Improving the distribution network's power quality using PV-STATCOM in compliance with Moroccan Grid Code regulations.

Sarih Saad, Boulghasoul Zakaria, Chaaba Samira, Elbacha Abelhadi, Tajer Abdelouahed

Abstract— **In the present work, we introduce a novel control strategy to optimize the use of a PV-STATCOM connected to the distribution network in case of recent Moroccan grid code. The device is implemented between a PV array module and the PCC to the distribution network, which is typical of a standard structure in presence of renewable generators. The device is proposed to achieve dynamic support of the distribution grid in the event of disturbances and faults and to ensure power factor correction while injecting active power. The control strategy is based on a PI controller widely used in such power electronics applications. The PV STATCOM is not yet used in Moroccan electrical network and the proposed system overcomes network uncertainties and grid disturbances and significantly improves the power quality at the point of common connection PCC while absorbing and providing reactive power to the network in an acceptable reversing time. The proposed PV-STATCOM ensures dynamic voltage support requirements and current THD mitigation according to the constraints of the Moroccan GRID CODE document. The simulation is performed using MATLAB Simulink software and shows best results in simulation while respecting the technical limits imposed by local regulations.**

Keywords: Moroccan Grid Code, PCC, PV-STATCOM, PF correction, Reactive power compensation, D-Facts.

I. INTRODUCTION

Within a few decades, electricity has taken more and more importance as a cornerstone of our society. It serves as the focal point of contemporary society and economic activity, supplying energy that is necessary to raise living standards for citizens and drive companies and other economic players.

The increasing integration rate of renewable production to distribution networks combined with their growing complexity, has conveyed a need for advanced technologies to enhance grid stability and general power quality. In this context, the Photovoltaic Static Synchronous Compensator (PV-STATCOM) emerges as a crucial solution combining renewable energy providing and FACTS functions [1] in a single power electronic device with lower integration price and good grid resilience in the same location. The PV STATCOM serves as an innovative and effective device designed to address these challenges by dynamically compensating for reactive power imbalances, voltage sags due to large load connection [2] or faulty conditions. This introduction delves into the role of PV STATCOM in distribution networks, exploring its key functionalities, benefits, and contributions to the evolving landscape of sustainable and resilient power distribution [3]. This work is a contribution to the enhancement of the power quality of the Moroccan distribution network by the study of the introduction of PV STATCOM functionality in accordance with the recent grid code requirements which introduces strict conditions for renewable production to be supplied to final customers via the distribution grid. It also aims the optimization of the dynamic behavior of electrical distribution network in the event of faults, presence of nonlinear loads [4] or a need of reactive current support and power factor correction, while ensuring continuity of service within the updated limits. The system is simulated in MATLAB/Simulink software to mitigate the power quality problems regarding the connected load near the PCC.

II. PROPOSED SYSTEM DESIGN

A. Fault tolerant Approach

The fault-tolerant control applied to a given system can be defined as the ability of a system to continue to operate independently of failures that may appear on one of the components of the system, its main objective is to determine a control strategy that makes it possible to cancel, or at least limit the effects of faults on the stability and performance of the system [5] and subsequently provide it with the ability to maintain the nominal objectives despite the occurrence of a default. It also makes it possible to guarantee the stability of the system and/or acceptable degraded performance in the presence of faults. Note that the objectives to be achieved during the two normal and faulty operating modes are of course different.

In various industrial fields, aeronautics for example, the management of the continuity of service rendered was based mainly on hardware redundancy based on actuators and sensors, a strategy which was costly and often expensive and greedy in terms of maintenance, and this is the evolution of this type of strategy towards the analytical approach which has made it possible to optimize the said purchase and maintenance costs as much as possible. This is noted specifically in the recent service industry [6].

Several studies and research have been carried out in the field of fault-tolerant control and which were initially applied in the industrial field, as well as critical processes that do not tolerate cuts or interruptions such as industrial processes (petroleum industry, electricity, water, and natural gas), and

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other systems that put people's lives or property at risk, such as air or maritime [7] transport.

Other research has focused on the application of CTD to nonlinear systems to allow them an ability to manage uncertainties, disturbances, and delays, knowing that most modern industrial processes are non-linear in nature and have more security-related constraints [8].

The use of STATCOM function is commonly adopted in power quality improvement by providing voltage and reactive power regulation in addition to the power factor correction and current THD mitigation.

