter-to-utility filter. In grid-tied mode, the voltage source produces a current rather than a voltage. Managed current from inverters results in a more effective grid integration. Controlling grid current using an inverter is crucial to the system's efficiency and dependability. It's an inverter, For PV to be in sync with the underlying voltage of the grid, there must be a requirementfor grid integration. [51].

Systems that are connected to the grid are proving to be a feasible option for networks that are already overburdened. Even if the grid fluctuates, grid-tied inverters must maintain their inverters in sync with it to stay connected and transmit the correct amount of electricity to the utility. If the inverter and utility have the same frequency, phase angle, and amplitude, they can be synced. The grid synchronization unit is in charge of gathering grid data. Using an inverter reference control signal for a grid-tied system, the recorded phase angle of the utility grid voltage is critical (Panda et al.,2016). An inverter in a grid-tied system is controlled by the grid's output voltage. When an inverter is employed, a current controller is used to create an output current that is

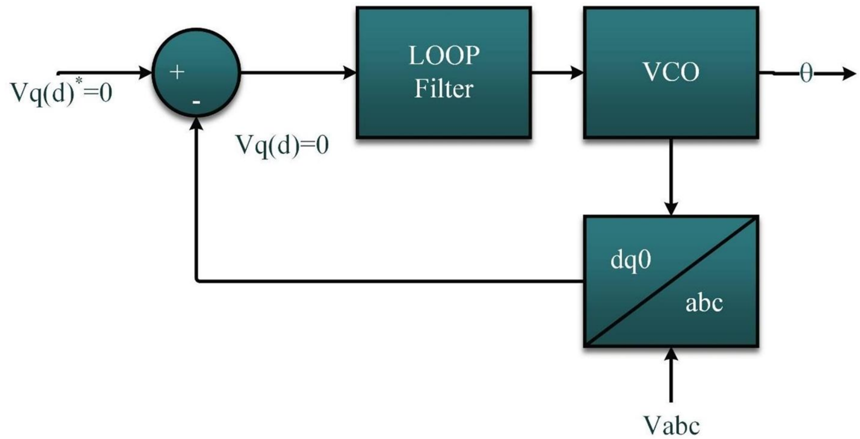

Figure.4. Structure of Synchronous reference frame Phase Locked Loop

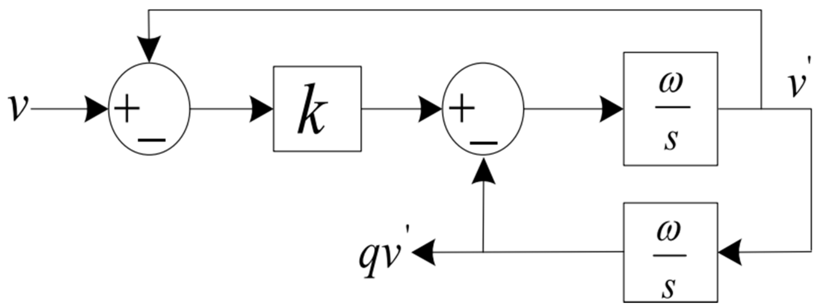

Figure.4. Structure of Second order generalized integrator Phase locked Loop

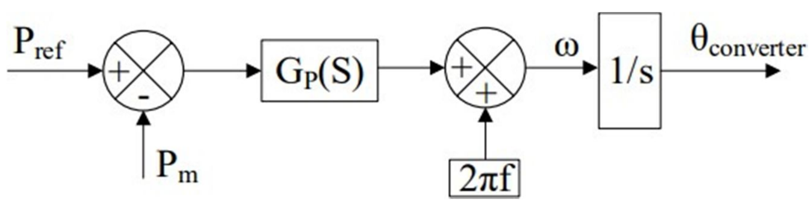

Figure.5. Structure of Active Power control-based grid synchronization

linked to an external source of current. Grid synchronization and other grid condition monitoring need precise measurements of utility voltage phase, amplitude, and frequency [52].Grid synchronization and inverter control are depending on the technique of synchronization. There must be synchronization between the grid and an inverter for maximum power extraction, regardless of grid phase, frequency, or amplitude of voltage variations.
Harmonics must be removed from the grid voltage signal, and the phase must be properly set. Grid fluctuations need a precise tracking of frequency and phase deviations. If you want your inverter to work reliably and continuously, you need to synchronize its output voltage waveform with the grid voltage. Because of the non-linear loads linked to the grid, harmonics and phase shifts in the grid's voltage are widespread. According to the research, there are several ways totransmit the electricity collected from renewable energy sources (RES) to the grid. These methods may be broken down into two categories: time and frequency. Open loop or closed loop synchronization is used for the three-phase system. Grid-connected three-phase systems each have their own set of challenges [53].

IV. Synchronization Techniques for Three PhaseSystem

Three-phase grid linked systems are frequently preferredto single-phase systems for high-power applications due to their near-constant power output and lack of utility grid current imbalance. There are two options for synchronization: one single-phase unit with three phases or single-phase three units. When installing a three-phase single unit, a three-phase inverter is commonly employed. Three- phase synchronization can be accomplished using either an open or a closed loop [54].Open-loop methods, which mainly rely on filtering units, are used to monitor the grid parameters directly. weighted least squares estimation (WLSE), Kalman filter (KF), space vector filter (SVF), and LPF are some of the most used openloop methods.

