# Hosting Capacity Enhancement and Voltage Profile Improvement Using Series Power Electronic Compensator in LV Distribution Networks

Ehsan Kazemi-Robati
*Department of Electrical Engineering*
*Shahid Beheshti University*
Tehran, Iran
e_kazemi@sbu.ac.ir

Hossein Hafezi
*Faculty of Information Technology and Communication Sciences*
*Tampere University*
Tampere, Finland
hossein.hafezi@tuni.fi

Roberto Faranda
*Department of Energy*
*Politecnico di Milano*
Milano, Italy
roberto.faranda@polimi.it

Mohammad Sadegh Sepasian
*Department of Electrical Engineering*
*Shahid Beheshti University*
Tehran, Iran
m_sepasian@sbu.ac.ir

Pierfrancesco Sodini
*Engineering & Construction*
*Storage Design Unit Italy & Rest of EU*
*Global Power Generation*
*Enel Green Power*
Rome, Italy
pierfrancesco.sodini@enel.com

***Abstract*—Different types of custom power devices proposed by the researchers can provide a diverse set of services in electrical energy systems. Among them, Series Power Electronic Compensators (SPEC) as Dynamic Voltage Conditioner (DVC) which are connected to the substation of the LV networks can effectively improve the voltage characteristics of the grid in a simple and practical way. In this paper, firstly a short review is given on the effect of the SPEC on the voltage profile of a LV distribution system with real measured data. Moreover, the grid hosting capacity improvement using SPEC is addressed and studied in the LV grid. Hence, a supplementary evaluation is performed by a focus on the min-max voltage curves with respect to the different demand-leveling scenarios. According to the results, the use of a SPEC can effectively enhance the network hosting capacity beside the considerable improvements in the grid voltage. Therefore, it can be effectively applied in modern networks to provide higher levels of power quality in presence of high load or generation conditions. So doing, it should be possible to increase the hosting capacity of a network and therefore to increase the amount of loads and distributed energy resources that the electric distribution network can reliably accommodate without significant grid upgrades.**

***Keywords— SPEC, DVC, voltage profile, hosting capacity, demand leveling.***

## I. INTRODUCTION

Beside the reliability of the electrical power supply, it is very important for the costumers to have an acceptable quality of power [1]. Furthermore, there are generally some renewable-energy-based Distributed Generation (DG) units with high intermittency of the output power in modern distribution systems which may introduce additional Power Quality (PQ) problems [2,3]. Therefore, PQ needs to be studied even with higher importance in presence of DG.

Accordingly, there is a considerable focus on PQ-oriented studies in the papers published on modern distribution systems [4-6]. Following their descriptions, voltage sags, voltage swells, flicker and harmonics are the main PQ problems which have been studied in the literature [7-12].

As well known, one very important aspect to be considered in PQ is the voltage stabilization. EN 50160 standard gives the main voltage parameters and their permissible deviation ranges at the customer's point of common coupling in public low voltage (LV - phase to phase nominal RMS voltage less than 1kV) and medium voltage (MV phase to phase nominal RMS voltage between 1kV and 35kV) electricity distribution systems, under normal operating conditions.

For the voltage-related solutions, the application of a Series Power Electronic Compensator (SPEC) called Dynamic Voltage Conditioner (DVC), which is proposed in [13], can be highly recommended due to its low-cost factor and its technical capabilities to solve the main PQ problems described in EN 50160 standard such as short-term voltage sags, voltage swells, long-term voltage deviations and harmonics of voltage.

It is important to underline that a smart strategy for voltage stabilization can reach additional advantages. Beside the importance of the PQ-oriented studies in modern grids, there may be many distribution networks especially in LV level facing with excessive request of load/generation connections due to the presence of new green generators and new loads like Electric Vehicle (EV) chargers [14-17].

Accordingly, the movement through this new combination of high loading/generation scenarios may lead in lower quality of power and in particular, lower or higher voltage values in the distribution grid as described in [18-20]. Therefore, a supply voltage outside the standard range (between 90% to 110% of the nominal value) is becoming the strongest limit to connect additional loads/generators to the distribution grid.

Hence, a very interesting service which can be provided by a DVC is the possibility of connecting additional prosumers by the simple control of the voltage value in the point of common coupling of the public network. Hence, it is possible to increase the hosting capacity of the network both for the loads and the generating units without the need of distribution network expansion.

