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Impact of grid-tied photovoltaic systems on voltage stability of tunisian distribution networks using dynamic reactive power control

Abdelaziz Salah Saidi

Department of Electrical Engineering, King Khalid University, Abha City, P.C.: 61411, Saudi Arabia
Université de Tunis El Manar, Ecole Nationale d'Ingénieurs de Tunis, Laboratoire des Systèmes Electriques, Tunis, Tunisie

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A B S T R A C T

Analysis of voltage stability of transmission network with high photovoltaic (PV) integration is a challenging problem because of the stochastic generation of a solar system. Stabilization of the output power is an important criterion for determining the degree of penetration of PV in active distribution networks, considering loading capability. This article describes the effective voltage regulation strategy for the transmission system using the STATCOM module to resolve the drop and the effect aspects on the voltage stability in the transmission network. This paper analyzes also the influence of the STATCOM control system on preventing the combination of injection voltage STATCOM with harmonics from achieving pure voltage compensation. The proposed test system under analysis is the 53-Bus Tunisian distribution power network integrating 12 MW solar PV plant. Simulation results are added to demonstrate the efficiency of the proposed control technique for enhancing the power system quality based on the Tunisian grid code. Investigation of voltage stability shows that the dynamic behavior of the voltage depends strongly on the short circuit capacity of the power network at the point of PVs integration.

1. Introduction

Currently, Distribution grids are solely designed for radial service, with large centralized power stations providing power to the delivery of networks over long distances. However, as decentralized and distributed generators with smaller capacities are added gradually to the electricity distribution system, it undergoes dramatic changes. Renewable sources of energy have appropriated a large share in the recently proliferating distributed mode of generation during the past few years, and especially in the 2000 s. A major chunk of this recent distributed mode of generation are contributed by renewable sources of energy. In such generation systems, renewable sources like biomass, fuel cells, hydroelectric, solar and wind have demonstrated promising potential and viability [2]. Renewable energy production is both attractive and advantageous as it offers a renewable option that considerably decreases rate of emissions from fossil fuels. Solar PV systems in a network can be connected in a two-tier manner and such systems can be categorized into three main types in terms of size: small, medium and large. Larger scale photovoltaic power plants (PVPP) have the capacity to produce more than 100 MW. Thus, they could be connected to high and medium voltages [3–4]. Usually delivered in three steps, this type of PV energy includes transformers in parallel with the power system. Another next category is medium-scale PV, producing between 1 and 100 MW, which is related to the stage of distribution [5–6]. The possible negative impacts of enlarged penetration levels of photovoltaic plants on power system stability are levitating trepidations to equipment's and utilities [7]. Solar generators operating in parallel to conventional types of synchronous generators are confronted with new challenges in terms of the control, operation and stability of the overall power system and its parts [8–9]. Voltage stability analysis of the transmission network is increasing challenging task due to modern power systems complexity and the ever-expanding photovoltaic system integration. Power system voltage stability has been explored and investigated by many researchers in [5–23,25–35] to reveal the influence of PVs with high degree of generations. In particular, DIgSILENT PowerFactory simulation package has been used in [28] to study the voltage stability during steady state and transient operations.

E-mail address: asaidi@kku.edu.sa.
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The presented work exhibits the effect of integrating large penetration of PV into the Egyptian power system. The performance of the Jordan's power system with integrated large PV plants and wind power generation has been scrutinized by DIgSILENT software platform in [29]. Simulation results determine that the penetration level of the solar and wind energy resources should not exceed beyond 10% of the annual peak demand of Jordan in order to avoid grid collapse. The effect of 1 MW PV plant integration to the Bahrain grid has been examined in [30] using PSSE and PVsyst softwares. Simulation results are concentrated to illustrate how weather condition of Bahrain can be exploited by PV systems to meet the peak demand. The voltage stability of the larger interconnected system has been presented in [31] by quantitative assessment of the effect of large penetration of embedded small PV units in the distribution networks. Moreover, it is required that larger PV power plants should remain connected with the transmission network during large grid voltage disturbances because the disconnection of massive PV power may further worsen voltage recovery throughout the disturbance and after fault recovery [32]. Thus, the voltage stability studies has attracted the concern of many scholars towards the Low-Voltage Ride-Through (LVRT) competency of PV generators with large penetration [5–22]. The photovoltaic power plants integrated into the grid through a diverse range of penetration capability, have been investigated in [33–40]. Nodal voltage stability get affected by integrating solar generators to medium voltage distribution networks, [10–11]. This delineated voltage stability is due to the inability of network to uphold acceptable voltage levels all over the network under different operating circumstances. Voltage instability arises due to unmanageable short or long-term disturbances causing a progressive drop in voltage level [12]. The crucial reason for voltage collapse is the inability of the grid to supply the requisite reactive power. Therefore, this problem desires to be examined meticulously specifically with the existence of the high solar PV generators. Over the long distances, the power system stability is impacted by the transmission energy, which, is needed for controlling the voltage and for solving challenges like variation of load conditions [13–14], saving the balance with active and reactive powers and also adding of renewable sources of energy. Reactive power compensation can be maintained by various means; but this might lead to unfortunate problems like harmonics injection, noncontinuous compensation and huge inrush current into the system [15–16]. Due to the rapid developments in power electronics, the Flexible AC Transmission Systems (FACTS) devices have received consideration as a very cost-effective means to affect the real network subject to variations in the operating conditions of the system, for maintenance of voltage levels and for controlling the reactive and active power flows. By employing FACTS control techniques, through the transmission network being in series or shunt modes, it is possible to control the voltage in all bus bars of the power system and there is flexibility through the control of the phase angles and line impedances [17–19]. The Static var compensation and the Static Synchronous Compensation (STATCOM) are the most popular modules among the FACTS devices [18]. The STATCOM unit can be considered as impressively fast and is also one among the most efficient modules among the FACTS devices, which are used for increasing transmission capacity, dynamic behavior and stability margin. It also serves to assure improvement in power quality [20–22]. One of the main objectives of the paper is to scrutinize the influence of the integration of PV generators on the steady-state/dynamic voltage stability behaviors of the radial Tunisian distribution system. STATCOMs are one remedy when a network is subject to a contingency to control voltage fluctuation and boost transient stability [23,25,26]. Large-scale PVs are installed to assist the test system at the power plant. In addition, and near the loads the uses of the renewable distributed generation (DGs) can help to save the stability of the system, consequently this is the favored technique, but the distributed generation depends on the ordinary circumstances for using the renewable generation [27].