It is dubbed a closed-loop technique when a loop mechanism is used to estimate grid parameters. Using this loop method, error signals may be reduced by changing the anticipated value in accordance with the reference or real value. For three-phase synchronization, the most common techniques are the SRF-PLL (Synchronous reference frame) and the FLL (Frequency lock loop). SRF PLL is the most often used technology for three-phase closed loop synchronization. In order to solve the shortcomings of the standard SRF PLL methodology, several filters and symmetrical sequence extraction methods have been included [55].

A. Synchronous reference frame Phase locked Loop

Due to the simplicity of its construction and the accuracyand speed with which it estimates frequency and phase, synchronous reference frames are commonly used in 3-phase grid-tied inverters. The SRF PLL is the standard PLL in 3- phase applications and is the basis for most current PLLs. The phase angle of a utility voltage signal may be measured in real time using an SRF PLL feedback servo system. Schematic representation of a conventional synchronous reference frame PLL (Fig. 3). The structure is composed of the PD, LF, and VCO blocks. It is up to the SRF-PLL to decide amplitude (V), frequency (g), and phase angle, while the SRF-PLL also calculates the nominal frequency (n), gains (kp, ki), and loop filter. To determine amplitude, the LPF cut-off frequency Kv is employed [56].

The Phase Detector is constructed by combining Clarke's and Park's transformations. SRF PLL features DC components Vd and Vq. The q-axis output of the phasedetector offers phase error information, while the d-axis output provides steady-state grid voltage amplitudeinformation. The PI-controller is fed Vq in this manner. The PI controller's output signal represents the projected grid frequency. Utility phase angle is calculated by integrating grid frequency. Based on the phase angle, feedback is given to PD (-dq).

The fundamental objective of SRF-PLL is to get Vd and Vqor Id and Iq by resolving the grid abc components. In order for the three-phase SRF-PLL to work, the closed-loop control system regulates Vd to zero and freezes to the input signal's phase angle. It is common practise to tune the PI- controller gain so that Vd closely follows the reference valueVd As a result, there will be a minimal phase error [57].

B. Multi reference frame Phase locked Loop

An exact detection of frequency and phase may be achieved using SRF-PLL, as previously stated. There is a two-fold inaccuracy in frequency in the unbalanced conditiondue to SRF PLL's improper performance and LF's failure to suppress harmonics. This is why the ISC is extracted using various reference frames that include multiple reference frame (MRF). The positive and negative sequence components of the grid voltage are extracted using the DDSRF-PLL technique, which employs two reference frames revolving at the same synchronous speed but in the opposite direction (PNSC). In order to remove components, the decoupling cell is employed, whereas the LPF is used to remove the dc component [58].

