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Impact of static synchronous compensator STATCOM installation in power quality improvement

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ABSTRACT

The present work investigates the flexible AC transmission system (FACTS) device's role to improve the voltage stability for a distribution network of various types of loads. Our analysis was based on using a static synchronous compensator (STATCOM) device over a test distribution system. Firstly, a detailed description of the mathematical model used in our system is presented. Then we studied the effect of inductive and capacitive loads with and without STATCOM. To investigate the efficacy and robustness of using STATCOM in a distribution network, a test system is developed using MATLAB/Simulink, where we analyzed the voltage profile in different cases. The results of the simulation demonstrate that the STATCOM plays a critical role in optimizing the voltage profiles of distribution systems, either capacitive or inductive.

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1. INTRODUCTION

The increased demand for electricity makes transmission management and distribution networks more complicated. Voltage stability has been more critical in industrial power distribution systems than residential utilities. It is even more severe nowadays with advanced networks with heavier loads and the recent integration of intermittent energy sources in the grid [1], [2]. Voltage instability may result in power system destruction [3]. Thus, solving the voltage stability problems has been the theme of exhaustive explorations for years [4], [5]. Generally, voltage stability can be defined as the stability of the power system by keeping constant voltages at all buses of the power system after being disturbed by different power devices. Fast load voltage regulation is necessary for a power distribution system to minimize time-varying loads such as variable wind generation output power, voltage drop, electric arc furnaces, and current consumption of parallel-connected loads recently started induction motors [6]. Improved system voltage stability necessitates reactive power control [7].

As a result, distribution systems require voltage regulation to keep the voltage profile of all system busses within acceptable limits, ensuring the power system's stability. To increase the operation of the electrical grid, new control systems are required to meet these challenges and needs [8]. Due to their agility and adaptability, the integration of flexible AC transmission system (FACTS) control systems in power systems such as static synchronous compensator (STATCOM) and static VAR compensator (SVC) contribute significantly to enhancing power transfer capability and providing system stability. FACTS devices can also control the reactive and active power flow in the electrical power system autonomously [9]. One of the FACTS devices used to adjust reactive power, enhance the voltage profile, improve the power factor, and decrease system power losses is the static synchronous compensator STATCOM [10]. Because of the incorporation of a battery energy storage system (BESS) into the DC output of the inverter, a STATCOM can now provide active power to the network [11]. The STATCOM also can regulate grid voltage at the common coupling point (PCC) by injecting or absorbing a specified amount of reactive power into voltage source converters (VSC) using energy storage [12]. STATCOM can also adjust the voltage magnitude and modify the phase angle in a very short period, which improves the quality of the signal [13].

Afzal *et al*. [14] proposed a STATCOM voltage controller that can significantly improve induction generators' steadiness performance. Singh *et al*. [15] described a modified version of the instantaneous reactive power theory employed for the STATCOM control. Moufid *et al*. [16] presented a power loss minimization using the integration of DGs and reconfiguration of distribution system. Hooshmand and Mohkami [17] presented bacterial scavenging utilizing particle swim optimization (PSO) for ideal area calculation of both fixed and changing capacitors to decrease force misfortunes' expenses and further develop the voltage profile. Arya *et al*. [18] proposed executing three-stage dispersion STATCOM utilizing single-stage p-q hypothesis-based control calculation for STATCOM in power factor adjustment under a nonlinear dissemination framework. El-Fergany and Abdelaziz [19] offered an effective heuristic-based way to deal with allocating static shunt capacitors. They utilized ABC calculation to upgrade the framework static voltage strength list and accomplish the most significant investment funds. Hussain and Subbaramiah [20] propose a strategy to recognize the ideal area of STATCOM to limit the misfortunes and improve voltage profile in the outspread dispersion framework.

