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A Voltage Regulator for Power Quality Improvement in Low Voltage Distribution Grids

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ABSTRACT: The time needed for permanent solutions, like grid restructuring or capacitor banks installation, to be operational may exceed the deadlines. In the case of failure to satisfy the deadlines, the facility company has got to refund every customer within the distribution grid during the time that the poor voltage regulation persisted. Aiming to prevent refunds, a voltage regulator can be utilized as a temporary solution. The voltage regulator must have fast voltage regulation, reduced weight and easy installation. Using the proposed solution, the grid power quality is established and the PCC voltage is restored in a short period of time. In the meantime, the permanent solution are often planned and installed in an appropriate time-frame. Once the definite solution is implemented, the transformer are often disconnected from the grid and connected to a different grid with similar problems.

KEYWORDS: DSTATCOM, Maximum Power Point Tracker, Power Quality, Static VAR, Voltage control, Voltage Regulator, Compensators.

I. INTRODUCTION

Customers connected at the top of low voltage distribution grids may experience poor voltage regulation. According to Brazilian grid code, power companies have constrained deadlines (15 to 90 days) to revive the Voltage levels at the purpose of Common Coupling (PCC) if the voltages are outside the admissible levels. The time needed for permanent solutions, like grid restructuring or capacitor banks installation, to be operational may exceed the deadlines. In the case of failure to meet the deadlines, the power company has to refund every customer in the distribution grid during the time that the poor voltage regulation persisted. Aiming to prevent refunds, a voltage regulator can be utilized as temporary solution. The transformer must have fast voltage regulation, reduced weight and straight forward installation. Using the proposed solution, the grid power quality is re established and therefore the PCC voltage is restored during a short period of your time. In the meantime, The permanent solution can be planned and installed in an appropriate time frame. Once the definite solution is implemented, the transformer are often disconnected from the grid and connected to a different grid with similar problems.

