UPQC – the best solution to improve power quality in low voltage weak distribution networks

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Abstract— **The answer to global problems challenging energy sector was to use more efficiently local alternative (non-conventional fossil fuel or renewable) energy resources. In power systems, the use of renewable energy (RE) based distributed generation (DG) has increased considerably all over the world; the presence of DG units at distribution voltage level determines the transition from traditional passive to new active distribution networks. Concurrently, the modern distribution networks supply a large variety of non-linear loads based on power electronics contributing to increased current and voltage harmonics issues; dynamic loads and unbalance in power systems cause other power quality problems. The Romanian power system faces some challenges in order to ensure the reliability and quality of the power supply, especially in low voltage (LV) rural and sub-urban grids; thus, the power quality issues must be appropriately identified in every network while their assessment is the key element in the design of measures aiming to diminish all existing disturbances. A research project aims to identify the power quality issues and the impact of DG or other non-linear loads on LV distribution networks in Romania; the final goal is to develop an equipment able to remove or, at least, to mitigate all electromagnetic disturbances considering the characteristics and sensitivity of end use equipment within customer facilities.**

Keywords—distributed generation, power quality, weak distribution networks, universal power quality conditioner

I. INTRODUCTION

Traditional power systems, mainly based on large central power stations and with only one direction of power flow, are still predominant in many countries all over the world. Unchanged for decades, they have several harmful characteristics: (i) relatively low energy efficiency, (ii) high emission levels, dramatically impacting the climate and environment (especially due to fossil-fuel power plants), and (iii) generation located in concentrated areas. In addition, the depletion of the primary fossil energy is another factor of concern.

Therefore, as the nowadays society asks for a secure, green and sustainable energy, nearly all national and international energy policies are taking into account this objective. For instance, on February 2015, the European Union proposed the latest strategy to implement a new resilient and forward-looking climate change energy policy in the 27 state members [31]. This policy embraces four main ideas, as follows: (i) solidarity clause, meaning to reduce the dependence on single suppliers; (ii) energy flows, i.e. the free flow of energy across borders; (iii) energy efficiency first, explicitly to increase energy efficiency in all sectors and to consider it as a powerful energy source; (iv) transition to a low-carbon society, as the final goal.

Worldwide, the answer to these problems was the implementation of friendlier ways to generate energy by using local alternative energy resources (LAER); these generation systems employ either non-conventional fossil fuel sources (biogas, fuel cells, combined heat and power, etc.) or renewable energy sources (mainly wind power, solar energy and hydropower) [1].

The presence of various local generators, connected to the existing public distribution grids is known as distributed generation (DG). Based on above mentioned energy policies, the use of renewable energy (RE) has increased considerably all over the world; making use of various governmental promoting programs and generous financial supports, technologies for renewable energy sources (RES) have developed rapidly and some of them are already well established. RES can provide the whole energy required in the future and, practically do not contaminate the environment; most existing studies underline the right RES management would generate suitable amount of clean power, with a reduced environmental impact [2].

Nowadays, the sizes for many DG units turn to be much smaller, making them suitable for either residential use or small commercial applications. The trend for developing better DG technologies continues and the 2015 EU strategy aims to promote the "EU technological leadership, through developing the next generation of renewable technology".

As Romania has an important and varied potential of RES (mainly wind, solar, hydro and biomass), the use of renewable energy has expended considerably in our country, too, and DG became more popular based on latest technological achievements. The state policies supported the installation of various generation entities and their integration into existing power systems; some of these facilities can produce large power outputs in single power stations (i.e. hydropower or wind farms), but the majority are relatively small in size. In low voltage (LV) networks, we are talking about small generation applications (typically based on renewable resources), located close to consumers and therefore geographically widespread.

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The presence of DG units at distribution voltage level means the transition from traditional passive to active distribution networks, with both benefits and weaknesses. Advantages can be found at customer (improving the continuity of power supply), utility (mainly reduced distribution power losses and improved grid utilization) or even national level; the main negative aspects deal with possible harmful impact on power quality, the cost of electricity, potential reverse power flow, etc.

