International Journal for Innovative Engineering and Management Research
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IJIEMR Transactions, online available on 31st Oct 2022. Link :http://www.ijiemr.org/downloads.php?vol=Volume-11&issue=Issue 10

DOI: 10.48047/IJIEMR/V11/ISSUE 10/10

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Volume 11, ISSUE 10, Pages: 86-96

Paper Authors

Dhulipudi Sri Shanmukha Subhash, Dr. Chappa Hemanth Chappa ,
Dhoni Sai Kumar

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EFFECTS DUE TO INTRACTION OF CONVERTERS ON GRID: A REVIEW

Dhulipudi Sri Shanmukha Subhash [1], Dr. Chappa Hemanth Chappa [2] , Dhoni Sai Kumar [3]

[1,3]B.Tech Student, Department of Electrical and Electronics Engineering, GMR Institute of Technology, Vizianagaram District, A.P, India
[2]ASST Professor, Department of Electrical and Electronics Engineering, GMR Institute of Technology, Vizianagaram District, A.P, India.

Abstract— This article will cover the effects due to converters on the grid as well as various solutions to these effects. It is observed that system instability is the key issue. For this instability in the system two main causes can be identified. 1) Due to line impedance effect especially under weak grid conditions and 2) If the micro distribution system is non ideal then the system it- self act as voltage source with significant impedance. As a result, the non-ideal grid interacts with power converters connected to the grid, leading to system instability. By employing techniques like virtual impedance method, Active damping method and Resister in series to the capacitor of LCL filter we may stabilize the system. By using methods like root locus analysis and bode plot we can find the stability. In this work, a thorough review is carried out to detect the converters stability while operating with renewable grid. This work also gives the classification of converters at which they are used in the system stably. The available analysis methods are also discussed in the present work.

KEYWORDS: Instability, Line impedance, non-Ideal grid, Converters, Virtual impedance, Root locus analysis, Bode plot, Active damping, LCL filter

INTRODUCTION:

The usage of converters has grown significantly in recent years due to many desirable features, such as high efficiency, controllable power quality etc. Converters operating in rectifier mode has wide range of usage in variety of industrial applications and commercial applications, such as power supple for telecommunication equipment's, battery storage systems and many more. It is clear that many converters can be connected to the power grid [1] as the range of converter usage has widen. When each converter connected separately to grid there will be no impact on stability. however, the mutual connection of these converters through grid in practice might result in a stability problem when the two converters have been developed separately based on their individual application requirements.

In this paper, we make an effort to address the significant issues of the interaction between the grid-connected converters under non-ideal power grid conditions. The bifurcation boundaries (stability regions) generally shrinks when the converters interact through the non-ideal grid. In this we are going to address some techniques which are used to find stable region in which the system is stable. And some techniques by which we may make the system to be stable. In section I we discuss about the instability, in section II challenges faced, III causes for instability in power grid, in section IV discussed about some methods to analysis stability.

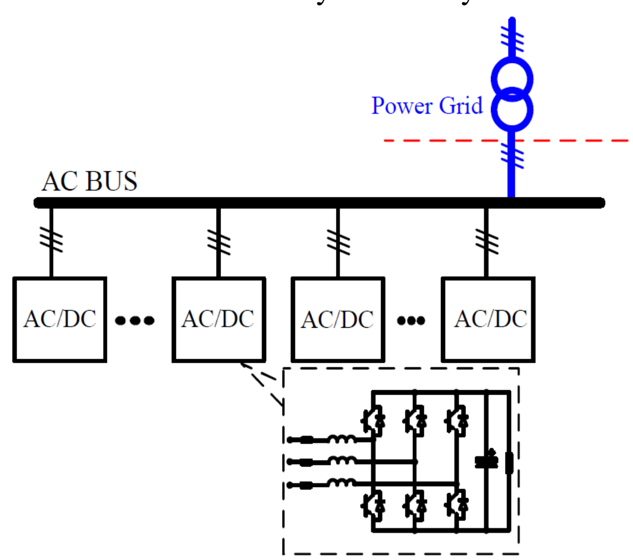

Fig:1 converter connected via power grid [1]

