Grid Forming Inverters to Strengthen Frequency Stability of a Very Low Inertia System: A State of the Art

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Abstract

As renewable power from DC sources is constantly increasing their power generation share compared to the high inertia generators that provide robustness to the grid, the overall stability of the grid decreases. A grid-forming converter could be the solution to this problem. Grid-forming inverters act as voltage source converter (VSC) and it has important characteristics of synchronous generators (SG). These also include the provision of inertia and voltage source behaviour. These properties are required to interconnect synchronous generator and inverter-based sources. However, grid-forming VSC cannot replace an important feature of SG: overcurrent capability. This property of SG contributes to power system stability. In the case of severe disturbances, SG may initially be overloaded before the load is gradually shared with other IBRs. Due to the risk of damage, VSC has overcurrent protection. The main mission of a grid-forming converter is to replicate the behaviour of the synchronous machine via different control strategies. Additionally, they can contribute to grid stability by providing voltage and frequency support. This paper includes a systematic review of recent advancements in grid-forming converters with BESS (GFM BESS), its modelling and different control techniques to enhance the frequency stability of large-scale power system networks. Inertia in the power system is the energy stored in a large rotation part of a conventional synchronous generator which helps during any contingency like load imbalance or generator outage. The inertia of rotating parts under such conditions will help to stabilize the frequency. With an increasing share of IBRs, the lack of inertia by grid-forming converters is provided with a pulse width modulation controller linked with conventional inverters. This concept of virtual inertia by emulating the behaviour of GFM as a synchronous generator has been discussed with different virtual inertia-based control techniques with their comparative study. Also, challenges and open issues related to the high penetration of GFM BESS and the transition from islanded to a grid-connected mode of grid-forming converters are discussed.

Keywords

Grid forming converters, Battery energy storage system, frequency stability, Power electronics based sources.

Indices

GFC= Grid forming converters

GFL= Grid following inverters

GFM=Grid-forming inverter

PBS= Power electronics-based sources

SG= Synchronous generators

BESS= Battery energy storage system

SO= System operator

IBR= Inverter based resources

BSD= Battery storage device

Parameters

P_{elec} =Electrical power output

P_{mech} = Mechanical power input

$\boldsymbol{\omega_e}$ = Grid frequency

$\boldsymbol{\omega_m}$ = Reference Frequency

J= Inertia constant

De = Damping constant

K_D and K_V = Droop co-efficient

L_g= Grid side inductance

R_g= Grid side resistance

L_c= Converter side inductance

R_c =Converter side resistance

C_f= Filter capacitance

V_g= Grid voltage

V_c = Voltage at point of common coupling

V_t= Converter terminal voltage

Introduction

The traditional electrical grid is required to rethink over a new era of increasing per cent shares of power electronics-based sources (PBS), its new control algorithm, load flow analysis for active and reactive power flow, protection system for any symmetrical and unsymmetrical fault, transient, small signal, frequency and voltage stability analysis is a challenging part. Traditional generators producing electricity for the grid have spinning parts They rotate at the right frequency to balance supply and demand and can spin faster or slower if needed. The kinetic energy 'stored' in these spinning parts is our system inertia. The renewable sources used nowadays for power generation doesn’t have similar rotating part and thus grid is referred to as a low inertia grid. These required paradigms to establish stable and dependable operation of electrical power systems with high shares of non-conventional energy sources like solar, wind or any other storage devices. When more inverter-based sources like solar, wind and BESS are integrated with such a grid having no or less inertia, grid synchronization is the most challenging part. It will create large voltage and frequency fluctuations and unstable operation of the grid. This may lead to trip IBRs or load. Also, it may arise reliability issues for the power system. Recently system operators (SO) in Europe, Texas, Denmark and Ireland are experiencing issues with a higher penetration level of IBRs. The issues are more challenging when penetration of IBRs goes above 50-60 % with very few traditional synchronous generators. The challenges that occur are specific to the system, their location and no. of SGs in operation, level of load unbalance, and interconnection between other IBRs. SO of Ireland and Great Britain faces such issues when more than 65% of the load has to be supplied by IBRs. System operators (SO) in Germany and Denmark are recently facing issues when supplying a major portion of load (nearly 100%) through IBPS. They are getting support from the rest of the synchronous area which helps to avoid total collapse. In contrast, a higher percentage of SGs slow down the overall system dynamic response, while currently used grid following inverters (GFL) have fast controllers to accurately track the angle and frequency. However, these fast-responding IBRs fail to synchronize with the system. Which requires robust controllers with high penetration of IBRs. Recently the SO of South Australia, Ireland and Texas are working by frequently limiting the output of IBRs and running with sufficient SGs. They have installed synchronous condensers to provide necessary reliable operations. Still, it is difficult to maintain a minimum number of SGs. Having operations constraints and extra investments, SOs of these countries face the common major challenges of reduction in mechanical inertia due to rotating part of SG to inverter-based static sources. The drastic decrease in stored kinetic energy (inertia) of rotating parts results in drastic frequency oscillations during load unbalanced. It may also give malfunctioning of IBRs and strikethrough non-reliable power supply.