C. Decoupled double synchronous reference frame Phase locked Loop

There are PNSCs of grid voltage due to unbalanced grid situations (Kamil et al., 2020). There are issues in SRF-PLL synchronization since these components are not regulated independently. For imbalanced grid-voltage synchronization, DDSRF is an expanded version of SRF. The utility voltage's PNSC is used to convert and control the DDSRF-PLL algorithm. The phase angle of the grid may be determined quickly using this approach. DDSRF-PLL, on the other hand,has a very strong ability to respond to grid frequency changes. Two Clarke–Park transformations are used to obtain the dq components of the PCC voltages. When building a DDSRF-PLL, two reference frames are used, one of which spins in the same direction as the grid frequencyand the other in the opposite way [59].

D. Enhanced Phase locked Loop

With the EPLL approach proposed by Karimi- Ghartemani, it is now feasible to track the frequency, phase-angle, and magnitude of a three-phase input signal. [60]. Forbasic parameters, EPLL gives a smoother and more accurateestimation with a better transient response. Adaptive non- linear synchronization (EPLL) is a frequency-adaptive non- linear method. Using a band pass filter (BPF), EPLL extractsthe PSC from the input signal. Noise and harmonics have noeffect on this method since it is frequency adaptable. It is possible to use EPLL with an uneven grid voltage. EPLL's voltage stabilization controller can also be used with anuniversal power quality conditioner (UPQC) (VSC). Quickly extracting the reference signal for load current and supply voltage in the event of voltage sags or harmonics is possible with UPCQ. After the integrator, an LPF can be added to the VCO to smooth out the estimate of phase angle. EPLL may shift an input signal by 90 degrees in single-phase applications [61].

E. Second-order generalized integrator Phase locked Loop

First, the SOGI is a sinusoidal integrator with better performance as a result of its use of two-adaptive filters. second order generalized integrator (SOGI) employing two adaptive filters for the sinusoidal integrator. By employing the SOGI-QSG filter in conjunction with the SOGI-PLL, frequency adaptive quadrature signals may be generated. The 'sinusoidal integrator' in this technology is a pair of adaptive filters with superior performance. Fig. 4 illustrates the usual construction of SOGI, in which v represents the voltage input signal from PCC. There are two sinusoidal outputs that are in phase with the input signal but have a 90^o phase shift between the two. When orthogonal signals are generated, the Q and D components are calculated using the Park- transformation in a rotating reference frame. There are QSG coefficients that can be set to a certain frequency range. [62].

F. Dual second order generalized integrator Phaselocked Loop

Using a dual second order generalized integrator, it is possible to recover positive sequence components from imbalanced voltage (DSOGI). During times of unbalance, it functions well. Voltage imbalance while monitoring phase angle may be solved by using the DSOGI PLL. DSOGI identifies the fundamental positive and negative sequences. The voltage sequence in the reference frame is constructed by using two SOGI-based QSG as adaptive BPF with a positive sequence calculator. DSOGI is based on an instantaneous synchronous approach using a stationary reference frame. By utilizing the SOGI algorithm, an input voltage signal is transformed into a reference frame quadrature signal. After deleting the positive-sequence vector, the q component drives zero. In the case of a utility delay, DSOGI provides precise phase angle measurements and sequence information. by employing two-adaptive filters and a sinusoidal integrator, the SOGI performs better than a standard integrator [63]-[67].

G. Type-N and Quasi type-N Phase locked Loop

Type 2 PLLs often employ PI controllers as LPs. Selecting various LFs or adding a control route to the PLL's current structure might modify its type. Some of the most common PLLs are the following: the type-1 PLL, the quasi- type -1 (QT1) PLL, the type-3 PLL, and the quasi-type-2 (QS2) PLL and the type-3 PLL [68].

H. Active Power control-based grid synchronization

Proportional integral controllers, which imitate the relationship between active power and synchronous machine speed were inspired by swing equation [69]. In order to get the angle from the speed, an integrator is used. Using this angle, the converter may adjust the active power flow (Figure 5).