As the maximum power generated from the photovoltaic power plants matches the peak load consumption during summer, solar generators are applicable for use in sunny areas as peaked power plant. The task is to use the potential of distributed resources and to alleviate the effect of the changing nature of the solar source on the power system stability to improve the reliability of the overall system. When there is an abrupt rise of load demand in the grid, simultaneously there should be sufficient control over voltage and power [27]. This work emphases on the control logic module STATCOM for improving the power quality and how to ensure a stable operation of an autonomous transmission system. This paper also simulates the control of the operating steps for the STATCOM module using Power System Analysis Toolbox to define the effect of adding the STATCOM on the system voltage and the ability of loading to reach the optimum system quality. The dynamic models of a solar photovoltaic unit will be briefly described in section 2. The Reactive power control using STATCOM is also described in section 2. The radial 53-Bus distribution network followed by a formulation of the various studies and methodology will be concisely provided in section 3. In section 3 too, we have included the results and related discussions. The overall conclusions are included in section 4. The steps of the study consists of: (i) computing load flow solution for all load buses, with generator dynamic PV/PQ state transitions recording, using the Newton Raphson algorithm. (ii) determining the critical voltage stability of the system with and without STATCOM and PV integration. (iii) computing smallest eigenvalue locus for the static load flow Jacobian matrix to critical modes, and (iv) analyzing the performance and the power quality of the system under study for compliance with the Tunisian grid requirement codes. These steps has been shown in Fig. 1.

2. Grid-Tied photovoltaic system

A Conventional Grid-tied Photovoltaic system comprises of a photovoltaic array, DC to DC boost converter, 3-Ø DC to AC inverter, maximum power point tracking (MPPT) controller, filters and transformer. In actual practice, parameters like voltage, current, insolation/ irradiation, temperature etc. of the PV Panel are neces-

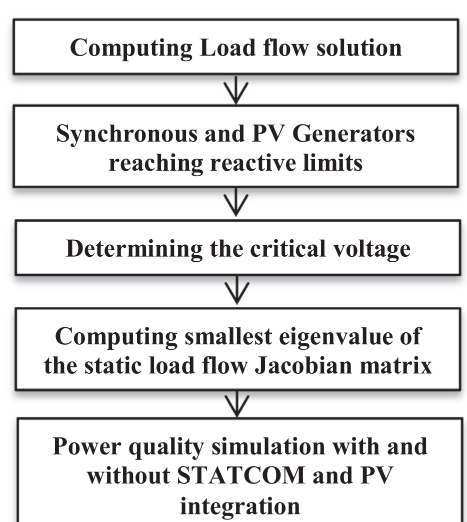

Fig. 1. Steps of the voltage stability.

sary to monitor continuously in the grid connected system. The approach for the implementation of the model with all parametric measurement required are shown below in "Fig. 2". The output value of current drawn from PV cell is shown in "(1)" which represents the Current-Voltage characteristics of the ideal P-V cell [38–39].

$$I_{cel} = I_{sc} - I_d - \frac{U_{cel}R_s}{R_p} \tag{1}$$

Where I_{sc} is the current produced by the incident irradiation, I_d is the current in the Shockley diode, R_s is series resistance and R_p is parallel connected resistance. In addition, the value of R_s is very low, as compared to R_p and the value of R_s may be neglected.

The value of diode current is calculated as shown in "(2)"

$$I_d = I_o \cdot [\exp\left(\frac{q_e U_{cel}}{a_i k T_c}\right) - 1] \tag{2}$$

Where q_e is charge of electron (1.602×10^{-19}C), k is Boltzmann constant with value 1.3806×10^{-23} Joules/Kelvin, T_c (Kelvin) is the temperature at the P-N junction, ai is ideality constant of the diode ($1 \le \alpha_i \le 1.5$) and Io is saturation current of diode and it is dependent on the temperature / Irradiation can be expressed in "(3)" as,

$$I_o = \frac{I_{sc} + K_i \cdot (T_c - T_n)}{\mathrm{e}_{xp}[(U_{oc} + K_V \cdot (T_c - T_n))/a_i U_t] - 1} \tag{3}$$

U_t represents the thermal voltage of N_s series-connected cells at the nominal value of temperature T_n. System requires a DC to DC converter for controlling and limiting the dc voltage. The value of resultant over voltage is less than the inverter output without DC-DC boost converter [9–23,25–37]. This is the only cause for using DC-DC boost converters shown in "Fig. 3". A Grid connected photovoltaic generator has V-I characteristics which is nonlinear in nature and it varies with irradiation and temperature. A specific operating point on V-I and Power-Voltage curves is maximum power point (MPP) tracking. This unique point on curve at which PV panel produces maximum output power at maximum efficiency and is dependent on these Voltage-Current & Power-Voltage characteristics on solar irradiation and temperature.