Concurrently, the modern distribution networks are more vulnerable to the different power quality problems due to the increasing demands for highly efficient consumption; practically, these grids supply a large variety of non-linear loads based on power electronics contributing to increased current and voltage harmonics issues. Dynamic loads and unbalance in power systems cause other power quality problems such as neutral currents, voltage dips, fluctuations, momentary interruptions, oscillatory transients, harmonics, harmonic resonance, etc.

In conclusion, due to the massive increase of nonlinear loads and local power generation in LV distribution networks, the Romanian power system faces some challenges in order to ensure the reliability and quality of the power supply. The distribution system operators have to pay a special attention to the LV rural and sub-urban grids where the short circuit power at the supply points is usually quite small and the network can be easily driven out of operating boundaries due to voltage variations or congestions. Consequently, the power quality issues must be appropriately identified in every network while their assessment is the key element in the design of measures aiming to diminish all existing disturbances.

Based on the above mentioned reasons, a research project was started in order to identify the power quality issues and the impact of DG or other non-linear loads on LV distribution networks in Romania; the final goal is to develop an equipment able to remove or, at least, to mitigate all electromagnetic disturbances considering the characteristics and sensitivity of end use equipment within customer facilities. The paper presents several results of this project, as follows: chapter 2 analyses some aspects regarding the power quality in weak distribution networks hosting small-scale DG units and non-linear customers; chapter 3 reviews the main existing solutions to improve power quality and justifies the selection of the Universal Power Quality Conditioner as the best equipment to mitigate disturbances in these grids. The fourth chapter gives some details related to the design of the shunt inverter (both power circuits and control system) in the UPQC's structure; finally, some conclusions are presented.

II. PQ IN WEAK DISTRIBUTION NETWORKS

Power quality (PQ) is a well-known term embracing all aspects associated with amplitude, phase and frequency of the voltage and current waveform in a power circuit; any issue related to voltage, current or frequency deviation that results in failure of the customer equipment is known as power quality problem [21].

The existing electrical power systems suppose a net separation between generation, transmission and distribution subsystems, with power plants at the top of the chain, and customers' loads at the bottom of the chain; consequently, the distribution networks have the function to transfer electricity from power plants to customers and are referred to as "passive". The presence of local generation units, mostly at distribution voltage level, means the transition from traditional passive to "active" distribution networks; the latest integrate various energy resources, electronic equipment and other nonlinear loads, as well as diverse energy conversion technologies, representing a nonlinear and intricate system [5].

A main feature of nowadays electric networks is the continuously increase of their complexity; the demands for highly efficient consumption, in addition to the recent development of power semiconductor and power electronics technologies, have led to the wide usage of power electronics related equipment in both industrial and residential applications. For instance, the solid-state controllers are extensively in use with industry, commercial and domestic sectors; personal computers, refrigerators, air conditioners and other electronic appliances are extensively used by almost all kinds of consumers. The sustainable supply of all these customers represents a huge challenge for power utilities.

Another important aspect related to active distribution networks is represented by the integration of new generators into existing power grids. It is important to say that they can be connected to any electrical system; however, incorporation of different technologies requires more restrictive standards and connection norms, specified by the grid codes existing in every country. Basically, the technically and economically feasible penetration levels as well as the connection solution depend on issues like status of infrastructure development, geographic location of RES, demand pattern, mix of generation technologies, etc. [2]. The main goal is to improve the efficiency of energy production and to ensure the load demand mostly at the distribution level.

In order to adapt the generated power parameters to those required by grid codes, most of RES use power electronics interfaces (PEI), offering better capabilities than traditional connection technologies [3, 16]; moreover, they can convert almost any form of electrical energy to a more desirable and usable form. Other benefits associated to the extended use of PEI are the reduced cost and the fast response time to various events in the grid (within in the sub-cycle range for the latest solutions), the possibility to integrate protective functions providing the right operation of the grid or some level of metering.

