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Uses StatCom to Improve the Power Quality and Power Factor Correction in Low Voltage Distribution System

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Abstract: The continuous development of human needs leads to increased demand for electrical energy, which is increases the complexity of power systems. During abnormal operating conditions, such as a high inductive loads, nonlinear loads, or may be some faults that leads to the deterioration of the power quality of the power system (swells or voltage drops). Reactive power compensation is linked to voltage regulation; traditional methods that use constant capacitor banks lack the flexibility and dynamic potential to satisfy power quality standards. In this paper proposed StatCom one of the more recent FACTS devices is used to quickly and accurately manage reactive power, which enhances the efficiency of electrical power transmission and distribution networks. This paper discusses the use of STATCOM for two types of loads: inductive loads and nonlinear loads. The effectiveness of STATCOM systems in compensating for reactive power losses and mitigating the effects of harmful harmonics caused by nonlinear loads was demonstrated. MATLAB Simulink was used to achieve the results.

Keywords: Power Quality, Power Factor Correction, STATCOM, FACTS

Introduction

The incorporation of renewable energy sources such a DG system and the growing need for enhancements have caused power systems to become more complicated and undergo dynamic changes. Power networks' stability and dependability are seriously threatened by voltage instability, which is typified by voltage sags, swells, and swings when consider the study on the sources side [1]. On the load side, nonlinear consumer and industrial loads in power systems include inverters, high-power diode rectifiers, computers, arc furnaces, and so on. Due to their functioning, these nonlinear loads require non-sinusoidal currents from utilities, resulting in poor power quality on the utility side. In addition, large inductive loads have an impact on network performance by lowering the power factor [2].

(STATCOMs) have developed as an important technology for reducing voltage fluctuations, enhancing power quality, and correcting for reactive power. The use of Voltage Source Converters (VSCs) in STATCOMs has various benefits, including higher waveform quality, lower THD, and increased power handling capabilities. This study will look at these advantages in a 1 MVA/420V low-voltage distribution system [3].

An essential consideration in electric power system management is reactive power compensation. High absorbing reactive power often lowers the power capacity of the distributors and transmission lines and increases power system losses. Furthermore, the receiving-end voltage may fluctuate significantly due to reactive power flowing via the lines [4]. older compensators like Synchronous Condensers or Capacitor Banks, are unlike now because the low response when we compare with FACTS system that using power electronics components like (TCR, TSC, and StatCom) [5]. There are many researchers who have presented their proposals to employ the StatCom in solving electrical network problems, including:

In [6], a selective HVC technique for STATCOM is suggested. This technique works really well to reduce voltage harmonics. An EMTP simulation is used to validate this approach.

In [7] proposes a solution for distributed STATCOM that uses (DVEC). Experimental findings suggest that this strategy may reduce negative sequence voltage and regulate voltage imbalance in the case of a fault.

In [8] illustrates how STATCOM can be used to provide stability and quality of electrical supply during dynamic relationships between transmission lines, wind turbines, and other electrical devices.

The IEEE bus system is beneficial for dampening low-frequency oscillations, as shown by a numerical case study. In a large, high-voltage power network, the imbalance between reactive power production and consumption might lead to voltage collapse. In order to address this issue, a low voltage rating STATCOM is suggested in [9].

There are different aspects of the StatCom model that can be summarized with the following points;

a. Voltage Source Convertor [10,11,12]
b. Pulse Width Modulation [13,14,15]
c. Software [16,17]
d. Load Flow Model [18,19,20]
e. Modular Multilevel Convertor [21,22,23]

Each model is used for several applications the employ to enhance the electrical power system.

This paper describes the relationship between power factor and electrical power distribution systems' efficiency, and the potential of using StatCom to improve power factor. This allows voltage adjustment and mitigation of the negative effects of harmful harmonics, thus improving power quality.

STATCOM

Is an electrical device that compensates the power system for dynamic reactive power, it is used to inject or absorb reactive power at certain grid locations in order to control the voltage (regulator). Voltage source converters (VSCs) and current source converters (CSCs) are the two most popular and operational variants of StatCom. Because the VSC approach is often more successful than the CSC methodology, STATCOM uses VSCs. This study employs a dynamic RPCs in the form of a VSC-STATCOM.

StatCom is usually connected via step-down transformers if the voltage in the transmission lines is high. However, in low-voltage distribution systems, step-down transformers are not required and are connected directly, as shown in the figure (1) [24,25].