In this paper, after the primary description and study on a LV network with real measured data, the voltage stabilization strategy is tested with respect to the leveling of the measured load-profiles. Accordingly, the combination of loads and generations will be maintained reasonable during the study of this paper. Finally, the effect of SPEC in increasing the grid capacity for hosting more prosumers is assessed while the voltage profiles are monitored. Hence, in this paper the application of the SPEC for stabilization of the grid voltage and improving its capability in hosting more prosumers is addressed.

The rest of this paper is organized as follows. A brief description of a topology of a SPEC called DVC is given in Section II. The study case grid is defined in Section III. The effect of SPEC on the grid is provided in Section IV. Results are discussed in Section V and the paper is concluded in Section VI.

## II. Series Power Electronic Compensator (SPEC)

The topology of a SPEC called DVC connected to a LV network is given in Fig. 1 [13]. This device includes a full-bridge converter placed in series connection with the grid through the use of a coupling transformer (highlighted area).

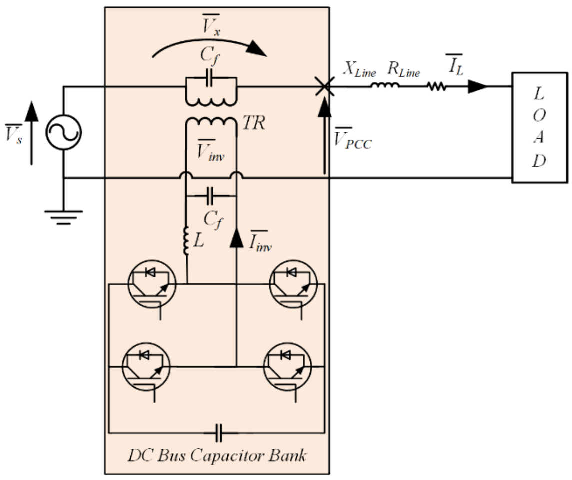


Fig. 1. Topology of DVC connected to the LV grid [13]

By providing the proper $V_x$, the DVC can play an important role in stabilizing the output voltage ($V_{PCC}$) in the grid with a defined reference value (usually the nominal value) with respect to the following equation.

$$\overline{V_{PCC}} = \overline{V_s} + \overline{V_x} \quad (1)$$

Furthermore, as an important design point, the device is managed to work in non-active operation mode in long-term assessment window. The details of the working principals and the formulations are provided in [13].

Regardless of these details in the implementation, the capability of the device in stabilizing the voltage in PCC can be found effective in improving the grid power quality and enhancing the capability of the distribution system for hosting higher levels of loads and distributed generation units (prosumers).

Accordingly, the application of SPEC in voltage improvement and hosting capacity enhancement is addressed in the following sections.

## III. Under Study Network

In this paper, a 4-bus LV distribution system with real measured data is implemented [21]. The single line diagram of the grid is given in Fig. 2. The line data of the grid is also provided in [21] and described in Table I.

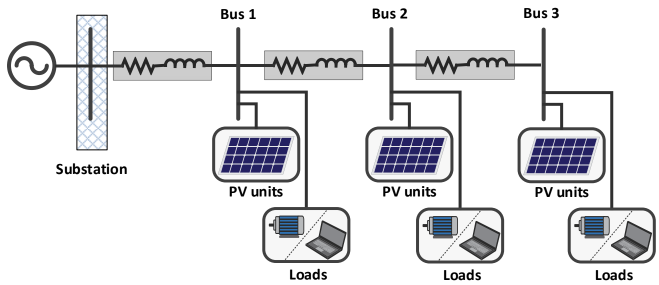


Fig. 2. Single line diagram of the studied LV distribution network

TABLE I. Specifications of the cables used in the studied network

| Nominal section ($mm^2$) | R ($m\Omega/m$) | X ($m\Omega/m$) | Current carrying capacity (A) |
|---|---|---|---|
| 185 | 0.123 | 0.0908 | 545 |

In all the assessments in the paper, the available 159-days measured data in a sample year are implemented. It should be emphasized that the data of the measured powers at busses include the summation of load powers and PV generations. However, a brief review of the assessments applied on the grid are given in the following subsection while it is labeled as the "main grid".

### A. Main Grid Without SPEC

Firstly, it should be emphasized that there are PV units installed in the studied grid [21]. Hence, the supply of the loads locally by the generation units in some days could decreases low-voltage problem. The voltage distribution in the grid is demonstrated for all three buses in Fig. 3.