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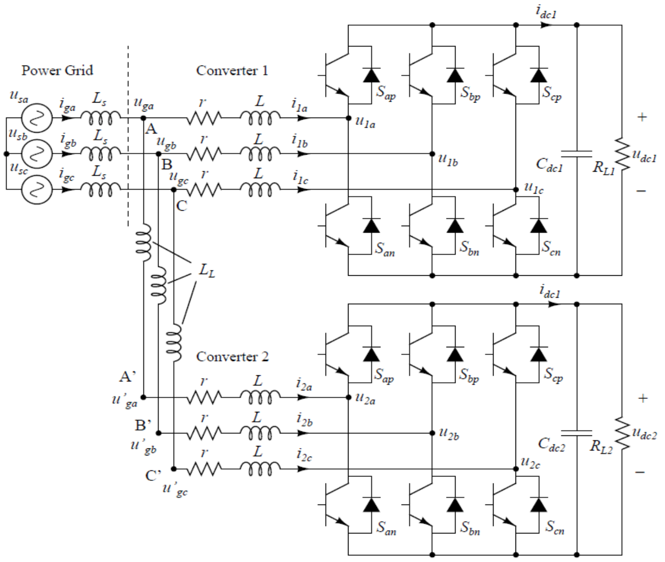
I. A BRIEF OVERVIEW ON INSTABILITY

When one converter connected separately to the non-ideal grid is stable and another converter connected separately to the same non-ideal grid is also stable [1]. From this we can say that the converters are designed separately according to their respective application conditions connected to same grid separately has no impact on system stability [1].

If n converters coupled to a non-ideal grid simultaneously then the system will be unstable [1]. This can be determined by mat lab code root locus analysis. The output graph will have irregular raisings and fallings of the curve which indicates instability of the system.

II. ANALYSIS

For analyzing the stability, we use Root locus analysis [2]. By using this technique, we demonstrate that when converters interact through the non-ideal grid, the bifurcation borders (stability regions in engineering viewpoint) often diminish. Previous research has shown that the impedance-based strategy is more advantageous and adaptable for grid connected converters. The impedance-based analysis [3] [4]is quite appropriate in the situation of the grid-connected system under study, as will be shown in the following subsections. In impedance-based strategy we have two conditions [4]. They are



It means there will be no impact on stability even if n number of converters connected to same grid separately. This can be determined by running MAT-lab code using root locus analysis. The output this shows have minimal raisings and fallings of the curve which indicates stability of system.

Fig: Common model of two converters connected to non-ideal grid. [1]

A. Interaction of converters in presence of Transmission line impedance.

If the two converters are linked to a non-ideal power grid at two different sites that are apart by an impedance, the stability of the system may be damaged [5]. In figure 2(a) the Thevenin equivalent circuit of the system in the presence of transmission line impedance is easily found using the same impedance-based method.

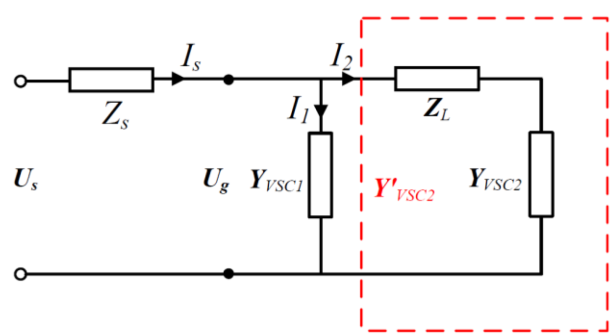


Fig: 2(a) Impedance model of the in *dq*-frame. [1]

B. Interaction of converters in absence of Transmission line impedance.

As shown in Fig. 2, a general system with several converters linked to an imperfect power grid at the same point of common (PCC) can have the stability of the entire system estimated (b). Only when there is no transmission line impedance is it feasible. [5] [6]. the associated system's total input admittance.

$$Yvsc = Y_{vsC_1} + Y_{vsc_2} + Y_vsC_3 + \cdots Yvsc_n$$

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From the previous studies, system is stable if the converters are connected at PCC.

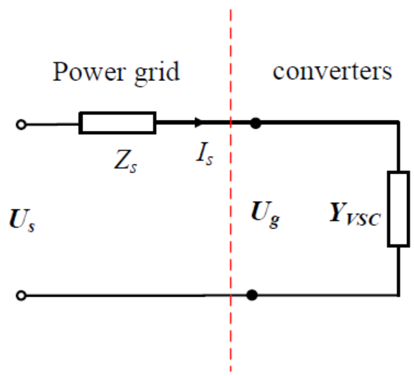

Fig: 2(b) Thevenin's equivalent circuit of numerous converters coupled to an imperfect power grid at the same point in time. [1]

We can infer that transmission line impedance causes system instability [6]. The interaction between the converters increases the instability risk as the transmission line impedance increases. It is abundantly obvious from the research shown above that while the individual, independently operated converters remain stable, the interacting converters may become unstable. It also demonstrates that this instability can occur when transmission line impedance exists between the sites of coupling. [6].