B. FRT in the Moroccan Grid Code

In many updated grid codes around the world, any photovoltaic power plant connected to the medium voltage network must be able to maintain its connection state to the network during short circuits and rapid transient voltage variations, and, thus, ensure a fault-ride-through or FRT capability as required [9]. It is imposed that the renewable production unit remain connected to the network as long as the voltage of the phase presenting the lowest voltage is higher than a specific profile [10]. The Moroccan Grid code FRT profile is presented in Figure 1, which describes the evolution of the minimum voltage permitted at the point of connection. It is noted that asymmetric faults follow the same profile.

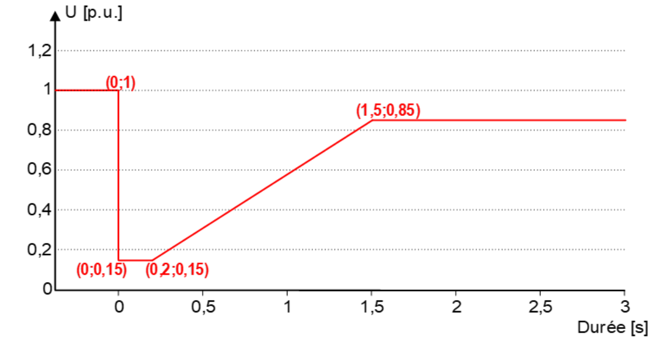

Figure. 1: FRT in Moroccan Grid Code

The proposed voltage dip withstand parameters are presented in relation to the nominal voltage (between phases) at the connection point.

Similarly, to international grid codes the recent Moroccan document includes technical requirements for generators to provide reactive power support, including the minimum and maximum levels of reactive power that must be provided, as well as the response time and ramp rate for changing reactive power output [11].

The operating principle is proposed by the figure given below.

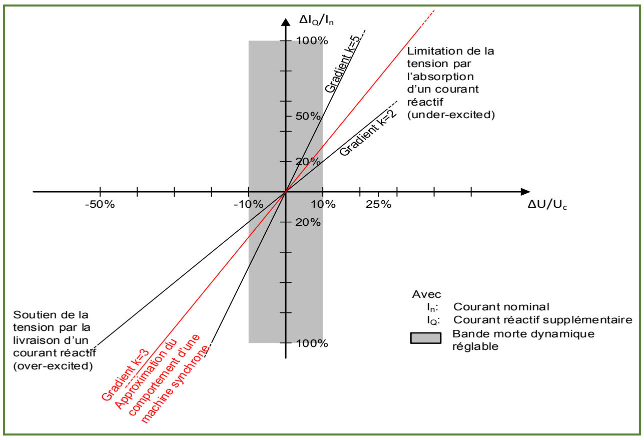

Figure. 2: Voltage support requirement during short circuit and voltage jumps

As presented in Figure 2, it is acceptable to reduce the active current when generating additional reactive current to be able to generate the reactive current as much as possible within the current limits of the production unit.

C. Static Synchronous Compensator and PV-STATCOM

STATCOM or Static synchronous compensator is part of FACTS devices and is principally used for its dynamic performance such reactive power source for voltage regulation and reactive power compensation. It can significantly boost the stability and the reliability of power distribution network by dynamically regulating the voltages in the point of common connection PCC. Typically, when a disturbance occurs such as power system fault, it reacts rapidly by regulating grid voltage and thus improving the power quality delivered in faulty condition [12]. Even after fault clearance, the voltage drops due to reconnection of the loads, and the STATCOM dynamically supplies necessary reactive power to boost voltage and prevent under voltage condition or eventually a complete loss of power [13].

It is important to note that such devices are integrated to the grid for their additional capability of voltage harmonics mitigation and network loss reduction via voltage level optimization in most cases.

The benefits of the integration of STATCOMs to the distribution network in the case of renewable energy injection are described in the Figure 3 presented below.

It is clearly noticed that STATCOM devices as FACTS, perform well in voltage control and reactive power regulation in comparison with TCSC, SSSC and UPFC's [14].

The integration of PV technology with a STATCOM involves combining the solar power generation capabilities with the voltage control and compensation features of the STATCOM.

