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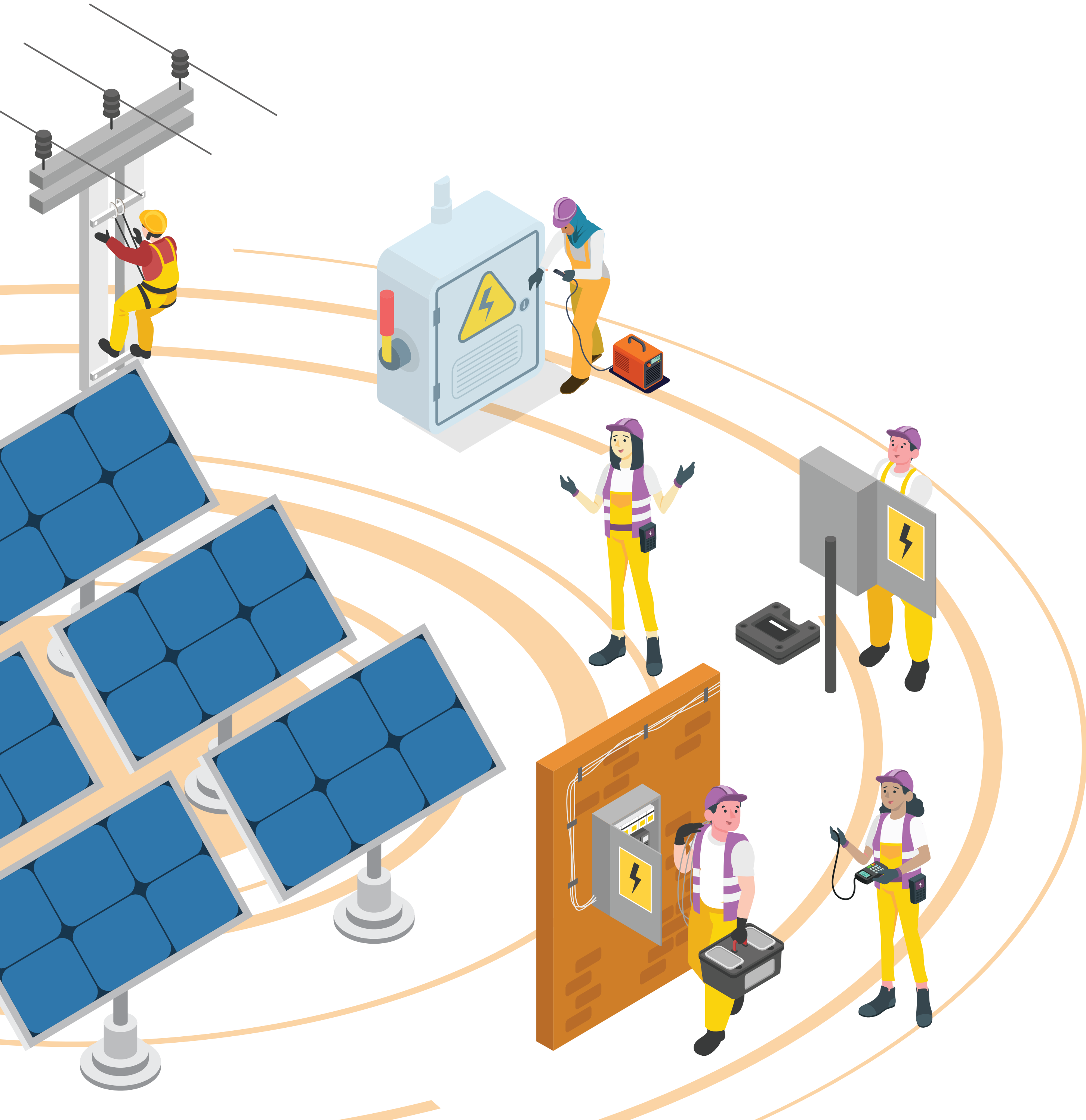