V. CHALLENGES AND PROPOSALS FOR THE FUTURE

When the grid goes down, grid-tied converters need to beable to continue operating. Grid-tied PV systems can be synchronized quickly, but a sensible synchronization method faces technological hurdles. The following are a some of thedifficulties we're facing:

a. The primary problem with the synchronization method described above is the ability of PV grid-tied systemsto continue operating even when the grid is experiencing abnormal circumstances. Even in low-power applications, there are no phase tracking algorithms that meet the grid code requirement for THD. An intelligent and effective synchronization method is needed to increase electricity quality and meet grid standards.
b. In practice, the PCC voltage is distorted and imbalanced by nonlinear loads that are continually connected and detached. This means that precise estimations of grid voltage characteristics like frequency and phase are challenging yet critical for inverter operation and control in atypical scenarios. Computational complexity, tracking precision and dynamic reaction speed, distortion rejection, and an overall unbalanced robustness are all problems. Unbalanced and non-linear loads necessitate an improved control strategy in order to ensure the grid receives AC power in a way that is safe, dependable, and of high quality.
c. For the researcher, it's all about figuring out how effectively the grid-side converter can handle fluctuations ingrid demand, voltage peaks and valleys, and other types of failures. As a result, the grid requires a mechanism to preventtransient failures, islanding, and quick shifts in reactive power use.

d. In the PLL-based grid synchronization methods discussed above, the phase angle and frequency are generally determined in the same loop. As a result of the varying phase angle, there are frequency transients. Transients in the phasevariable might derail the phase detection and synchronizationprocess. As a result, a more dynamic and efficient solution must be devised in order to deal with harmonic distortion andvoltage drops.
e. Temporary power outages are known to have ahigher utility frequency variability than a lower voltage phase angle. Although the system's transient dynamic response is sensitive to phase jumps, most synchronization techniques described thus far rely on input signal phase detection. Consequently, emphasis should be paid to the synchronization mechanism that uses grid frequency and voltage detection in the future.
f. Overall, there have been no publications or studies on the use of artificial intelligence in grid-connected power converter sync. There are studies that may be started to evaluate this method's performance in grid fundamental estimate in combination with other conventional approaches
g. With the advent of grid-connected PV systems that use artificial intelligence (AI) for synchronization, new issues will arise. In the future, using AI technologies in combination with conventional synchronization techniques for grid-tied systems can be more popular and successful. As a result, an investigation of its performance in grid basic estimates may be undertaken. A grid-tied inverter's efficiency is enhanced by accurate estimation of grid voltagecharacteristics.
h. The inverter must be able to perform more than only DC/AC conversions due to the need for new technological advancements. It is imperative that current grid-side converters enhance their PV synchronization, voltage/voltage control, and frequency regulation. The next generation of inverters, dubbed "smart inverters," may be thought of as such. The investigation of these difficulties will aid in the development of reliable and efficient grid- connected PV systems.

VI. Fault Ride through Capability in Grid Connected PV System

An in-depth examination of grid-connected PV system management issues under fault circumstances is provided in this part, which discusses the following topics: low voltage ride through capability; control of imbalance voltage; grid formation converter.

A. Low Voltage ride through capability

The operators face a significant challenge in maintaining grid stability and dependability as the amount of PV generation grows across the network. Due to the grid code's need for low voltage passing capacity, a solar system must be linked to the grid at all times, even when the voltage is low. Several methodologies have been utilized in [70] to examine and improve the LVRT capability of PV systems connected to a single-phase network. A control approach based on the solar system's actual and reactive power control is proposed in this method. Researchers in [71] have gone so far as to use the same control method to transformer less photovoltaic (PV) systems. According to [72], short-term voltage stability is affected by the dynamic performance of PV systems. PI cascade control is used to govern the grid-side inverter. Studies using the PI controller to enhance PV systems linked to the network through long-term processors are numerous and well-researched. There have been several studies in the past that rely significantly on the designer's experience in order to construct a PI controller. Though it is widely used in industry, the PI controller is susceptible to parameter changes and nonlinearity in dynamic systems despite its high dependability. [73]-[74] have imposed a variety of optimization strategies to deal with this problem. Complex mathematical algorithms, long periods of time, and significant effort are required to achieve the high processing efficiency of these non-linear systems. PNorm Mixed Continuous is the key reason for the authors to employ an adaptive PI controller for PV plants linked to their network. The CMPN technique can be used to enhance filtering (AF). DC-DC boost converter LVRT capability increases when the CMPN method, based on adaptive control, is employed in grid-connected PV facilities [75]. The inverter's PCC (PCC) terminal voltage is monitored using the fractional open circuit voltage method, which generates MPPT operation.