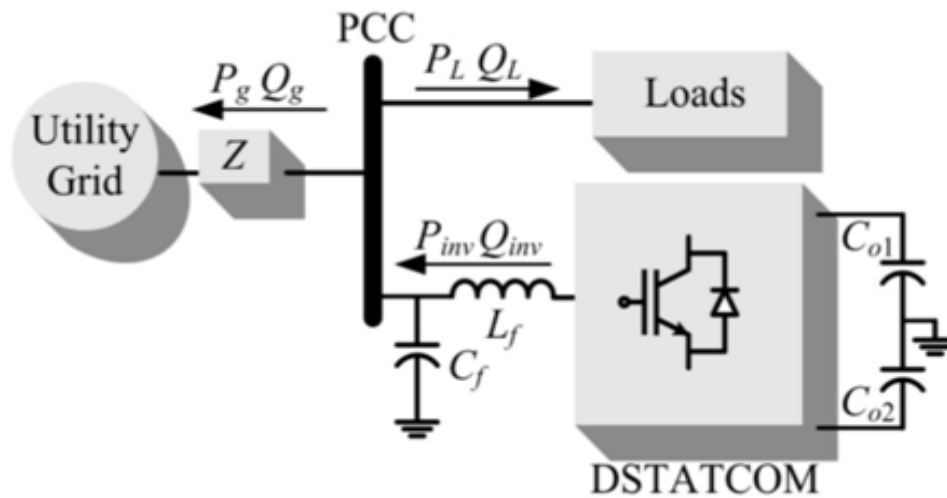


Fig 1.Low Voltage Distribution Grid

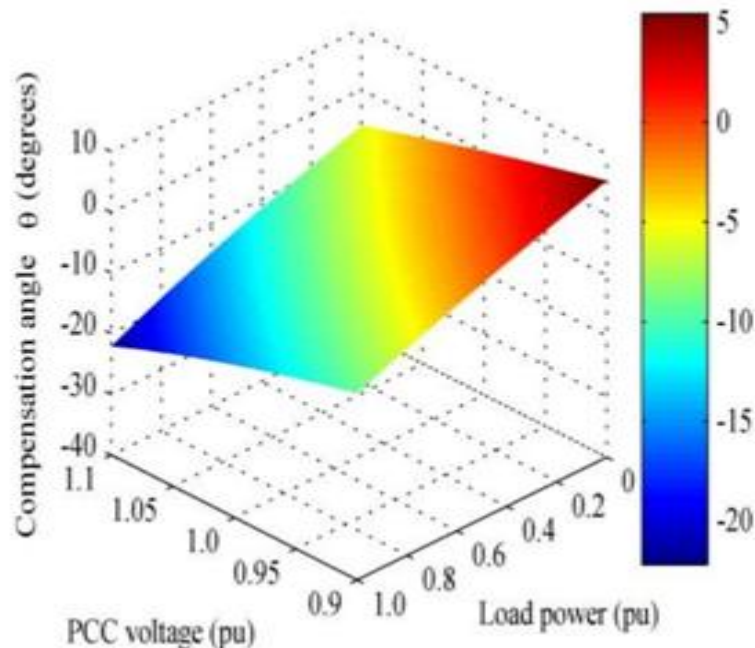


Fig 2.Compensation angle as a function of PCC voltage and load power

II. MAXIMUM POWER POINT TRACKER

The voltage amplitude to be regulated at PCC changes the facility flow between the grid, load and DSTATCOM, as demonstrated in Section II. Suitable VPCC makes the processed apparent power be minimal. When the VPCC is between the specified voltage limits, the MPP T minimizes the converter apparent power and no reactive power at the grid frequency is processed. Apparent power minimization means current minimization, which lower the losses and extends the equipment life cycle. For the MPP T analysis, apparent power is chosen to be minimized rather than reactive power due to: (i) active power in DSTATCOMs may be a small fraction of the apparent power; (ii) the harmonic currents from the grid and cargo also are processed; (iii) the converter power rating and therefore the losses are given by the apparent power; and (iv) apparent power is simpler to calculate as compared to extracting the reactive power at the grid frequency from distorted current waveforms.

A. The P&O-based MPP T Algorithm The reduction of transformer apparent power are often performed by tracking algorithms. An example of tracking algorithm is that the Maximum point Tracker (MPP T), which is widely utilized in PV systems. Among several MPP T algorithms, the Perturb & Observe (P&O) method was

chosen to compose the MPP T algorithm thanks to its simplicity, low computational effort and a little number of sensors, although it's slow transient response and operates around a Maximum point (MPP) [12]–[19], which may be an area or a worldwide MPP [20]–[21]. Two parameters must be set to the P&O algorithm: perturbation amplitude and sample time. The perturbation amplitude defines the convergence time to succeed in the MPP and therefore the amplitude of the oscillations in steady state [14]. The sample period must be greater than the reaction time of the system to avoid instabilities [12]. One interesting feature of the P&O method is its independency of PV arrays parameters [14], [18]. This feature makes the P&O not restricted to PV systems. The P&O-based MPP T algorithm presents an equivalent features of the P&O algorithm applied to MPP T, but is meant to realize the Maximum point. The MPP T are often derived analyzing Fig. 5 (a). The marker 1 represents a rise of VPCC and therefore the marker 4 represents a decrease of VPCC which results in reduction of the S_{inv} . In these cases, subsequent perturbation will conserve the perturbation signal (positive for marker 1 and negative for marker 4) and the MPP T will converge to the MPP. On the opposite hand, the marker 2 represents a decrease of VPCC and therefore the marker 3 represents a rise of VPCC diverging from MPP. Therefore, the direction of subsequent perturbation must be positive for marker 2 and negative for marker 3. The MPP T algorithm is summarized in Table I. Comparing the perturbation logic of the P&O MPP T with the traditional P&O MPP T algorithm, one can conclude that the P&O-based MPP T are often obtained by simply changing the perturbation signal of the traditional P&O MPP T. The processed power at the MPP was intentionally considered as S_{min} , the minimal power to be processed. DSTATCOM losses and harmonic distortions contributions to the apparent power can't be minimized to zero. B. The Amplitude Loop The amplitude loop consists of the P&O-based MPP T algorithm and has voltage constraints to satisfy, which are imposed by the Brazilian grid code [1]. The voltage constraints aren't considered in [6] and directly affect the apparent processed power. There are three different cases when voltage constraints are present as depicted in Fig. 5 (b). In case 1, S_{min} requires a VPCC below the minimum allowable PCC voltage (V_{min}). The MPP T goes toward the MPP, but VPCC can't be less than V_{min} . VPCC is kept at V_{min} and therefore the transformer supplies reactive power to take care of the VPCC regulated. Therefore, the MPP just in case 1 are going to be at MPP L and therefore the processed power is represented by S_{minL} . The Case 3 shows an identical outcome to case 1 with VPCC kept at the utmost allowable PCC voltage (V_{max}). The converter operates at MPP H and process reactive power adequate to S_{minH} . In case 2, the MPP occurs with VPCC between V_{max} and V_{min} . The MPP T tracks the MPP and therefore the converter process S_{min} , the active power to compensate the losses and therefore the harmonic distortion from the grid and load. control strategy aims to synthesize three balanced voltage waveforms at PCC with adequate amplitude, low THD and also regulate the voltage of the dc bus capacitors. Therefore, the control strategy has three output voltage loops, one total and one differential dc bus voltage loop. The aforementioned controllers were designed with the parameters presented in Table II and evaluated for a variety of the grid impedance through frequency response analysis. during this range the designed controllers work properly. Additionally, this paper includes two loops: a loop liable for the PCC voltage amplitude and another one liable for mitigating the grid frequency effect on the transformer A. Output Voltage Loop The inputs of the output voltage loop are three voltage references (v_{ref}). The voltage references are composed of the dc bus controllers output, the MPPT and therefore the frequency loop, as depicted. To realize adequate synthesis of the voltage references, the output voltage loop must have fast dynamic response. The output controller may be a PID controller. The output voltage loop has active damping controllers to reinforce the steadiness of the transformer against grid impedance variations [6]. B. Grid Frequency Variation and therefore the Total dc Bus Controller. The DSTATCOM operation causes power losses within the power converter as a results of semiconductor switching. The losses diminish the entire dc bus voltage (v_o) the displacement angle θ determines the active power flow at the PCC. Therefore, the entire dc bus loop compares v_o to the reference v_o^* and, through a PI plus pole controller, set an appropriate θ to empty active power from the grid and reestablish the facility balance between the grid, the hundreds and therefore the DSTATCOM. The DSTATCOM consists of three-phase four-wire VSI and therefore the voltage balance at the split capacitors is required. The difference between the split capacitor voltages (v_d) is compared to the reference (v_d^*) and a PI plus pole contributes to the reference generator with a little dc component (VPCC,dc). This dc component charges one capacitor quite the opposite.