Static VAR compensator (SVC) gives a compelling responsive pay for voltage profile during potential occurrences, which would make some way or another push down the voltage for a colossal. This device utilizes electronic ability to control power and voltage on the force framework. They are likewise ready to expand transitory security by raising or decreasing the force move limit. Wang *et al*. [21] examined the disseminated age facilitating limit assessment for dispersion frameworks thinking about the vigorous ideal activity of SVC. Farsangi *et al.* [22] proposed picking the data signals for FACTS gadgets in tiny and colossal force frameworks. Haque [23] proposes a control strategy for FACTS devices that use a bang-bang method to improve the power system's initial swing stability limit.

This paper proposes the use of STATCOM to enhance the distribution network's voltage profile. The paper is organized as follows: in the first section, the description of STATCOM as a FACT device is presented. In the second part, the modeling of STATCOM was discussed. The third section is divided into two parts. In the first part, the simulation is done before using STATCOM, and in the second part, the STATCOM was installed in our system. Finally, some significant conclusions are outlined.

2. FACTS DEVICES

The FACTS devices are one of the equipment that depends on a power electronic capability to change parameters like line impedance, voltage magnitude, and transmission phase angle. The main goal of these FACTS devices is to expand the power flow through a transmission line, diminish the heavily loaded, improve power flow transfer capability during transmission systems, enhance voltage regulation and minimize power system oscillations. Among the different types of fact devices, we find thyristor-controlled series capacitor (TCSC), thyristor-controlled series reactor (TCSR), thyristor switched series capacitor (TSSC), static synchronous series compensator (SSSC), static VAR compensation (SVC), and STATCOM. In this work, we focused on the use of STATCOM in the distribution system and its impact on power quality improvement.

2.1. Static synchronous compensator

2.1.1. Description of STATCOM

STATCOM has evolved into one of the most powerful devices for reactive power adjustment in response to the network's major dynamic performance. STATCOM is the most common new generation device for FACTS, and it is used to manage voltage via reactive power compensation by injecting or absorbing reactive power in a network. The STATCOM is shunt connected to the power network's bus to offer steady-state voltage regulation and increase transient voltage stability in the short term [24].

The STATCOM basic configuration is shown in Figure 1. This shunt-connected device regulates the voltage and angle of the voltage source to control the voltage connected to the specified reference value. To compensate the reactive and active power required by the network, a voltage source inverter is used to transform DC input into AC output voltage. More info concerning STATCOM structure and functions may be found in [25].

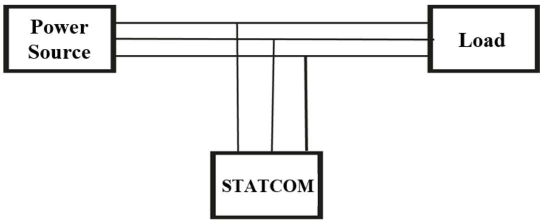

Figure 1. Equivalent circuit STATCOM

2.1.2. Modeling of STATCOM

The STATCOM model presented in this section is based on the principle of convenience [26]. Figure 2 shows the STATCOM simplified design circuit, which illustrates that this device is a sinusoidal voltage source coupled to a network node via the coupling transformer inductance. A series resistor is also included in the circuit to simulate the transformer power losses as well as the losses in the inverter switches.

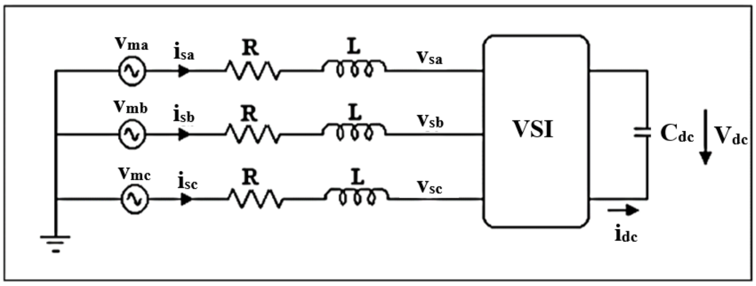

Figure 2. The simplified circuit of STATCOM

The global model of the static synchronous compensator is described by (1), using the reference frame in [26]. The mathematical model of the STATCOM after park transformation (d q) frame is obtained as (2).