As a solution to these challenges recently the concept of Grid forming converter with battery energy storage system (GFBESS) technology has been investigated by researchers. It offers recent advancements in control techniques, fault right-through capabilities and stability strengthening of a weak grid. Recently Australia, UK and USA have taken up projects to underline trends in power industries by adding GFBESS to address the issues of frequency stability in weak grids.

This paper includes a systematic survey on micro-grid concept and control strategies, low inertia issues with high penetration of IBRs, operation characteristics of grid backing and grid setting up converters and its control strategies to support the grid, challenges faced by the implementation of the mixed system including grid supporting, grid forming and traditional alternator on a massive scale. Also, it needs an assessment of the future scope in the era of grid-forming inverters.

The micro-grid concept and its control strategies are divided into centralized and decentralized control. Micro-grid control strategies must fulfil the required study for power management, power quality coordination control and stability studies[1,2,3]. For this study hierarchical control architecture has been discussed which is classified as: (i) primary control provides primary current and voltage control, power contribution, frequency and voltage stability in the islanding approach. (ii) secondary control includes dynamic and responsive power control, grid synchronization and capability of restoring electrical power management (iii) tertiary control provides coordination of no. of micro-grids, fault supervision and optimization of variables like cost, efficiency, etc. With increasing shares of IBRs in the power system, issues with low inertia and its solution have been reviewed by Tamarakar in 2017[4]. The virtual inertia concept has been introduced by the author in 2008 by J. Driesen[5]. The behaviour of IBR has been emulated as a conventional synchronous generator by providing virtual inertia support for improving grid stability and reliability under contingency conditions. Virtual inertia control techniques are required to be developed for the successful operation of IBRs. Which have been investigated by J. Driesen, 2008, and H. Bevrani, 2014 and in 2017 J. Liu[5,6,7]. The virtual synchronous generator currently works as a current source inverter that controls the grid's frequency and voltage under the grid-supporting mode of operation.

Operation of a micro-grid with solar and wind integrated with the power grid through the inverter is considered as grid following mode of operation. This concept has been introduced by L.Liu [8]. This grid-following inverter has a low over-current rating due to power electronics devices. Also, solar and wind farms are located at a far distance with high impedance which creates voltage variation issues at the point of common connection through conventional control of the grid resulting in a fragile grid. Looking at the above issues with increasing shares of PBS the researcher D. Pattabiraman has proposed a concept of grid forming inverter with a battery storage device (GFM BSD) capable of supporting grid operation under grid-associated mode and isolated mode under normal and contingency action without depending on service of synchronous generator and synchronous condenser to completely work on 100% IBR[9]. In the era of 2019-20 authors Matevosyan, Rosso, and P. Unruh have worked on the grid forming converters control approach and its successful grid synchronization[10,11,12,13]. They have also discussed the overview of GFM, and their basic operation in grid-connected and islanded modes. Control techniques for voltage and frequency regulation, grid synchronization of GFM. The advanced control techniques of GFM have been investigated by W. Du and N. Pogaku[14,15]. Both papers have discussed basic governing methods like sink control, synchronization with the power controller, effective synchronous mechanism control, synchronverter, identical control, and computer-generated oscillator controller. These control techniques determine to control frequency and voltage for the large imbalance in load. Researcher W.Du has given a detailed comparative analysis of different GFM control techniques, which is not considered in papers by Rosso[13,14]. Comparison parameters are virtual tunable inertia, PLL synchronization, and overcurrent protection[15]. After reviewing papers by Rosso, W. Du, and R. Majumder on Grid forming converters control approaches, grid-synchronization and future trends, a comparison between various techniques has been shown in table-II[13,14,16]. Challenges with existing control techniques of GFM and a wide perspective of research opportunities have been discussed by W. Du, N. Pogaku, and J. Hu. The challenges are about GFM stability analysis with a low inertia system, weak grid, the optimal location of GFM with the smallest short circuit ratio (SCR), and frequency stability as the high penetration of GFM BESS drastically changes grid dynamics and give impact on system frequency and re-occurrence of frequency[14,15,17,18]. This will impact security strategies and load-detaching schemes to rethink. Transient stability analysis of GFM BESS has been studied through equal-area criteria. Capabilities of GFM BESS in grid-connected mode have been investigated by S.D'Arco. The GFM is capable of providing synchronization stability without the need for PLL, Generating Units and Power Park Modules to ride through fault, and smooth transition from isolated mode to grid-associated mode[19].

