Indo – German Energy Program

Energy Transition with DISCOMs

Report for TECHNICAL STANDARDS FOR DER INTEGRATION WP04:

RECOMMENDATIONS ON TECHNICAL STANDARDS AND COMPLIANCE MECHANISMS

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Abbreviations

DER	Distributed Energy Resource
DGR	Distributed Generation Resources
DSO	Distribution System Operator
FRT	Fault Ride Through
HVRT	High Voltage Ride Through
IT	Information Technology
LVRT	Low Voltage Ride Through
MAC	Media Access Control
NREL	National Renewable Energy Laboratory
OT	Operational Technology
PKI	Public Key Infrastructure
RBAC	Role Based Access Controls
TLS	Transport Layer Security
TSO	Transmission System Operator

1. Introduction

After reviewing Distributed Energy Resource (DER) regulations in Germany, the United States and Australia and analysing the current regulations in India, the gaps between the regulations in India and the International study cases were identified. To compliment this analysis, recommendations are provided in this report covering technical standards for voltage control, voltage and frequency ride-through, ramp rate limitations, power quality, islanding, measurement accuracy for protection and control, interoperability and cyber security. In addition, recommendations are given regarding compliance mechanisms to enforce the technical requirements proposed.

Furthermore, a timeline for the implementation of the recommended requirements will be outlined, considering the current capabilities of inverters in the Indian market as well as the cost and complexity associated with implementing the requirements.

2. Recommendations for a DER Technical Standard and Compliance Mechanisms in India

2.1 Recommendations towards technical requirements

2.1.1 General recommendations

DER technical standards should include default parameter envelopes based on power-system level reliability studies. It is recommended that default setting provided within technical standards be centric to India and be uniform among DER classes. Additionally, it is recommended that DER technical requirements offer a wide range of adjustability to suit the capabilities of different technologies as well as fulfil the requirements of distribution system operators.

It is recommended to define DER performance categories within the technical standard based on type of technology, capacity and current or projected DER penetration. This can offer greater flexibility for DER integration, as not all desirable DERs that can meet the full extents of capabilities compatible with power-system level requirements, such as frequency ride through and voltage regulation requirements. For example, IEEE 1547-2018 defines categories I, II, and III specific to voltage and frequency ride through capabilities. Category I provides essential power-system level needs and applies to all state-of-the-art DERs, whereas category III provides a broad set of capabilities which address distribution system reliability needs and power quality needs in addition to essential power system requirements. Category III DERs would require DERs with advanced capabilities and is applicable to certain grids with high DER penetration that may see more voltage and frequency disturbances.

Additionally, the regulatory framework related to DERs must be revised alongside technical standards in order to regulate the extent of which certain DER functions are utilized. One example is that conditions for use of the capability to limit active power by the DSO must be clearly defined, as it results in curtailment of the DER active power feed-in. It is necessary to clearly define under which conditions curtailment is allowed (e.g. under which emergency situations), whether compensation to system owners is provided and how it is calculated, as well as whether a justification for the need for the curtailment must be provided to the system owner. In Germany for example, Distribution System Operators (DSOs), are allowed to curtail up to 3% of the generation from Variable Renewable Energy (VRE) sources connected to their system and the operators of these resources must be compensated in the event their system is curtailed. This provides DSOs headroom to mitigate frequent system upgrades required from increased DER penetration. In South Australia, DER curtailment is used to increase the operational load (electrical load minus VRE generation) in order to keep conventional synchronous generators online to maintain system inertia at a level that ensures reliable system operation.

As DER penetration increases, considerations must be made regarding the standards and regulations governing other equipment connected to the network, namely protection devices. Protection issues may arise with the gradual increase of DERs in the system, impacting protection schemes. Depending on the location of the DER, the fault current contribution may increase or decrease the actual fault current. Hence, protection design must cope with the issues arising from maximum and minimum fault current changes. Additionally, high DER penetration will reduce the available load on certain feeders and may cause certain feeders to operate in reverse power flow during some periods. In this case, under frequency protection schemes must be adapted to cope with the reduced load and the protection relays must be capable of identifying the feeders' flow direction in order to not trip when the feeder is in reverse flow, which would further exacerbate frequency disturbances.

2.1.2 DER response prioritization

Recommendation

It is recommended to clearly define and list the priority of DER grid support functions. Following international good practice, DER responses should be prioritised from highest to lowest priority as follows:

1. Cessation of active power delivery and limit reactive power exchange upon receiving an external input
2. Requirements for the response to short circuit faults and open phase conditions, and voltage/frequency tripping requirements
3. Voltage/frequency disturbance ride through requirements
4. Voltage active power mode and frequency-droop response requirements
5. Capability to limit active power upon receiving an external signal
6. Voltage and reactive power control requirements

Justification

As DER penetration increases and more grid support functions are required from DERs, the priority of the various DER responses must be clearly defined to avoid conflicting DER responses and maintain system reliability. The recommended response prioritization is based on the requirements of standard IEEE 1547-2018, which provides a clear list for the priority of DER responses and is aligned with the requirements of the DER technical standards in Germany and Australia.

