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Power quality enhacement using Static Synchronous Compensator based on wind turbine hybrid system

BERBAOUI Brahim*, SABA Djamel* , MAOUEDJ Rachid*, DEHINI Rachid**

*Unité de recherche en Energie Renouvelables en milieu saharien, URERMS, Centre de Développement des Energies Renouvelables, CDER, 01000, Adrar, Alegria,
**Department of Electrical Engineering, Bechar University

Abstract
Among the Static Synchronous Compensator (STATCOM) objectives, the correction of power factor, as well as the protection of sensitive loads against voltage swell/sag voltage. The STATCOM acts as a voltage source inverter, which is connected in shunt with a sensitive load and controlled to generate the required compensation reactive power. Only power-factor correction is the concern of this paper, which will mean operating the STATCOM as Var compensation mode. The proposed system is founded by the PLL concept in a wind energy conversion system (WECS). The planned WECS is formed by permanent magnet synchronous generator (PMSG) wind turbine system connected to the grid through Static Synchronous Compensator. The ability of fuzzy logic to handle rough and unpredictable real world data made it suitable for a wide variety of applications, especially, when the models or processes are too complex to be analyzed by classical methods. This paper investigates the application of a fuzzy controller for controlling the DC capacitor voltage under steady and transient condition. Simulations using MATLAB / SIMULINK are carried out to verify the performance of the proposed controller.

I. Introduction

Owing to rapid advances in semiconductor switch technology, high-speed and high-power devices such as MOSFETs, MCTSs, IGBTs, IGCTs, IEGTs, etc. have been developed. These switches have become very practical for the compensation of currents and harmonic voltages, as well as to ensure the stability of the voltage. From a wide range of very flexible controllers, the Flexible AC Transmission System, such as active filters, Unified Power Quality Conditioner (UPQC), Distribution Static Compensator (STATCOM), dynamic voltage restorer (DVR) have been emerging for applications in the distribution network[1,2]. Currently, electrical distribution systems are continually confronted with sudden changes in load [1,2]. When the balance between supply and demand for reactive power is lost, the problem of energy quality occurs at the distribution level. This has a negative impact on the electrical product which, in turn, affects industrial consumers, results from major financial losses and causes a malfunction of equipment that has very sensitive performance [2], and equipment based on electronic devices such as programmable logic controllers, and variable speed drives [2]. The main purpose of the Static Dispenser (STATCOM) is to protect the consumer against power supply voltage drops, overvoltage and ensures a power factor equal to the unit at the distribution point for different loads.

STATCOM is a voltage-source inverter (VSI) controllable, connected in shunt to the distribution network via a coupling transformer. It can exchange reactive power with the distribution system by varying the amplitude and phase angle of an internal voltage source with respect to the voltage at the line terminals resulting in the flow of controlled current through the coupling transformer. It can provide fast and flexible voltage control response to the PCC for improving the electrical power quality at distribution level. The high switching frequency of its inverter power switches, make viable to use PWM in high power applications. The response of a D-STATCOM can be changed from its complete inductive to its full capacitive in a cycle. This speed means that such a device is perfectly adapted to the application of a rapidly varying load [3]

Proper control strategies corresponding to the control objectives are necessary in order to achieve efficient utilization of STATCOM. Most of the controllers used for this device are based on the PI controller [4]. Although the PI controllers are simple and easy to design, their performance deteriorates when the system operating conditions vary widely and large disturbances occur. Unlike the PI controllers, fuzzy logic controllers (FLCs) are capable of tolerating uncertainty and imprecision to a greater extent. So, they produce good results under changing operating conditions and uncertainties in system parameters [4]. During the past few decades, there are many successful applications with Fuzzy Logic Controllers (FLCs) in industry. It has been reported that they are successfully used in a number of complex and non-linear processes [5]. Moreover, the experience has shown that fuzzy controls are often a favored method of designing controllers for dynamic systems even if traditional methods can be used [6].

In this paper, the analysis are focused on the system configuration with a direct coupling between a PMSG wind turbine and a (STATCOMF) employed to inject the wind power into the utility grid under fixed and various wind speed conditions. The proposed design is not only able of delivering the wind power to the grid, but will also act as a voltage source inverter to generate the required compensation reactive power. The fuzzy logic controller (FLC) is proposed for controlling the STATCOM DC capacitor voltage under steady and transient conditions. The STATCOM is operating in Var compensation mode. Simulations using MATLAB/SIMULINK are carried out to verify the performance of the proposed controller. The results show that the proposed controller has fast dynamic response, high accuracy of tracking the DC-voltage reference, and strong robustness to the load change.

II. STATCOM Configuration system

Figure 1 shows the proposed STATCOM system configuration. In its simplest form, The STATCOM consists of a coupling transformer, a voltage-sourced inverter, a control system and a dc capacitor. In this arrangement, the

steady-state power exchange between the device and the ac system is mainly reactive [7]. Regulating the amplitude of the STATCOM output voltage controls the reactive power exchange of the STATCOM with the ac system. If the amplitudes of the STATCOM output voltage and the ac system voltage are equal, the reactive current is zero and the STATCOM does not generate or absorb reactive power. If the amplitude of the STATCOM output voltage is increased above the amplitude of the ac system voltage, the current flows through the transformer reactance from the STATCOM to the ac system, and the device generates reactive power (capacitive). lf the amplitude of the STATCOM output voltage is decreased to a level below that of the ac system, then the current flows from the ac system to the STATCOM, resulting in the device absorbing reactive power (inductive). Since the STA'I'COM is generating or absorbing only reactive power, the output voltage and the ac system voltage are in phase, when neglecting circuit losses. The current drawn from the STATCOM is
90°- shifted with respect to the ac system voltage, and it can be leading (generates reactive power) or lagging (absorbs reactive power). A capacitor is used to maintain dc voltage to the inverter.