MINI REPORT
Webinar Hosting Capacity

March 2023

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Imprint

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List of Definition

Active power	Actual power that is utilized or consumed by a load to perform work and is measured in units of watts (W)
Distribution code	Technical obligations that a licensed electricity distributor must meet to distribute electricity within its service area
Distributed Energy Resources (DER)	Small scale unit of local generation (typically in the range of 3 kW to 50 MW) connected to the grid at the distribution level
Hosting capacity	Amount of DER that can be added to the distribution system before control changes or system upgrades are required
High Voltage (HV)	Voltage value above 35kV
Medium Voltage (MV)	Voltage value between 1 kV and 35 kV
Nominal voltage	Voltage value that is assigned to an electrical circuit or system
Ramp rate	The increase or reduction of power generation per minute in spinning mode
Reactive power	A power that does not do real work and is measured in units of kilovolt ampere reactive kVAR) or MVAR
Relays	An electrical device that is used to control circuit breaker locally or remotely
Reverse power flow	A condition where power is flowing from the lower voltage network to the higher voltage network
Short circuit current	A condition where an electrical current flows in the wrong or unintended path with little or no electrical resistance
Spinning reserve	Unused capacity which can compensate for power shortages or frequency drops within a given time
Technical Minimum Loading (TML)	Minimum power that must be drawn from a power supply to operate reliably
Variable Renewable Energy (VRE)	Renewable energy sources that are not dispatchable due to their fluctuating nature

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A. Overview

Indonesian Ministry of Energy and Mineral Resources launched Ministerial Regulation No. 26 Year 2021 on Rooftop Photovoltaics (PV) in 2021. The regulation aims to improve and encourage people to install more rooftop PV, nevertheless, there are many hurdles to the implementation as there is a debate on how the additional solar PV might impact the system stability. This is particularly related to how much the maximum solar PV capacity that can be added to the existing system.

There is a view that sees that more additional solar PV capacity might violate the power system stability. But on the other side, the hosting capacity is not a static value, which can be improved with certain measures as we learned from other country's experiences. This is where the analysis of hosting capacity is necessary to identify which suitable mitigation measures to increase the hosting capacity limit.

In short, hosting capacity (HC) is the amount of PV that can be added to the distribution system before control changes or system upgrades are required to integrate additional PV safely and reliably. The hosting capacity is not a static value but can be increased through suitable mitigation measures but may only address a specific PV impact. We will discuss how the analysis on hosting can be conducted and what kind of measures are possible to increase the hosting capacity limit.

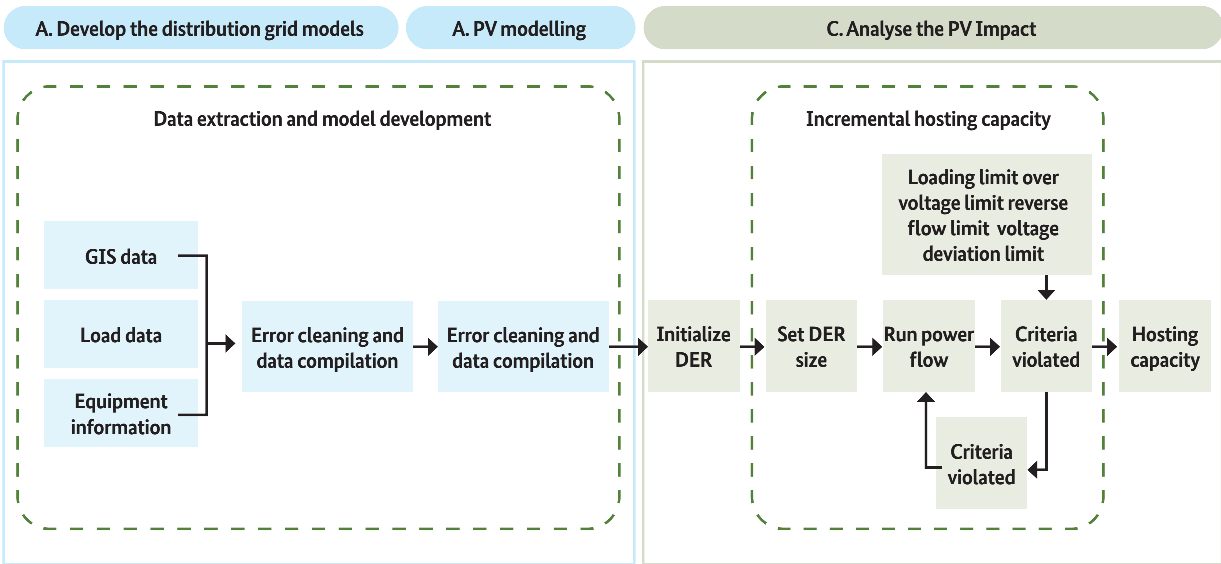
B. PV Modelling in the Distribution System

Electricity distribution networks cannot accommodate arbitrary amounts of distributed generation. The limit of a specific distribution feeder is commonly referred to as the hosting capacity.