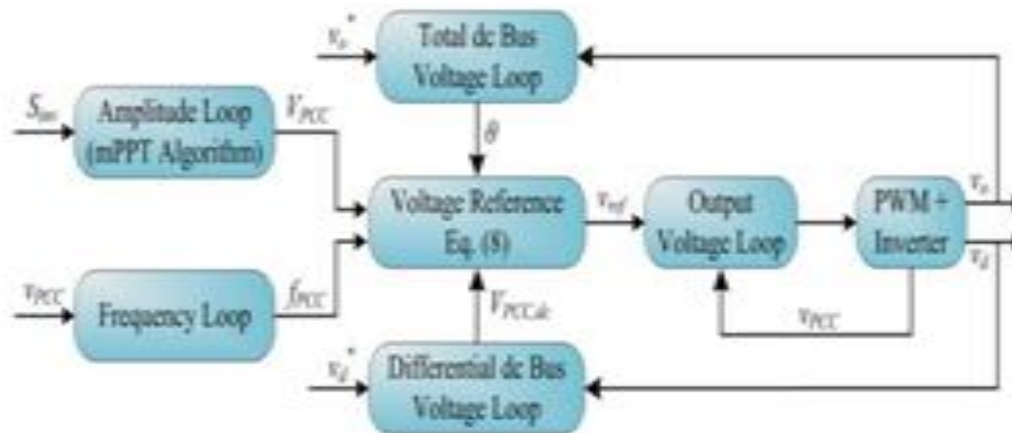


Fig 3. Proposed Control Strategy

III. EXPERIMENTAL RESULT

In order to verify the voltage regulation capability, the MPPT and therefore the frequency loop, a prototype was implemented, depicted . At first, this paper presents experimental results for the MPPT , which weren't presented in [6], and therefore the frequency loop separately. At the end of the section the simultaneous operation of both proposed loops is presented, enhancing the results obtained. A. Prototype Implementation and Initialization The prototype uses analog control to compose the output and therefore the dc bus voltage loops. The controllers are supported PI and PID controllers and designed via frequency response [6]. The θ and $V_{PCC,dc}$ are sampled by the digital signal processor (DSP) at f_s via Analog-to-Digital Converters. On the opposite hand, the MPPT algorithm and therefore the frequency loop are implemented within the DSP TMS320F28335. The apparent power is calculated using moving average filters (MAF) to get the rms current of the DSTATCOM. The MAFs have 80 samples for every period of the grid. The PCC voltage amplitude (V_{PCC}) is intrinsic to the DSP and is about by the MPPT . The apparent power is given by the merchandise of V_{PCC} and therefore the calculated rms current. The sum of the three apparent powers is applied to the MPPT . The voltage step of MPPT was set to 0.2 V with a period of 0.1667 s. For the fPCC measurement, the PCC voltage waveform is compared to zero and therefore the signal period is counted with the improved Capture Module of the DSP every 500 ms.