$$\frac{d}{dt}\begin{bmatrix}Isa\\Isb\\Isc\end{bmatrix} = \begin{bmatrix}\frac{-Rs}{Ls} & 0 & 0\\ 0 & \frac{-Rs}{Ls} & 0\\ 0 & 0 & \frac{-Rs}{Ls}\end{bmatrix}\begin{bmatrix}Isa\\Isb\\Isc\end{bmatrix} + \begin{bmatrix}\frac{1}{Ls} & 0 & 0\\ 0 & \frac{1}{Ls} & 0\\ 0 & 0 & \frac{1}{Ls}\end{bmatrix}\begin{bmatrix}Vma - Vsa\\Vma - Vsa\\Vma - Vsa\end{bmatrix} \quad (1)$$

$$\frac{d}{dt}\begin{bmatrix}Isd\\Isq\\Idc\end{bmatrix} = \begin{bmatrix}\frac{-Rs}{Ls} & w & \frac{-m}{Ls}cos\theta\\ -w & \frac{-Rs}{Ls} & \frac{m}{Ls}sin\theta\\ \frac{3m}{2c}cos\theta & -\frac{3m}{2c}sin\theta & \frac{-1}{RsC}\end{bmatrix}\begin{bmatrix}\mathrm{Isd}\\Isq\\Udc\end{bmatrix} + \begin{bmatrix}\frac{1}{Ls} & 0\\ 0 & \frac{1}{Ls}\\ 0 & 0\end{bmatrix}\begin{bmatrix}Vd\\Vq\end{bmatrix} \quad (2)$$

Where θ is the VSI firing angle. Linearization of (2) about the working firing angle θ_0, gives a set of linear equations as shown in (3).

$$\frac{d}{dt}\begin{bmatrix}I_{sd}\\I_{sq}\\U_{dc}\end{bmatrix} = \begin{bmatrix}\frac{-Rs}{Ls} & w & \frac{-m}{Ls}cos\theta_0\\ -w & \frac{-Rs}{Ls} & \frac{m}{Ls}sin\theta_0\\ \frac{3m}{2c}cos\theta_0 & -\frac{3m}{2c}sin\theta_0 & \frac{-1}{RsC}\end{bmatrix}\begin{bmatrix}\mathrm{I}_{sd}\\\mathrm{I}_{sq}\\\mathrm{U}_{dc}\end{bmatrix} + \begin{bmatrix}\frac{1}{Ls} & 0 & \frac{m}{Ls}U_{dc0}sin\theta_0\\ 0 & \frac{1}{Ls} & \frac{m}{Ls}U_{dc0}cos\theta_0\\ 0 & 0 & -\frac{3m}{2c}(\mathrm{I}_{sd}sin\theta_0 + \mathrm{I}_{sq}cos\theta_0)\end{bmatrix}\begin{bmatrix}V_d\\V_q\\\theta\end{bmatrix} \quad (3)$$

The scheme of the controller is illustrated in Figure 3. It is constructed of different blocks assembled: i) a current regulation loop, ii) a phase-locked loop (PLL), iii) two measurement systems, iv) a dc-link voltage regulator, and v) a voltage regulation loop. To supply the synchronous reference sin (wt) and cos (wt) required by the ABC-dq transformation, the PLL is synchronized to the fundamental of the transformer primary voltage.

The d-axis and q-axis components of voltages and currents are calculated using the measure blocks “Vmes” and “Imes”.