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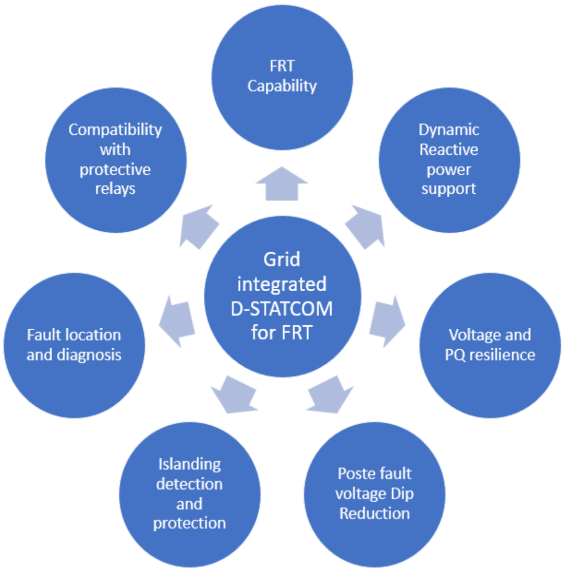

Figure. 3: D-STATCOM benefits

This integration allows the device not only to contribute clean energy but also to actively support the stability and quality of the electrical grid. It offers the benefits of both renewable energy generation and grid support. It can contribute to the reduction of greenhouse gas emissions, enhance grid reliability, and improve the overall efficiency of the power system [15].

In is noted that fault tolerant aspects of integrating PV-STATCOMs to the distribution networks manifests essentially in dynamic reactive power support, reduction of post fault voltage dip, grid support during fault recovery and preventing islanding by remaining synchronized to the grid.

The general grid integration schematic of the PV-STATCOM is shown below in Figure 4:

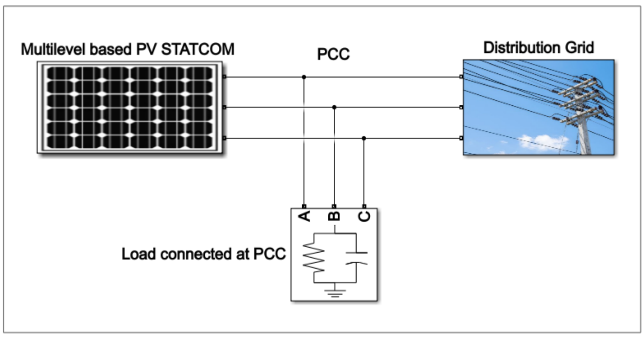

Figure. 4: The general use case of the PV-STATCOM in electrical networks

The PV-STATCOM is used in the distribution network to inject reactive power in faulty condition and when the solar production is turned off to maintain acceptable power quality and is designed to inject or absorb reactive power at the point of common connection to the network PCC if necessary and mitigate voltage flickers [16].

D. Controller Design

This section describes the control strategy of the PV system coupled with a smart inverter connected to a PCC of distribution network. The inverter controls reactive power flow and active power injection to the grid and is capable of power factor correction.

As mentioned before, the PV STATCOM is controlled to operate according to various modes which are the full PV mode when the device provides active power to the grid rated to the maximum power delivered by the MPPT control, PV STATCOM mode which is a partial STATCOM behavior and finally a full STTACOM mode with the maximum reactive power capacity delivered to the grid when needed or the control the power factor and voltage drop in case of faulty condition.

The controller is based on classic PI modules and could be enhanced by the implementation of intelligent control such as ANN or ANFIS technics [17].

The controller diagram is given below:

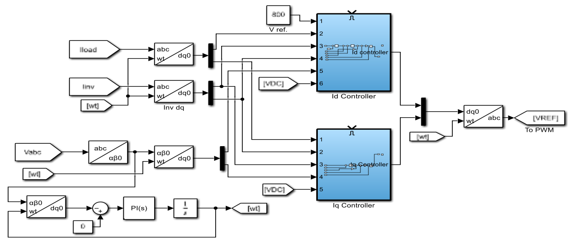

Figure. 5: PV STATCOM current controller.

The PCC voltage is transformed to its (α, β) components and then synchronized to the grid frequency, a phase locked loop is applied on (α, β) components of grid voltages to generate (wt) parameter, and the reference for the PWM module is generated by the combined (d and q) axis current controllers and DC bus controller based on a given voltage reference (VDC = 800 V). An LCL filter is integrated between the inverter and the PCC. The power factor and angle calculation are determined by a MATLAB function in reference to the 3-phase load current and voltage.