III. CAUSES FOR INSTABILITY IN POWER GRID

1. Short circuit.
2. High-Frequency interactions between converter and HVDC grid.
3. LCL filters of grid-connected converters

1.SHORT CIRCUIT

Under grid failures (short circuit), converter-based generation can perform very differently from conventional alternators. [6] [7] It is required to consider a number of current management schemes for voltage source converters (VSC) during unbalanced faults in order to assess the possible impact of converter-based power systems on protective relays. This is because the performance of converters is primarily dependent on their control objectives. When considering semiconductor capabilities and the converter current limit issue, it is important to keep the fault current produced by converters within secure operation limits [8].

Usually, the control system for a current-controlled VSC system comprises of a slower outer controller and a quicker inner current controller. Depending on the application, the outer controller regulates the PCC's output power, the DC side voltage, the AC side voltage, and generates current references for the converter current's inner current controller [8]. The method used to create current references is a key factor in determining how well the converter performs in grid unbalanced failures.

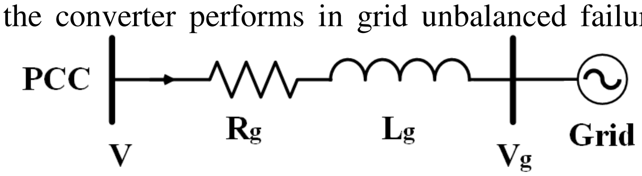

Fig: Power system simplified as seen from the PCC [2]

Control solutions for unbalanced grid failures may also be created based on regulation of phase voltage, as grid codes mandate converter-based production to inject reactive current to sustain grid voltage during voltage dips [9]. The voltage support notion is initially presented in this section utilising symmetrical sequence theory [10]. Following the explanation of two broad control strategies that may change the relative relationship between positive and negative sequence power either semi-flexibly or flexibly, a discussion of how to choose the values of flexible coefficients is provided [9]. Next, a discussion of the interactions between various flexible control systems follows.

2.HIGH-FREQUENCY INTERACTION BETWEEN CONVERTER AND HVDC GRID

Recently, converter-related instabilities caused by high-frequency oscillations at the converter's ac side have surfaced, raising the issue of whether equivalent interactions can also occur at the converter's dc side [10]. Analytical impedance-based approaches are used to assess the dangers posed by such interactions inside an HVDC grid, as well as the effect of the internal dynamics of the MMC and dc system resonances on the stability.

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The impact of MMC dynamics on system stability, However, the non-passive behaviour is what really causes the instability. behaviour of the MMC since this results in a positive feedback effect with amplification of the HVDC grid's resonances. The MMC dc-side admission YMMC may be modified by modifying the control parameters it was seen that the output control has no issues on the non-passive in the kHz-range but it has influenced the system interactions of the lower frequency's [12]. The internal control loops and time delay may still have an impact on the non-passivity in the kHz range, though.

3.LCL FILTERS OF GRID-CONNECTED CONVERTER.

Due to its compact size and good attenuation of current harmonics, The LCL filters are mostly used for the interface of dispersed generating systems to the grid. However, due to the resonance of LCL filters [6], the converters current controllers often have a bandwidth that is only slightly greater than the LCL filter's resonant frequency. If not, the stability of the system would be in danger, particularly in high power systems when internal loss and switching frequency are relatively low [13].

It is suggested to use an active damping technique that is equivalent to connecting a resistor in series with the filter capacitors in LCL filter. It is demonstrated that using the suggested damping technique, the LCL filter's bandwidth can be extended the further than with a typical capacitors current feedback damping technique [13].

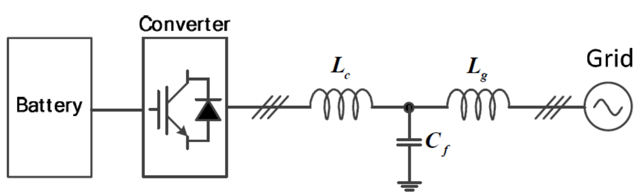

Fig: Setting up a pulse width modulation converter linked to the grid [3].