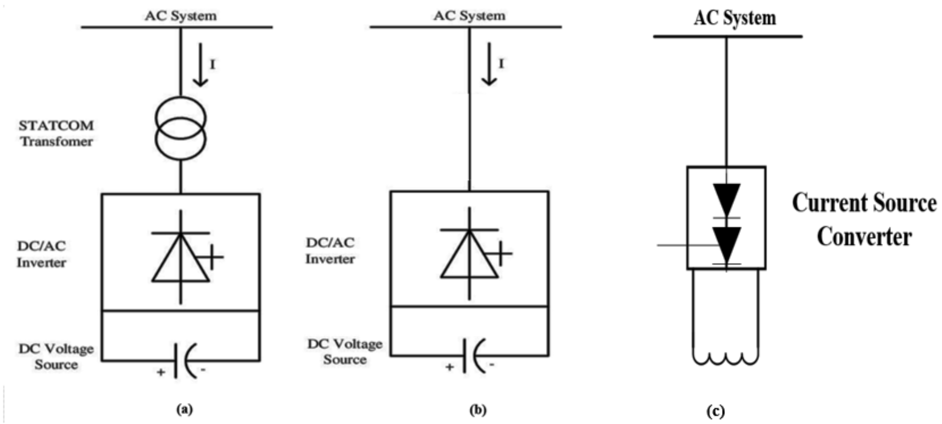


Figure 1. (a, b) VSC StatCom model, (c) CSC StatCom model.

Methodology

The Theory of Power

May be generically divided into AC and DC power. Real power (watt), imaginary power (VAr), and apparent power (VA) are further categories for AC power. Understanding the transport and use of electrical energy in various circuits and systems is made easier by these categories. The quantity of energy per unit of time is called power. In essence, it provides the rate at which energy is produced or consumed.

a. **Real Power (P):** The amount of electrical power that is really transformed into usable work, such as heat, light, or mechanical energy, is referred to as active power, or true power. The power that generates work in an electrical circuit is expressed in watts (W). The formula $P = Vrms * Irms * \cos\theta$, where θ is the phase angle, is used to compute active power in AC circuits by taking into account the phase difference between voltage and current.

b. **Reactive Power (Q):** In AC circuits, reactive power is the portion of electrical power that is required to create and sustain magnetic and electric fields in inductive and capacitive components but does not aid in performing beneficial tasks. Instead of being consumed, it alternates between the source and reactive parts like capacitors and inductors. VAr, is the unit of measurement for reactive power.

c. **Apparent power (S):** is the volt-ampere (VA) value of the total power flowing in an AC circuit. Regardless of whether the power is really consumed by the load or reflected back to the source, it reflects the product of voltage and current. It's an essential idea for comprehending and controlling electrical systems, especially for figuring out how much power electrical equipment can handle. When sizing electrical infrastructure, such as transmission lines, transformers, and generators, apparent power is crucial. It guarantees that these parts can manage the whole power flow, even if a portion of it is not put to good use [26]. Figure 2 illustrate the relationship between these the power components.

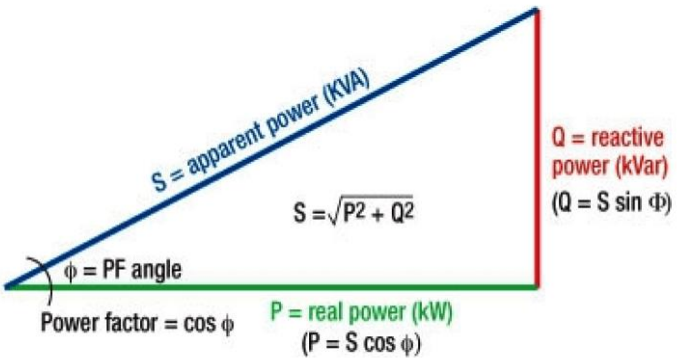


Figure 2. Power Triangle [27].

d. **Harmonics:** are caused by the presence of nonlinear electric loads. These frequencies are a primary source of reduced power quality, which affects a system's power factor.

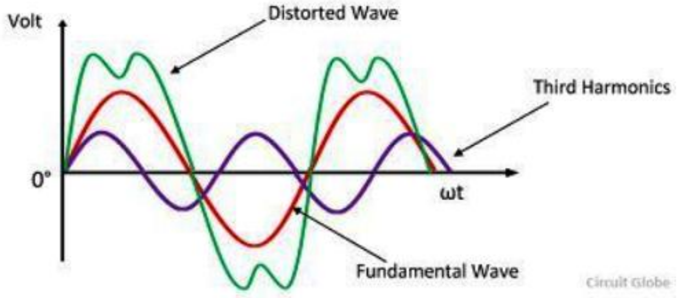


Figure 3. Current & Voltage Harmonics.

Power Quality and Voltage Stability Improvement by using StatCom

In power systems, (STATCOM) may greatly enhance voltage stability and power quality. In order to control voltage, adjust power factor, and lessen voltage sags and swings, STATCOMs provide reactive power into the system. As a result, the power supply becomes more dependable and steady [28].