The purpose of hosting capacities is therefore to find the maximum limits for DER connections in distribution networks including suitable mitigation measures to increase these limits. This also means that hosting capacity (HC) is also part of distribution network planning. An important aspect in this regard is how future PV expansion can be modeled. Hosting capacity analysis can show where the true technical limits for distributed generation in distribution networks lie and replace overly restrictive regulatory limits (such as the 15% rule in Indonesia)

In general, the process of HC analysis can be described as follows:

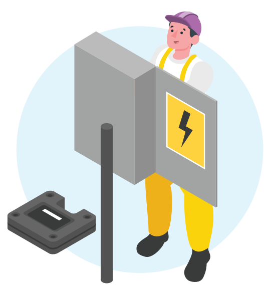
Graph 1. Hosting Capacity Analysis Process



Developing Distribution grid models

Distribution grid models can be used for detailed analysis. One of them is to look at the voltage profile.

In developing the distribution grid models, no need to model the entire network, but only the primary substations and secondary substations as well as primary distribution feeders.



Once we have the model then we can figure out the distribution transformer loading, voltage profiles, short-circuit currents, and others.

The important aspect to be considered in the data validation is whether the modeling results make sense and whether the measurement data to which the model result can be compared.

PV Modeling

After the distribution grid model is set up, we can look at how will future expansion of distribution (rooftop photovoltaic) affect the distribution network.

The unclear or undecided exact location of PV may be a challenge during the modeling. To deal with this, different scenarios can be used where we will have different options to add a new PV system to our distribution grid. Some examples of those options are as follows:

- Scale existing PV capacity
- Add new PV capacity according to load distribution
- Add new PV capacity according to the available rooftop area
- Add new PV capacity randomly

Analyze the PV Impact

Several impacts distributed generation (solar PV) can have on the distribution grids assets as will be explained below:

PV impact on thermal & voltage limit
It's important to do this assessment to understand where the true technical limits of rooftop PV systems. PV impact on thermal and voltage limit is also in order to have a good regulation that facilitates the installations of rooftop PV systems in the distribution network.

Impact on overloading
With increasing PV penetration, reverse power flows will eventually occur. Reverse power flow can be an issue if it's too much which causes the distribution assets get overloaded. Depending on local regulations, the loading of lines/transformers may be allowed up to 80-100%.

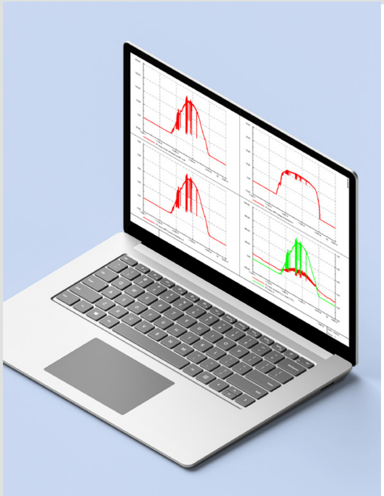
Impact on voltage profile
Initially, low to moderate PV penetration levels lead to a reduction of voltage drop and improved voltage quality. With increasing reverse power flows, however, a voltage rise will occur. Depending on local regulation, voltage levels in distribution networks need to be kept within a range of 90-110% of nominal voltage (in Indonesia: 90-105%).

Impact on protection
Typically, overcurrent relays are used as protection. PV systems due to being connected through inverters usually have very small short-circuit current contributions. Therefore, in most distribution networks, distributed PV has only a limited impact on the correct behavior of protection relays. In a few cases with extreme PV penetration, protection relay parameters should be checked to ensure proper protection coordination.

Impact on harmonics
Harmonics is the combination of different frequency components that results in a distortion of the fundamental frequency. The harmonic content of voltages and currents is one of the aspects of power quality. Harmonics from PV inverters are guided by international standards and grid codes. These ensure that negative impacts on distribution feeders are very rare.

In conclusion, the impact of PV systems on distribution networks can be analyzed with power flow analysis software. To improve forward-looking power system planning, hosting capacity analyses can be performed on distribution feeders. The most important impacts of PV systems are potential line/transformer overloading and voltage quality.