1. PASSIVE DAMPING METHOD

Passive damping approaches may be divided into several groups based on the many ways resistors are added to the LCL filter.

one by splicing a resistor into the filter's series connection. The second order component is added to the denominator as a result of the damping resistor, which produces the damping effect. In comparison to the scenario when there is no passive damping filter, this strategy reduces the LCL filter's attenuation slope from -60 dB/dec to -40 dB/dec, which lessens the suppression of the switching ripple components. [14].

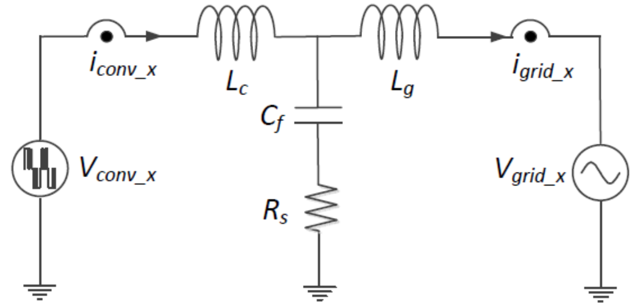

Fig: Passive damping method with a resistor in series with LCL filter capacitor.[3]

Another option is to connect a resistor in parallel with the filter capacitor. Resonance is reduced because of the parallel resistor's (Rp) lower impedance, which is lower than the filter capacitors. Additionally, the characteristics of the original LCL filter are maintained in the switching frequency range due to the filter capacitor's impedance being lower than that of the parallel resistor [3] [14]. The switching harmonics are effectively suppressed as a result of the attenuation slope remaining at -60dB/dec. However, because the losses from the parallel resistor are often higher than those from the series resistor approach, parallel resistor insertion is less frequently taken into account for passive dampening methods.

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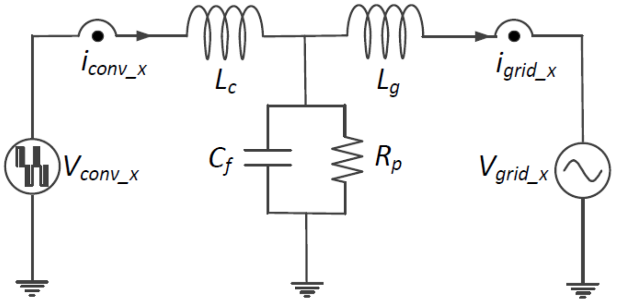

Fig: Resistor paralleled to the filter capacitor for non-negative dampening. [3]

2. ACTIVE DAMPING METHOD

By altering the regulator's structure, the active damping techniques provide effects similar to those of virtual resistors. To achieve the active damping, the converter voltage reference is frequently added to the filter capacitor current with a proportionate gain (Kd). The transfer function from the grid current to the converter voltage reference is modified, which leads to the addition of the second order component to give a damping effect, when the PWM voltage synthesis is conceived of as having unity gain [3] [15].

A fictitious passive damping system can stand in for the traditional active damping technique. It has been found that when the PWM gain is unity, the passive damping approach utilising a resistor in parallel with the filter capacitor and the active damping technique using the typical filter capacitor current feedback are equivalent. Therefore, by choosing the right value of the parallel damping resistor, Rp, the feedback gain, Kd, for the active damping in the classic technique may be established.

$$k_d = \frac{Lc}{c_f R_P}$$

IV. HIERARCHICAL CONTROL STRUCTURE

Synchronous generators (SG) are currently being replaced with power electronics converter-based generators, which is leading to two issues for overall power systems:
In order to solve these issues, a hierarchical control method that regulates the active and reactive power requirements of the PCC of the ADN by coordinating the output powers of the network's DGs is presented.

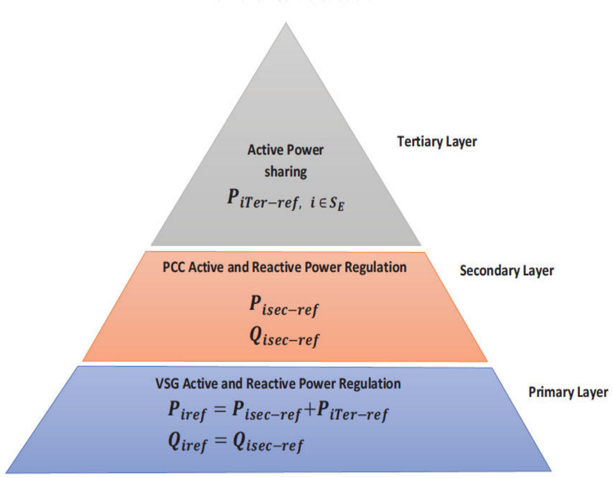

Fig: Hierarchical Structure of the proposed strategy [10]

A generic ADN with four bidirectional converter-interfaced DGs is employed to carry out this technique. To accomplish our intended aims, we a damping effect are achieved with the addition of second order components [10].