B. Unbalanced Voltage control

Unbalanced voltages in the power supply are one impact of increased PV integration. It's highly likely that this one will bear a heavy price for this, and the imbalance will inevitably lead to instability. Series active power filters are linked to the distribution line and create negative sequence (NS) voltage in series as a technique of rectifying voltage imbalances. Other investigations are focusing on shunt compensations. [76-78]. Power quality issues can be compensated for with proper control measures outlined in [79]. [80]-[81] provide some ideas on how to go about this. inverter structure, parallel and RP flow are controlled by separate filters, while an unbalanced network voltage is compensated by a series filter that is connected to the network, balancing current and voltage across sensitive loads. NS voltage is used to inject the medication. According to [82], Unbalanced loads can be compensated for by using an Interline Photovoltaic Power System (I-PV) system, which uses photovoltaic power plants to generate NS currents. This controller consists of the positive and NS loops. The PS controller's major role is to restore a balanced voltage, whereas the NS controller's primary role is to decrease the unbalanced voltage.

C. Grid forming converter and control

In grid-fault conditions, grid-forming converter control is complicated for a variety of reasons, which are addressed in this section.Removing massive synchronous machines as part of the power system's shift to renewable energy sources is a critical challenge. Because of their high inertia and synchronization torque, synchronous machines dominate conventional power systems, which provide the principal network auxiliary assistance during disturbances. In the event of a grid breakdown, synchronous machines can inject up to 6–8 pu of short-circuit current. [83]. Inertia and synchronizing torque are lacking in power electronics generators, therefore there is worry about the overall stability of the power system as a result of the increasing capacity of converter-based generation [84]. Grid-tied converters often align the current reference of the vector current control with a voltage-based sync unit like an SRF PLL (phase-locked loop synchronous reference frame).

When the system is linked to a weak grid or when the grid is experiencing a power outage, the system is susceptible to low-frequency oscillations and synchronization loss. Grid-following converters, on the other hand, can't handle the trend toward connecting generation at all voltage levels and the potential of system splits, because there is no designated voltage to respond in line with. Due to their reliance on the external environment, grid-following PLL- synchronized converters are limited by this fundamental restriction. It's for this reason that grid-forming converter research is becoming increasingly popular. Simulating synchronous machines, grid-forming converters provide fake mass and a synchronization mechanism that is driven by the grid [85-87].

Virtual Synchronous Machine, Droop Control, Synchronverter, Synchronous Power Controller and Power Synchronization Control [88]-[103] are just a few of the many control systems available for grid-forming converters. They can also be referred to as grid-forming converters because of the fact that the control systems previously described do not establish a voltage magnitude and frequency set-point but instead alter these based on readings from the local connection point. It is generally accepted that grid-following converters are also known as grid-supporting, although they still have the fundamental problem of having to be connected to an ac grid via the synchronization unit. However, even though grid forming converter control has been found to be beneficial under normal operating conditions, little effort has been made to analyses and understand its transient characteristics and fault behavior, as current-sensitive semiconductor devices are not able to replicate the short-circuit behavior of an inductive synchronous motor.

Using a virtual admittance structure and switching the control structure to grid-following mode, grid forming converters may be stabilized during large-signal disruptions. When the converter control allowable current is exceeded,

[106] switches to hysteresis control. No one discusses how to cope with the saturation of the outer control loops during this time period, and the grid-forming control loses all usefulness. When the fault occurs, it is recommended to switch to grid-following control [107], [108]–[110]. In weak- grid contexts, this technique faces stability issues due to the requirement of a backup PLL to maintain synchronization.