Major challenges with GFM and the future scope for further research in the area of GFM BESS have been covered by Ndreko in 2018, Tayyebi in 2020 and Rathnayake in 2021. The authors of these papers have come up with some open research questions like how the system will function and what will be the solution of network reshaping sources with backup energy storage provided for very low inertia of synchronous generation. How much reserve capacity is available to keep frequency within the limits mentioned by the IEC standard? What are the new limits provided by the IEC standard for a strong inverter-based grid?[20,21,22]

The answer to this question has been presented in this paper. Major topics covered in this paper are (I) modelling of synchronous generators, operational structure of grid following and grid forming inverters with battery storage (II) Control techniques of GFM for a system without rotating parts with high percentage shares of power electronics-based sources (III) Challenges with GFM converters control to enhance frequency stability (IV) future scope in the area of grid-forming control techniques.

(I) Modelling structure of Synchronous generator and Grid integrated inverters

(a) Synchronous generator

A typical synchronous generator behaves as a voltage source with small internal sub-transient reactance. When there is a sudden load change, it supplies the required current, but its internal voltage remains the same. At the same time, prime mover action takes place slowly. This will create an imbalance between electrically generated energy (P_{elec}) and mechanically generated energy (P_{mech}) and it strengthens the rotor to rotate at its new speed. The primary control action of the generator is to regulate voltage and frequency which is achieved by exciter and governor control. The swing equation (1) provides the required inertia constant to be varied as per the imbalance between P_{mehc} and P_{elec}. The inertia constant H is significant for a synchronous generator to maintain frequency firmness during any inequality of load, also it is having high fault current handling capability. Active power flow and frequency can be easily controlled using P-f droop control characteristics represented by equation (2).

$$\boldsymbol{P_{mech} - P_{elec} = 2H\frac{d\omega}{dt}} \qquad \text{............(1)}$$

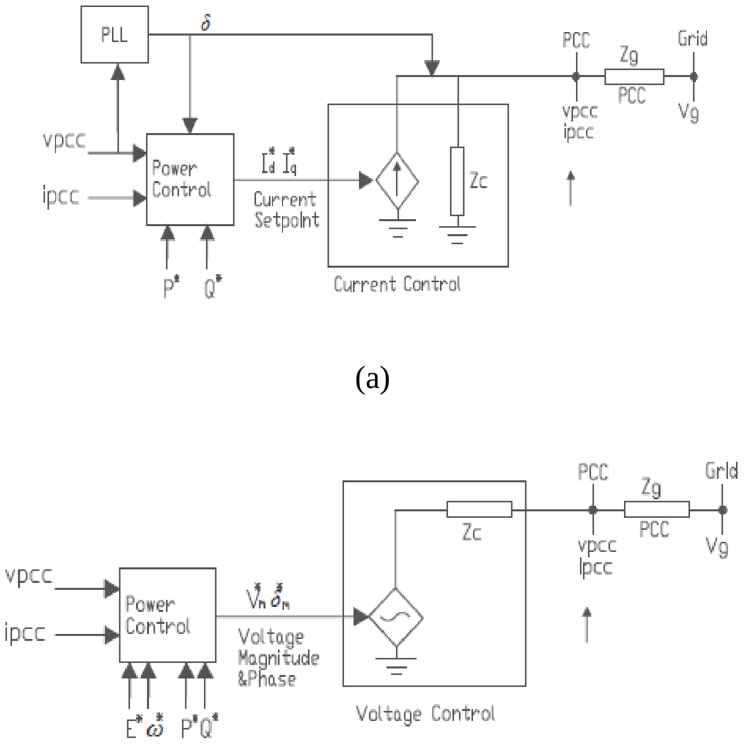
$$\boldsymbol{P_{in} - P_{out} = J\omega\frac{d\omega}{dt} + De\Delta\omega} \qquad \text{........... (2)}$$

$$\text{Where, } \Delta\boldsymbol{\omega} = \boldsymbol{\omega_m} - \boldsymbol{\omega_e}$$