III. Simulation Results

In this simulation, we are considering inductive and capacitive loads connected to the injection point of the PV power plant and powered by both the grid and the PV power plant. This configuration is adopted to test the system under tense conditions.

The simulation concerns full STATCOM mode, PV STATCOM mode providing power factor correction.

The simulation parameters are given in the appendix.

A. STATCOM Mode

In the present section, the PV STATCOM is used in full STATCOM mode (illustrated by nighttime mode or daytime faulty condition). The power plant provides reactive power through the inverter to the PCC and the grid continues to

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feed the active power demand of the connected loads. The simulation is performed using MATLAB Simulink environment.

At t=0.2s the STATCOM mode is active, and no active power is provided by it whereas the full active power demand is fulfilled by the grid and the reactive power is delivered by the STATCOM.

At t=0.35s a capacitive load is connected to the system and the STATCOM continues providing reactive power need as illustrated in Figures 7 and 8 presented below.

The PCC voltage is shown in Figure 6. The voltage remains regulated after connection of the second load at the point of common connection PCC.

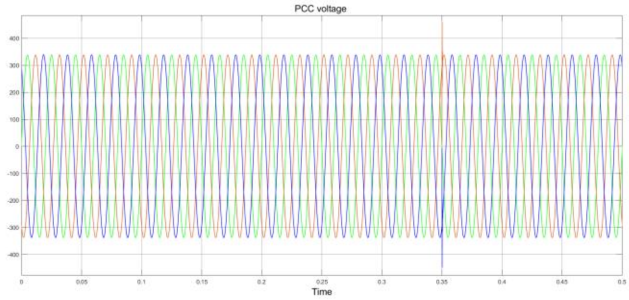

Figure. 6: PCC voltage during simulation

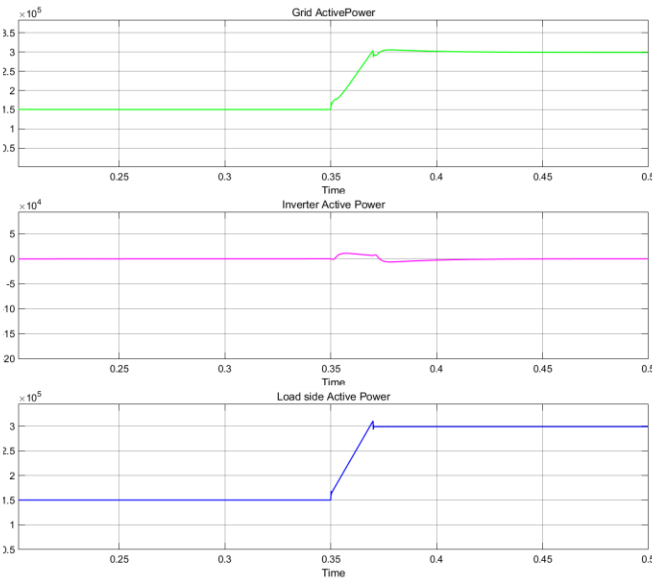

Figure. 7: Active power of the grid, inverter, and load.

The device acts in STATCOM mode and provides necessary reactive power in both inductive and capacitive configurations.

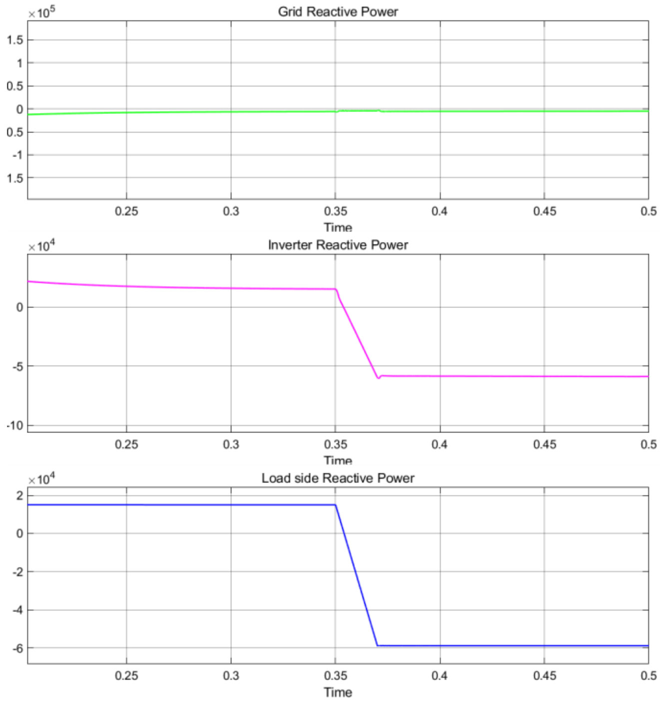

Figure. 8: Reactive power of the grid, inverter, and load.