Hosting capacity is not a static limit. This depends on the location of PV systems and demand and changes over time. Therefore, the hosting capacity should be regularly assessed, following the development of PV systems. Furthermore, the hosting capacity can be increased through mitigation measures as will be explained next part.

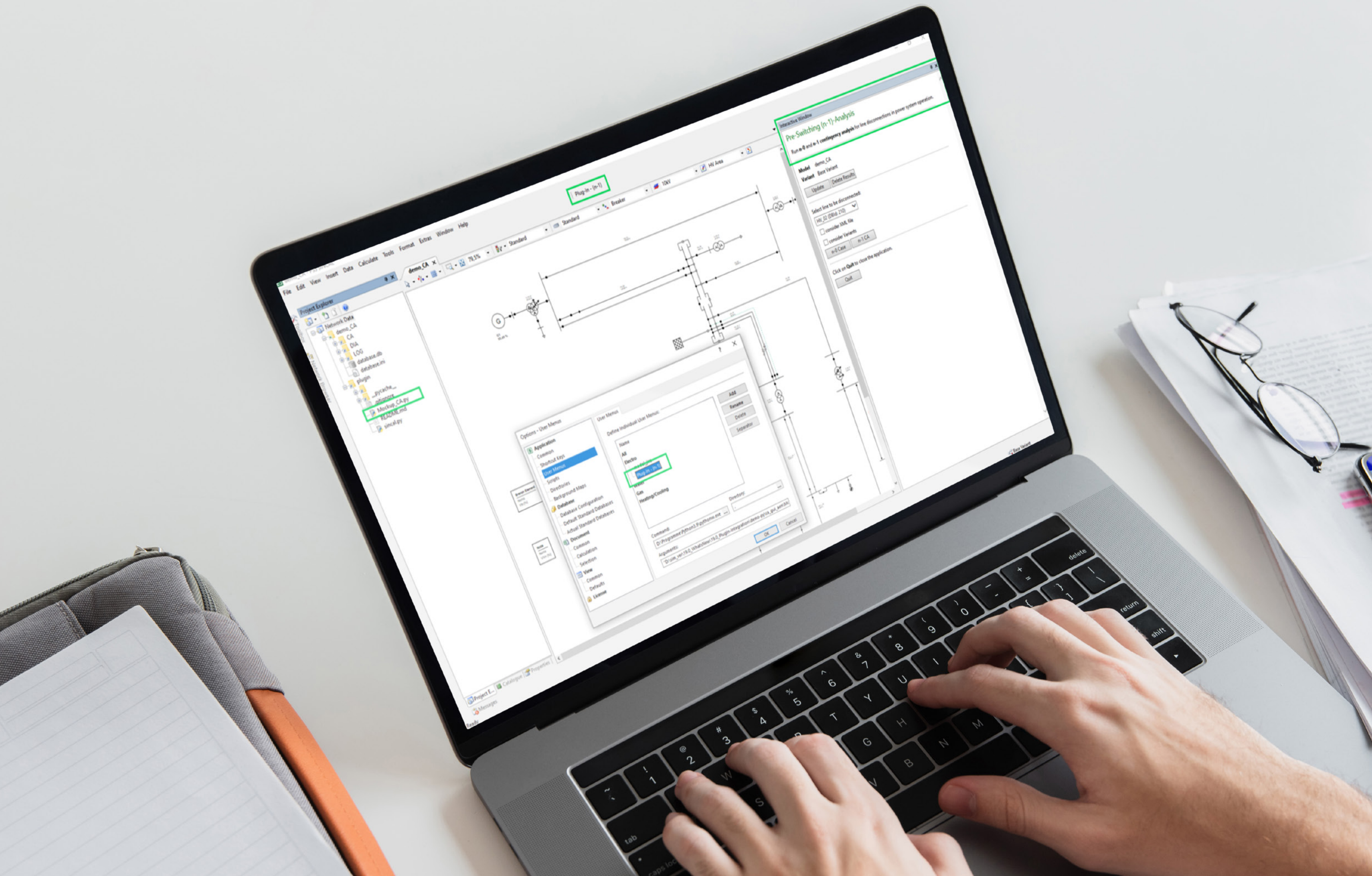


Box 1 Tools for Hosting Capacity Analysis

Nowadays, there is commercial software offering hosting capacity as one of their functionalities. These allow the user to investigate hosting capacity in a fast and standardized way. Tools for conducting hosting capacity analysis such as:

PowerFactory: PowerFactory is a power system analysis software used in zanalyzing generation, transmission, distribution, and industrial electrical power systems developed by DIgSILENT GmbH.