Where D_e is the damping constant, $\boldsymbol{\omega_e}$ is the grid frequency and $\boldsymbol{\omega_m}$ is the reference frequency. With the increasing demand for renewable energy sources like solar, wind, and battery storage due to their intermittent behaviour, the overall control of a mixed power system needs to be rethought and re-designed.

(b) Modelling of the grid-following inverter

Recently most of the grid-connected renewable sources work in grid-following mode. It means that all the time it gets synchronized with the grid using phase lock loop (PLL) control. Grid following inverter (GFL) behaves exactly as a current source. They follow the network voltage and frequency but do not have the ability to control frequency output. They don’t have intrinsic voltage source behaviour. Also, these GFLs are not considered with sufficient storage to provide inertia response. Power electronics-based inverter sources have very low fault current level capability compared to conventional synchronous generators. The major challenges with increasing levels of IBRs with GFL behavior are voltage and frequency stability. Figure 1 (a) and (b) show control diagram of GFL and GFM. (Rathnayake D., 2021)



(a)

(b)

Figure 1: Approximate control diagram (a) GFL inverters and (b) GFM inverters[22]

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(c) Modelling of grid-forming inverters with battery storage

From the latest research study, it has been noticed that as the percentage shares of the grid following inverters increases, by eventually decreasing synchronous generators, the system stability is greatly affected. Micro-grid can function as a grid synchronization mode or isolated mode. When it is in a grid synchronized mode its function is to control voltage and frequency as per grid code i.e. it follows the grid. In an island mode, one or many inverters regulate voltage and frequency and form the local power grid. This instigates the concept of grid-forming converters. GFM BESS act as a voltage source converter to provide the local voltage and frequency support to the grid as shown in fig.1 (b). Thus GFM has a self-synchronization capability in absence of grid signals. This makes the power system completely work on 100% IBRs.

The desired functionality of GFM are as follows:

i) Under normal operating conditions it should work as an AC voltage source with a small internal impedance.

ii) It should work satisfactorily when there is a transition from grid synchronization mode to isolated mode.

iii) It should provide black start service with sufficient energy storage capacity (like battery storage, and super capacitor.

iv) It should be capable of arresting frequency dip and increase the frequency nadir under sudden load imbalance or contingency of SGs.

v) It should be capable of providing optimum inertia support to maintain the system’s safety.

With the above-required features, GFM is required to emulate the behaviour of SGs in the concept of a microgrid. Initially, this concept was developed for islanded operations but now the same is adopted for large-scale distribution systems especially when wind and solar are integrated into large power systems [19]. A comparison of operational functionality between GFL and GFM has been summarized in Table-I[20,21,22].

(II) Control strategies of GFM for low inertia system

Currently, all Grid following inverters (GFLI) is operating on current control, while grid-forming inverters (GFMI) can form voltage vectors at their common point of connection. To coordinate with the grid this voltage vector is dynamically controlled. In a grid-connected mode of GFM, the reactance to resistance ratio (X/R) plays an important role in deciding the relation between active power and reactive power. The power stages of GFM have been shown in figure 2. In this Lg and R_g are responsible for the X/R ratio of a line connecting GFM with the grid. If this ratio is very high, then active power is used to control frequency called power-frequency droop control. The Responsive power controls the magnitude of the voltage at the PCC called reactive power-voltage droop control. On the contrary, if X/R is less then it follows Q-f droop and P-V droop characteristics. In general, the approach for all control techniques is to enhance the strength of the system.