A virtual passive damping system can be used to represent the traditional active damping approach. It has been found that when the PWM gain is unity, the active damping technique with the conventional filter capacitors current feedback and the passive damping method with a resistor in parallel to the filter capacitor are equivalent [10]. Therefore, by choosing the right value of the parallel damping resistor, Rp, the feedback gain, Kd, for the active damping in the classic technique may be established.

$$k_d = \frac{Lc}{c_f R_P}$$

Synchronous generators (SG) are currently being replaced with power electronics converter-based generators, which is leading to two issues for overall power systems:

1. Negative effects of extra electricity from producing units that are not dispatchable that is not used. lower inertia constant [14].
2. This method should be used with a three-layered construction, as shown in Fig. 3. VSG control is used at the primary control layer to link each bidirectional converter to the grid. An additional control layer is used to manage the PCC's active and reactive power requirements. This layer detects the output necessary to calculate the difference between the desired and real PCC powers, which is equal to zero. In the tertiary control layer, a consensus-based distributed control mechanism is utilised to give the network the ability to coordinate [14]. Each DG communicates with its neighbour using a consensus-based mechanism to divide active power sharing proportionally among them. Depending on the layer's importance, each layer's time frame varies. For example, the primary layer responds to changes in active and reactive power in accordance with local knowledge and takes action first, whereas the secondary layer acts later. whereas the tertiary layer functions following the secondary layer. Under each subsection, a thorough description of each layer is provided [15].

S.NO	Methodology	Advantages	Disadvantages
1	In this paper it is stated about the effects that are caused due to converters when they are coupled to grid, for this they have used techniques like root locus analysis and state space approach is also used for finding the stability of the system [1].	✓ Easy to implement ✓ Stability is increased. ✓ Can handle large output current. ✓ Can anticipate the system's performance with ease.	✓ May not be suitable for non-linear system. ✓ Decreases in Significance at High Frequencies or High Damping.
2	In this paper they have mentioned about the problems faced by the power system due to replacement of synchronous generators with converters. For this they have used the Hierarchical control strategy [2].	✓ Feasibility of the network is improved. ✓ Harmonics can be filtered ✓ High efficiency	✓ Complicated design ✓ Low over load capacity
3	In this the main problem is system instability due to line impedance effect especially under weak grid conditions. To over come they have used virtual impedance method to stabilize the system [3].	✓ Easy to implement ✓ Improved power quality ✓ Stability is improved ✓ Performance is enhanced	✓ Voltage distortion problem due to harmonics. ✓ Difficult to optimize.
4	This study discusses the implications of various weak grid situations, including reduced bandwidth and longer reaction times, on the converter's control system. In order to Compensate we need to inject energy externally [4].	✓ Compact size of installation ✓ improved power quality. ✓ Ac voltage compensation	✓ High power losses. ✓ High capital cost.
5	The issue raised in this study was that the LCL filter's resonance frequency was typically far from the bandwidth of the current controller of the converters, which is a limitation. For this an active damping technique is suggested for grid connected converters [5].	✓ Bandwidth is increased. ✓ Small size. ✓ Effectiveness of current harmonics attenuation.	✓ More power is required due to resister in series with the filter.
6	In a grid converter architecture, the effects brought on by the switching frequency are investigated. A laminated iron-core inductor is anticipated to offset this impact on the grid side. For increased precision during optimization, the grid-side inductor is analysed using an analytical high-frequency model [6].	✓ The stored energy in the inductors is minimized. ✓ higher accuracy. ✓ Higher switching frequencies result in a considerable reduction in the LCL filter's size.	✓ Design is Complicated.