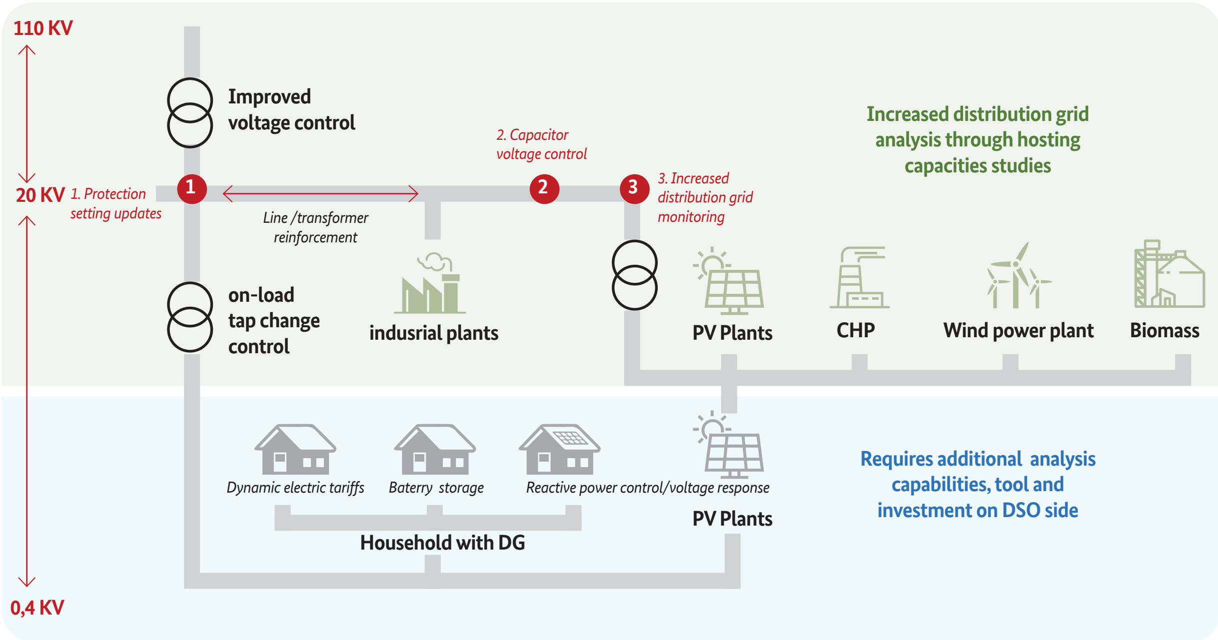
PSS Sincal: PSS Sincal is a simulation software developed by Siemens Company for zanalyzing and planning electric and pipe networks.



C. Hosting Capacity Mitigation Measures

In general, there are a lot of mitigation measures that we can use but needs technical understanding to figure out what are good measures. These mitigation measures may only address a specific impact of distributed generation (for example only overloading, or only over voltage). Therefore, it needs to determine what issue is prevalent in the distribution network which should be improved.

Graph 2 Mitigation Measures Options



We can categorize the above mitigation measures option into three main strategies for increasing the hosting capacity as will be further explained below: **(1) Voltage Control, (2) Active Power Control, and (3) Grid Reinforcement strategies**. Grid Reinforcement is often considered the least economical option.

C.1 Voltage control strategies

a. HV/MV voltage setpoint optimization

- Aim: Reduce voltage setpoint of on-load tap changer (OLTC) at primary substation if no Undervoltage problems on that feeder exist
- HV/MV voltage setpoint optimization is a very simple measure without costs involved. However, it only works in distribution networks without UUndervoltage problems.

b. Active power-dependent voltage control at the HV/MV transformer

- Aim: Measure power flow at a primary substation. This can be done by increasing the voltage setpoint during high demand and decreasing the voltage setpoint during high reverse power flow (also called compound regulation).

c. Wide area voltage control at the HV/MV transformer

- Aim: Measure voltage at distribution feeder endpoints and regulate voltage in such a way that voltage boundaries at the measurement points are kept
- This is the most effective method and can greatly increase PV hosting capacity. However, this is also much more expensive.

d. Reactive power control of PV inverters

- Typical distribution codes require that the PV inverter must be able to contribute and generate reactive power.