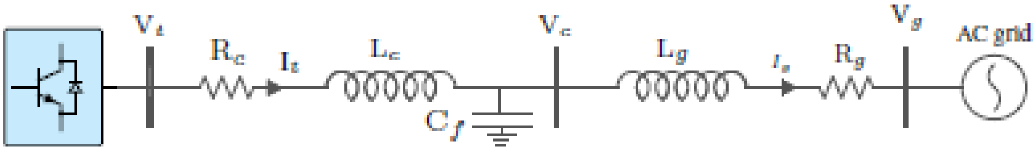

Figure 2: Power stages of Grid forming inverter[22]

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(a) Droop control technique

The Droop regulator method was being used for operating many SGs in parallel to share the dynamic and responsive power and accordingly common frequency and voltage at the PCC. This method has been successfully used for two decades and it requires no communication with other operating power grid centers. That is the reason these control techniques fall in a decentralized mode of control over major load imbalances. The control equations are shown in equations (3) and (4).

$$\omega = \omega_{ref} + K_D (P_{ref} \; . - P) ....(3)$$

$$\upsilon = \upsilon_{ref} + K_v (Q_{ref} \; . - Q) ....(4)$$

Where, ω_{ref} is the standard grid frequency, K_D and K_V-are the droop coefficient. To eliminate high-frequency harmonics normally droop controllers are used with low pass filters. Researcher Tayyebi A. has explained the droop control method to improve the transitory response of the conventional droop control method where droop control is applied with derivative and integral control. This overcomes the issues of transient current and power-sharing accuracy. Sometimes this droop control technique is used to regulate the angle and magnitude of the voltage at the grid connection point. The advantage of phase angle droop control is no internal inverter communication is required and values of droop co-efficient are selected based on load distribution and voltage variation[21].

(b) Virtual synchronous machine-based control

The droop control technique does not provide inertia and damping support. Thus it persists with stability issues. To overcome this virtual inertia-based control was proposed by S.F.Zaveri, and Lopes in the last decade. In this control technique, a virtual machine is modelled exactly like a synchronous generator, with armature winding, excitation winding and damper winding[23]. The virtual machine voltage is calculated based on the measured current then it has been fed to the grid. The latest virtual inertia control offers the measurement of grid current, generating reference voltage signal for active and reactive power control. It is controlled in a similar way to SGs i.e. dynamic power is controlled by torque and responsive power is controlled by the voltage at the excitation. A virtual synchronous generator (VSG) has a minor frequency concavity due to virtual inertia and damping which reduces the transient peak and it is provided by virtual impedance. The author in paper ref [24] has proposed tunable inertia constant (J) and damping constant (D), according to load imbalance and required active and reactive power sharing. Also, this will help to provide a stability margin for the rating of the power grid, no. of GFC and SGs connected in the power system. These variable values of J and D are related to the D.C. link capacitance value which is connected between the inverter and filter. From the results of the paper [24], it has been observed that if the DC link capacitance value increases the settling time of frequency response decreases. Also the other parameters like DC link inductor, AC-side inductor and capacitor and moment of inertia constant help to decrease the frequency dip and provide faster settling time[24]. The overall effect on frequency dip by adding virtual inertia can be seen in figure 3. Classification of different virtual inertia control techniques is shown in figure 4. After reviewing control techniques of GFM proposed by Rathnayake and S.F. Zaveri, one can easily compare their operational functionality in terms of virtual inertia tuning, grid synchronization, fault-ride through capabilities which have been summarized in table-II[22,23].

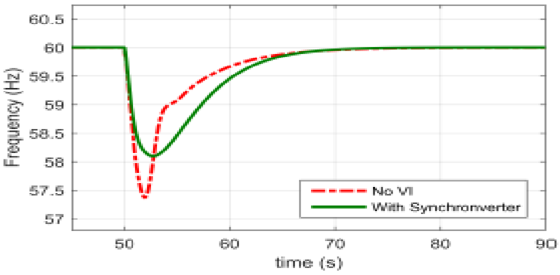

Figure 3: Effect of inertia on frequency response[4]