2.1.3 Capability to limit active power

Recommendation

It is recommended to require all DERs to have the capability to limit active power as a percentage of their nameplate rating upon receiving an external input sent remotely from the system operator. For smaller DERs (e.g., below 7 kWp), DER owners can be given the option to apply a static limit to the DER's active power output. This limitation can be specific to different regions/distribution grids in India and be based on, for example, the DER installed capacity threshold for single phase interconnection.

Justification

In order to ensure grid stability, transmission and distribution grid operators must be capable of curtailing the power generating systems in their area, including DERs in areas with high DER penetration. Typically, the use of this functionality is only allowed under emergency operating conditions and the conditions for curtailment must be clearly defined in the regulations.

In Germany for example, up to 3% of the forecasted annual electricity production of PV in the respective grid area can be curtailed in order to ensure grid stability while saving on grid expansion costs, since curtailing the output of renewable energy systems during peak periods is cheaper than expanding the electricity grid [1].

DERs with an installed capacity of less than 25 kWp (to be reduced to 7 kWp in the future when smart meter gateway regulations apply) in Germany are given the option to limit their system's active power fed into the grid to 70% of its installed capacity instead of facilitating the ability for system operators to remotely limit the active power of their system. This option would allow smaller DER system operators to avoid the costs incurred purchasing and installing the necessary communication and power management devices required to facilitate the capability of remote active power reduction.

Additionally, in Australia, DER active power can be limited upon the request of the transmission system operator during times when operational demand too low. This is required to maintain conventional generation online, in turn maintaining system inertia to ensure power system reliability.

The capability to limit active power of DERs as a percentage of their nameplate rating allows system operators to distribute the amount of power that needs to be curtailed among a large number of DERs, instead of targeting a few to cease active power delivery; thus, allowing system operators to implement fairer curtailment strategies.

2.1.4 Reactive power capability

Recommendation

It is recommended to require all DERs to have the capability to supply or absorb reactive power within a minimum specified range, to support the local voltage. This is based on the capability of the inverter and modern inverter technology can provide a wide range of reactive power.

Justification

It is international good practice to request DERs connected to the medium and low voltage distribution grid the capability of operating at least at off-unity power factor to autonomously support the local voltage. For this, a minimum reactive power capability range is defined. Within this range, DERs are then required to operate under a certain reactive power control mode and absorb or supply reactive power to the power system.

This specification of minimum requirements for reactive power contributes to not only making the situation more predictable for distribution operators but also allows for DERs to support the grid autonomously with a reactive power response based on the activated control mode at the unit (selected to best fit the needs of the local grid). For example, at high distributed PV penetration levels, overvoltages outside regulated limits may be observed. In these cases, reactive power consumption can reduce the distributed generation induced voltage rise.

2.1.5 Reactive power control modes

Recommendation

It is recommended to clearly specify which reactive power control modes DERs should be capable of operating under. While the regulations should require the capability of DER systems to operate in several of the control modes, the decision of which mode to activate in each DER is left to the Discom.

Recommended control modes include:

- Fixed power factor (fixed cosϕ),
- Fixed reactive power (fixed Q),
- Power factor/voltage characteristic: cosϕ(V),
- Power factor/active power characteristic: cosϕ(P),
- Reactive power/voltage characteristic: Q(V) or volt-var mode,
- Reactive power/ active power characteristic: Q(P) or watt-var mode.

It would be recommended to request the capability to operate under at least fixed power factor mode and one active power-based and one voltage-based characteristic.

Justification

It is international good practice to require the capability of DERs to operate under different reactive power control modes and the distribution system operator will select which mode should be enabled in each system based on local grid conditions.

In Germany, for example, all generators connected to the LV level are required to be able to realize fixed cos ϕ as well as a cos ϕ(P) characteristic. Generators above 4.6 kVA are also required to be capable of Q(U) operation. In Australia, the capability to operate under a fixed power factor, fixed reactive power and Q(U) modes is required, with the latter being the mode activated by default.

2.1.6 Active power control mode

Recommendation

It is recommended to require DERs to be capable of operating under the active power control mode (also called volt-watt), and the decision left to the Distribution System Operator (DSO) whether to activate it or not. This mode limits active power production based on measured voltage, following a predefined response curve. It can be enabled at the same time as one reactive power control mode and acts as a backup solution for overvoltage situations.

