Over the past few years, the number of PV installations in the Netherlands has grown exponentially, increasing the installed capacity from 149 MWp in 2011 to 14.4 GWp in 2021[1]. The rapid adoption by (larger) commercial customers, driven by attractive subsidy schemes, has led to voltage limit violations in the Dutch medium-voltage grid. Annual netting of generation and demand caused a short return on investment for households (over 20% has a PV systems installed), but also led to complaints about inverters switching off due to over-voltages.

Especially in rural areas, the rapid adoption of distributed generation caused voltage violations in the medium-voltage network. Historically, these networks were designed to facilitate loads of (agricultural) customers. The voltage control was chosen accordingly, starting with a relatively high voltage at the primary substations to allow for voltage decrease over the distribution networks. All such that the voltages at the customer connections were still within the allowed limits. As PV systems were widely adopted on agricultural roofs and land, the voltage increased rather than decreased causing voltage limit violations (both maximum voltage and voltage variation). As a result, customers requesting additional transport capacity for generation had to be put on a waiting list.

In the long term, (one of) the solution(s) to these constraints is network reinforcement. A process that may take several years, whereas the customers want to generate renewable electricity sooner rather than later. Having to wait for additional transport capacity, they might lose their right to subsidy and thereby their business case altogether.

As a short-term alternative to not receiving any transportation rights, Liander (one of the Dutch DSOs) has developed an autonomous voltage-based power control. The customer measures the (grid) voltage at the point of common coupling and reduces the output power of its generation unit as the voltage exceeds predefined limits.

The setpoints for the control scheme are chosen such that the existing worst-case voltage does not worsen. This voltage may for example arise when the medium-voltage grid is in a rerouting configuration, due to maintenance or following an outage event, while the generation is at its maximum (bright spring or summer day). For a large part of the time, though, the actual grid voltage will be significantly better. After all, if less PV power is generated (on off-peak hours, a cloudy day or in winter), if the load is higher and/or if the network is in a more optimal configuration, the voltage is not at its maximum leaving room for additional generation. Consequently, a customer will be able to feed in a substantial part of the energy generated.

After the existing worst-case voltage has been determined, additional network calculations are used to determine the equivalent maximum voltage at the point of common connection of the customer requesting transport capacity (U_2). If this voltage occurs, the customer has to make sure to curtail its generation unit's active power to zero (P_2). Voltage instability and unnecessary ageing of the inverter are prevented by a linear output power reduction in the voltage range leading up to the maximum voltage (from P_1 to P_2 between U_1 and U_2). To

[1] For reference: the Dutch annual peak load is around 18-19 GW.

limit the impact on active power generation, the power factor of the generation unit is set to 0.9 inductive. This reduces the voltage rise due to the generator itself by around 20%.

More advanced (autonomous) voltage-based control schemes may be thought of. Some examples:

- $Q = constant$. This control scheme causes (high) reactive power flows at all times, resulting in reduced hosting capacity; and increased grid losses.
- $Q = f(U)$. This control scheme is not effective with large R/X, typically the case in Liander's grid, consisting mostly of underground cables.
- $\cos(\varphi) = f(U)$ and $\cos(\varphi) = f(P)$ control might be more effective theoretically, but are hard to implement in practice with limited added value.

In the end, a combination of $P = f(U)$ control and $\cos(\varphi) = 0.9$ was chosen due to its simplicity (no need for communication) and because most inverters do allow for this type of control scheme. Currently, the autonomous control scheme is adopted by several dozens of customers. This allows them to feed in most of their generated electricity, whereas otherwise they could not until the grid reinforcement was completed. In many cases, over 80% of the generated electricity can still be fed into the grid.