How Power Quality Improve by STATCOM?

a. **Regulating Voltage:** StatCom systems are characterized by their very rapid response in absorbing or injecting reactive power, as they are power electronics devices that maintain a constant voltage even when the load is in a changing state.

b. **Power Factor Correction (PFC):** StatCom enhance the system's overall power factor by compensating for loads' reactive power demands by the injection of reactive power.

c. **Mitigation of the Voltage Sag:** When there are brief drops in voltage, known as voltage sags, STATCOMs may swiftly provide reactive power to maintain the voltage and save equipment from tripping or breaking down.

d. **Enhanced Capacity for Power Transfer:** STATCOMs may be used to transmit more active power over existing transmission lines by controlling voltage and making up for reactive power.

e. **Better transient stability:** may be achieved by using StatCom to increase the power system's resilience to disruptions such as faults or abrupt changes in demand.

f. **Damping Oscillations:** By using StatCom to reduce oscillations in the power system, the system's overall stability may be increased.

Proposed distribution StatCom constriction Model

Figure 4 depicts the overall layout of the STATCOM, a shunt FACTS device that controls the voltage at PCC and compensates or absorbs reactive power according on the voltage magnitude. It is made up of a DC voltage source coupled to a three-phase inverter [29]. The power circuits of the STATCOM and the distribution system are modeled by specific blocks from the Power System Block set, while the control system is modeled by Simulink blocks as shown in figure 5.

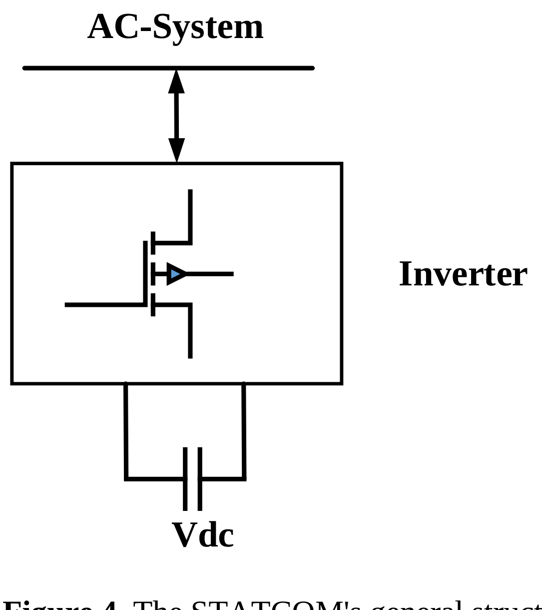


Figure 4. The STATCOM's general structure.