Justification

Similar to the reactive power control modes, DER inverters can also reduce their active power output in response to the locally measured voltage. Typically, this operation mode is only applied if the reactive power control is already fully utilized but a high voltage persists. This mode therefore acts as a backstop to occasional persistent high voltages.

This operation mode reduces in certain situations the active power output of the distributed generator. Therefore, voltage settings should be sufficiently high to not penalize the distributed generator owner. Analyses in South Australia for example have shown that the expected curtailment with control settings according to the Australian grid code is less than 2 % for any of the analyzed distribution feeders [2]. As another example, various studies from the National Renewable Energy Laboratory (NREL) have found the curtailment risk to be insignificant and that rare cases of consistent high voltages causing significant curtailment are caused by pre-existing issues related to line impedances, grid configurations and distribution transformers. These issues need to be addressed by the utilities by reinforcing the distribution grid through, for example, adding or replacing existing distribution transformers and reducing the resistance of the lines in the low voltage grid by replacing lines and/or adding additional lines in parallel [3].

2.1.7 Ramp rate limitations

Recommendation

It is recommended to require DER inverters to have the capability to limit changes in power, with an adjustable power rate limit and a specified default value. It is recommended to have the possibility to specify separate limits (one for increasing power output and one for decreasing power output). This capability's activation and value adjustment can be left as a choice for the system operator.

Justification

The speed with which inverters are increasing or decreasing their power output (or input in case of inverters associated to battery systems when these are charging) can be regulated. This reduces the impact on the system that would be caused by abrupt changes in the inverter power level and therefore contributes to maintaining system stability.

The applied ramp rate limit may be constrained by several factors including availability of resources, priority of other control signals, among others. In Australia for example, such ramp rate limits do not apply in the case of a command to disconnect the device. Power rate limits apply to obtain: a soft ramp after connecting/reconnecting, a soft ramp up/down after a response to a frequency disturbance and after changes in the energy source operation (for cases when inverters are connected to an energy storage and there is a change to the energy resource available to the inverter).

This capability can be an important capability in critical networks, e.g., in smaller isolated networks, so that the rate of power output is limited, giving the operator more time to react.

2.1.8 Voltage Ride-Through

Recommendation

It is recommended to require DER inverters to continue operation during voltage disturbances, defining for which voltage range and duration of the fault this applies. It is recommended to define the performance of DERs during low voltage ride through (LVRT) and high voltage ride through (HVRT).

During undervoltage or overvoltage events, DERs above a certain size and/or connected to the medium voltage system should be capable of supporting the voltage by adjusting (increasing or decreasing) their active and/or reactive current output with a magnitude proportional to the voltage variation with respect to the normal operating voltage. DERs connected to the low voltage must not generate any current during voltage disturbances while remaining connected to the grid.

Both frequency and voltage ride through requirements can be based on dynamic stability studies and actual fault recordings.

Justification

The main purpose of LVRT and HVRT is to avoid a widespread disconnection of generators due to a fault in the transmission grid, in which case the voltage excursion will affect a large area. In this case, generators connected to the distribution grid will see a remaining voltage in the range of 5 – 30 %. Hence, to avoid the sudden loss of a large amount of generation, DERs are required to withstand such conditions for a certain period.

Synchronous generators inherently provide current support during a voltage disturbance, whereas inverter-based generators need to be programmed to have a current contribution for voltage support. The local conditions determine whether an active or reactive current priority during the voltage ride through is more suitable. Whereas reactive current is usually prioritized in large interconnected systems, active current is usually prioritized in small systems due to lower inertia.

DERs connected to the low voltage are required to not generate any fault current during a voltage ride through for two main reasons. First, to avoid potentially harmful interaction with the grid protection (e.g. protection blinding effect). The second reason is the limited voltage support contribution that can be provided by generators connected to the low voltage grid due to the high grid impedance.

2.1.9 Frequency Ride-Through

Recommendation

It is recommended to require DER inverters to be able to ride through a wide range of frequencies for both under and over frequency situations. Additionally, the must-trip and may-trip settings, including the time when the generator should trip, must be defined.

Justification

The simultaneous trip of many distributed generators in response to frequency excursions, which can be caused by the lack of inverter frequency ride-through capabilities and/or narrow and homogenous trip setting requirements, should be avoided as it may result in a large loss of generation and a subsequent blackout.

An example is the “50.2 Hz problem” in Germany. PV inverters were supposed to disconnect at a narrow setting of 50.2 Hz, with distributed PV already contributing in 2005 to more than 3 GW of installed capacity. The simultaneous disconnection exceeded by far primary reserves and therefore posed a threat to system security. 180,000+ inverters subsequently were retrofitted at a cost of EUR 190 million. The same issue became also evident in Hawaii: 800,000 inverters were retrofitted. However, due to remote communication to most inverters, they could be changed with little effort and cost within two days [4].