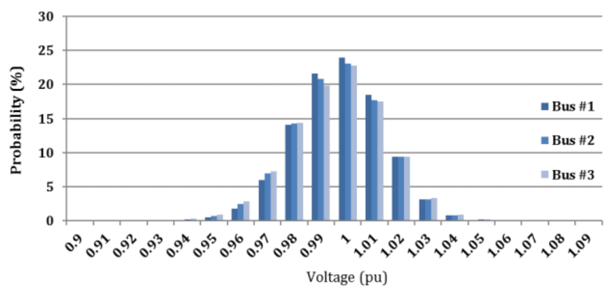


Fig. 3. Voltage distribution assessment at different busses of the grid

It should be noted that there is no voltage violation in any busses of the network with respect to EN 50160 standard (±10% limits in any of the busses of the grid for 95% of the time). Hence, although the grid assessment verified that network is working without any problem in the study period, an increase of load/generation levels in future may change the grid operation specifications. By increasing prosumer power levels in modern distribution systems, the voltage deviations get more severe and it can result in inacceptable PQ conditions in the grid due to the violation of the ±10% limits in one of the busses of the grid for more than 5% of the time.

Therefore, it is possible to anticipate that in future, PQ problems will be probable during the times when Electric Vehicle (EV) chargers will be connected to the network (surplus of load). Similarly, the PQ problems are also probable in April, May, September and October in which there is high PV generation and less load (e.g. lower air conditioner loads) in the grid (surplus of generation).

Therefore, with respect to the descriptions, it is very important to study the future of the grid to understand the necessary steps to maintain the correct PQ standards and to use each distribution line as close to its physical limits (e.g. line thermal capacity) as possible. In the next subsection, the measured active and reactive powers in the whole year will be increased to evaluate the hosting capacity of the network.

### B. *Hosting Capacity analysis without SPEC*

In this paper, the demand profiles of the main grid are gradually increased to see the ability of the LV grid in hosting the excessive combination of load and PV generation. Hence, it will be possible to see what happens during the conditions with a surplus of PV generation or with surplus of load. It should be noted that in all the studied scenarios, equal multiplier $M$ is used for all load busses. Accordingly, the apparent power ($S$) at each bus can be calculated using the following representation.

$$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} = M \times \begin{bmatrix} P_1 + jQ_1 \\ P_2 + jQ_2 \\ P_3 + jQ_3 \end{bmatrix} \quad (2)$$

The multiplier $M$ is increased from 1 by 0.1 steps and the grid is monitored during the whole study period in each case. It should be noted that the assessments are terminated for the case in which voltage constraint violation is occurred in one node for 1 minute or more during the study period.

The summary of voltage assessment results is given in Fig. 4 in which the voltage distribution is shown for the different scenarios with 5 steps from $M$=1 to $M$=1.7. It should be noted that for each step, the voltage values are given for all busses in the aggregated form.

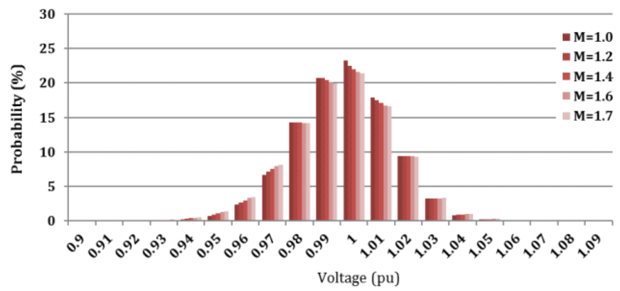


Fig. 4. Voltage distribution curve of grid for different $M$ values

According to the results, when the grid active and reactive powers are multiplied by 1.7, there are violations in voltage constraints during the year. So, $M$=1.6 is assumed to be the maximum allowed power increment in the main grid without any complementary PQ improvement strategy able to stabilize the voltage profile in the network. It should be noted that in this condition, the maximum line current flow in the grid in the study period is 289.6A and this value is lower (quite far) from the line capacity reported in Table I. Hence, from the current capacity point of view, the connection of further load /PV-units can be allowed to the grid. However, the voltage deviations in the grid have strongly limited the hosting capacity. Therefore, the power multiplier $M$ must be equal to 1.6 or lower to ensure that all constraints are satisfied, which means the connected prosumers cannot be increased more than 60%.

Therefore, to increase the hosting capacity, it becomes strongly important to manage the voltage in the network and in particular in the point of common coupling and, additionally, to manage it properly in case of surplus of generation or load. So, in such a condition, especially by the possibility of both high and low voltage scenarios in the grid, it is very important to have a tool for stabilizing the voltage in the grid. Furthermore, to increase the PQ level in the future, it could be necessary to supply loads by a lower voltage variation range.

Hence, managing the voltage in point of common coupling by a SPEC, there would be the possibility of hosting both new loads and PV units. Such a possibility would be more effectively provided if the device can have the possibility of shifting grid voltage distribution curves. In the next section, a SPEC is added to the substation of the grid to see the effect of this device in increasing the grid hosting capacity.