By using various MPPT techniques and algorithms we can arrange the point at that level where to get maximum power irrespective of the irradiation level [41]. Consequently, for the same solar radiation, the power delivered will be different according to the load. An MPPT controller can therefore be used to control the converter connecting to the load and the photovoltaic panel in order to supply continuous maximum power to the load. Since these parameters change continuously, operating point vary too [12]. The Perturb and Observe (P & O) is one of the famous conventional MPPT technique. Perturb and Observe is extensively used method among all MPPT techniques because of its simple operation [41]. P&O easily calculates the P-V output current and terminal voltage, from which actual Power to be measured and by changing the duty ratio of dc-dc converter is made unless the maximum power is achieved. This MPPT technique is utilized in the dc-to dc converter, which his duty Ratio/ cycle is adjusted to locate the current value of MPP on the Photovoltaic array. Even, perturb and observe (P&O) MPPT algorithm can fail under quickly varying weather situations [14], under changes in illumination/irradiance and temperature levels and the operating point is tracked, then the rate of sampling is optimized for carrying out the MPPT perfectly, [14]. In P&O, the duty ratio/cycle is changed to attain the value of maximum active power of P-V array. Model of Voltage Source Converter (VSC) is implemented and connected to the transmission network along with first order filter (consider the value of resistances are neglected). A transformer is connected between P-V system and the Grid network in Power Grid block as shown in "Fig. 4".

Here, inverter injects the active power into the Power Grid and also controls the injection of reactive power in the grid. The Three Phase Voltage equations can be expressed in "(4)" as:

$$\frac{d}{dt}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \frac{Udc}{L}\begin{bmatrix} Da \\ Db \\ Dc \end{bmatrix} - \frac{1}{L}\begin{bmatrix} Ua \\ Ub \\ Uc \end{bmatrix} \tag{4}$$

Being D_a, D_b and D_c are ratio/cycles on Photovoltaic inverter on phases a, b and c, by "(4)", for phases a-b-c can be re-written to dq coordinates by "(5)" and "(6)", using Parks transformation technique [14].

$$\begin{aligned} U_d &= U_{id} - L\omega i_q - L\frac{di_d}{dt} \\ U_q &= U_{iq} - L\omega i_d - L\frac{di_q}{dt} \end{aligned} \tag{5}$$

Where U_{iq} and U_{id} are respectively the dq inverter voltages coordinates. Being $U_i = U_{dc}$. d is inverter voltage, this is the input dc voltage multiplied by duty Ratio/ cycle, i.e. D_a, D_b, D_c. A maximum current I_t is injected by P-V inverter. This current limits/ controls the active and reactive powers, are then injected over the photovoltaic inverter by PV generator. This limit is calculated from the equation of a circle which is expressed as in "(6)".

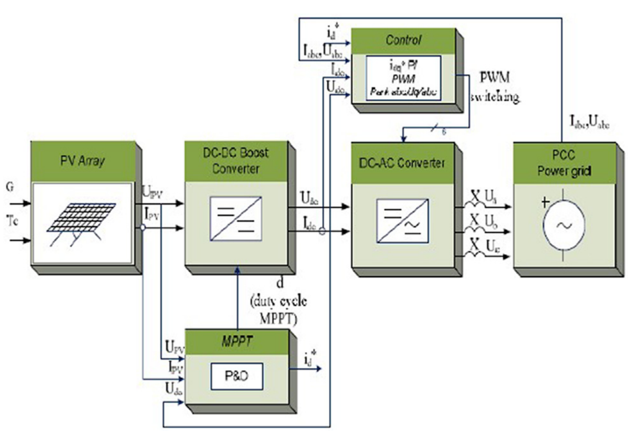

Fig. 2. Block diagram of Grid-Tied Photovoltaic system.

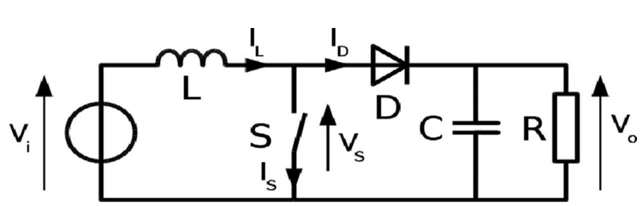

Fig. 3. Circuit diagram of Boost converter.