This limit on current flow can be established by limiting the current references immediately during a failure. However, this can contribute to instability in the outer power loops [111]. The use of linear or nonlinear virtual resistors to reduce the converter voltage reference value has been advocated by several researchers [112] and [113]. Virtual impedance structures are also investigated in [114]. If a fault site and virtual impedance are selected, the current limitation may be limited in practice since the highest converter current is wanted during any fault situation. Virtual impedance can pose issues in parallel operation because of this [113]. Using the virtual impedance concept, [111] investigates decrease in voltage and reduction in internal current references. Wind-up in the outer loops is prevented by using the virtual impedance approach. The virtual impedance still has the problem of its precise limit being reliant on several unknown factors, as previously mentioned

The robust grid-forming capabilities of the converter are lost in systems that switch to a grid-following structure when a fault occurs. In order to avoid wind-up and instability, techniques that restrict the current references directly neglect external power loops and droop controllers. In order to avoid wind-up in the outer power loops, a virtual impedance might be used. In the actual world, there are a lot of unknowns that might impact how well this works, making it less desirable.

Synchronous Power Controller can perform grid- supporting functions if they are coupled with current limiters, which improve the network's transient stability, but this compromises the converter's synchronization stability when there is a failure in the grid [107]. Voltage-referenced outer loops may have an impact on the responsiveness when current magnitude is restricted. Because of this, assessing the utilization of an asymmetrical grid fault voltage mode control structure requires testing various limiting techniques. This means that the current limit is necessary, although synchronization instability may be at danger during grid disturbances when the converter is saturate.

Defect detection may necessitate an increase in virtual admittance inductance, which may necessitate a rise in the current reference inductance. Therefore, the current reference will create an ac signal with a diminishing component of dc, which is not desired. As a result, the converter's current reference will be restricted directly to avoid these issues. When operating with sinusoidal signals, an instantaneous hard limiter will clip the peak of the signal, resulting in a reduced output current. Fault Current Limiting Control Using Grid-Forming Converters with Improved Dynamics in [115].

D. Under Extreme Symmetrical Grid Faults, the Stability of Grid-Connected PV system

Renewable energy systems, such as wind turbines and solar panels, can be connected to the grid via the Voltage-Source Converter (VSC) [116]. LCL filters are widely used to minimize high frequency switching harmonics generated by the converter, and their compactness compared to a single hefty output reactor makes them a popular choice [117]– [119]. Most grid-tied converters used in PV and wind power systems may be classified as grid-feeding/following converters that aim to pump maximum power into the grid in the form of sinusoidal currents [115], [120].. In order for today's grid-connected RES control to support the network in accordance with grid code standards, LVRT and auxiliary support characteristics of grid-feeding converters must be assessed.

WT and PV power plant control under grid fault circumstances has been extensively explored, including LVRT capability [121–129]. Despite the fact that some grid rules call for LVRT to be capable of restoring grid voltage in the event of a total loss, most studies only address voltage drops of 10% to 50%. When the voltage is close to zero, this drastically alters the notion of how to regulate the transition.

When a grid-supporting converter fails, it is more common to use voltage-controlled models than current-controlled ones [130]. In the case of a catastrophic grid failure, grid feeding (i.e., a current-controlled converter) can be used to practically any control structure.

A grid-feeding method may fail to establish synchronization with the grid during power system outages, and the Phase-Locked Loop (PLL) is unable to keep synchronized with the grid, resulting in unstable current controllers at almost zero voltage conditions [131, 132]. Loss Of Synchronization is the term used to describe this situation (LOS). Different voltage sag profiles are investigated with various PLL techniques in [133]. Phase lock loop instability isn't caused by the voltage sag that follows from this suspected three-phase symmetrical fault (PLL). To improve the PLL construction and tuning technique, grid-feeding converters must be able to anticipate PLL instability and determine whether any action or adjustments are necessary during a fault. PLL instability under weak grid settings has been the subject of numerous investigations, The PLL's LOS during severe grid failures has not been properly understood, yet this is a problem. Numerous researchers have investigated the PLL instability in low-voltage conditions, employing a variety of modelling and analytic techniques. [131, 134–140]. Controller mitigation techniques to avoid LOS during low and zero-voltage grid events include the PLL being blocked or frozen [131], [132], no or limited current injection [33], voltage-dependent active current injection [24], current injection based on X/R characteristics of network impedance [137], and active current injection based on PLL frequency error [131], [140]..