The asynchronous phase between the phase A voltage and current is given by Figure 9.

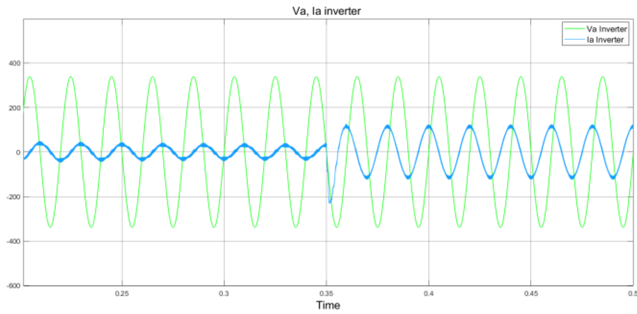

Figure. 9: Voltage and current of the STATCOM in inductive and capacitive modes.

The voltages at PCC are kept stable even after the reconnection of a large load and the inverter response is within 0.02s which is enough to satisfy the requirment of the local grid code.

B. *PV-STATCOM mode*

In this part of the work, the PV STATCOM is used in PV injection and partial STATCOM mode. It uses the available capacity of the inverter to compensate for reactive power at PCC in parallel of injecting its rated active power. The power plant also provides reactive power through the inverter to control the power factor and to bring its value to an acceptable value close to unity as much as possible.

The load considered is set to fixed values of resistance and inductance requiring 20 KW and 15 KVAR respectively, the power factor is initially at 0.75 and the PV STATCOM mode is enabled between t=5s and t=8s.

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The system response in active and reactive power of the Grid, Inverter and Load are given in Figures 10 and 11.

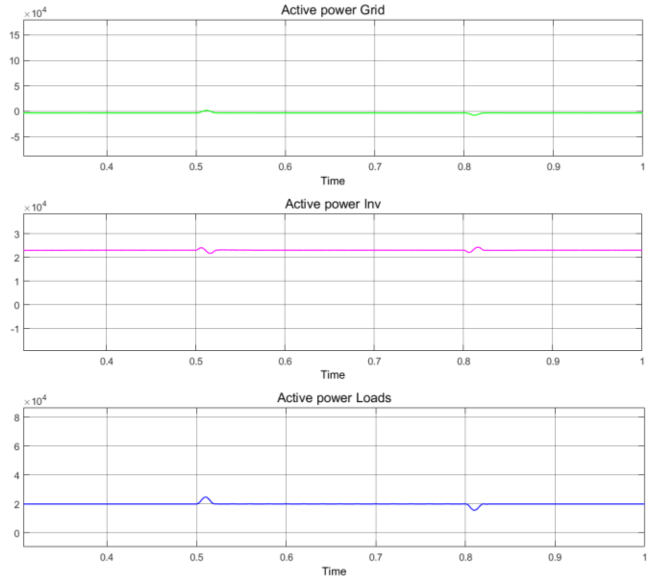

Figure. 10: Active power of the grid, inverter, and load in partial PV STATCOM mode.

The PV STATCOM is connected to the system and supplies the full active power of the PV power plant through the inverter and is sufficient to feed the connected load. At time 5s the partial STATCOM mode is activated, and the device injects reactive power equal to the load requirement to compensate for it while satisfying the active power demand.