2.1.10 Frequency droop

Recommendation

It is recommended that DERs follow international good practices and define DER responses to frequency events to help stabilize the frequency during these events. A frequency-watt response curve must be defined and applied to the inverter. Each DER unit must reduce its active power with rising frequency and if additional power is freely available, increase active power during underfrequency events.

Thresholds and droop settings selection should be coordinated with relevant parties to ensure that appropriate settings are applied based on power-system level requirements.

Justification

Requiring DERs to support frequency control for both underfrequency and over frequency conditions provides a significant reliability benefit. Most modern DER inverters are already capable of operating in frequency-watt mode; hence, this requirement would not lead to any additional costs and no intervention is needed from system operators during the operation of the DER in this mode.

Additionally, as more resources are able to provide support to grid frequency events, each individual resource will need to provide a less magnitude of response, reducing the consequent curtailment during an over frequency response for each unit.

2.1.11 Inertial response

Recommendation

It is recommended to address decisions related to inertial response in the long term and not have it as a mandatory requirement in the short term.

Justification

Considering international practices, inertial response is not required in DER technical standards for Germany, Australia, and the United States. However, as more DERs displace conventional generating resources, the ability of DERs to respond to rapidly changing frequency can support power system reliability, especially in systems with low system inertia.

2.1.12 Voltage phase angle changes ride-through

Recommendation

It is recommended to include a requirement for DER inverters to withstand voltage angle shifts following international practices in Australia and IEEE 1547.

Justification

This requirement is recommended in order to mitigate the risk of incorrect behaviour during disturbances. After a voltage phase angle shift, there may be a misinterpretation of the waveform measured leading to large deviations in calculated frequency that may cause maloperation and nuisance tripping of devices.

This requirement originated with the use of voltage vector shift relays to detect unintentional islanding. Due to its sensitivity to nuisance tripping, a few countries such as Germany and Denmark have forbidden the use of voltage vector shift to detect islanding. [5] Other countries such as the USA and Australia added a requirement to withstand voltage phase angle jumps.

2.1.13 Intentional islanding

Recommendation

Based on international good practices, it is recommended to permit DER to run islanded and define DER requirements while islanded as well as intentional island configurations in the long term.

Justification

Intentional islanding requirements and definitions within DER technical standards of Germany, Australia and the United States have been added only recently and the capability of the DER to operate in islanded mode is not mandated.

In order to be implemented reliably, intentional islanding requires sophisticated control schemes and a great deal of coordination between DERs and loads in the respective portion of the power system. The practicality of intentional islanding capabilities is highly conditional. During a catastrophic utility failure, intentionally islanding DERs can be a possible solution to ensure critical loads are reliably provided with necessary power.

2.1.14 Anti-islanding protection

Recommendation

The DGR standard in India is in line with the international standards regarding a passive anti-islanding protection. It is recommended to additionally request at least one method of active anti-islanding protection.

Justification

If a feeder or grid section with distributed generators connected is tripped either by a fault or manually by the operator for any other reason, the generators on that feeder need to detect this and disconnect.

In distribution networks unintentional islanding can appear for example when the feeder is disconnected from the upstream network for maintenance and the PV continues to feed the existing load in the distribution feeder. This may appear if PV and load at this instance is balanced. This may pose a threat to human life if maintenance work is conducted on the line and the line is still energized.

There are passive and active methods to detect an unintentional island. It is international good practice to require the passive detection method and at least one active detection method, which could be chosen between for example frequency shift, frequency instability, power variation and current injection. The motivation behind the addition of an active anti-islanding detection method is to prevent a situation where islanding occurs due to multiple inverters providing a frequency and voltage reference for one another and/or because load and generation is balanced.

2.1.15 Power quality

Recommendation

Form the gap analysis conducted, the power quality requirements regarding direct current, flicker and harmonic currents defined for Distributed Generation Resources (DGR) in India are overall aligned to those in the international standards or directly refer to an IEC or IEEE standard.

However, provisions for rapid voltage changes are absent as compared with the international standards reviewed. It is therefore recommended to require DER inverters to not cause rapid voltage changes higher than a pre-defined limit. International experience is well established and recommended to be used as reference.

Justification

Only measuring flicker will not ensure the correct treatment of rapid voltage changes. The main known effect of rapid voltage changes is light flicker. Therefore, although this is not an issue related to system security, it is recommended to set limits for types of rapid voltage changes that are visible in order to avoid a high frequency of occurrence and consequent annoyance to consumers.

2.1.16 Measurement accuracy for protection and control

Recommendation

It is recommended to establish measurement accuracy requirements for the DER systems to conform with. Such requirements should address voltage, frequency and (re)active power measurement accuracies, as well as measurement time window (or cycle) and parameter range. The international practices reviewed can serve as reference.