C.2 Active Power Control

a. Remote DER Control

- All PV systems should have a mandatory interface for remote control. However, DSO may only establish communication to some PV systems above a certain size (e.g., 100 or 500 kWp) due to the high costs of communication
- Enables the remote control of DER (e.g., curtailment of PV systems for re-dispatch measures)
- Enables the remote update of DER settings (e.g., voltage response/reactive power control

b. Simple cap for smaller inverters (rooftop PV)

- PV plant only rarely reaches more than 70% of its PV panel capacity (sunshine availability, reduced efficiency from high temperatures and dust)
- This mitigation measure aims to limit PV inverter capacity to 70% of PV panel capacity, so that the peak of PV infeed is shaved off, i.e., maximum PV infeed is reduced to 70%
- Drawback: 2-4% of annual PV energy production is lost
- Advantage: Extreme feed-in peaks are avoided
- Can be an alternative to remote control for small rooftop PV system

c. PV peak shaving by battery usage

- Battery storage needs to be optimized for reducing maximum PV infeed while maximizing own consumption as far as possible.
- Appropriate requirements and incentives are necessary to encourage grid-friendly behavior.

C.3 Grid Reinforcement: Reinforcement of lines and transformers

Typically, the least economical option because upgrading lines/transformers before their end of a lifetime is quite expensive. However, in some cases can be the only option to increase the PV hosting capacity.

Box 2 International Case Studies on Mitigation Measures

Where? Bhopal and Delhi

Who? BRPL and MPMKVVCL, GIZ, Energynautics

What Assessment of challenges for 40 GW of rooftop PV by 2022

Results: Transformer capacity limits can be upgraded from:

30%-60% > 75%

For higher capacities, active power control measures include:

- PV curtailment
- Peak shaving batteries
- Fixed cap on 70 -80%

Where? Dominican Republic

Who? Organismo Coordinador (OC), GIZ, Energynautics

What? PV hosting capacity assessment

Results: Limiting PV to 15% of MV network peak load was too low. Recommended to increase the penetration limits based on hosting capacity analysis and at least.

15% > 25%

15% > 50%

Case study German DSO: Hosting capacity was performed on rooftop PV, electric vehicles, heat pumps:

- **GIS database**
- **Electricity customer database**
- **Gas customer database**
- **Open StreetMap building information**

Matched database with:

- Full distribution network
- Household connections
- Individual power and gas consumption
- Building area

Hosting capacity analysis (with secondary substation granularity)

Study showed that majority of rooftop PV potential could be used - without distribution grid issues

Box 3 Vietnam PV Rooftop Monitoring and Forecasting Tools

VRE forecasting is one of the important mitigation to anticipate the uncertainty of PV production. Vietnam utilizes VRE Forecasting using solar irradiance forecast data including satellite imagery from an independent supplier.

Recommendation for Mitigation Measures:

- Power system planning should consider smart system alternatives to grid reinforcement to improve network conditions and increase distributed generation levels.
- Regular assessments are required following PV development in distribution feeders.
- DSO should be required to investigate and apply cost-efficient mitigation measures, before limiting allowed PV penetration.
- A study case in Bhopal dan Delhi shows that transformer capacity limits can be upgraded by implementing Active Power Control.
- A study case in the Dominican Republic indicates that limiting PV penetration based on 15% of MV network is too low.
- A study case on PV rooftop penetration in Germany shows that the majority of rooftop PV potential can be used without distribution grid issues.

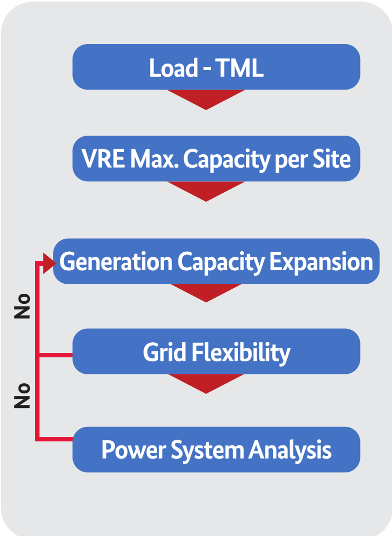
D. Hosting Capacity Analysis and Regulation on Maximum Capacity

To answer the question of how much the maximum solar PV capacity can be added to the system, requires a hosting capacity analysis as we have discussed earlier. LAPI ITB had analyzed on the Java Bali grid system with the result discussed in the following part.