Multiple zero crossings are filtered in order to improve the measure accuracy. After the update of V_{PCC} and f_{ref} , the DSP generates the voltage references. The output voltage loop receives the voltage references through Digital-to-Analog circuits. The DSP also protects the DSTATCOM against dc bus overvoltage and overload, and performs routines as precharging and synchronization. The initialization procedure is depicted . At the time t_0 the auxiliary contactor (AC) closes and inserts the precharge resistors (PCR) serial with the DSTATCOM while the PWM is maintained disabled. The dc bus charges through the switches diodes, as shown . Meanwhile, the PLL circuit synchronizes the voltage references with the PCC voltages. At the time t_1 , the most contactor (MC) short circuits the PCR and therefore the PWM is enabled. The dc bus voltage reference rises with a slow slope to avoid overshoot. At the time t_2 , AC is opened. B. Linear Loads The linear loads are composed of 10.4 kW three-phase resistive loads. The PCC voltage amplitude without compensation is 212 V . One can see that the PCC voltages contain some harmonic distortion inherent to low voltage distribution grids. The compensated PCC voltage was arbitrarily chosen as 220 V. The PCC voltages are regulated with low THD (0.2%). The compensation currents have different rms values for each phase, highlighting the natural unbalance of the low voltage grids. The harmonic distortion present in the grid voltage is compensated by the regulator presents the compensation current waveforms. The quality of the b-phase grid current (i_{gb}) for linear loads . The transformer supplies the load with low THD voltages, as seen by the load current (i_{Lb}). The harmonic content in i_{gb} is given by the grid voltage distortions. C. Nonlinear Loads The considered nonlinear loads are three 2 kVA singlephase rectifiers with a capacitive filter, one in each phase added to five .2 kW three-phase resistive loads. The PCC voltage amplitude without compensation is 203 V with 6.4% THD. The compensated PCC voltage is depicted in having three regulated and sinusoidal waveforms with 0.6% THD. The compensation currents contain the elemental frequency for the reactive compensation and every one the harmonic distortion from the nonlinear loads. The b-phase grid current (i_{gb}) waveform for nonlinear load is shown .

The transformer absorbs the harmonic content from the load current (i_{Lb}) leaving i_{gb} freed from load harmonic distortions. one can notice the grid current waveforms present similar distortions from the grid voltage. MPPT gets on the brink of the minimum power, the present amplitudes are small and therefore the measurement precision becomes relevant. In the present case, the MPPT algorithm has large oscillations round the mPP. The processed power decreases from 8 kVA to 1.6 kVA, a reduction of around 80%. The remaining 1.6 kVA is S_{min} , the minimal necessary power for DSTATCOM operation, composed of active power (converter losses) and grid voltage voltage is kept regulated at the nominal value and therefore the ripples are caused by the frequency updates. The reference frequency update cannot maintain a secure operation under any quite disturbances, or indefinitely. In this case, a frequency protection routine was implemented by adding a continuing frequency to fPCC, leading the compensation angle back to zero. . The total dc bus voltage has a 12 V step perturbation and returns to nominal voltage. To verify the entire dc bus voltage controller performance under the frequency loop, load perturbations are applied to the transformer . Total dc bus voltage remains regulated under sudden load changes, from 5.2 kW to 10.4 kW at t_1 and backward at t_2 . The parallel operation of the proposed loops to compose the DSTATCOM is additionally evaluated. The a-phase current is near zero because the MPPT is in steady state. At to, the grid voltage is slightly perturbed so as to maneuver the operating point from the mPP. The a-phase current decreases with the time thanks to actions of the MPPT and reaches a replacement mPP. During the MPPT perturbations, the compensation angle changes because the grid frequency varies thanks to the frequency loop.



Fig 4.DC Bus Voltage during STATCOM Initialisation



Fig 5.PCC Voltage Compensation for linear loads

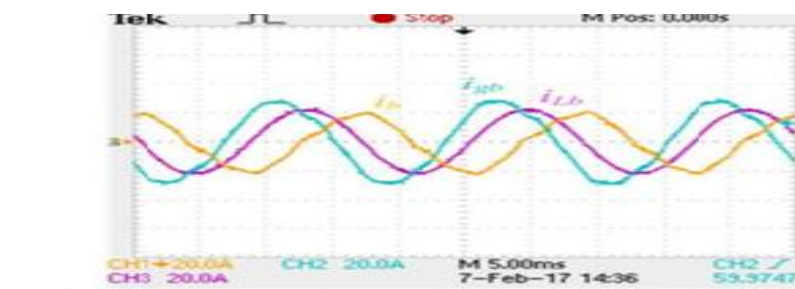


Fig 6. Grid, Load and Voltage Regulator for linear loads

IV. CONCLUSION

This paper presents a three phase DSTATCOM as a voltage regulator and its control strategy, composed of the conventional loops, output voltage and dc bus regulation loops, including the voltage amplitude and the frequency loops. Experimental results demonstrate the voltage regulation capability, supplying three balanced voltages at the PCC, even under nonlinear loads. The proposed amplitude loop was ready to reduce the transformer processed apparent power about 51% with nonlinear load and even more with linear load (80%). The MPPT algorithm tracked the minimum point within the allowable voltage range when reactive power compensation isn't necessary. With grid voltage sag and swell, the amplitude loop meets the grid code. The MPPT can also be implemented in current-controlled DSTATCOMs, achieving similar results.

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