## IV. SPEC CAPABILITY ASSESSMENT

As described, in this Section, the SPEC is added to the substation (beginning of the study network, Fig. 2) to stabilize the voltage in the first bus of the feeder on a certain value. In order to clarify the capability of this device in voltage profile stabilization, firstly a short review is given on the main grid voltage assessment in presence of SPEC without any load/generation increasing scenario. Then the increase is applied to see the effect of SPEC on grid hosting capacity.

### A. *Main grid with SPEC*

A comprehensive assessment on effect of the SPEC on the voltage of the base grid (without load-increasing) is provided in [21]. Hence, a comparison of the voltage distribution curves in the main grid and in presence of the SPEC are provided in Fig. 5. It should be noted that the distribution curves are provided by the assessment of the study period data of the RMS voltage of all buses. According to the results, the bus voltage in grid has been successfully stabilized using SPEC to provide the higher level of PQ in the grid. Moreover, it can be seen that there is the possibility of successful shift in the voltage distribution curve by the use of SPEC with simply setting different reference value of the voltage in the point of common coupling (1.00pu, 1.03pu and 0.97pu). Then, using SPEC and its capabilities, the network operator can take advantage of this feature of the device by adjusting the value dynamically and continuously to solve problems due to the continuous variations of the demand profiles that can occur every day.

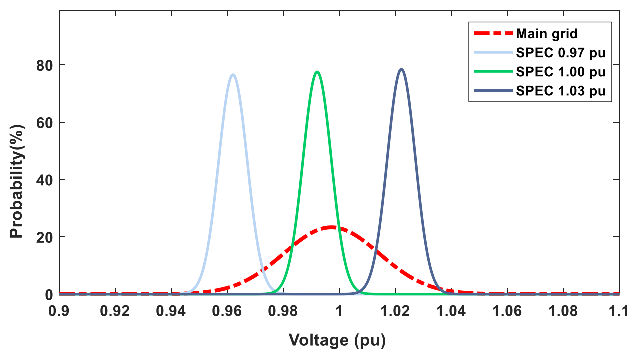


Fig 5. Effect of SPEC on voltage distribution curve of the grid

To understand the ability of SPEC in increasing the hosting capacity of the network, its effect on the voltage profile of the grid while different incremental loading and/or generation scenarios are applied to the distribution network, has been analyzed in the next subsection.

### *B. Hosting Capacity analysis with SPEC*

In this subsection, the load profile of the grid is increased by 0.1 steps from *M*=1, in presence of a SPEC with constant setpoint (1.00pu). The demand increase is accomplished until a voltage violation in one node occurs for 1 minute or more in the grid during the study period. A brief presentation of the results in presence of the selected power leveling scenarios is given in Fig. 6. Similar to Fig. 5, here the data is given for all busses in the study period in aggregated form.

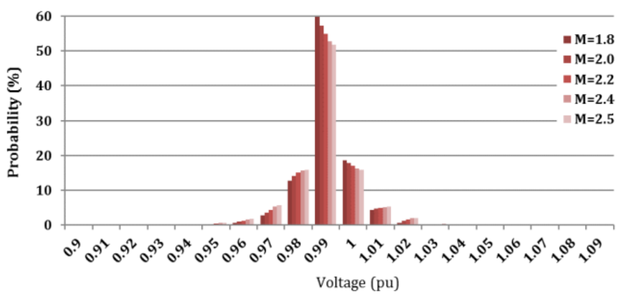


Fig. 6. Voltage distribution in the grid for different multipliers in presence of the SPEC

When the multiplier is increased to *M*=2.5, there are voltage constraint violations in node 3 during the study period. In this condition, the maximum current flow in the grid during the whole year is 452.3A which is lower than current carrying capacity of the cable as reported in Table I. However, the load multiplier must be *M*=2.4 or lower to provide the constraint satisfaction in the grid, which means that the hosting capacity is effectively improved in comparison with the previous case. In this case the maximum current flow in the grid during the whole year is 433.0A.

## V. RESULTS COMPARISON

As described in the previous Sections, the hosting capacity of the network can be increased from 1.6 to 2.4 using SPEC. It is important to underline that the studied limit here is the voltage constraint violation (out of the 0.9-1.1pu range) in one node for 1 minute during the study period. The voltage distribution curves of the whole grid are compared with respect to the SPEC presence status in Gaussian form in Fig. 7. As it is clear in the figure, the SPEC has successfully stabilized the voltage around the desired value ($V_{ref}$=1.00pu) for *M*=2.4.