D.1 Hosting Capacity Analysis in Indonesia (Java Bali System)

There are two criteria in deciding how much solar PV we can add to the grid: (a) **system capability analysis** (in this case the Java Bali grid) (b) **distribution grid analysis** (20 kV and below)

a. For the first criterion, the analysis will follow the process to know whether the system can receive additional solar PV, as explained in a flow chart below:



1. **Estimates Day Load and Technical Minimum Loading:** this is to estimate the maximum vRE candidate using the formula below

   Max vRE candidate = Day load – Technical Minimum Limit

2. **VRE maximum capacity per site:** looking at the system stiffness (IKS), if high then the system capacity is also high.
3. **Generation expansion planning:** to estimate the possibility of adding new solar PV based on the least cost comparison to the other option.
4. **Grid flexibility/production cost simulation:** spinning reserve & duck curve (system ramp rate).
5. **Power system analysis/Quasi dynamic analysis:** To analyze frequency fluctuation in determining the max. VRE penetration so that the system still operates in a secure and stable condition.

Based on the analysis (least cost & system criteria) following the above process on the Java Bali grid system the result as shown below the maximum for adding solar PV is to have 9600 MW (by 2030) with the below combination for utility-scale & rooftop

Cases	PV Utility scale	PV Rooftop	Frequently Deviation	Conclusion
Case 4 (PV utility scale and rooftop	**25% (2400MW)**	**75% (7200MW)**	**OK**	**Not violated**

b. Then for the second criterion on the distribution level. The analysis is using several factors below:

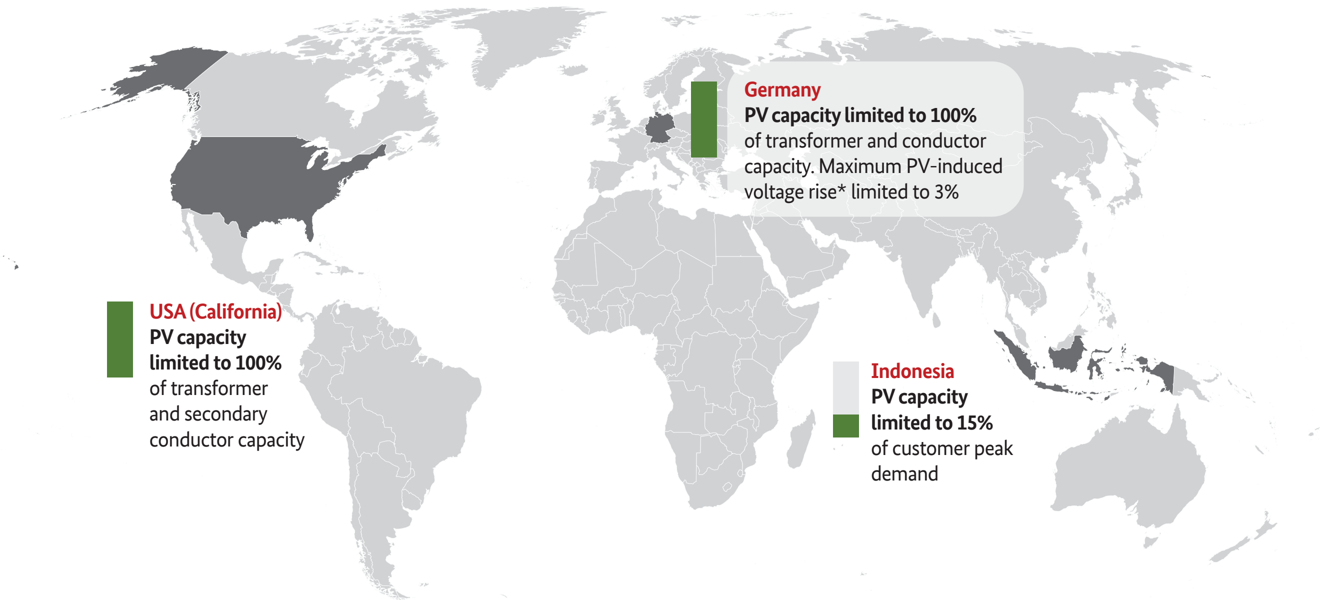
1. **Coincidence factor:** Coincidence factor can be defined as the ratio between the peak load of the system and the sum of the peak load of individual components.
2. **Distorsion factor:** Distortion can be shown by many customers shifting to higher voltage customer categories such as from 900 VA to 1200 VA and from 1200 VA to 2200 VA.
3. **Load factor:** Ratio between the average load in a specific time to the maximum demand.