The incorporation of new distributed RES as well as the development of flexible, demand-responsive customers may considerably alter the performances of the distribution network, mainly the power quality. First, the existence of local generation units, connected to public grid through PEI, can significantly influence the flow of power and voltage conditions at customers and utility equipment. At the same time, they may affect the power quality (PQ) as experienced by other customers connected to the same grid; the main concerns are related to voltage stability (both slow and fast variations), voltage unbalance, frequency variations, harmonics and inter-harmonics, grid availability and capacity, reactive power flow, etc. On the other hand, the high frequency switching of inverters contained by PEI can inject additional harmonics to the systems, possibly creating major PQ concern especially by harmonic resonance.

Second, the modern distribution networks are more and more vulnerable to the different power quality problems due to the increasing demands for highly efficient consumption; most of modern efficient equipment is based on power electronic devices and uses microprocessor-based controllers. As a result, these grids supply a large variety of non-linear loads contributing to increased current and voltage harmonics issues; at the same time, controllers are quite sensitive to deviations from the ideal sinusoidal line voltage. Dynamic loads and unbalance in power systems cause other power quality problems such as neutral currents, voltage dips, fluctuations, momentary interruptions, oscillatory transients, harmonics, harmonic resonance, etc.

Often, the presence of DG does not produce problems; however, with the extensive application of non-linear loads and the increasing penetration level of DG based on power electronics equipment, PQ problems in the distribution network have become a significant issue in recent years. Most components of the grids behave like nonlinear loads and generate various electromagnetic disturbances; disturbances propagate into the power system impairing the normal operation.

Usually, poor power quality may result into increased power losses in lines and/or equipment, abnormal or undesirable behaviour of apparatus, communication interferences, etc.; the major power quality issues which disturb the consumers are harmonic distortion, voltage sag and voltage swells. For instance, a lot of sensitive loads, such as computer or microprocessor based AC/DC drive controller, require a good voltage profile; they can operate improperly or even lose valuable data in inappropriate voltage sag and swell conditions.

Therefore, both electric utilities and end users are increasingly concerned about the quality of supplied electric power. From this point of view, the distribution system operators have to pay a special attention to the LV rural and sub-urban grids where the short circuit power at the supply points is usually quite small; here the impact of local generation units is important and, under some circumstances, if DG is operating, the grid can be easily driven out of operating boundaries due to voltage variations or congestions. On the other hand, the rural networks are weaker compared to the urban ones, that is to say more vulnerable to electromagnetic disturbances generated by either customers or local generation units (especially due to power converters used to interface the PV panels with the electric grid).

In general, the term “weak grid” is used without any rigorous definition, usually describing a grid with significant impedance; in this case, in order to have valid conclusions, it is necessary to evaluate carefully the voltage level and its fluctuations for various load and production cases because the recommended values might exceed [15]. On the other hand, weakness also means significant ratios between resistance and reactance components in impedances and/or large power flow compared with rated power level (power flow stress). Based on the second criterion, some authors uses the short-circuit ratio (SCR), defined as the ratio between the short circuit power at a generator’s point of common coupling (PCC) and the maximum apparent power of this generator, to characterize the grid; a network with $SCR \leq 10$ is considered to be *weak*, while one with $SCR \geq 20$ is *strong* [16].

Medium and low voltage rural networks, designed for relatively small loads and with long feeders, represent a typical example of weak grids. When the consumption overpasses the rated value, the voltage level will decrease too much and/or the thermal capacity of the grid will be exceeded. As a result, the development of the region is limited due to the limitation in the maximum available power; contrary, if local generation units are present, the absorbed energy is limited by the grid capacity and not e.g. by operating limits of the conventional generation.