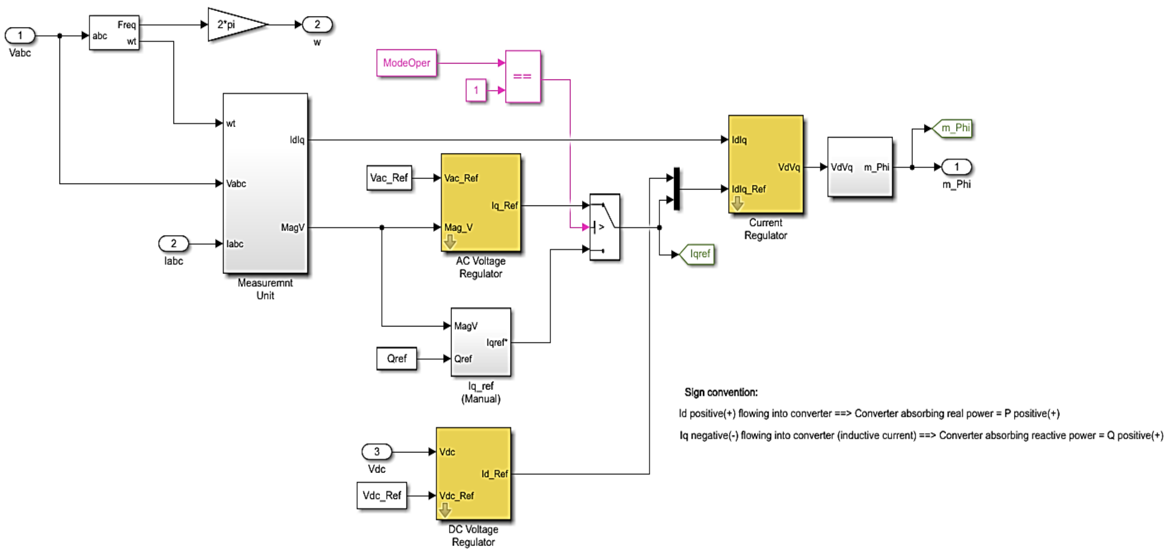

Figure 3. STATCOM control system

The d-axis and q-axis currents are controlled by two proportional-integral (PI) controllers in the current regulation loop. The voltage direct-axis and quadrature-axis components (V and Vs) that the pulse width modulation (PWM) inverter must create are the controllers outputs. The phase voltages Va, Vb, and Vc are used to generate the PWM voltages from the Vd and Vq voltages. A PI controller regulates the voltage on the distribution network bus, creating the current I, reference for the current controller. The current reference is provided by the dc-link voltage regulator, which ensures the DC link voltage stability.

3. SIMULATION RESULTS AND DISCUSSION

3.1. Absence of STATCOM

To investigate the efficacy and robustness of using STATCOM in a distribution network, a test system is developed using MATLAB/Simulink, where we analyzed the voltage profile in different cases. Our test system in this study is presented in Figure 3, it is composed of a feeder of 25 kV, 50 HZ, and 100 KVA, a transmission line with 25 km of length, and a three-load applied to the system at different times. Figure 4 illustrates the proposed system model without STATCOM.