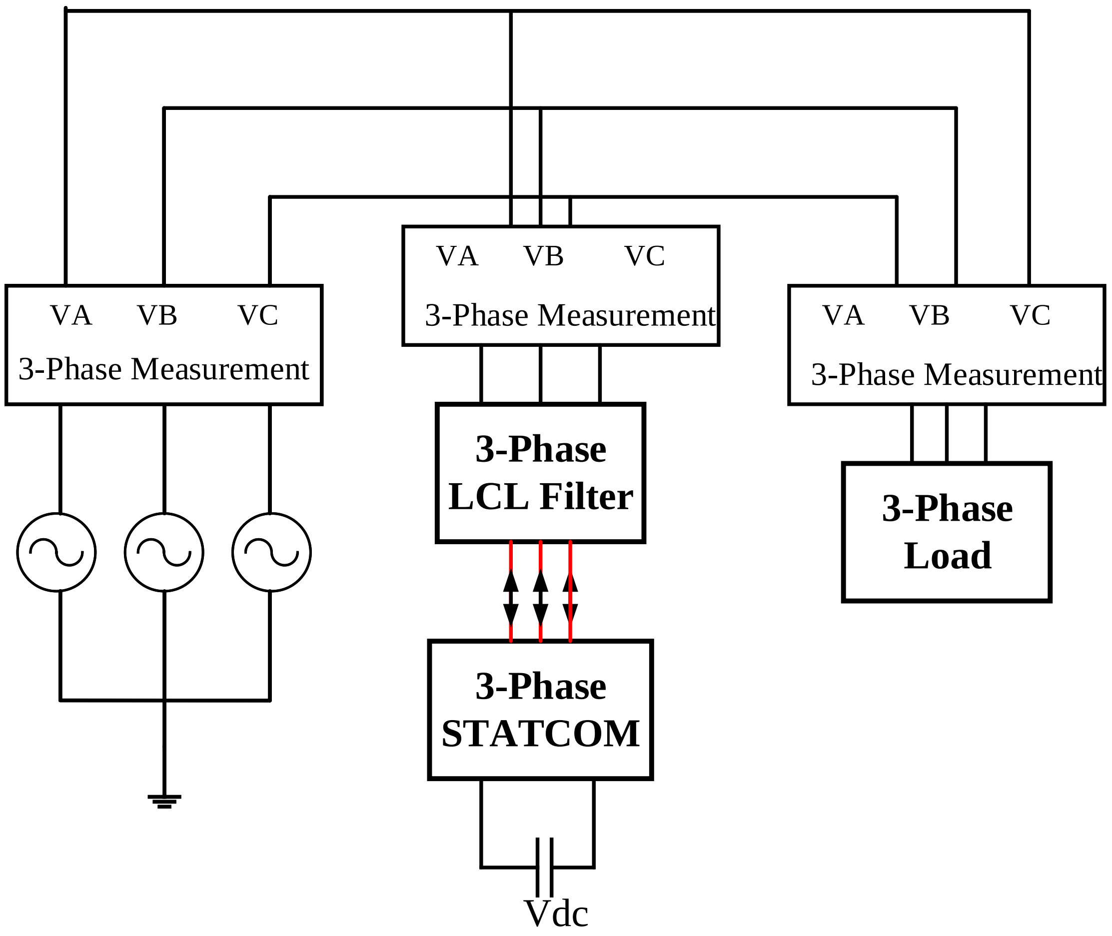


Figure 5. The Proposed Power StatCom System.

Control Method: There are three primary controllers of StatCom: the outer controller, reactive power, and DC voltage. Figure 8 shows the external StatCom control unit, which is the first unit. To compensate the reactive power, the second controller unit is used, which calculates the potential difference at the PCC point and the nominal voltage of the system by using PI controller [30,31]. The amount of active power needed to manage the DC voltage for StatCom capacitors is determined by the DC voltage controller. Based on Clark's transformation (abc to dq), this controller computed Id-ref using the traditional PI and the difference between the Vdc reference and capacitor voltage [32].

Figure 6 illustrate the voltage and current measurement; grid voltage presents the reference voltage, by using Clark's transformation to transfer Vabc to VD, VQ. The second parte related to the load current and inverter current its also transfer from abc to dq.

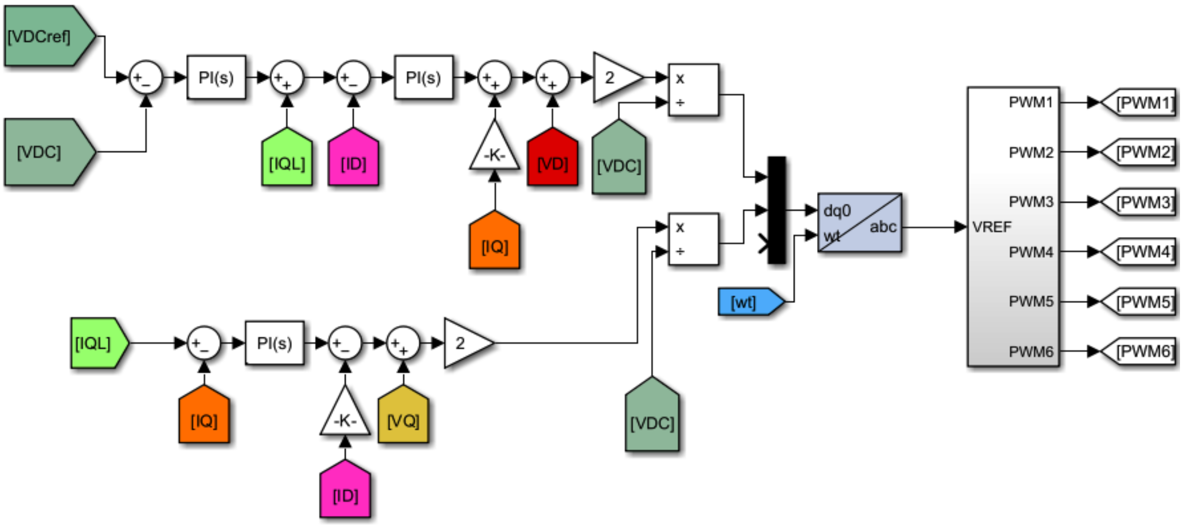


Figure 6. Voltage and Current Control /Matlab Simulink Block Diagram.

Result and Discussion

In a power distribution system, an inductive load, or nonlinear load, significantly affects the efficiency and stability of the electrical power grid. Reactive power regulation using StatCom has been proposed as a viable way to preserve voltage stability, improve power quality, and power factor correction.

In this paper MATLAB/Simulink is used to implement the distribution system based on StatCom technique for two types of load (Inductive and nonlinear). Table below is contant the important data which are need in the simulation program.

Table 1. Observe the practical values are using in the Matlab simulation.