Justification

Establishing measurement accuracies specifications will ensure a reliable operation of the inverter's protective and control functions and is international good practice. If the inverter uses an external measurement device, the combination of the inverter and such device should conform to such requirement.

2.1.17 Interoperability

Recommendation

It is recommended to mandate communication capabilities for DERs and specify the communication protocols the local DER interface must support.

Information exchange should enable the nameplate information and present operating conditions of the DER to be read at any time. In addition, the DER's communication interface must enable functional and mode settings to be read and written, allowing the functions described in previous sections to be remotely enabled/disabled as well as adjust the parameters associated with these functions.

Considering the smart meter rollout program in India, the importance of standardizing communication protocols for DERs and other devices connected to the network must be emphasized. In doing such, DERs on the network can be effectively monitored and controlled by utilizing the existing smart meter communication infrastructure which, in turn, would significantly increase the network's DER hosting capacity.

Justification

It is considered international good practice to mandate communication requirements that facilitate remote monitoring and control of DERs. Through remote control, any of the previously described capabilities and operation modes can be changed by the system operator. This allows the system operator to adapt the setpoints to system needs over time. For example, in some systems wider frequency ride-through setpoints had to be specified retrospectively. While in Germany this retrofit had to be done mostly manually resulting in high extra costs, in Hawaii most inverters were remote controllable (albeit not required) which allowed for an easy update of inverter settings.

Not addressing communication protocols could create challenges for equipment manufactures that commonly use proprietary protocols in their equipment. This could generate competing standards, negatively impacting the effectiveness of the communication system. In the U.S., the IEEE 1547-2018 standard mandates that DERs support either the Sunspec Modbus, IEEE 1815 (DNP3) or IEEE 2030.5 communication protocol.

2.1.18 Cyber security

According to the international practices reviewed, cybersecurity requirements are not defined within DER technical standards. However, cybersecurity is recognized as an issue of critical importance for DERs connected to broader communication networks for monitoring and control.

Currently, cyber security requirements of specific DER deployments can vary across jurisdictions. There exists several international cyber security standards and guidelines that may be applicable to DER deployment. Among these standards and guidelines some of the most recognized include IEC-62351, ISO/IEC 27000, IEEE 1686, NERC CIP, NISTIR 7628 and IEC 62443 .

Table 1 shows the recommended basic and advanced guidelines for cybersecurity based on protocol-level DER vulnerabilities.

Table 1 Basic and Advanced Security Control Guidelines

Basic Security Controls	Advanced Security Controls
• Network segmentation—By segmenting information technology (IT), operational technology (OT), and management networks with access-control lists that avoid broadcast storms and establish hyper-quiet data links for effective intrusion detection, damage can be contained if one of the networks is compromised. • Systemic security—Secure the network systemically by implementing context- and signature-based intrusion detection and intrusion prevention systems as well as inline blocking tools. • Inline-blocking devices—To protect critical nodes from unauthorized access in a SCADA system within the OT network, inline blocking tools with transport layer token authentication and data diodes with hardware layer filtering of Modbus TCP messages can be used. • Intrusion-detection systems—Use context-based and signature-based ID/IPS for network-based anomaly detection and business process security. • Selective encryption—Encryption creates an overhead for resource-constrained device communications where latency might also be critical. Therefore, selective encryption of the data will help utilities to minimize the processing overhead and application latency. Use of public key infrastructure (PKI) and digital certificates is preferred to guarantee a chain of trust using software and hardware policies. • Role-based access controls (RBAC)—Use access-control lists on networking switches with strict restrictions on the traffic based on the need to minimize unauthorized access of network devices, power systems appliances, and IT servers. • Port security—All used ports should be locked in by the media access control (MAC) addresses of authorized devices with initial connection to avoid device swapping for cyberattacks launched from inside the trusted networks of the organization. Also, disabling all unused ports on the firewalls and switches to eliminate unauthorized access is a sound practice. • Patching—Any out-of-date critical infrastructure creates vulnerabilities that can be exploited. By making periodic updates of software security patches, cyber-risks from known vulnerabilities of older software versions can be mitigated. • Least privilege—Give users access only to those applications they need to perform assigned tasks. • Visualization—Real-time monitoring dashboards that interactively visualize system events and logs ingested from heterogeneous devices in the DER ecosystem provide situational awareness. • Multi-factor authentication—Two-factor authentication gives users an added layer of security. • Strong usernames and passwords—All networked devices must be capable of avoiding brute force and dictionary attacks from hackers both outside and inside the network, which can be enforced using strong username-password combinations.	• Activate transport layer security (TLS) in DER devices such as smart inverters and microgrid controller systems. • Implement session resumption when the session is severed for a time less than the TLS session resumption time by using a secret session key. • Implement session negotiation when the session is severed for a time more than the TLS session renegotiation time. • Use a message authentication code. • Support multiple certification authorities. • Terminate the session if a revoked certificate is used to establish the connection; this is done using a certification-revocation list. • Identify and terminate the session if an expired certificate is used to establish the connection

2.1.19 Grid forming inverters on the distribution level

Recommendation

It is recommended to not include any grid forming requirements for DERs in technical standards at this stage.