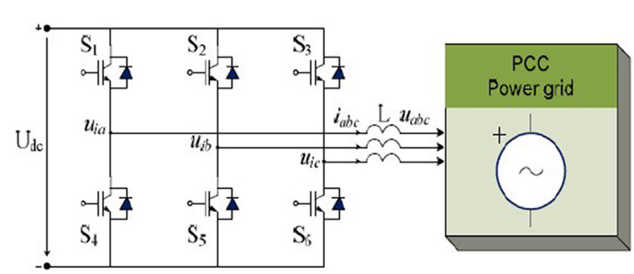

Fig. 4. Circuit block diagram for VSC to power grid.

$$P^2 + Q^2 = (U_g + I_i)^2 \tag{6}$$

Where U_g is 1-ϕ voltage in the power system, I_i is 1-ϕ current in P-V system, and P-Q presents the active and reactive power in the network at the Grid. Now "(4)" can be rewritten as:

$$I_i = \frac{\sqrt{P^2 + Q^2}}{U_a} \tag{7}$$

The I_i is inverter current limit (8), R_2 and C_2 represents the Radius and Center, $R_2 = U_g{}^*I_i$ and $c_2 = (0, 0)$.

The maximum voltage of P-V inverter, U_i, imposed this limit. This voltage describes an supplementary limit capacity of active and reactive powers is expressed in "(8)":

$$P^2 + \left(Q + \frac{U_g^2}{X}\right)^2 = \left(\frac{U_g U_i}{X}\right)^2 \tag{8}$$

I_i, and U_i represent the 1- ϕ current & voltage of the P-V inverter, further, U_i depends on the continuous value of voltage from Inverter input, X represents the reactance values from the Inverter terminals. Again "(9)" can be rewritten as:

$$U_i = \sqrt{P^2 + (Q + \frac{U_g^2}{X})} - \frac{U_g}{X} \tag{9}$$

3. Numerical analysis

All the numerical analysis has been carried out using MATLAB-based toolbox for power system studies known as PSAT. It includes load flow analysis, dynamic stability analysis, optimal power-flow continuation power flow and transient stability tools. This software affords a SIMULINK-based, one-line network and a full graphical interface.

3.1. System description

"Fig. 5" show the structure of a distribution system applied in the presented analysis. Since the length of the distribution lines in every segment of the distribution system structure do not exceed two kilometers. The system consists only of one synchronous generator, 48 constant PQ loads, 53 bus-bar, one transformer and 53 branches with a nominal base value of power and voltage respectively 100 MVA, and 33 kV. In the base case, the total loading system is 12.107 MW and 3.952 MVAR. The distribution grid functions at one voltage level 33 kV. The main power station connected to bus 53 is fitted with a TG and AVR and chosen as the swing bus [25]. The Solar Generators labelled as PVPP 1, PVPP 2 and PVPP 3 are connected to buses 13, 18 and 46 respectively.

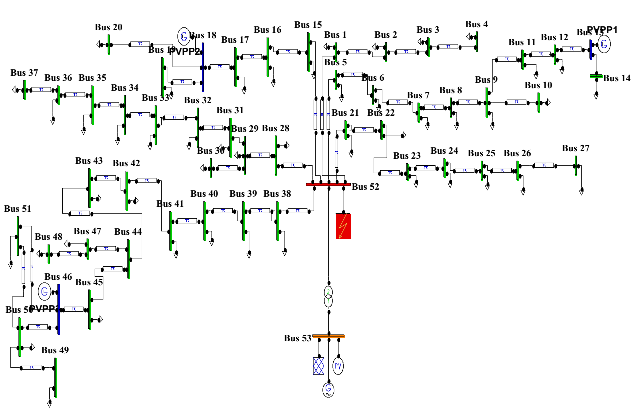

Fig. 5. Single line diagram of a distribution system connected PVPP.

The maximum installed capacity for photovoltaic power capacity for each solar generator is 4 MW, operating with power factor ranging between 0.95 lag and 0.95 lead. The solar irradiation and temperature are assumed to be constant throughout the analysis. The parameters of the transmission lines, the load distribution for each path, the synchronous power station (SG), the values of the parameters adopted for the turbine governor and exciter model, and the parameters assessed for the PVPPs are taken from [35–5]. We present the test results for the transient responses of the grid-tied photovoltaic power plants when a grid-fault happens. We have analyzed the performance of the system for compliance with grid requirement codes [5–21]. For this, we applied three-phase short-circuit faults at one regular transmission network bus (ie., bus '52'). Also, we chose the network bus-52, as a faulty bus, because it is the main bus to distribute the power to the rest of grid. A three-phase, short-circuit was applied at time t = 5 s. To examine the power quality, the fault is cleared after 150 ms and simulations were executed without and with the photovoltaic solar power for comparison. The STATCOM module is used for voltage control through reactive power compensation [26]. In the real case study, for investigating the impact of integrating STATCOM on the transient voltage stability, we have taken the distribution network located in the state of Hammam-Lif, which is in the north of Tunisia near the Mediterranean coast, having a PV penetration of 12 MW.