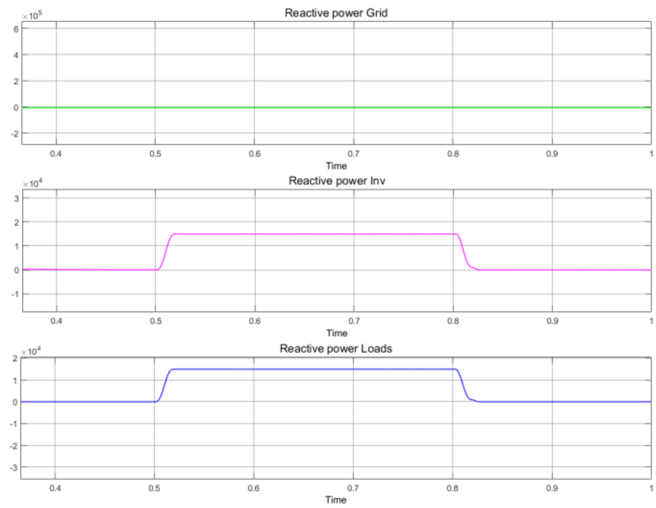

Figure. 11: Reactive power of the grid, inverter, and load in partial PV STATCOM mode.

The phase A voltage and current are given in the Figure below.

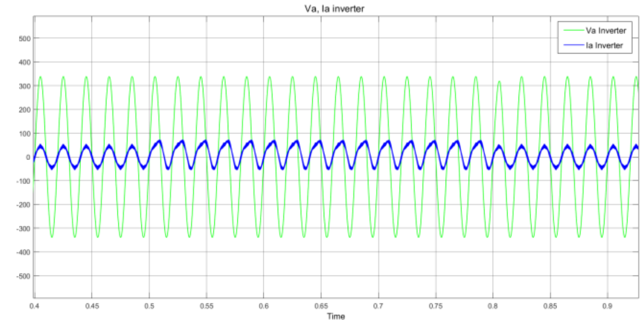

Figure. 12: Voltage and injected current by the PV STATCOM.

The power factor (PF) representation of the simulated system from Load side is presented in Figure 13.

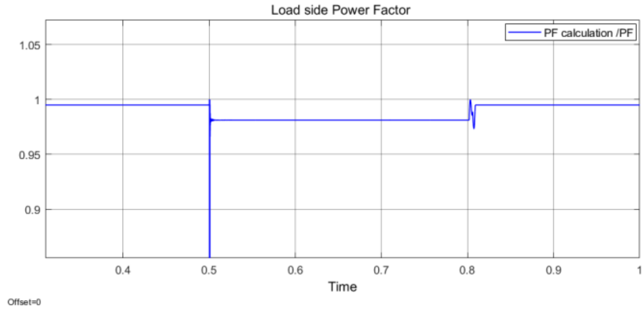

Figure. 13: Power factor (PF) representation in PV STATCOM mode.

The previous results prove that the PV-STATCOM provides the required reactive power of the inductive load as required. The current THD in the load side is below the limited value of 2% required by the local grid code. As shown in Figure 12 the poser factor is regulated above 0.95 value which prove that the system performance could be used to provide power factor correction in daytime while ensuring active power injection to the distribution grid.

IV. Conclusion

In final, it is noted that the use of PV-STATCOM in distribution grid is cost effective compared to standalone DSTATCOM devices and is an affordable solution to support electrical network when faults and disturbances occurs in the limit of the capacity of its inverter. Thus, it improves the general quality of power delivered to the grid and the PCC connected loads and offers good transient performance in line with the Moroccan grid code requirements.

APPENDIX

System parameters:

TABLE I. SYSTEM PARAMETERS

Parameter of the simulation	***Value***
Grid voltage	400 V
Load 1 Active Power	150 KW
Load 2 Active Power	150 KW
Load 1 Reactive Power (inductive)	15 KVAR
Load 2 Reactive Power (capacitive)	75 KVAR
Frequency	50 Hz
Filter inductance	500 e-6 H
Filter capacitance	100 e-6 F
Vdc bus reference	800 V
Rated power	100 KW
SF	10 KHz

REFERENCES

[1] Belatel, Mimi. « Compensation dans les Réseaux Electriques par un Système FACTS de Type STATCOM », 5th international conference of renewable energies CIER-17, Vol 30 pp 37-42, 2017.

[2] Pattanaik, Balachandra, Ruthramurthy Balachandran, S Prakash, et Reta Dengesu Haro. « PV-STATCOM Based Smart Inverter for Reliable Distribution System ». In 2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS), 733-38. Madurai, India: IEEE, 2021. https://doi.org/10.1109/ICICCS51141.2021.9432364.

[3] Varma, Rajiv K., et Ehsan M. Siavashi. « PV-STATCOM: A New Smart Inverter for Voltage Control in Distribution Systems ». IEEE Transactions on Sustainable Energy 9, nº 4 (october 2018): 1681-91. https://doi.org/10.1109/TSTE.2018.2808601.