Justification

Grid forming is still a topic of current research regarding its application on the distribution grid. The technology has been proven successful in a few projects, such as in Saint Eustatius Island with grid forming battery and PV, and the grid forming battery in Dalrymple Australia. International requirements for grid forming capabilities in grid codes are now starting to emerge (e.g in the United Kingdom, Germany, and Hawaii), however up to now these are focused on the transmission level. Therefore, it is recommended to follow the international development of the grid forming technology applied to the distribution level, and based on upcoming findings and recommendations potentially consider adding requirements in future revisions of the DER technical standard in India.

2.2 Recommendations for benchmark grids and simulations studies

Developing benchmark grids that represent the variety of the Indian distribution system and using these grids in simulations with different DER scenarios and configurations would aid in fine tuning requirements and would be recommended to be part of the process of developing an Indian standard for DER technical interconnection requirements.

Benchmark grids can be generated using a variety of methods and clustering methods are being increasingly used internationally due to unbiased clustering of the data and advances in clustering techniques. The choice of the most suitable method to generate representative grid models will depend on the intended use case, available data and confidentiality of the data in resulting grid. A methodology for the creation of benchmark grids has been proposed as part of Task 3. It is recommended to make the benchmark models developed publicly available, to accelerate research and enable future comparison and validation of different solutions in India. Furthermore, a detailed documentation of the methodology and a clear statement of the intended use case of the benchmark grid is important to allow the correct later use of the benchmark grids and further development (e.g. later updates or creation of new ones). The main use cases for distribution benchmark grids were recommended as (1) reactive power supply, to quantify/fine tune general reactive power capability envelope; (2) reactive power control, to analyse reactive power control methods of DER inverters and quantify envelopes; and (3) voltage ride through, to quantify low/high voltage ride through envelopes, which must co-exist with the must trip provisions that address protection/coordination issues.

In order to create such benchmark grids, data must be collected from different DISCOMs regarding existing feeders. A data list indicating the most relevant data to be collected from the DISCOMs in order to create the benchmark grids has been listed in Task 3. The level of effort to obtain such data was estimated via a survey sent to experts from 3 DISCOMs located in Kerala and Gujarat. The survey results indicated that most data necessary for the development of distribution benchmark grids can be obtained with low to medium level of effort, with the exception of information on the share of cable and overhead lines in the LT level.

Once benchmark grids have been generated, simulation studies can be conducted using these to fine tune DER technical requirements (related to the benchmark grids' use cases) within the standard development process. The simulation studies would require iterations over different parameters and analysis using different benchmark grids in order to compare results and identify what are the best centric requirements for India. International good practices should be considered in this process, as they often relate to functionalities that are state of the art and available in many inverters sold in markets worldwide. Consulting manufacturers to identify the capabilities of existing products in the Indian market and evaluate potential costs of extended capabilities is also recommended when developing technical requirements for DER.

2.3 Recommendations for compliance mechanisms

2.3.1 Certification and approval of equipment

Recommendation

It is recommended that DER compliance with technical requirements be proven during the DER interconnection process by means of written manufacturer statements of compliance for the corresponding product/model type.

The compliance procedure should be done through type testing (lab test) that may be performed on one device or a combination of devices operating together as a system. The conformance criteria must be based on DER grid support functions required within technical standards, as well as fundamental requirements that ensure secure system operation and reliability such as testing for asymmetries in the equipment, temperature stability and interconnection integrity.

Additionally, the test procedures to verify conformance for each of the DER grid support functions must be defined and standardized among DISCOMS[1] and accredited test centres in India which include:

- National Institute of Solar Energy, Gurugram
- CSIR-Central Mechanical Engineering Research Institute, Durgapur
- UL India Pvt Ltd, Bengaluru
- TUV Rheinland (India) Pvt Ltd, Bengaluru
- Central Power Research Institute, Bengaluru

Justification

The recommendation above is based on international best practice. Resources and guidance such as detailed tests and procedures must be provided to stakeholders for successful adoption of DER interconnection standards.

2.3.2 Periodic Testing

Recommendation

It is recommended that periodic testing of DERs be conducted following their interconnection and for the duration of the DER's lifetime. The responsibilities of the distribution system operator and the DER operator regarding the testing procedure should be clearly defined as well as the time frame for the periodic tests.