3.2. Steady state voltage analysis

In static load flow studies, the photovoltaic power plants voltage control capacity and active power generation are typically assimilated to PV generator buses. If they reach their limits on reactive generation, they are called load buses. In terms of this hypothesis [18], we assessed the voltage profile of the network with and without photovoltaic power plants in peak-load conditions. In Fig. 6, we have plotted this characteristic. We observed that, when photovoltaic power is zero (Fig. 6.a), the voltage at the connection photovoltaic buses are within 1.01p.u. When all three photovoltaics farms are injecting their maximum solar power (Fig. 6.b), voltage levels increase at the connection buses with the condition of peak-load and no over-voltages are depicted. The voltage profile of the grid and photovoltaic buses in particular increased to 1.045 percent. The voltages in the network's multiple buses are included in the appropriate 10% tolerances. Fig. 7 presents the smallest eigenvalues locus for the static load flow Jacobian matrix. For clarity of the figure, the rest of the eigenvalues locus have been unnoticed, taking only loose value. We have noted that, the minimum eigenvalue of the static load flow Jacobian matrix is equal to 0.2 showing that the system is stable. The comparison between the voltage magnitude with and without introducing the STATCOM can be shown in Fig. 8. After integrating the Static Synchronous Compensation to busbar 52, the voltage magnitude has been enhanced for all the busbar, moreover the voltage has been improved specially at PVPPs connection buses as presented in Fig. 8 by generating their maximum solar active power as illustrated in Fig. 9.

3.3. Simulations results for power quality

In this section, we present the test results for the transient responses of the grid-tied photovoltaic power plants when a grid-fault happens. We have analyzed the performance of the grid for agreement with the Tunisian requirement grid codes [19]. For this, we applied three-phase, short-circuit at one transmission regular grid bus '52'. Also, we chose the network bus-52, as a faulty bus, because it is the main bus to distribute the power to the rest of grid. A three-phase, short-circuit fault was applied at time 5 s.

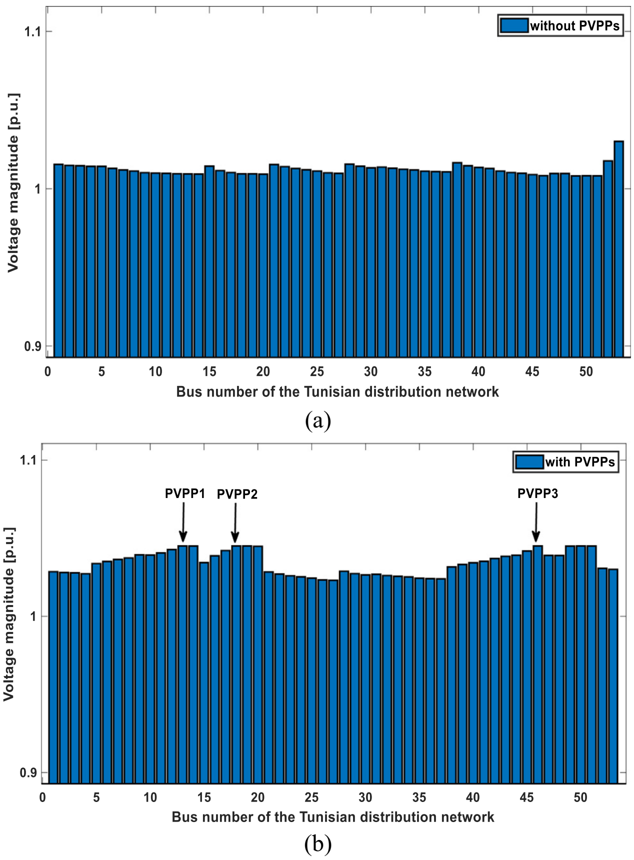

Fig. 6. Voltage magnitude profile of the Tunisian distribution network with (a) and without (b) PVPPs.

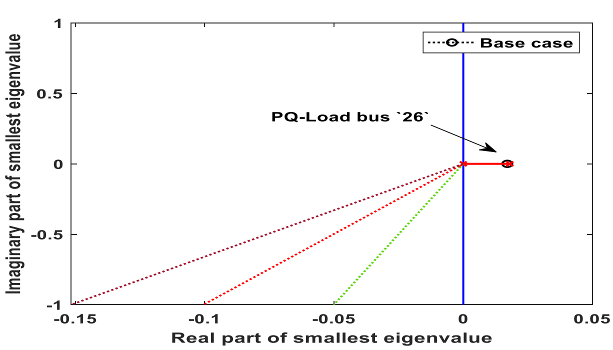

Fig. 7. Smallest eigenvalue locus for the static load flow Jacobian matrix.

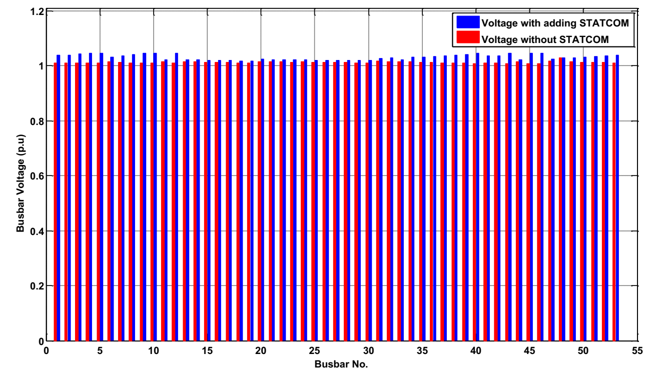

Fig. 8. Tunisian distribution network busbar magnitude voltage value with and without introducing STATCOM.