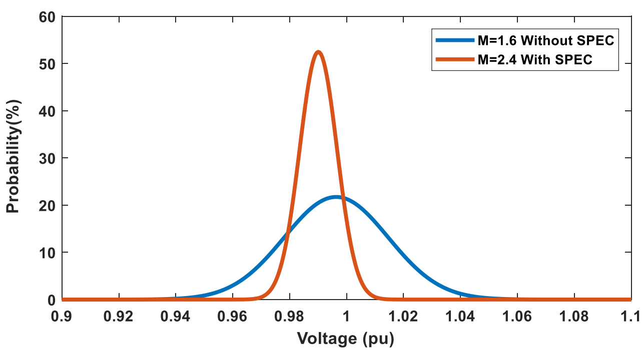


Fig. 7. Voltage distribution curve of the grid in Gaussian form for M=1.6 without SPEC and M=2.4 with SPEC

In order to provide a more focused assessment on the effect of SPEC, the min-max voltage of the nodes of the grid are monitored for different multiplier values starting from *M*=1. These curves are given for the main grid and the grid in presence of the SPEC in Fig. 8 and Fig. 9, respectively.

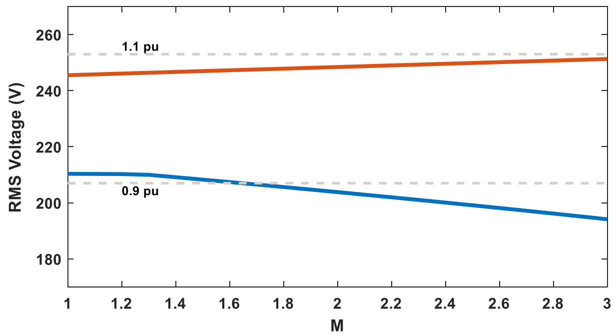


Fig. 8. Min-Max voltage of the grid without SPEC

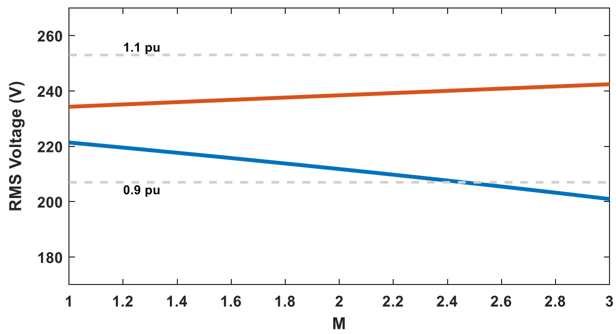


Fig. 9. Min-Max voltage of the grid in presence of SPEC

According to these results, the level of voltage stabilization using the SPEC can be clearly seen which proves the capability of the device for hosting the excessive load and PV generation in the grid. It is important to underline that due to the constraint violations, without the use of a correct strategy to stabilize the voltage profile in the network, it can reach only 53% (290.6/545.0) of its hosting capacity. Instead, using a SPEC like DVC, it is possible to increase its hosting capacity to about 80% (433.0/545.0).

However, the maximum and minimum voltage can reach 240.0V and 207.6V at least for 1 minute during the studied limit in presence of SPEC in the grid. It is clear that voltage is far from the upper limit; Hence, by increasing the voltage set-point or applying a control strategy which provides different SPEC voltage set-points during the day with respect to the different grid conditions in the grid, higher hosting capacity can be reached. However, by hosting the higher levels of power with the aid of SPEC voltage stabilization capability, the limits in the current flow in the grid lines or the probable increase in the SPEC investment cost should be taken into account; while the latter can be of course decreased by the aid of transformer tap.

## VI. CONCLUSION

In this paper, an assessment is carried out on the capability of a Series Power Electronic Converter (SPEC), such as DVC, on increasing the hosting capacity of the under study LV grid. In order to provide such an assessment, after a description on the studied LV network, the effects of increasing the load/generation levels are assessed. Then the SPEC is added to the grid to provide a review on its effects on the voltage profile of the grid. Finally, the capability of the device on increasing the hosting capacity is investigated. According to the given detailed results, the SPEC has the capability of stabilizing the grid voltage while higher levels of loading/generation scenarios are implemented. Hence it can effectively increase the hosting capacity of the line (around 50% improvement). Moreover, it is evident that supplementary control and management of the mains voltage using transformer tap changer or additional control strategy for the adjustment of the device reference voltage can maintain operational constraints of the grid within the limits while providing further increasing in hosting capacity of the grid.

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