## Objectives and context

Electricity grid is subject to change with the increasing installed capacity and gets harder to operate with the increasing renewable penetration. That is why grid operators require ancillary services not only from conventional generation units but also the renewables. Reactive power generation is one of these capabilities that renewable sources to possess. Thanks to the four-quadrant structures of the inverters, they can both absorb or inject desired active and/or reactive power values.

There are several cases in which grid connected inverter can be utilized for generating reactive power. The first case is operating as a reactive power compensator. Standard reactive power compensation units (RPCU) which are installed in low voltage systems are basic capacitor banks. If the load is capacitive, then they cannot compensate the reactive power. On the other hand, grid connected inverters can be utilized to compensate reactive power in both capacitive or inductive modes. Secondly, voltage regulation on the power system can be corrected with reactive power injection. Especially, low voltage systems are designed in a tree-like shape (radial design), so that it is not appropriate for the reverse power flows which is a common case in the renewable energy installation. Therefore, load voltage might increase rapidly and result in tripping on the load or renewable system inverter. In such a case, the PV inverter might find a better operating point than MPP with unity power factor.

There have been a few studies in the literature for utilization of PV inverters as reactive power compensators which do not include seeking an optimum operating point, and rely on constant reactive power commands. Moreover, several algorithms and methods have been proposed, tested and implemented for MPPT such as perturb and observe, incremental conductance, fuzzy logic etc. In this paper, a novel algorithm is proposed for grid-connected PV systems which is called Optimum Power Point Tracking (OPPT). In this method, the PV system (only inverter or DC/DC converter + inverter) is aimed to operate at maximum power point possible while maintaining a load voltage within specified limits and supplying or drawing sufficient reactive power not to get penalized by the utility due to poor power factor. Implementing these with only MPPT requires increase of the PV inverter kVA ratings significantly.

## Methods/approach

The algorithm to be constructed at the end of this study will monitor the PCC active and reactive powers as well as the PCC voltage. Then the required reactive power will be computed and possibility of such generation will be investigated. This value depends on the available active power from the PV panels and the total power rating of the inverter. If the inverter has sufficient reactive power capacity, then MPPT algorithm will not be disturbed. However, if the active power generation is very close to the inverter rating or reactive power demand is high, then the active power curtailment is necessary in order to enable reactive power compensation. Then, algorithm will find an Optimum Power Point (OPP) and the operation will leave the MPP. This will not only correct the power factor of the customer, saving it from reactive power penalty, but also give the PV inverter the ability to interfere when a voltage regulation is present enough to disrupt the operation. When power factor correction is required which would result in exceeded converter ratings, the algorithm will compare the benefits of keeping the active power as it is (at MPP) and correcting some part of the reactive power problem.

## Outcomes

The proposed method will operate as following:

- When the PCC voltage and system power factor are within acceptable limits, the algorithm will keep the existing MPPT operation, supplying all the available PV panel power.
- When over-voltage or under-voltage occurs, which is possible especially with sudden load or PV generation changes, the algorithm will compute the necessary amount of reactive power injection/absorbtion to correct the PCC voltage. In this case, depending on the PV power generation at the specific moment and PV inverter size, the algorithm will leave the MPP decreasing the PV panel power.
- In case of very poor power factor, which may cause reactive power charge to customer, the amount of reactive power will be calculated to correct the power factor above acceptable values. Leaving the MPP and finding an OPP may still occur in this case depending on the inverter size.
- The algorithm will also be able to regulate the PCC voltage, enhance the power factor and inject the maximum available PV panel power with this order of importance, respectively. Unless an emergency situation is present such as load tripping due to over-voltage, optimum power point will be determined by considering the cost of decreased efficiency due to increased inverter current, the money saved by the injected active power and the penalty avoided by power factor.

## Conclusions

In modern low voltage distribution systems, it is not feasible to leave the system as it is, since distributed generation installation such as PV or wind increases rapidly each day. Auxiliary systems to overcome the power quality problems such as voltage regulation or reactive power are required. In this paper, it is proposed that the PV inverters which can operate in four quadrants can be operated with non-unity power factor inductive or capacitive at the cost of increasing losses to overcome some of these problems, without any additional measures. A novel method is proposed devoted to grid-connected PV systems, which are aimed to be used for reactive power compensation, to operate at an optimum power point which takes into account both active and reactive power. This point may be different than maximum power point, which is always used in standard PV inverters due to power ratings of the system. It is proposed that in several cases, the optimum power point tracking can save the system from tripping from over-voltage or under-voltage and save the customer from reactive power charge and penalty.