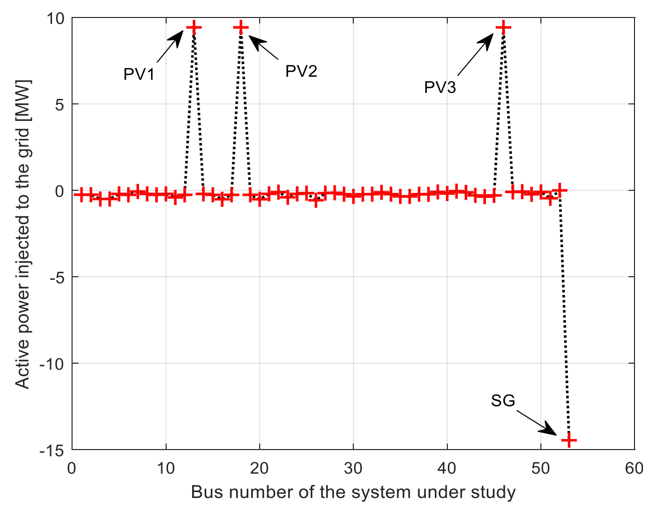

Fig. 9. Active power injected at PVPPs and at swing bus SG.

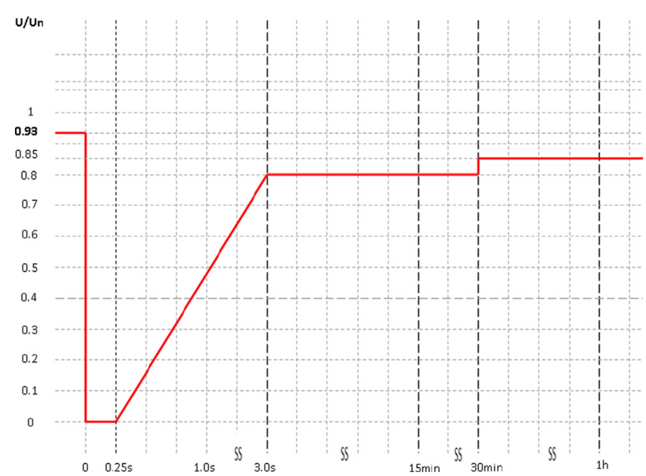

Fig. 10. Typical LVRT requirements curve for Tunisian Grid.

The fault is cleared after 150 ms to test the power quality, and for comparison, the simulation results were executed with and without photovoltaic power plants.

1. Fault ride-through

According to the Tunisian Gas Company, the minimum voltage specifications that solar photovoltaic generators must resist is as presented in Fig. 10. It shows that every solar photovoltaic generators with transient stability remains connected with the grid without deteriorating with an average fault clearance period of 250 ms. Within the operating range of the solar photovoltaic power plant, such faults should not lead to instability or isolation from the transmission network. Moreover, Fig. 10 indicates that solar photovoltaic power plant should have the capability for uninterrupted operation of a duration of 250 ms and a voltage drop up to zero. Tracked by a voltage recovery upto 85% of the nominal power system voltage with a voltage recovery duration of 30mn at the point of common coupling. In solar inverters, the LVRT capability is essential to keep the stability of the system.

Under abnormal operation, the recovery duration of the solar power plant is shown in Table 1. The ranges of the network voltages are defined in per unit system.

Table 1
Solar power plant requirements with respect to the grid voltage variations [5].

Voltage Ranges	Requirements
0.8Un – 0.85 Un	30 mn
0.85 Un – 0.95 Un	3 hrs
0.95 Un – 1.05 Un	Unlimited
1.05 Un – 1.1 Un	1 hr
1.1 Un – 1.2 Un	15 mn

2. Network short-circuit without PVPP

For this first test, the grid is simulated without the PVPPs farms. The resulting voltage profiles at the PVPPs buses connection '13, 18 and 46' is shown in Fig. 11. We could observe a significant drop in voltage at the connection buses reaching to 0.65p.u and at the faulty bus '52', dropping down to 0.70p.u, as is seen in Fig. 12.

3. Network short-circuit with PVPP

For the second test, the distribution network is simulated with the PV farms. We apply the fault at the connection bus '52'. Figs. 13 and 14 show respectively the behavior of the PVPPs and the faulty bus '52'during the fault-ride through. It is seen that after the occurrence of the fault, immediately the voltage at the Photovoltaic buses decreases near 0.7p.u, and on clearing the fault at 5.150 s, as the PVPP commences a regulation mode voltage, the Photovoltaic terminal voltage starts rising to reach 1.3p.u.

The reactive and active power production of the photovoltaic bus '46' is depicted at Fig. 15. The regulation of voltage at this photovoltaic generator is assured because the photovoltaic generators have been expanded by a simple and continuous controller as according to [5]. The reactive power generation of photovoltaic

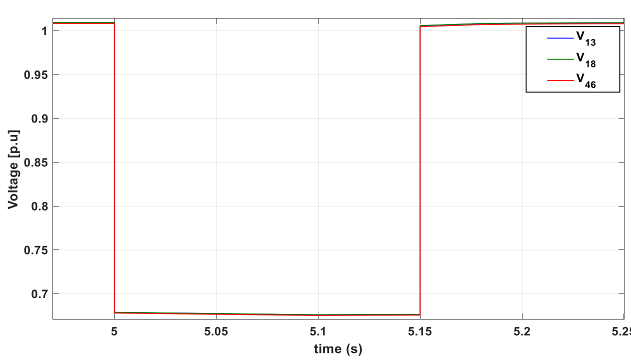

Fig. 11. Voltage response in p.u at PVPPs connection buses during the short-circuit – system without PV.