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S.NO	Methodology	Advantages	Disadvantages
7	This study provides a quantitative and illustrative analysis of the effects of the current limit in grid forming converters on the transient stability of a system composed of grid forming converters as well as how a high frequency event, phase jumps, and voltage dips under fault conditions affect potential transient stability. It is advised to use a solution-based virtual active power to boost the grid forming converters' transient stability margin when they hit their current limit [7].	✓ Enhanced transient stability. ✓ Accurate.	✓ Less reliability.
8	The point of common coupling voltage enables communication between the current control and the phase-locked loop when a three-phase LCL-type grid-connected converter is linked to a weak grid. PLL dynamic might exacerbate grid Current control and lead to system instability as a result. They improved a current controller's capacitor design, which is a proportional-integral controller, to achieve this. Active current feedback dampening is suggested as a way to decrease the detrimental effects of PLL on current control [8].	✓ Good transient response. ✓ Reduce the steady state error. ✓ The slow response of the over Damped system Can be made faster.	✓ Takes large time to stabilize. ✓ Can be un stable unless turned properly.
9	In this paper it is stated about the effects due to low order background harmonics, which is due to the existence of grid impedance. The current quality of grid-connected converters is decreased as a result of these low order harmonics. The robustness of two single loop control modes of LCL-Type grid connected converters, namely grid-side current feedback (GCF) and converter-side current feedback (CCF), taking the delay effect and weak Grid into consideration, has been assessed in order to improve the current quality of the grid current under distorted grid conditions [9].	✓ Good stability ✓ Good power quality. ✓ The hardware cost is reduced	✓ Takes large time to stabilize.

S.NO	Methodology	Advantages	Disadvantages
10	In this study, the implications of not designing the stable zone of the dual-loop system below a particular critical frequency are discussed. In order to improve the stable region, the have proposed some time delay compensation method. It is suggested to use a time delay compensation method based on Second Order Generalized Integrators to increase the stable zone of the dual-loop Grid Current Feedback (GCF) control system [10].	✓ Easy to implement ✓ Stable region is increased.	✓ Difficult to optimize. ✓ Cost is high as compared to other compensation methods.
11	The stability of the system is examined in this work in relation to high-frequency interactions between a modular multilevel converter (MMC) and high voltage direct current (HVDC). To assess the stability of the system as a result of this interaction, they used an analytical impedance-based methodology. This method is used to examine the impact of transmission line length, grid topology modifications, and fault current-limiting inductors, among other characteristics [11].	✓ Enhance stability. ✓ Accuracy is high.	✓ Less reliability
12	The implications of high-frequency interactions between a Modular Multilevel Converter (MMC) and High Voltage Direct Current on system stability are examined in this research (HVDC). An analogous three-phase grid-connected converter's impedance and coupling admittance models are used for this. The impact of important variables such as grid impedance and the LADRC's bandwidth on stability and the frequency coupling effect is then carefully evaluated [12].	✓ Stability is improved ✓ Performance is enhanced	✓ Voltage distortion problem due to harmonics. ✓ Difficult to optimize.

S.NO	Methodology	Advantages	Disadvantages
13	According to this research, it is difficult for the grid-connected converter to function properly when the ac grid is weak and that power quality and stability problems are present. In addition to Nyquist diagrams and Bode plots, a method of calculating the impedance ratios for different inverters is used to forecast the harmonic stability of the power system [13].	✓ Stability is improved. ✓ Power quality is increased. ✓ Reduce the steady state error.	✓ Difficult to optimize
14	The stability of the system as a result of the interaction between the modular multilevel converter and high voltage direct current is analysed in this research. For this analytical impedance-based method is used [14].	✓ Enhance stability. ✓ Accurate.	✓ Less reliability ✓ Difficult to optimize.
15	In this paper they have stated about some technique in order to overcome the stability issues in the interaction of smart transformer and grid-connected converter. A stabilisation technique based on virtual impedance is suggested to address the stability issue and can be effortlessly included with the ST voltage control [15].	✓ High Accuracy ✓ The hardware cost is reduced	✓ Takes large time to stabilize.

Conclusion:

In this research, we studied about voltage source converters coupled to a non-ideal power grid. The connection of two or more converters via the grid is the focus, along with how that interaction may impact the system's stability as a whole. This work is crucial because converters are being used more and more for applications involved in power conversion that require interfacing with power grid which is often non-ideal. Converters might become more unstable under specific circumstances due to their interaction with one another. In this we have analysed stability using impedance-based approach and hierarchical control strategy. For current harmonics attenuation resistors in series to the capacitor in LCL filter is suggested. This paper points out the overall system stability should be takes into account when converters connected to the grid at a common point of coupling or different points of coupling.

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