In steady-state network conditions, current injection limitations are determined in [131] and [134]. The destabilizing positive feedback component in the PLL model is found as a result of the coupling between the injected current and the grid voltage [135]– [137] together with the PLL dynamics in a quasi-static large-signal model. [138– 140] use the Equal Area Criterion (EAC) to analyses the LOS mechanism by using the rotor-angle transient stability of the synchronous machine as an example. As a last step in [138], nonlinear techniques are used to test transient stability of the intrinsic nonlinear system.

VII. For the Future and Unresolved Problems

The LCL filter and the inner current regulator are not taken into consideration in any of the techniques presented. Improve stability assessment by eliminating the assumption that injected current matches its reference value.

Although the model's credibility has grown, it is still a complex simulation model that does not give any more information or tuning advice in stability assessment model.
Under specific assumptions, the steady-state model's injection limitations were constructed. This may be a more effective strategy. An updated version of the quasi-static or revised PLL controller design guideline would be greatly appreciated. Self-synchronization loop instead of only depending on negative feedback for improved PLL controller (grid-synchronization loop). Because low-voltage fault occurrences are similar to weak grid scenarios in terms of PLL stability, studies on the impact of PLL tuning under weak grid conditions may also apply here. Poor grid conditions have a destabilizing impact, which is why self- synchronization loop controllers are employed. The proportional gain of the PLL should be decreased to avoid instability when the power transmission capabilities are very low. Due to the PLL's destabilizing impact caused by a large grid impedance being negated, a virtual impedance structure has been incorporated to counteract this effect. An improved synchronization stability can be achieved since the converter is virtualized and linked to a stronger point in the system, which increases the transfer capacity. The robustness of the grid against weak grid conditions can be improved by using a synchronization mechanism that does not use a PLL, including power synchronization control. Because of the converter current constraint, synchronization may not be preserved during big disturbances when using transient active power transfer for synchronization. Apart from that, it may be worthwhile to investigate the technique of adaptively changing controller parameters in the event of grid anomalies, simply by applying adaptive voltage normalization, in regard to any potential improvements in LOS stability.
A well-documented knowledge of how LOS is influenced by a multi-converter system, such as a wind farm string with long cables, is lacking. Stability difficulties become more difficult to comprehend when the quasi-static model is changed to include dynamics of an inner current regulator. If you have a multi-converter system, it may not be practicable or even computationally viable to construct a comprehensive model for each converter system in order to investigate local and global synchronization issues. Simpler models, which just include the most essential data, may be a preferable choice because they contain less details. The LOS evaluation of huge systems is carried out. It's still an open question, according to a number of recent studies. Paralleled converter grid-connected microgrids and inverter-based systems under poor grid situations can be reduced in model order.
We'll go through what transient stability is and how to deal with it in a more solution-focused way. The dynamics of the PLL may cause an overshoot, preventing the PLL from achieving equilibrium. If a specific fault condition results in a stable or unstable system, all of the aforementioned procedures are applied.
Alternatively, it's possible if a short-term problem is considered. Even though the converter system is unstable in a steady-state fault condition, stable steady-state operation can be restored due to the brief length of the fault. The important clearing time is a good indicator of how long it will take to return the system back to its pre-fault condition. Power electronic-based integration of renewable energy sources (RES) has also been included using this technology.
Use a low-bandwidth PLL or freeze it when you don't need large damping coefficients. To put it another way: A real-world defect is frequently rectified within just a few basic cycles in the actual world. As long as the PLL doesn't deviate much from its initial conditions, it may return to a stable working point if a problem occurs, which means that the fault duration is shorter than crucial clearance time. However, this method has a flaw in that it fails to address the underlying issue. PCC voltage phase jumps are prevalent in the case of a grid outage.
PLLs that are too sluggish or frozen will fail to fulfil the grid code's need for reactive current, which implies that the injected currents will not meet the grid code. As an alternative, it's possible to argue that the system will have trouble maintaining grid voltage at all with the PCC voltage so low and the converter's maximum current limit so high..
Slower synchronization units necessitate faster PLLs, which slows down post-fault recovery. Therefore, future power electronic-based power systems are still unknown on how to address synchronization loss. It is feasible to apply a low/zero bandwidth PLL during the fault, as well as an adaptive controller change. The second-order nonlinear differential equation with no known analytical solution governs the PLL's enormous signal stability, as shown.
Because of this, the various approaches covered here represent the current state of the art in terms of studying and comprehending such complex systems and their transient.