[4] Youssef Ait El Kadi, Fatima Zahra Baghli, et Yassine Lakhal. « PV-STATCOM in Photovoltaic Systems under Variable Solar Radiation and Variable Unbalanced Nonlinear Loads ». International Journal of Electrical and Electronic Engineering & Telecommunications, 2021, 36-48. https://doi.org/10.18178/ijeetc.10.1.36-48.

[5] Temmar Romaissa, "commande tolérante aux défauts adaptative floue pour les systèmes non linéaires incertains siso via backstepping", Thèse de Doctorat, Université UNIVERSITE KASDI MERBAH OUARGLA, 2017

[6] Mikaël Rodrigues, « Diagnostic et commande active tolérante aux défauts appliqués aux systèmes décrits par des multi-modèles linéaires », THÈSE Doctorale, Université Henri Poinaré,2005

[7] Amin, Arslan Ahmed, et Khalid Mahmood Hasan. « A Review of Fault Tolerant Control Systems: Advancements and Applications ». Measurement 143 (September 2019): 58 68. https://doi.org/10.1016/j.measurement.2019.04.083.

[8] Yepes, Alejandro G., Oscar Lopez, Ignacio Gonzalez-Prieto, Mario J. Duran, et Jesus Doval-Gandoy. « A Comprehensive Survey on Fault Tolerance in Multiphase AC Drives, Part 1: General Overview Considering Multiple Fault Types ». Machines 10, no 3 (14 March 2022): 208. https://doi.org/10.3390/machines10030208.

[9] Marchgraber, Jürgen, et Wolfgang Gawlik. « Dynamic Voltage Support of Converters during Grid Faults in Accordance with National Grid Code Requirements ». Energies 13, nº 10 (14 May 2020): 2484. https://doi.org/10.3390/en13102484.

[10] Salah Saidi, Abdelaziz. « Impact of Grid-Tied Photovoltaic Systems on Voltage Stability of Tunisian Distribution Networks Using Dynamic Reactive Power Control ». Ain Shams Engineering Journal 13, nº 2 (March 2022): 101537. https://doi.org/10.1016/j.asej.2021.06.023.

[11] Nivedha. R, Narmatha. B, Prakash. A, « Enhancement of Grid Power Transmission Limits using Photovoltaic Solar Farm as STATCOM (PV-STATCOM) », International Conference on Computing Technologies and Intelligent Data Engineering (ICCTIDE), IEEE, 2016, 10.1109/ICCTIDE.2016.7725325.

[12] Popavath, Lakshman, et Palanisamy Kaliannan. « Photovoltaic-STATCOM with Low Voltage Ride through Strategy and Power Quality Enhancement in a Grid Integrated Wind-PV System ». Electronics 7, nº 4 (12 April 2018): 51. https://doi.org/10.3390/electronics7040051.

[13] Balachandra. P, Ruthramurthy. B, Prakash. S, Reta. D, «PV STATCOM based smart inverter for reliable distribution system». Fifth international conference on intelligent computing and control systems (ICICCS 2021), IEEE Xplore CFP21K74-ART; ISBN: 978-0-7381-1327-2

[14] F. OUAGUENI, « Modélisation et commande d'un DSTATCOM à base d'un convertisseur multiniveau ». Mohamed Boudiaf university – M'SILA, thesis document, 2020.

[15] Mali, Manav J. « Voltage Management by Grid-Connected PV-STATCOM Inverter for Distribution System ». In 2019 Innovations in Power and Advanced Computing Technologies (i-PACT), 1-6. Vellore, India: IEEE, 2019. https://doi.org/10.1109/i-PACT44901.2019.8960228.

[16] Nivedita, S.R. Gaigowal, P.S. Patil, « Cascaded H bridge Inverter based PV STATCOM ». International Conference on Smart Electric Drives & Power System, IEEE, 2018.

[17] Niraj. S, Jatinkumar. P, « Fuzzy logic-based PV STATCOM operation for grid voltage regulation in night», International Conference on Soft Computing and its Engineering Applications (icSoftComp), December 2017, DOI: 10.1109/ICSOFTCOMP.2017.8280080

Manuscript 141 submitted to 2024 10th International Conference on Control, Decision and Information Technologies (CoDIT). Received February 2, 2024.