Parameters	Values (Unit)
V_{DC}	800 (Volt)
$C_{dc\text{-}bus}$	4700 (μf)
V_{Grid}(rms)	420 (Volt) ph-ph
Load Power	1MVA
Power factor	o.65 logging
Switching freq.	10 KHz
LCL filter design	L1= 120 μH =L2
	C = 900 μf

Inductive load

The figure 7 shows the results obtained when connecting the StatCom in the case of an inductive load and its value P= 650KW, Q = 760KVAr, and 0.65 P.F. From the results we see the grid is injecting just the real power (P) when the all reactive power (Q) is injecting from the StatCom to load. So, in this case the grid power factor is increased and arrived to 0.9957. in the same figure the load power consumption consists from the active power absorbing from the grid and the load reactive power is compensating from the StatCom system and improved the power factor as shown in the simulation results shown in figure 7.

$$P.F = \cos \Phi \tag{1}$$

$$\Phi = \tan^{-1}\frac{Qg}{Pg} \tag{2}$$

$$Qg = -6.09 \times 10^4 \& \ Pg = 6.581 \times 10^5 \quad (3)$$

$$\Phi = \ -5.287^o \ , \cos -5.287^o = 0.9957 = P.F$$

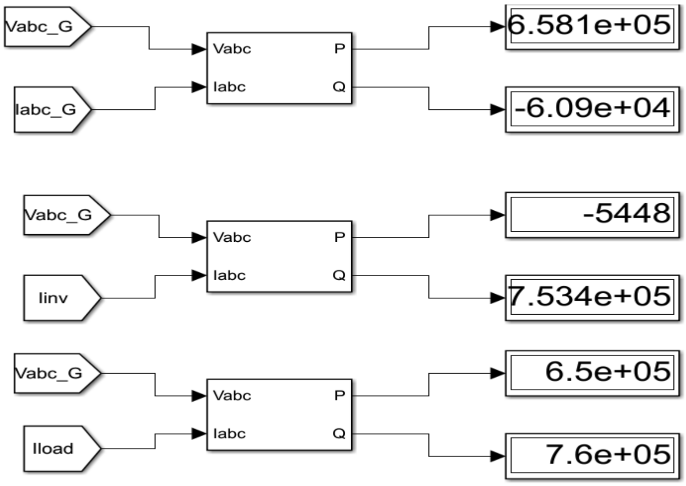


Figure 7. The Active and Reactive Power for the Grid, StatCom and Load.

The power quality is also improved in order to the high power consumed form the load in this case the load power and current should be constant no fluctuation no sag. Figure 8 demonstrate the load results and the inverter current.

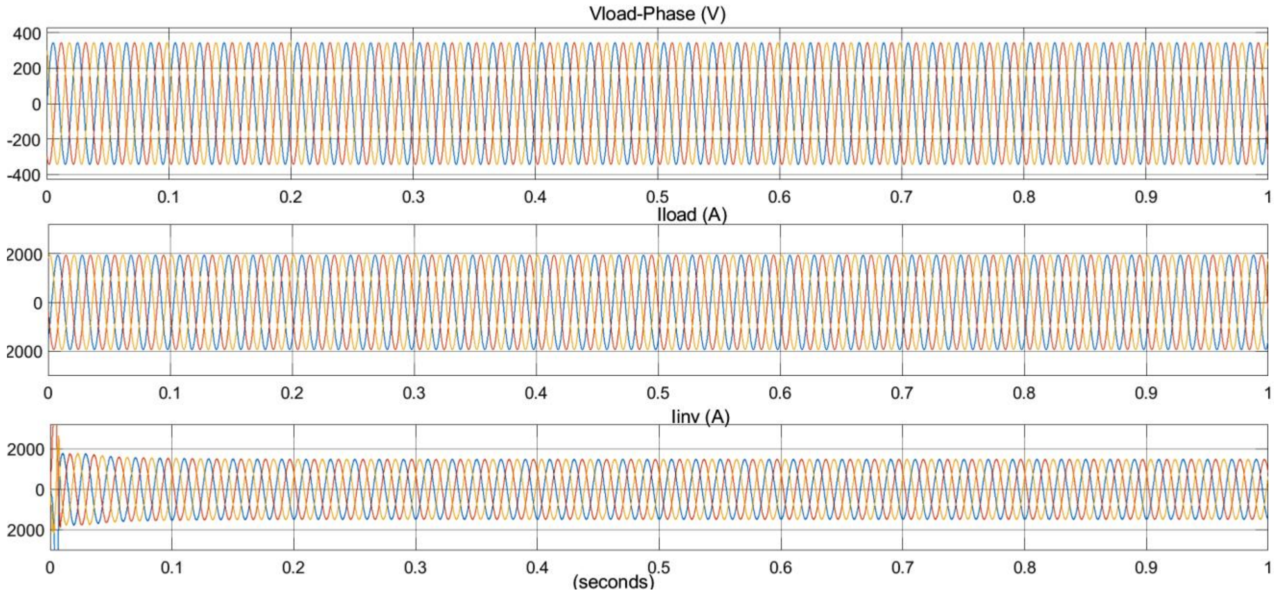


Figure 8. Simulation Results for the Load Voltage, Current and Inverter current.

Figure 9 illustrate the simulation results for the grid phase voltage and current in this case the grid phase voltage is remained constant and the grid current is become less then the value without used Statcom, approximating to 1.2 ×103 (A) peak value compared with the absorbing load current, approximating to 2 ×103 (A) peak value. The difference between these two values is compensate from the Statcom system. Figure 10 is the DC-bus voltage is still constant 800 V according to the reference value.