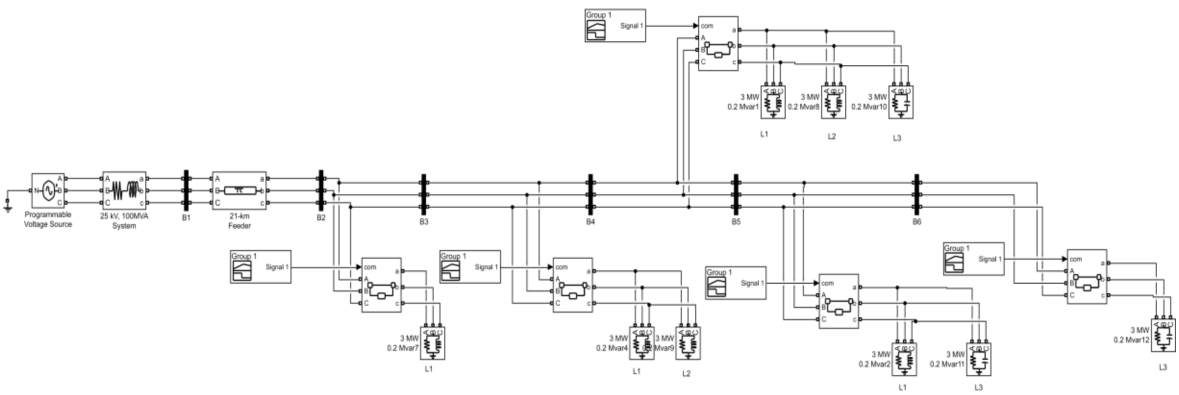

Figure 4. Proposed system model for simulation without STATCOM

The feeder is generating Vs.=1.0 Pu, the energy system supplies different load inductive and capacitive. In our simulation, at time (t=1 s) a load L1: (P=10 MW; QL=8 MVAR) is applied, then at the instant (t=2 s) both L1 and L2 (P=10 MW; Ql=7 KVAR) is applied, at (t=3 s) L1, L2, and L3 (P=30 MW; Qc=35 MVAR) is added , and at (t=4 s) the load L2 is disconnected, and finally at (t=4 s) just the capacitive load L3 is integrated in the system. The voltage profile of our distribution network before using STATCOM is illustrated in Figure 5 and Figure 6. The parameters of load used in the simulation are presented in Table 1. In the first time, we will simulate our system without using STATCOM Figure 4 shows the voltage drop generated by the inductive load L1 at (t=1 s), and the value of voltage droop increases when the inductive load L2 is added at (t=2 s); This value will be automatically decreased by integrating the capacitive load L3 at (t=3 s), (t=4 s), and (t=5 s), and by disconnecting the inductive load L1 and L2 respectively.