Through the nowadays massive increase of nonlinear loads and local power generation in LV distribution networks, the Romanian power system faces the same challenges in order to ensure the reliability and quality of the power supply. Consequently, the power quality issues must be appropriately identified in every network while their assessment is the key element in the design of measures aiming to diminish all existing disturbances.

III. SOLUTIONS TO IMPROVE PQ IN WEAK DISTRIBUTION NETWORKS

As mentioned above, both electric utilities and end users are increasingly disturbed by the poor quality of electric power as an increased number of activities and equipment ask for high levels of PQ. Unfortunately, the extensive use of power electronics devices and nonlinear or unbalanced loads has continuously degraded PQ in LV distribution networks; furthermore, the integration of RES has imposed new challenges, especially for weak grids [6, 11]; today, the main issues are related to (i) fundamental reactive power requirements of the connected loads; (ii) voltage sags and swells at the PCC; (iii) voltage and/or current harmonic distortion due to the presence of nonlinear loads [4]. Supplementary, the continuity of supply is of major importance.

The power disturbances generated at a certain busbar propagate upstream and/or downstream affecting the PQ into the entire power system; this may affect the utility (increased power losses in lines and other equipment, abnormal operation of measuring devices or protection systems, etc.), customers (production and/or financial loss in manufacture industries, inappropriate function/shutdown of sensitive loads or home appliances, loss of valuable data) and local electricity generating units (inaccurate operation, disconnection from the grid, etc.). Therefore, developing efficient solutions to mitigate the power quality problems has become a main topic of research activity in power engineering.

As a general rule, there are three possibilities to meet user’s and utility’s requirement, specifically (i) system upgrading, (ii) use of mitigation equipment, and (iii) improvement of equipment immunity [12]. This paper is dealing only with the second topic.

The classical approach for reducing disturbances such as line current and voltage harmonics uses passive filtering circuits, containing inductors and capacitors, installed at specified locations in power systems; however, they are designed for a definite circumstance and then less effective for random or sudden variations in loads. Other drawbacks are resonance condition versus system impedance and the change of parameters due to aging or continuous usage [12, 21, and 25].

As conventional PQ mitigation equipment is inadequate for an increasing number of applications, power engineers have developed new dynamic and adjustable solutions based on power electronics; the first solutions are known as active power filters (APFs), much better in filtering performance than the passive filters. They have higher cost and complex control but are preferred as the solution to harmonic disturbances generated at the load or supply side due to the following reasons: (i) design almost independent of power system parameters, (ii) no resonance possibility, and (iii) no change of parameters or performances during the life cycle [12, 13].

APFs can be classified as shunt APF, series APF, and hybrid APF. Shunt APFs, connected parallel to the complex loads, deliver the harmonic currents needed by loads while the mains supply only the fundamental; with an appropriated control strategy, it is also possible to correct power factor and unbalanced loads. Series APF are series connected with the line providing high impedance at certain harmonic frequencies; as a result, they prevent those harmonic currents from passing among various parts of the grid. Finally, hybrid APF represents a combination of passive and active filters aiming to optimize the cost and overall system efficiency by designing the active filter only for a fraction of total load power.

All above presented solutions are able to mitigate only one or a reduced number of disturbances. Unfortunately, the complexity of power systems nowadays is increasing rapidly as a result of the rising number of complex loads and DG's penetration level; therefore, several disturbances, such as current or voltage distortion, voltage sags or swells, unbalance both in voltages and currents, etc., may coexist at the same time in the electric grid. In the particular case of weak grids, voltage fluctuations may appear supplementary.

The best way to manage the PQ problems is to mitigate all disturbances at the PCC; in this manner, all loads connected to the grid are provided with clean power. Nowadays, the most attractive solution to obtain this goal is to install in PCC a combination of both series and shunt APFs known as a unified power-quality conditioner (UPQC); this equipment has high performance and the ability to mitigate almost all load current (harmonics, unbalance, reactive current, and neutral current) and supply voltage (sags, swells, unbalance, flicker, harmonics) imperfections. Therefore, the UPQC is expected to be the most powerful solution assuring the PQ level required by large-capacity sensitive loads [3 – 6, 11 - 13, 21, 24, 29].