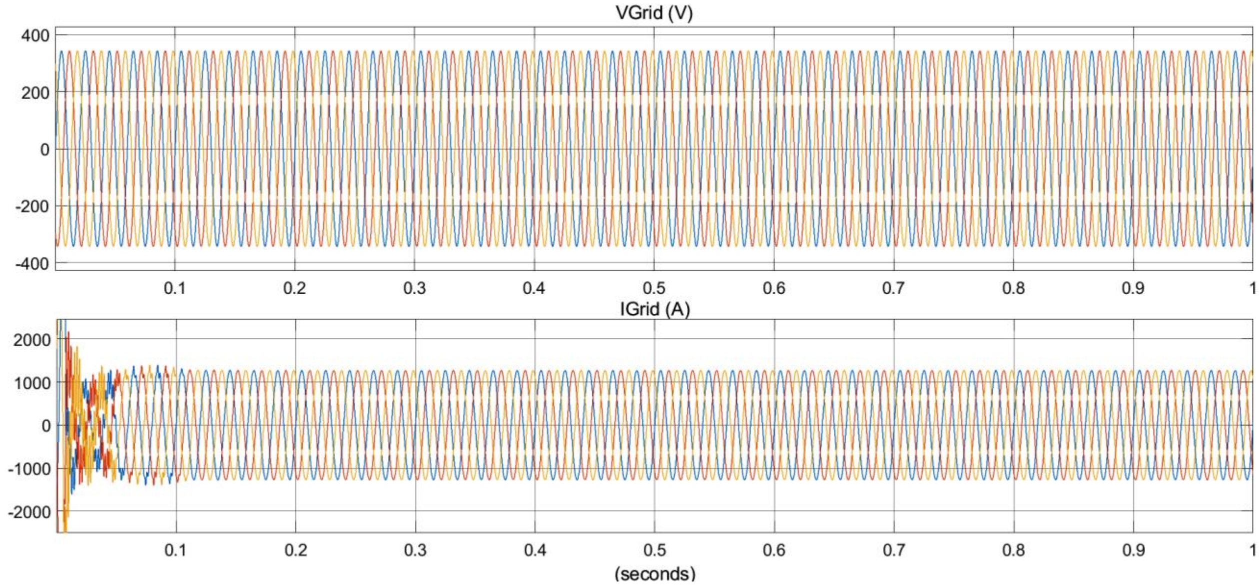


Figure 9. Simulation Results for the Grid Voltage and Current.

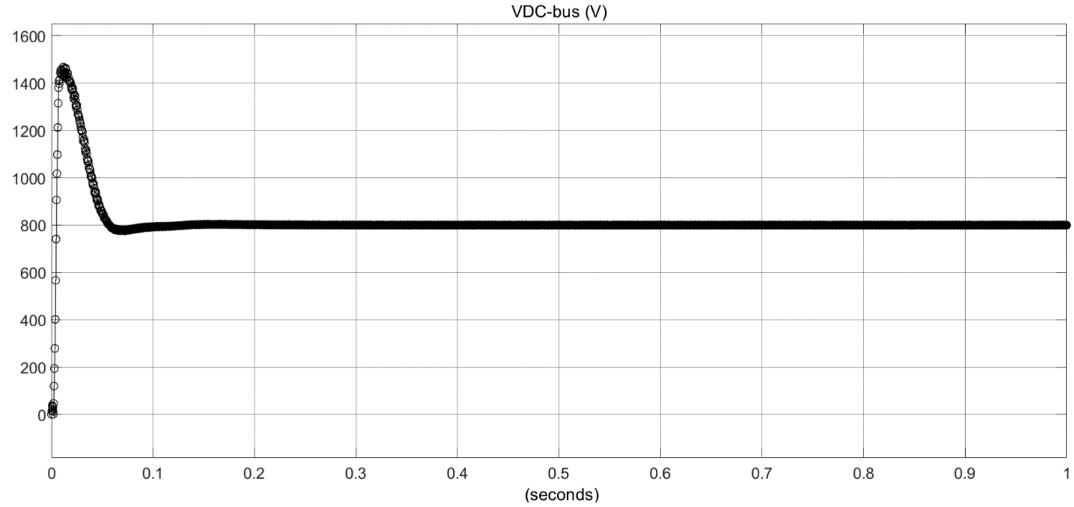
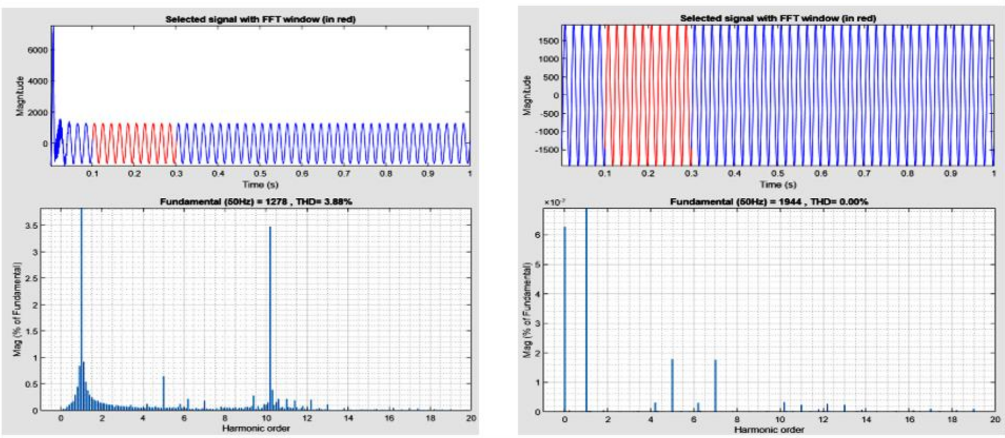