According to the above considerations, the proposed amount of maximum PV rooftop penetration per customer is **15.4% against the distribution transformer capacity if all the customers are installing PV rooftops**. If all customers **do not** install PV rooftop, the allowable maximum penetration should be calculated accordingly.

D.2 Regulation on PV Maximum Capacity in the International Practice

In some countries, the maximum capacity of solar PV is not highly restricted for example in California and Germany as can be seen in table 3.

Graph. 3 International Comparison of Maximum PV Capacity



*This can be checked through a simple voltage rise calculation based on the secondary conductor impedances

Examples of Good and Bad Practices of Technical Regulation

Good practice on technical regulations for maximum DER impact:

- Reverse power flow loading up to 100% of line and transformer capacity.
- Maximum overvoltage up to 110% of nominal voltage.
- Special technical regulations may be in place regarding voltage and short circuit current contribution from DER.
- Harmonic limits are enforced on the DER level (e.g., at the inverter).

Bad Practice on technical regulations for maximum DER impact:

Overly restrictive requirement on maximum PV installation capacity. This should be replaced by a regulation that fosters PV growth while keeping distribution network expansion to a minimum.

Box 4 Lesson Learned on Hosting Capacity Regulation from California

The origin of regulation on limiting the amount of PV to 15% of distribution transformer capacity or limiting it to 50% of peak demand, was a practice that originated in the U.S., but that was around 25 years ago. And they already removed this regulation and improved it, so, it is important also to take these lessons learned from California and other places to improve regulation.

E. Recommendations

Based on the above analysis and discussion during the webinar on hosting capacity, there are several key takeaways & recommendation as follow:

1. Hosting capacity analysis in Indonesia should consider the coincidence factor and transformer capacity.
2. Initially, some countries limit the hosting capacity to up to 15% of the transformer capacity. However, after a more detailed assessment and experience, it showed that the hosting capacity could be higher than 15%.
3. Hosting capacity results should be published for example, through hosting capacity analysis maps to provide transparency and visibility to PV developers. Countries, for example, the US States and Mexico publish the remaining hosting capacity in different regions/distribution feeders to inform potential developers/users of PV.
4. Capacity building on PV impact in the Distribution network is important, mainly for PLN and Regulator, as most of the discussion and capacity building is on the VRE impact in transmission. This will encourage the development of Rooftop PV in Indonesia.
5. A comprehensive review and analysis of Hosting Capacity are needed to evaluate a better measure of PV Rooftop capacity development. This will also increase knowledge on the characteristic of PV Rooftop in the distribution network.

Box 5 Discussion

How important is it to have a clear Grid Code for the installation of PV inverters in the early stages of integration of renewable energy? What can be the impact of postponing this into the future?

Hosting Capacity is measured in Distributiion Network, so the applied code is Distribution Code. Indonesia has Distriibutiion code, that has benn enacted since 2009. Update on new development is a must and critical, as PV Roodtop is start to emerge in Indonesia.

We are still experiencing some blackouts here in Indonesia. Are there any studies/experiences on whether PV in the distribution grid will help or worsen the blackouts?

It depends on many factors if PV may have a positive or negative impact on the likelihood of blackouts, so this cannot be generally said without a more detailed study. Causes for a blackout may also often be unrelated to PV generation, so it is also just important that the grid operator takes appropriate measures to reduce the likelihood of blackouts regardless of PV development.

How often is the hosting capacity assessment done, is it enough once?

On the topic of the 15% maximum PV limit: I disagree with the principle for each consumer to have the limitation as to have the same capacity. Giving the same limitation for everyone in every single household, then you very much restrict any PV capacity, because of the probability, not all consumers to install the PV system. On the topic of hosting capacity assessments: The update for regulation in California is still in the process. You calculate once, and at a point, the PV capacity would surpass the limit, it then requires another assessment, to evaluate whether the hosting capacity could be raised further.

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