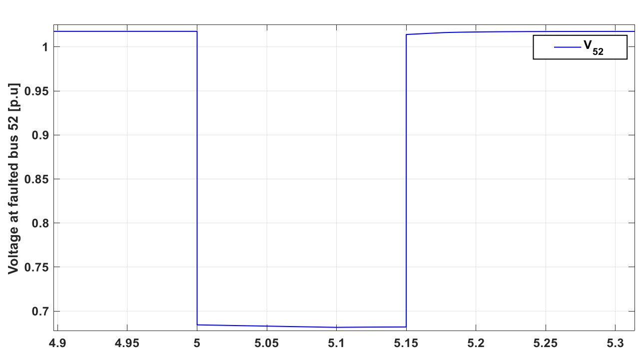

Fig. 12. Voltage response in p.u at faulted connection bus 52 during the short-circuit – system without PV.

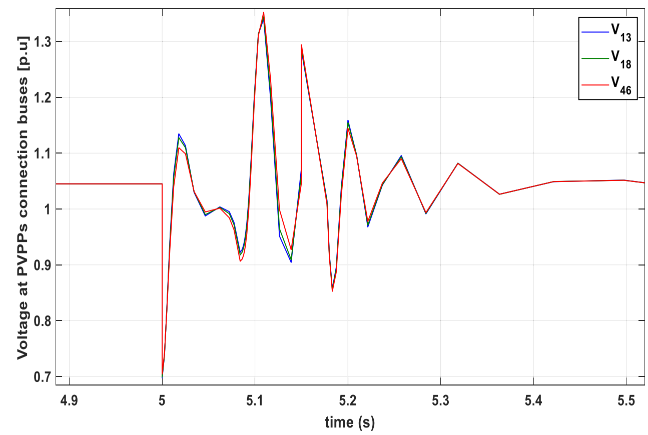

Fig. 13. Voltage response in p.u at PVPPs connection buses during the short-circuit – System with PV and without STATCOM.

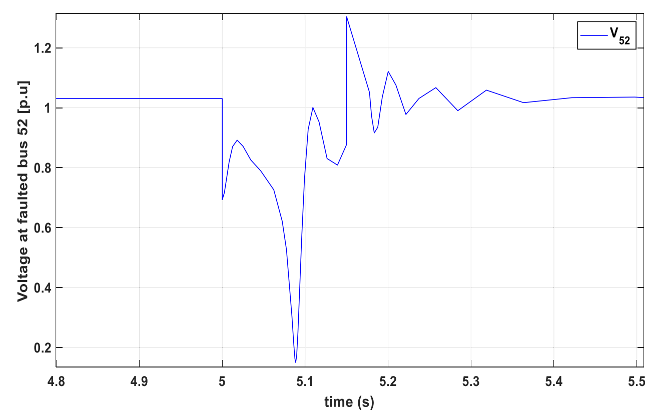

Fig. 14. Voltage response in p.u at faulted connection bus 52 during the short-circuit – System with PV and without STATCOM.

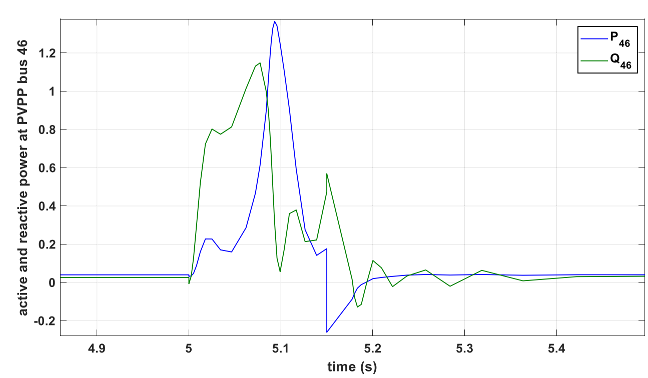

Fig. 15. Active and reactive power response in p.u at PVPP bus '46' during fault–system with PV and without STATCOM.

bus '46' was depicted to render voltage support during the low-voltage period as shown in Fig. 15. The photovoltaic bus '46', contributes the most to support the network voltage since it is the most PV bus near the faulty bus. During the transient process, the active power generated from the solar power plant decreased as a result of the short circuit. Simulation results do confirm the fact that the Photovoltaic generator controllers have the capability to reestablish the PV terminal voltage once the short-circuit fault is cleared.

4. STATCOM Simulation with the Distribution Network During Short-circuit

The voltages at PVPPs and faulty bus '52' buses with the STATCOM, throughout the short-circuit analysis, are shown respectively in Figs. 16 and 17. It is obvious that the Static var Compensation could manage mitigation of the voltage sag at both PVPPs buses and faulty bus '52'. In addition, the voltage enhancement at bus 52 is greater, as this is the STATCOM connection point. The STATCOM's dynamic behavior influences grid voltages, but without adverse effects, shortly after clearance of faults. Fig. 18 shows the STATCOM's reactive power supply in secure and dynamic environments to minimize the voltage decrease. The supply of reactive power is decreased after clearance of the fault. In order to keep a DC stable bus voltage, the STACOM consumes active power and indicates that the active power is decreased when the supply of reactive power increases. It is observed that the presence of STATCOM lowers the voltage level towards its nominal value.