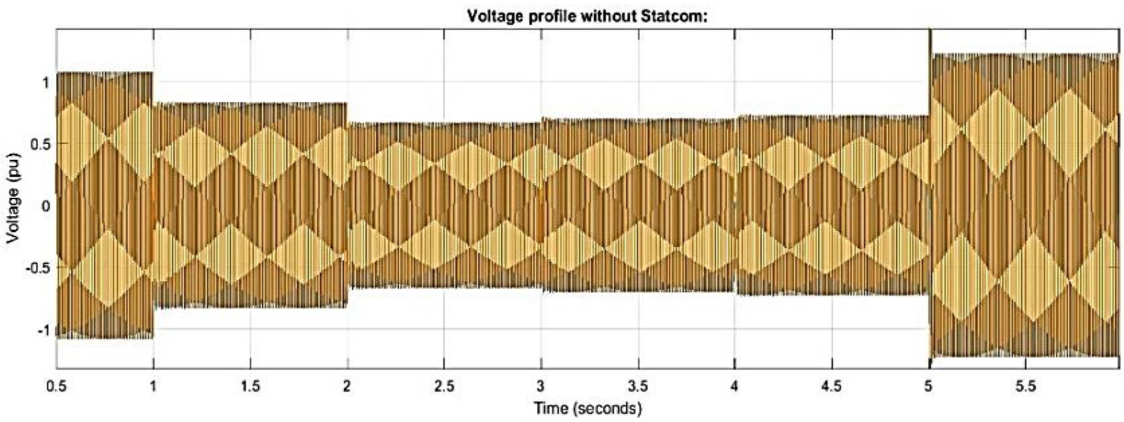

Figure 5. Voltage magnitude before using STATCOM

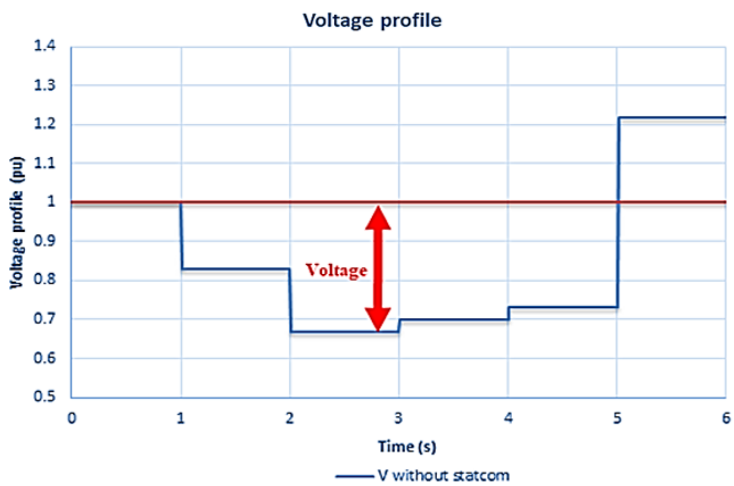

Figure 6. Voltage magnitude before using STATCOM

Table 1. The parameters of load used in the simulation

Time	Load
1s-2s	L_1 (P=10 MW; Ql=8 MVAR)
2s-3s	L_1 (P=10 MW; Ql=8 MVAR) L_2 (P=10 MW; Ql=7 KVAR)
3s-4s	L_1 (P=10 MW; Ql=8 MVAR) L_2 (P=10 MW; Ql=7 KVAR) L_3 (P=30 MW; Qc=35 MVAR)
4s-5s	L_1 (P=10 MW; Ql=8 MVAR) L_3 (P=30 MW; Qc=35 MVAR)
5s-6s	L_3 (P=30 MW; Qc=35 MVAR

3.2. Presence of STATCOM

In this case, we will keep the same test system with the same loads on the network. The simulation is carried out by inserting a STATCOM on the system as shown in Figure 7. From the simulation results shown in Figure 5, can see the improvement in the voltage magnitude after introducing STATCOM in our system. The comparison of the voltage profile after using STATCOM are illustrate in Figure 8.