As seen in Fig.1, UPQC is a power conditioning device consisting of two APFs (bidirectional voltage source inverters - VSI) connected back-to-back through an energy storage device (a common dc bus capacitor); one of them compensates the supply voltages (it is connected in series with the load – series AF) whereas the second compensates the load currents and regulates the dc-link voltage (connected in parallel with the load – shunt AF). Thus, the compensated current drawn from the network and the compensated supply voltage delivered to the load are sinusoidal, balanced and minimized [7].

Basically, the shunt component has to: (i) balance the source currents by injecting the required negative and zero sequence components, (ii) compensate for the harmonics in the load current, (iii) control the power factor by injecting the fundamental required reactive current, and (iv) regulate the DC bus voltage. Conversely, the series converter must (i) balance the voltages at the load bus by injecting negative and zero sequence voltages, (ii) isolate the load bus from harmonics present in the source voltages, (iii) regulate the magnitude of the load bus voltage by injecting the required fundamental active and reactive components depending on the power factor on the source side, and (iv) control the power factor at the input port of the UPQC [15].

The interest in UPQC research area was stimulated by the emergence of fast switching semiconductor devices (IGBT and power MOSFET) as well as of cheap digital signal processors

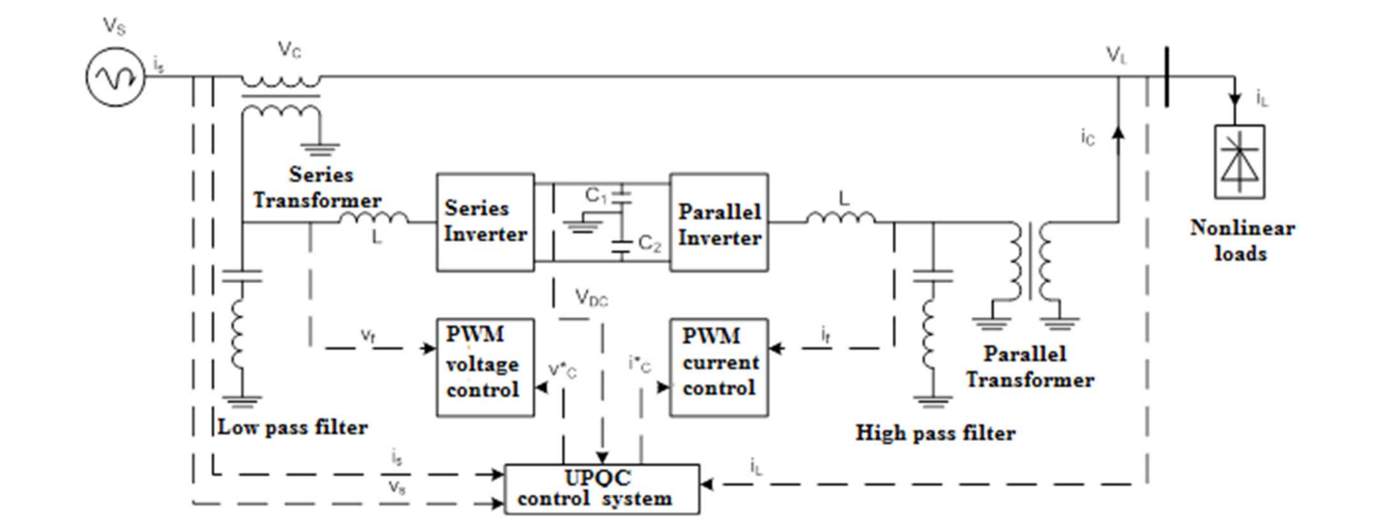

Fig. 1. Schematic configuration of UPQC

(DSP), field-programmable gate arrays (FPGA), analog-to-digital (A/D) converters, Hall-effect voltage/current sensors, operational and isolation amplifiers, etc.