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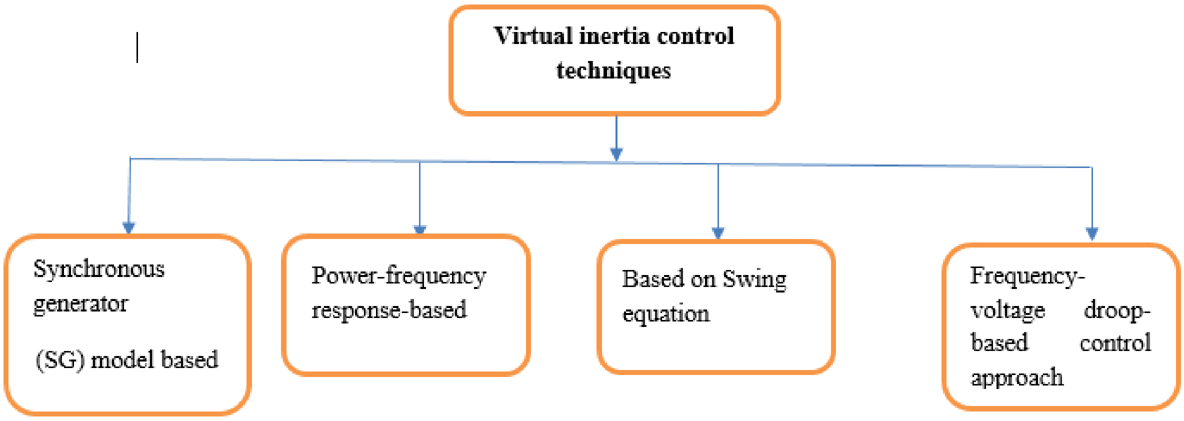

Figure 4: Classification of virtual inertia techniques

(III) Challenges with grid forming inverter control

The ultimate function of GFM is to work as a voltage source inverter not as a current source inverter, which creates some limitations. The inverter current is not strongly controlled in a basic GFM control method. As a consequence of this, when load changes or any contingency condition occurs such as a fault or grid transient it becomes a difficult task to limit the overcurrent of GFM. Thus advanced regulatory control methods like current limiting using virtual impedance is required to achieve overcurrent limitation.

Normally GFC acts as a voltage source in isolated mode, so implementing its operation in grid synchronization mode is a crucial task. Existing grid-tied inverters are working in the grid-following mode, in future, if they are replaced with grid forming mode of operation then it is important to study the dynamic behaviour of the power system with a combination of GFL-GFM-SG. Major difficulties with GFM operation have been resolved for the microgrid. But a more detailed research is required for the application of GFM to a larger power system.

Major challenges with GFM and the future scope for further research in the area of GFM BESS have been covered in this paper like how the system will function and what will be the solution of network reshaping sources with backup energy storage provided for very low inertia of synchronous generation. How much reserve capacity is available to keep frequency within the limits mentioned by the IEC standard? What are the new limits provided by the IEC standard for a strong inverter-based grid? What percentage shares of GFM can be optimal for power system stability and security? The optimal location of GFM is also a challenging task for the overall system loss reduction[11].

(IV) Research gap analysis and future scope

Non-isolating for distributed inverters is one of the biggest difficulties. In case of sudden disconnection of SM, the GFM is required to supply the total load with the given power limit. But at that time DC source current exceeds the limit and saturates the DC source for a prolonged period. At the same time due to the slow response of SM with fast responding GFM for large load disturbances up to several seconds, the SM doesn't reach its stable power injection. During this time, the reaction of droop control results in a power inoculation which exceeds the DC source limit and collapses the DC voltage. Also results in exhausting the DC link if the alternating current of the converter is not limited. In the GFM converter, AC side measurement is used to drive the angle dynamics with active power measurement and improves the frequency performance of GFC. DC voltage measurement using matching control gives direct current limits. Review analysis shows that combined AC side and DC side control for complementary benefits by GFCs is yet not taken for study[21]. Further research can be carried out on combined AC and DC control along with frequency stability constraints with GFM.

Also, these research papers have not included how reactive power load demand could be supplied by Power electronics-based resources. For supplying sufficient active and reactive power demand, how much battery energy storage is required in contingency conditions is not considered in an existing grid forming inverter control techniques. Along with frequency stability how the voltage stability gets affected due to insufficient reactive power supply from PEB sources is still an open challenge.

Some significant research can be done in this sector for the advancement of this concept in the future. For example, the combination of multiple grid-forming concepts (e.g., a hybrid model of a virtual oscillator and matching control) can be conducted by highlighting the strengths and neglecting the drawbacks of specific methods.