Figure 10. The DC- bus voltage.



(a) **(b)**

Figure 11. The THD Results for the, (a) Grid Current, (b) load Current.

Figure 11 observe the THD factor for the grid and load currents are equal to 3.88% for the grid current and 0.00% for the load current, these values is acceptable with IEEE Std. 519-2014 Harmonic Limits 5% when the voltage less than 1kV.

Nonlinear Load

In this case the load is nonlinear considered by three phase rectifier with RL load. This types of loads are more effect on the ship of the source current, this leads to the emergence of a number of unwanted harmonics, which increase losses and distort the sinusoidal waveform of the current drawn from the source. in order to mitigate the negative effects caused by non-linear loads, STATCOM systems are used to improve the performance of the electrical power system for the previously mentioned distribution model. Their primary role is to reduce the damage caused by harmful harmonics by reducing the operating ratio of the THD.

Figure 12 illustrate the simulation results for nonlinear load, the third figure represent the waveform of the 3-phase line current drown from the PCC by the nonlinear load, this waves appearance irregular and distorted due to the shape of the current drawn by the non-linear load. The second ship related to the grid line current on the PCC point it’s be more improved when it is comparing by the third waveform and the first is the grid voltage is regular and stable.

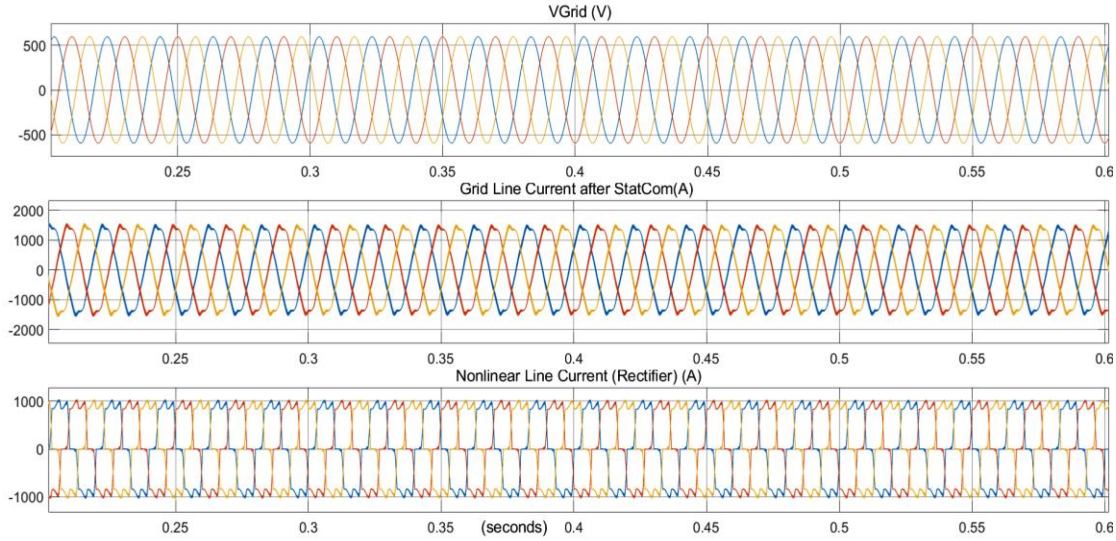


Figure 12. Simulation Results for the Grid Voltage, Grid line Current after StatCom and nonlinear line current.

Figure 13 shows the DC-bus voltage in this case the voltage is stable on the 800 V matching to the reference value and the second and third waveform related to the DC-output of rectifier circuit load these two results is still constant and accordant to the load design.