The research activity in our project has indicated that UPQC is nowadays the best solution to mitigate simultaneously several electromagnetic disturbances in LV distribution networks. As we are talking about a three-phase four-wire network, and the zero-sequence components from the source currents must be also eliminated, the neutral-clamped topology was selected; this configuration enables the independent control of each leg of both the shunt and series inverters, but it requires a supplementary control circuit to balance the capacitor voltage [11]. For the case of the studied weak grid, such equipment must be installed in the public substation, at the LV general busbar, and at various neighbouring busbars according to results provided by the PQ analysis for a variety of generation/consumption scenarios.

The main components of the UPQC are the two IGBT based voltage source power converters settled in a UPQC-R topology (the shunt inverter is located on the right side of the series inverter), dc capacitors, low-pass and high-pass passive filters, series injection transformer (used to connect the series inverter in the network) and shunt coupling inductors (used to interface the shunt inverter to the network).

The shunt inverter must be controlled in current control mode aiming to inject currents in the grid according to the references imposed by the UPQC's control algorithm; the second task is to maintain a constant average voltage across the dc storage capacitor. In opposition, the series inverter is controlled in voltage control mode and injects three voltages in order to assure a sinusoidal voltage (of a mandatory magnitude) at the load bus; in the case of voltage sag condition, the injected voltage must also assure the rated voltage magnitude at the load terminals.

The operation of UPQC is exclusively managed by the existing control strategy: it determines the current and voltage reference signals, thus imposing the switching instants of inverter switches. The existing literature presents several such strategies, practically framed in two main categories, i.e. Frequency Domain and Time Domain Analysis. The first category is usually based on Fourier Transformer and requires large computation and delay time; the last one is based on instantaneous derivation of compensating commands in the form of either voltage or current signals [21, 22]. From the large range of time-domain methods, the two most used are the instantaneous active and reactive power (or p-q) theory and the synchronous reference frame method (or d-q theory); the first one was selected to control the experimental UPQC developed in this research project.

IV. Design of Shunt Inverter in UPQC's Structure

The appropriate design of both power and control subsystems of a UPQC is of critical importance for the proper operation of the compensation equipment; this procedure, asking for a systematic study and investigation, will be further presented for the shunt inverter.

If we are talking about power structure, the most significant parameters of this VSI are dc link voltage, value of dc storage capacitor, switching frequency of the electronic devices, hysteresis band, and interface inductance; they have to be carefully selected in order to offer reasonable performance while tracking the reference currents generated by the control circuits [14].

A. DC link voltage V_{dc}

Simulation and experimental studies have underlined the importance of an appropriate dc link voltage [14, 30]; as a rule, it must be higher than the peak value of the line-to-neutral voltage in order to ensure a proper compensation at the peak of the source voltage, namely

$$V_{dc} = m * V_{PCC-m} \tag{1}$$

where V_{PCC-m} is the peak voltage at the point of common coupling, while $m = 1.2 \ldots 2$. On the other hand, practical constraints impose the following condition:

$$V_{PCC-m} \leq V_{dc} \leq V_{CE-rated} \tag{2}$$

where $V_{CE-rated}$ represents the rated value of power switches' collector-to emitter voltage.

B. DC storage capacitor C_{dc}

The dc capacitor serves as a storage element; therefore, its value must be selected on the basis of load transients and/or voltage sag/swell expected in the grid as well as on the allowable limits of the dc link voltage, i.e.

$$C_{dc} = \frac{2*S*n*T}{V_{dcmax}^2 - V_{dcmin}^2} \tag{3}$$

where S is the apparent power that must be compensated for n cycles with T time period of each cycle; V_{dcmax} and V_{dcmin} are the limits of dc voltage.