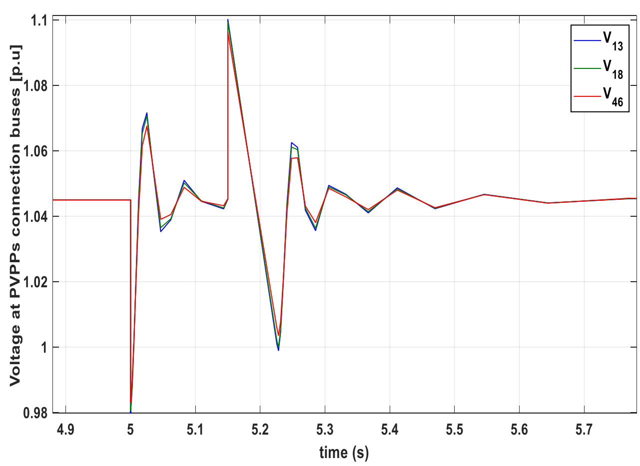

Fig. 16. Voltage response in p.u at PVPPs connection buses during the short-circuit – System with PV and with STATCOM.

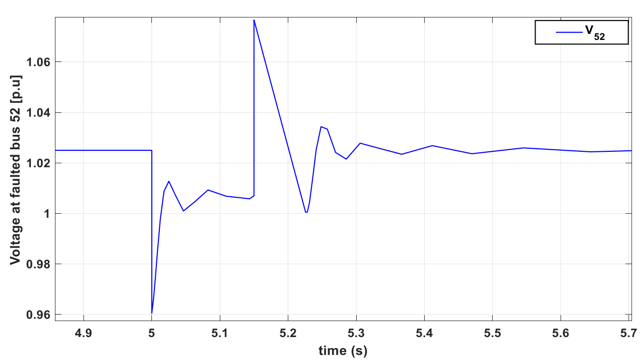

Fig. 17. Voltage response in p.u at faulted connection bus 52 during the short-circuit – System with PV and with STATCOM.

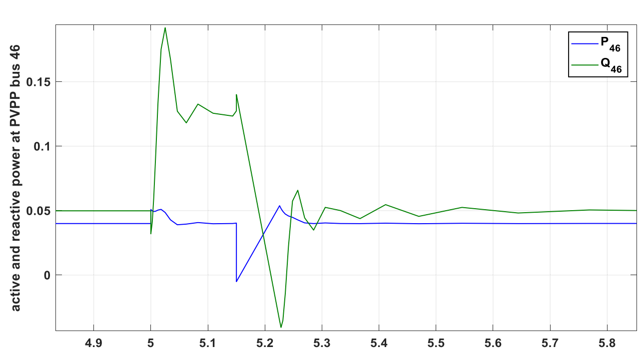

Fig. 18. Active and reactive power response in p.u at PVPPs bus '46' during fault–system with PV and with STATCOM.

4. Discussion

The distribution network located in the state of Hammam-Lif which is in the north of Tunisia near the Mediterranean coast, having a PV penetration of 12 MW was studied. A large-scale PV penetration including STATCOM is connected to the power system as shown in Fig. 5 respectively to buses 13, 18 and 46. The MATLAB software platform was used and the power network was described by a set of differential and algebraic equations, from the initial conditions of the static power flow method. The simulations results aimed at analyzing the impact of STATCOM and PV farms on power system transient stability. The STATCOM controls the current in order to deal with the reactive power, since the voltage at the point of common coupling is significant for computing the control variables. The STATCOM had a significant impact on reducing the overvoltage level towards its nominal value at the PV bus and minimizing reactive power losses in a system that included large PV generation with fault disruption. Despite the fact that the imposed voltage was greater than the reference voltage, the PV inverter was kept at its nominal voltage, so it improved system stability. It is observed that the presence of STATCOM lowers the voltage.

5. Conclusion

This paper investigated the influence of photovoltaic integration on the voltage stability of the 53-Bus distribution grid. Efficiency and quality of voltage in PV system degrades due to instability in voltage in Grid connected system. To overcome this problem, the STATCOM is implemented for improving the power quality and the power system voltage stability under various scenarios based on the Tunisian grid code. STATCOM contributes better alternatives to increases static voltage stability margin and power transfer capability. STATCOM is also implemented to regulate the injected P-Q power to the power transmission network. In this paper, we also presented some appropriate models for the STATCOM in the steady-state analysis and with a rigorous discussion. Thus, we have derived a technique for identifying optimal placement of FACTS devices. The related equations are also derived. Simulation results show that there is a significant improvement of these parameters and steady-state stability of the system with insertion of STATCOM.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Dr. Abdelaziz Salah Saidi was born in Tunisia, in 1979. He joined the Higher Institute of Computer Science of Kef as assistant Professor in 2012. He is currently Assistant professor of Electrical Engineering at King Khalid University in Abha. He is received his M.S in Electrical systems from the national engineering school of Tunis in the year 2003. He received his Ph. D degrees in electrical engineering in 2011 from the same school. His main interest research areas focuses on dynamical systems theory applied to power systems integrating Renewable Energy, power systems voltage stability using load flow techniques and power systems controland operation.