	GFL inverters	GFM inverters
1.	Behaves like a current source.	Behaves like a voltage source.
2.	Can be operated only in grid-connected mode by following grid voltage and frequency.	Can be operated in both modes by giving stable operation of the grid.
3.	The primary objective is to supply dynamic power with a maximum power point tracker therefore responsive power supply is the least. The secondary objective is to support the grid	The primary objective is to vary grid frequency and voltage by changing the active and reactive power reference of the grid.
4.	Need PLL for synchronization with the grid.	It may use PLL to change the mode of operation from grid connected to isolated and vice versa.
5.	Measurement in delay makes its response slow for a sudden change in load.	Depending upon a change in grid voltage angle it gives an instantaneous response.
6.	The strong dependency on active and reactive power control.	Slight coupling between active and reactive power
7.	Requires reference voltage at the point of common connection to supply necessary active and reactive power.	Can back-start a power system.
8.	The stability margin reduces for a weak grid.	Having self-synchronization property under weak grid operation with concern on current limitation.
9.	Cannot operate at 100% IBRs: instability threshold exists.	Can be operated at 100% IBRs penetration: can co-exist with grid following inverters.
10.	It gives a more oscillatory and under-damped response which increases the frequency peak.	It gives a better-damped response and decreases frequency peak.

Table 1: Comparison of operational functionality between GFL and GFM inverters

Control Techniques	Advantages	Limitation
Synchronous generator (SG) model-based	• Perform the same as SG dynamic characteristics. • Derivation of frequency term is not required.	• The absence of frequency derivative terms creates noise in the System • The absence of a current-control mode, cannot protect the system against over-current faults.
Swing equation-based approach	• The Mathematical model is very simple compared to SG based model. • Derivation of frequency term is not required.	• The absence of a current-control mode, cannot protect the system against over-current faults. • False tuning of the damping factor and moment of inertia system gives fluctuating reactance.
Power-frequency response-based topology	• Implementation of a control strategy is very easy. • It applies current source operation. • It has in-built over-current Protection.	• ROCOF gets affected with inertia constant tuned as per demand. • only suited for a grid-synchronized mode of operation where the system works as a grid-following inverter. • Problem is to deal with the uncertainty of the PLL, and the sensitivity related to the frequency derivative.
A frequency-voltage droop-based control approach	• No communication is required. • Basic control is very much similar to conventional droop control in a synchronous generator.	• sluggish transitory response • Compromise between power-sharing and voltage oscillation precision. • Harmonic current sharing is unstable. • Control of voltage and frequency is highly dependent on the output impedance of the inverter.

Table 2: Comparative analysis of GFM control techniques

Conclusion

This paper discusses the conceptual difference between grid forming and grid following inverters for the large interconnected system. From the critical review of the literature, it has been proposed that with increased sharing of IBRs, the GFM with sufficient storage capacity is capable of supporting power system dynamics by using appropriate control techniques. The purpose of GFM control is to provide the required voltage and frequency at PCC in grid-connected mode and isolated mode, i.e., acting as a voltage source inverter. This is achieved by using a suitable control technique. Various GFC control methods have been reviewed in this article. Concept of virtual inertia by emulating the behaviour of GFM as a synchronous generator has been discussed with different virtual inertia-based control techniques with their comparative study. Looking at the potential of GFM, it is capable of providing ancillary services like fault ride-through capability, system strength for the weak grid, contribution to system inertia, fast frequency response to any load variation or other contingencies like disconnection of any generating unit, power restoration capabilities on the occurrence of larger black-out with the high percentage shares of power electronics based sources. The areas which require the next step toward research and development are also discussed.

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Glossary:

Electric Grid- The electric grid is a network which connects the electric power generation with the consumer through transmission and distribution lines controlled through one or more control centers.

Inverter- The inverter converts DC energy to AC energy, which is the standard form of electricity used by utilities and most of the home appliances.

Battery energy storage system- Battery storage, or battery energy storage systems (BESS), are devices that enable energy from renewables, like solar and wind, to be stored and then released when customers need power most.

System Operator (SO)- A system operator is responsible for ensuring sustainable energy distribution to customers, businesses, and industry.

Inertia- Inertia is the property of a body due to which it opposes or resists any change in its state of rest or uniform motion.

Virtual inertia- Virtual inertia is the short-term stored energy in the DC link of the renewable energy sources power converters, which should be injected to the AC side for the virtual inertia control under load imbalance.

Droop- Droop is a method of controlling the reactive power of an alternator as the load increases. This is used in synchronizing applications, where multiple generators are in parallel.

Damping- Damping is a reduction in the amplitude of an oscillation as a result of energy being drained from the system to overcome frictional or other resistive forces.