C. Switching frequency of the electronic devices f_{sw}

The switching frequency of the electronic devices depends on a large variety of system parameters such as the inverter's power, electronic switches used, dc link voltage, interface inductance, etc. Basically, the maximum switching frequency f_{swmax} depends on the type of power switches and on inverter rated power (the large value of current cannot be switched at high frequency); on the other hand, the minimum value f_{swmin} depends mainly on dc voltage as the amplification factor m in (3) can be expressed by the following relationship:

$$m = \frac{1}{\sqrt{1 - f_{swmin}/f_{swmax}}} \tag{4}$$

D. Hysteresis band (±h)

The hysteresis band of the current controller will depend on the tolerable limits of the switching frequency discussed above; as the compensation goal is to limit the current wave's distortion, the value of $\pm h = 2*h_1$ may be between 5 and 15% of the rated compensator current.

E. Interfacing inductor L_f

The interface inductor must allow an excellent tracking of reference currents. As a large value of L_f requires a large value of dc link voltage, the design procedure may use the maximum value of switching frequency:

$$L_f > \frac{m * V_{PPC-m}}{4 * h_1 * f_{swmax}} \tag{5}$$

As mentioned above, the shunt inverter acts as a controlled current generator aiming to compensate the load current; therefore, the current supplied by the network will be sinusoidal, balanced and in phase with the positive-sequence system voltages. The associated control system has to generate proper reference currents in order to charge the dc link capacitor with enough energy for driving the inverters and to compensate the harmonic currents.

The inverter effectiveness primarily depends on the control strategy; from this reason, a control algorithm based on p-q theory was proposed to decide the switching instants of inverter switches. Developed initially for three-phase three-wire systems, with a brief mention to systems with neutral wire, the theory was later extended to three-phase four-wire systems. It transforms voltages and currents from the natural A-B-C frame to stationary reference frame *α-β-0* (Clarke Transformation), where coordinates α-β are orthogonal to each other, and coordinate *0* corresponds to the zero-sequence component. Then, it computes instantaneous active and reactive powers for both steady-state and transient operation, allowing the control of the inverter in real-time; besides, it is easy to be implemented. Additional information on this theory is presented in [18 - 20, 27 – 29].

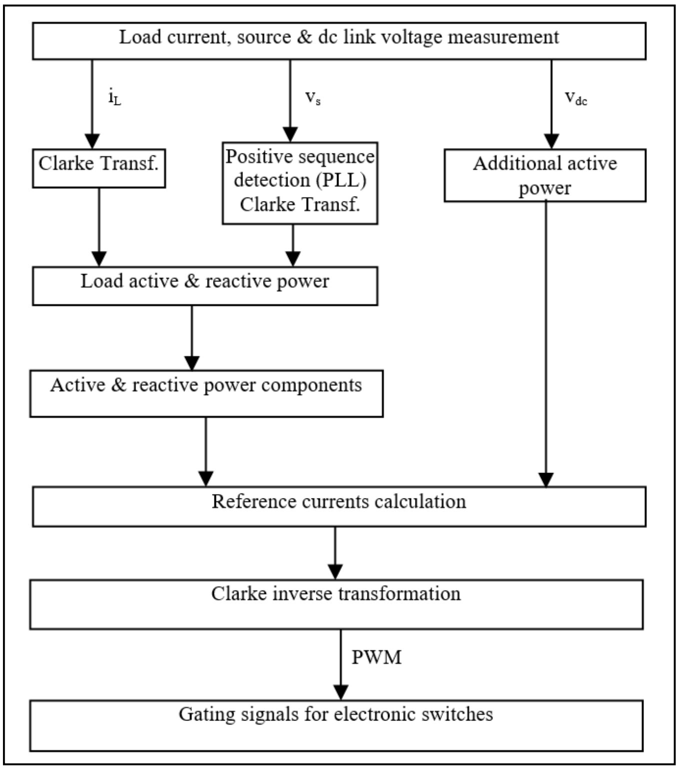

Fig. 2. Schematic configuration of UPQC

Figure 2 shows the basic algorithm used to control the shunt inverter. Practically, the control strategy is implemented in three stages [7, 12, 21 and 26]:

Stage 1: voltage and current signals are measured using appropriate sensors;

Stage 2: based on p-q theory, the average and oscillating components of real and imaginary powers are computed; the amount of energy that must be stored in a the dc link, in order to compensate real oscillating powers that are exchanged between source and loads, is also determined. Finally, the reference currents are obtained.

Stage 3: using PWM techniques, gating signals for semiconductor switches are generated according to the compensated commands obtained in the previous stage.

The main algebraic operations performed in the Stage 2 are as follows:

a) Clarke Transformation for load currents and source voltages

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_0 \end{bmatrix} = \boldsymbol{T} * \begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix}; \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \boldsymbol{T} * \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} \tag{6}$$

where

$$\boldsymbol{T} = \sqrt{\frac{2}{3}} * \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}; \tag{7}$$

b) Instantaneous real, imaginary and zero-sequence powers

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \end{bmatrix} * \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix}; \tag{8}$$

c) Reference currents in *α-β-0* frame

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} * \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} * \begin{bmatrix} p^* + \bar{p}_{DC} \\ q^* \end{bmatrix} \tag{9}$$

where p^*, q^* are the active and reactive powers that must be compensated, while $\bar{p}_{DC}$ is the power transferred to DC circuit. Based on the above relationship, the Clarke inverse transformation will provide the reference currents in the A-B-C frame.

V. CONCLUSIONS

The use of renewable energy resources (RER) has increased significantly last decades in order to secure the rising energy consumption and to reduce the environmental impact. All over the world, technologies for electricity generation based on renewable energy have developed rapidly, and some of them are already well established. Romania has an important and varied potential of RES (mainly wind, solar, hydro and biomass); according to the EU energy policy, and based on promoting programs and generous financial supports, the utilization of renewable energy is continuously extending in Romania, too.

Various local renewable sources are used to drive power electricity generators connected to the existing public distribution grids. While some of these generators can produce large power outputs (i.e. hydropower or geothermal power stations), the majority are relatively small in size and used in small-scale applications away from the large sized generation plants. From operational point of view, the presence of these DG units at distribution voltage level means the transition from traditional passive to active distribution networks.

The nowadays massive increase of local power generation has produced new integration problems for distribution utilities bound to ensure the reliability and quality of the power supply. Especially for LV weak distribution networks, the main negative aspects deal with possible harmful impact on power quality.

On the other hand, the modern distribution networks host a large variety of non-linear loads based on power electronics contributing to increased current and voltage harmonics issues. Dynamic loads and unbalance in power systems cause other power quality problems such as neutral currents, voltage dips, fluctuations, momentary interruptions, oscillatory transients, harmonics, harmonic resonance, etc.

The paper presents the nowadays situation in Romania where distribution network operators (DNOs) face some challenges in order to ensure the reliability and quality of the power supply. The major problems are related to the LV rural and sub-urban grids where the short circuit power at the supply points is usually quite small and the network can be easily driven out of operating boundaries due to voltage variations or congestions.

The research activity has highlighted that, taking into account the complexity of disturbances generated by both DG and consumers in LV weak distribution networks in Romania, the best solution to ensure the continuity of supply and the required power quality is the unified power-quality conditioner. This equipment has high performance and the ability to mitigate almost all load current (harmonics, unbalance, reactive current, and neutral current) and supply voltage (sags, swells, unbalance, flicker, harmonics) imperfections.

UPQC must be connected at the PCC or at different busbars of the envisaged network considering the characteristics and sensitivity of end use equipment within customer facilities. Taking into account the complexity of this equipment, the paper details only some aspects related to the shunt inverter.

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