Justification

Periodic tests are already a requirement in the international study cases reviewed (Germany, Australia, and the United States). The distribution system operator must verify that DERs continue to comply with performance and safety requirements for the duration of their lifetime and disconnect any DER that might jeopardize the reliability of the electric distribution system.

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[1] In India, it is the responsibility of the DISCOMs to ensure DER compliance with the regulations prior to its connection to the grid.

3. Considerations for Implementation

3.1 Commercial availability

Most of the DER capabilities described in Chapter 2 have been implemented by most commercial inverter manufacturers. For example, since DER capabilities were specified by Californian Rule 21 and Hawaiian HECO 14H, most inverter manufacturers have obtained certification for these capabilities. Testing procedures to prove compliance with both regulations have been established in US regulation through UL 1741 SA in 2017.

This includes North American and European inverter manufacturers, e.g., SMA, Fronius, SolarEdge, as well as the top Chinese inverter manufacturers, e.g., Huawei, Sungrow and even micro-inverters with capacities below 1 kW, such as Enphase.

3.2 Recommended timeline for implementation

Technical standards must be technology neutral and the timeline for the implementation and enforcement of the standard must not cause administrative or technical barriers for products that do not have the required certifications to be interconnected to the grid.

From the international review, it can be observed that the DER technical standards in the selected countries have undergone multiple revisions, and with each revision, new DER technical requirements were introduced. Through this process, the technical standards applied in Germany, Australia and the United States have evolved to include a wide range of grid support functions and other capabilities. Some of the requirements within these technical standards may not yet be utilized until they become necessary at a future date. This is to avoid retrofitting DERs once installed in the field, which would entail a high degree of difficulty and cost.

Given the foreseen rapid uptake of rooftop solar in order to meet national targets, it is recommended to define/update the requirements listed in the previous chapter in the technical standard based on most recent revisions of the international technical standards. In addition, it is recommended to define DER performance categories for which specific requirements would apply. Performance categories would be defined based on the DER penetration level, the first DER category encompassing the minimum required DER functionality for regions with low DER penetration and should apply to all DERs in the market, the second including additional functionality and grid support functions required for moderate DER penetration, a third category would include advanced functions required for high DER penetration.

The DER functions required within each performance category are depicted in Figure 1. It must be considered that inverters installed in the near future and compliant with a certain technical standard version will be in the system for 10-15 years. Therefore, it is good practice to require in the technical standard as many capabilities as possible from those shown in Figure 1. This way the operator will have the option to gradually enable these (i.e. utilize the capability required) when DER penetration increases to medium and high shares, as opposed to having to retrofit devices. If requiring all capabilities listed in Figure 1 is considered too stringent for the first DER technical standard in India, then at least those capabilities for low and moderate DER penetration are recommended to be included.

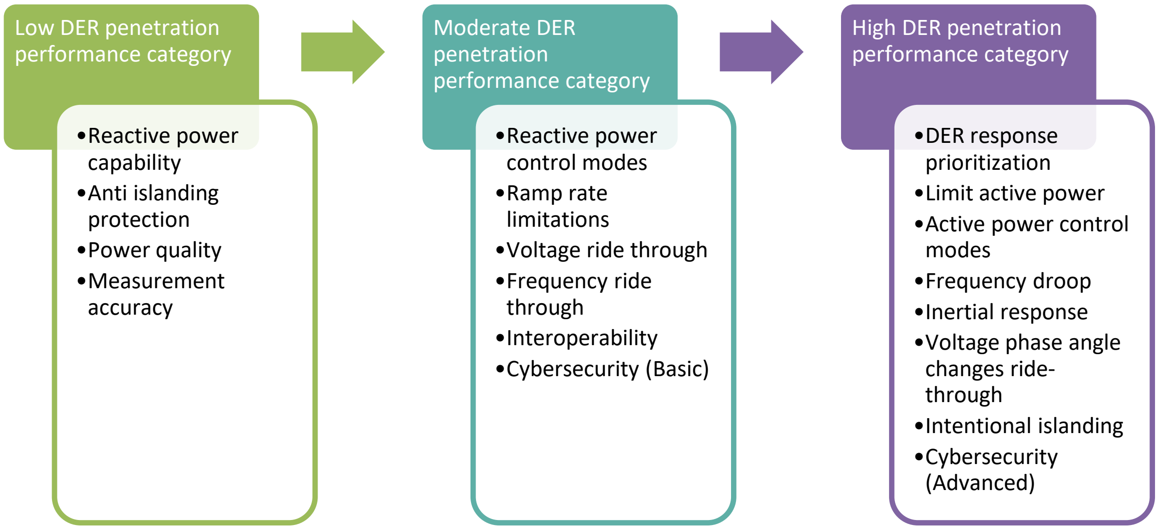

Figure 1 DER requirements categorisation

Stakeholder coordination will be required to identify the performance category that must be enforced for different regions as well as the timeline for enforcing compliance with the performance category[2]. According to international experience, upon publishing the testing procedure used for equipment certification, at least one year was required for DER manufacturers to implement the necessary firmware and hardware changes in their equipment to comply with requirements given in the second performance category; after which, the requirements were mandated [10]. For the requirements listed in the third performance category, compliant products were expected to be available 18 months after the publication of the testing procedure [11].