VIII. Conclusion

The current state of grid synchronization approaches has been thoroughly evaluated in this work, which also classifies a wide range of papers on the subject. For phase angle, frequency, and harmonic component identification, the advantages and disadvantages of grid- connected converter detection systems were discussed in chapter 3. PLL is still a popular choice despite the fact that various innovative techniques outperform the traditional PLL. Many improvements have been made to the PLL to improve and increase its performance when the grid is weak.These hybrid and intelligent solutions for grid- synchronization under unfavorable grid situations should begiven more attention, as summarized in Section 3 of this document.

During severe symmetrical fault occurrences, converters linked to the grid are at danger of losing their capacity to maintain grid synchronization, resulting in both local instability and worldwide destabilization. A major concern here is how converter-based renewable energy sources will be incorporated into future power electronic-based power systems. Methodologies for measuring synchronization stability and an explanation of what causes grid-connected converters to lose synchronization during severe symmetricaldisturbances were examined in this research. In the end, this review provides a comparison of current models and methods for revealing the mechanism for synchronization loss to clearly explain how stability should be understood, what elements are responsible for causing instability, and what actions should be taken to minimize the risk of synchronization instability. As a way to evaluate the stated approaches for determining synchronization stability, three case studies are employed. Models based on steady-state equilibrium points confine current injection in the first approach described. This research also looks at the quasi- static large-signal model, which integrates the dynamics of the SRF-internal PLL. The sync-process description and system damping terms found in mathematical equations that regulate sync-machines are analogous, and we'll see thislater.

Low grid voltages and large impedances are cited as factors that contribute to instability. It is possible to increase. stability. Control theory, physics, and power system engineering all rely significantly on the Lyapunov technique,which hasn't been explored in this article. Using Lyapunov's technique and energy functions, the EAC works as intended.In the end, no consideration was given to dissipative forces. To account for system damping in the synchronization unit under study, it may be advantageous to tweak the Lyapunov function. Lyapunov functions exist for generic lossy one- machine infinite bus systems, although it may be difficult to create one from scratch.

As a result, the authors' best knowledge suggests that developing an adequate Lyapunov function and applying it toassess grid-connected converters' loss of synchronization is currently an unresolved difficulty in the field. By utilizing this data, it is possible to construct a more specific description of stability conditions, including tuning recommendations and control actions intended to improve system robustness and avoid instability during severe grid failures. The damping coefficient by increasing the PLL's proportionalgain or reducing its integral gain.

Another option is a visual solution that is non-linear and may be used to solve the problem. This research makes use of reactive current injection since previous studies on synchronization loss have required subjecting the converter to reactive current injection in order to verify it. In order to evaluate the pros and disadvantages of the various options, adetailed simulation model is employed. Analytical study is supported by experiments on a grid-connected converter subjected to a severe symmetrical fault.

This research shows that a direct method for measuring grid-connected converter stability, including the dampingcoefficient of a nonlinear synchronization unit, is still necessary for determining its stability. An energy function- based technique may be possible, but more study is needed to have a clearer picture of how this works.

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