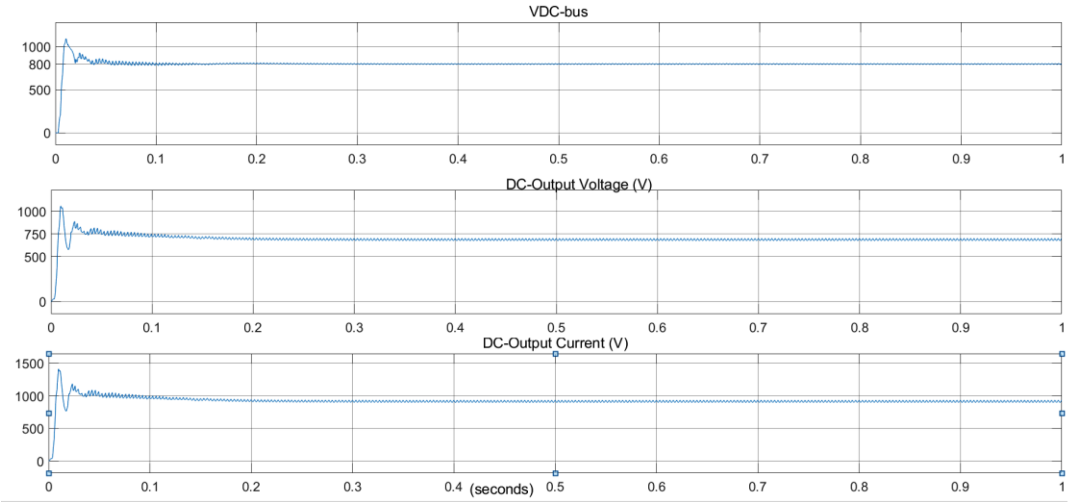
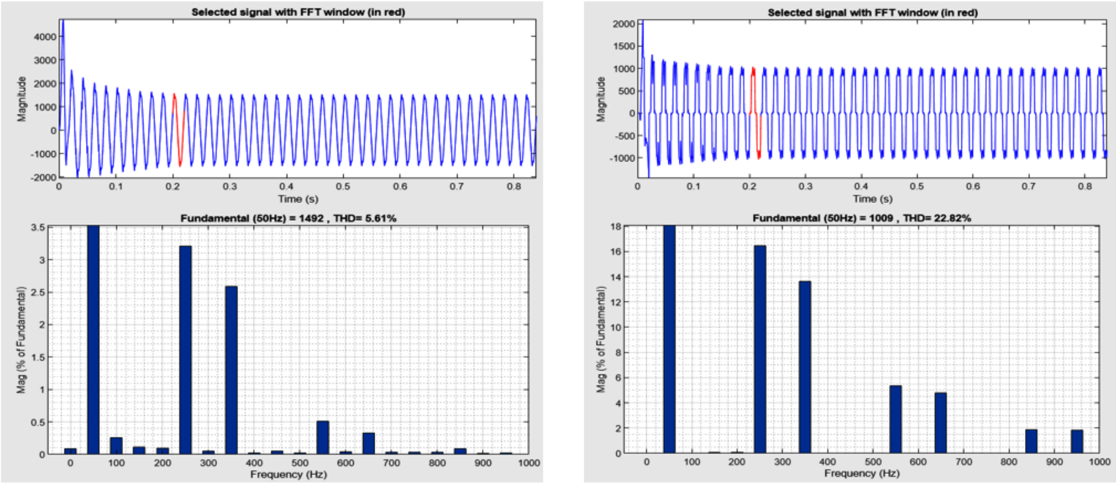


Figure 13. Simulation Results for the DC-bus, DC output voltages and the DC output Current.

Fig 14 observe the simulation result for the THD percentage, for the 3-phase nonlinear load the THD = 22.82% and this value is high and unacceptable, when used Statcom technique the THD is reduce and become 5.6% for the grid line current.



(a) **(b)**

Figure 14. THD results for (a) the Grid Line Current, (b) the nonlinear Line current.

Conclusion

In this Paper, used one of the FACTS technique called STATCOM, which aims to improve the performance of electrical power systems, depending on whether they are working on high-voltage lines or low-voltage distribution systems. This research focused on a low-voltage distribution system with a capacity of 420 volts and of (1 MVA) appearance power. I worked on two types of loads which are considered the most widespread and have the greatest impact on the electrical energy environment, inductive loads and non-linear loads which use rectifiers. In the one case of high inductive loads, the amount of current flowing from the source (Grid) to the load is high, causing significant power losses, in addition, to caused poor in power factor. when combined these effects, leads to a decrease in the electrical network voltage and a loss of the voltage regulation factor. Therefore, STATCOM was used to regulate voltage in power distribution systems by inject the reactive power Q-VAr to compensate the high power consumption, this enhance the power factor, which in turn enhances the performance of the distribution system and increases the efficiency. Thus achieving acceptable power quality. In the second case of nonlinear loads, the effect is primarily on the waveform of the load current. This is due to the effect of rectifiers, which convert the current form from AC to unidirectional DC, and whose components include a DC component that negatively effects on the fundamental component. StatCom systems have been used to mitigate and reduce the negative effects of harmful harmonics that means to reduce the THD factor on the power grid. When THD increase (more than 5%) the iron losses and eddy current losses in the core of transformers and generators are increasing.

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