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[2] Relevant stakeholders include DISCOMS, LDCs, Chief Electrical Inspector General (CEIG), testing agencies, state nodal agencies, subject matter experts, equipment manufacturers, developers and consumers.

4. Summary and Conclusion

The recommendations provided in the report are based on the gaps analysed between current DER technical requirements in India and international best practices. Furthermore, gaps have been found within standards of the international study cases reviewed. Among the reviewed standards, IEEE 1547-2018 has been found to be the most stringent, defining the widest range of DER grid support functionalities. Hence, it is recommended to define DER technical requirements that conform with IEEE 1547-2018 in India.

In Table 2, the DER technical requirements that should be revised/introduced in India are listed. It is generally recommended to follow current international practice and define and require capabilities from DERs that may not yet be utilized until a future date as DER penetration increases. Table 2 also shows the DER penetration level at which the technical requirements has been introduced in international standards. This can provide guidance on which technical requirements to define in upcoming standard revisions in India. It is highly recommended to include requirements introduced at low and moderate DER penetration levels in the next standard revision, as these functions are considered crucial for achieving the national DER targets in India.

According to the findings of work package 1, rapid uptake of rooftop solar is expected in India in the upcoming years. Hence, PV inverters are assumed to be among the DERs of highest relevance. The complexity of implementing the technical requirements in PV inverters is outlined in the table below. Most of the requirements can be implemented through inverter firmware upgrades. The implementation of other requirements, such as interoperability and inertial response might require additional components to achieve the desired functionality. Interoperability will require PV inverters to facilitate remote communication through a communication protocol specified from the DSO. Inverters must be designed with a communication interface compatible with the specified communication protocol. Otherwise, the use of an external communication (gateway) device will be needed to relay signals between the inverter and system operator

Table 2 Aspects of DER technical standards implementation

Requirement	DER penetration level at which requirement was introduced in international standards	Customization required for India	Complexity of implementation for PV inverters	Implementation cost	Recommended timeline for implementation	Definition of default settings within India
DER response prioritization	High	Low	Implemented through firmware upgrades	Low	Long term	Centralised
Capability to limit active power	High	Low	Implemented through firmware upgrades once interoperability requirements have been fulfilled	Moderate	Long term	Localised
Reactive power capability	Low	None	Requires the inverter to be sufficiently dimensioned	None	Short term	Localised
Reactive power control modes	Moderate	Low	Implemented through firmware upgrades	Low	Medium term	Localised
Active power control mode	High	Low	Implemented through firmware upgrades	Low	Long term	Localised
Ramp rate limitations	Moderate	High	Implemented through firmware upgrades	Low	Medium term	Centralised
Voltage Ride-Through	Moderate	High	Implemented through firmware upgrades	Low	Medium term	Centralised
Frequency Ride-Through	Moderate	High	Implemented through firmware upgrades	Low	Medium term	Centralised

Requirement	DER penetration level at which requirement was introduced in international standards	Customization required for India	Complexity of implementation for PV inverters	Implementation cost	Recommended timeline for implementation	Definition of default settings within India
Frequency droop	High	High	Implemented through firmware upgrades	Moderate	Long term	Centralised
Inertial response	High	High	Deriving synthetic inertial response may require energy storage	High	Long term	Centralised
Voltage phase angle changes ride-through	High	Low	Implemented through firmware upgrades	Moderate	Long term	Centralised
Intentional islanding	High	High	Implemented through firmware upgrades	High	Long term	Localised
Power quality	Low	None	Requires integrated filters	None	Short term	Centralised
Measurement accuracy for protection and control	Low	None	Requires integrated measurement devices	None	Short term	Centralised
Interoperability	Moderate	High	Requires a communication interface that supports data exchange through the specified communication protocol	High	Medium term	Centralised

Requirement	DER penetration level at which requirement was introduced in international standards	Customization required for India	Complexity of implementation for PV inverters	Implementation cost	Recommended timeline for implementation	Definition of default settings within India
Cyber security	Medium (basic) High (advanced)	Low	Implemented through firmware upgrades and may require the installation of a secure cryptoprocessor	Moderate	Medium term (basic) Long term (advanced)	Centralised
Anti-islanding protection	Low	Low	Implemented through firmware upgrades	Low	Short term	Localised

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