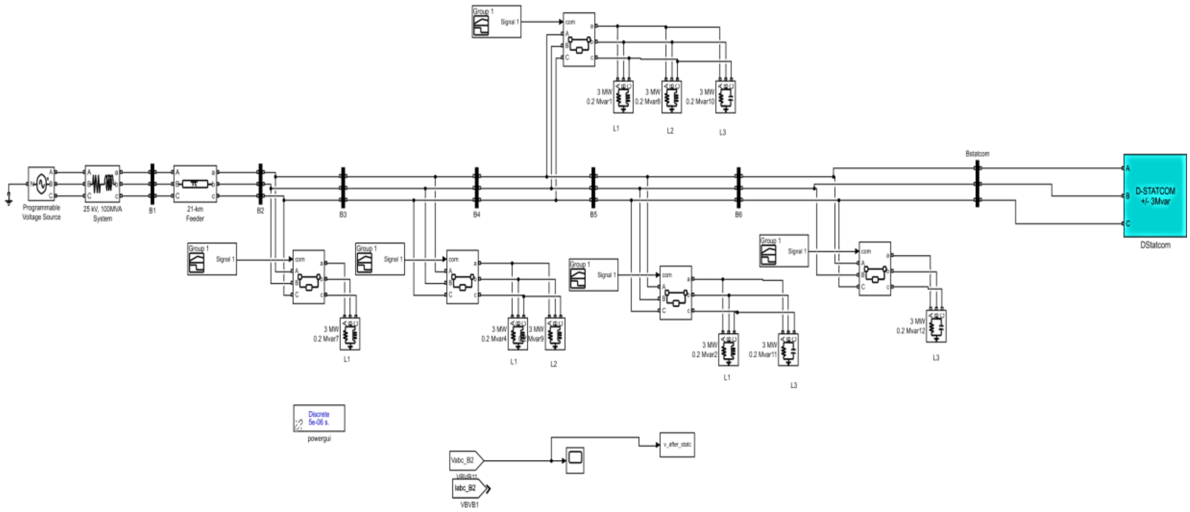

Figure 7. Proposed system model for simulation with STATCOM

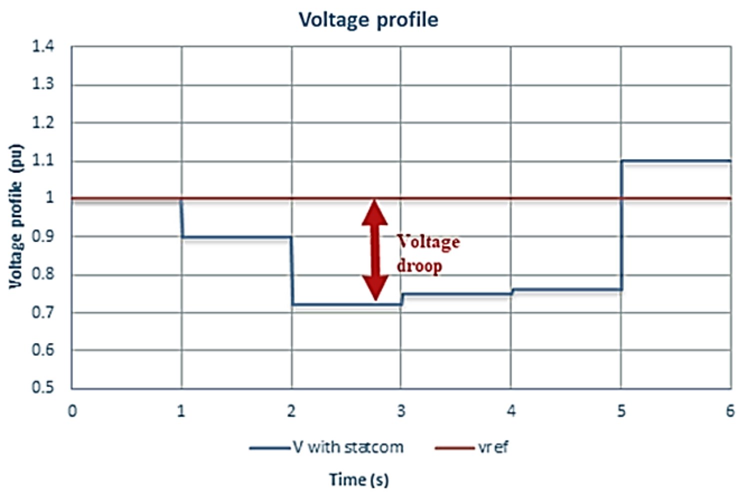

Figure 8. Voltage magnitude with STATCOM

The use of STATCOM in our system improves our distribution system's voltage magnitude, as we can see in Figure 8. The voltage drop of our distribution system is significant in the first case when we don't use the STATCOM in the system. But, with the current injected by STATCOM and reactive energy compensation, the voltage drop can be reduced by 0.1 pu. This explains the importance of using STATCOM in a distribution system. The simulation results with and without STATCOM are illustrated in Figure 9.

From Figure 9, we can see that the type of load can affect the voltage profile of the distribution system, so when the system works with inductive load, the voltage drop is more significant. It increases proportionally when the load increase. However, when the load is capacitive, the voltage magnitude outrun 1 pu (the voltage reference of the system). Therefore, by integrating STATCOM in the simulation, we can see the voltage profile in both cases with an inductive and capacitive load. The STATCOM can absorb and inject the reactive power to keep the voltage profile near the reference voltage Vref=1 pu.

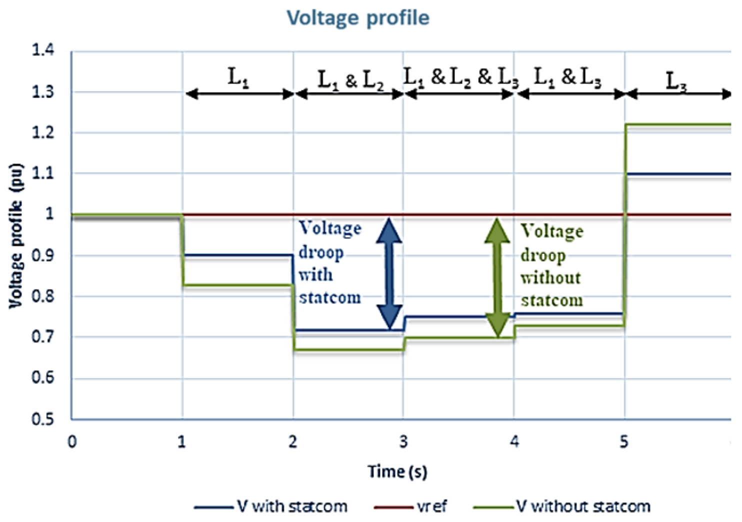

Figure 9. Voltage magnitude with and without STATCOM

4. CONCLUSION

In this study, STATCOM has been implemented on the distribution system, two scenarios of improved voltage profiles for loads that are inductive and capacitive have been simulated using MATLAB-Simulink. Results have shown that the compensation system enhances the load voltage. For two load types-inductive and capacitive-the simulation was analyzed before and after applying STATCOM. The STATCOM can return the load's voltage to its nominal value in two situations (within 1 pu). The obtained simulation results have demonstrated that the use of STATCOM in our test system can improve the voltage profile with various types of loads. In order to improve power quality, our next work will compare several FACT devices, including shunt devices, static VAR compensators (SVC), and static synchronous compensators (STATCOM). Additionally, to significantly reduce power losses, we'll investigate integrating metaheuristic algorithms like the Butterfly optimization algorithm BOA and the PSO algorithm.

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