The principle of control reactive power via STATCOM is well known that the amount of type (capacitive or inductive) of reactive power exchange between the STATCOM and the system can be adjusted by controlling the magnitude of STATCOM output voltage with respect to that of system voltage. The reactive power supplied by the STATCOM is given by:

$$Q = \frac{V_{stat} - V_s}{x} V_s \qquad (1)$$

Where

Q is the reactive power.

V_{stat} is the magnitude of STATCOM output voltage.

V_s is the magnitude of system voltage.

x is the equivalent impedance between STATCOM and the system

When Q is positive the STATCOM supplies reactive power to the system. Otherwise, the STATCOM absorbs reactive power from the system.

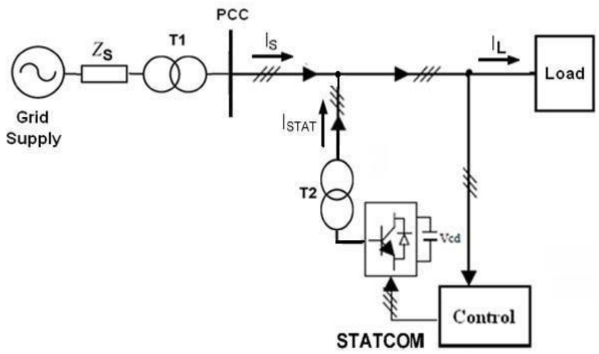


Fig.1 The studied system configuration

III WIND Turbine model

There are many different generator concepts for wind-power applications in use today. The main distinction can be made between fixed-speed and variable-speed wind-generator concepts. A fixed-speed wind-generator is usually equipped with a squirrel-cage induction generator whose speed variations are only very limited. Power can here only be controlled through pitch angle variations.

Because the efficiency of wind-turbines depends on the tip-speed ratio, the power of a fixed-speed wind generator varies directly with the wind speed. In contrast to this, variable speed concepts allow operating the wind turbine at the optimum tip-speed ratio and hence at the optimum power-coefficient for a wide wind speed range. Varying the generator's speed requires frequency converters that increase investment costs *10 - 11]. In most modern designs, a synchronous generator or a permanent magnet generator is used [12]. In this case the total generated power flows through the converter as shown in fig.2.

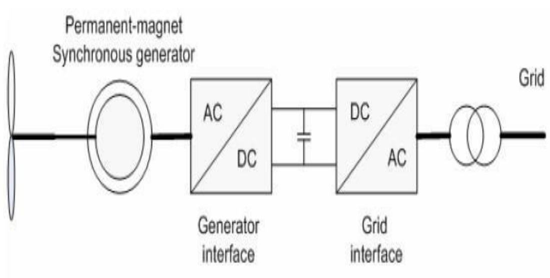


Fig. 2. Permanent magnet synchronous generator based wind turbine

III.Synchronous Reference Frame (SRF) Method

Several control methods involved in generating reference signals have been discussed in literature among them being the Synchronous Reference Frame method. This method is based on the transformation of the currents in a-b-c frame to synchronously rotating d-q-0 frame. Fig. 3 explains the basic building blocks of the method and its implementation in MATLAB/SIMULINK. The abc_to_dq0 Transformation block computes the direct axis, quadratic axis, and zero sequence quantities in a two-axis rotating reference frame for a three-phase sinusoidal signal. The following transformation is used:

$$\begin{cases} i_d = \frac{2}{3}\left(i_a \sin(\omega t) + i_b \sin\left(\omega t - \frac{2\pi}{3}\right) + i_c \sin\left(\omega t + \frac{2\pi}{3}\right)\right) \\ i_q = \frac{2}{3}\left(i_a \cos(\omega t) + i_b \cos\left(\omega t - \frac{2\pi}{3}\right) + i_c \cos\left(\omega t + \frac{2\pi}{3}\right)\right) \\ i_0 = \frac{1}{3}\left(i_a + i_b + i_c\right) \end{cases} \quad (2)$$

Where ω = rotation speed (rad/s) of the rotating frame.

The reference frame is synchronized with the ac currents, and is rotating at the same frequency (ω=2πf). The angle of the transformation is detected by using a phase locked loop (PLL).To return back into a-b-c frame, the following transformation is used:

$$\begin{cases} i_a = i_d \sin(\omega t) + i_q \cos(\omega t) + i_0 \\ i_b = i_d \sin\left(\omega t - \frac{2\pi}{3}\right) + i_q \cos\left(\omega t - \frac{2\pi}{3}\right) + i_0 \\ i_c = i_d \sin\left(\omega t + \frac{2\pi}{3}\right) + i_q \cos\left(\omega t + \frac{2\pi}{3}\right) + i_0 \end{cases} \quad (3)$$

i0 is the zero sequence component which is equal to zero in 3-phase 3-wire balanced system.

One of the most important characteristics of this method is that the reference currents are obtained directly from the loads currents without considering the source voltages. This is an important advantage since the generation of the reference signals is not affected by voltage unbalance or voltage distortion, therefore increasing the compensation robustness and performance.

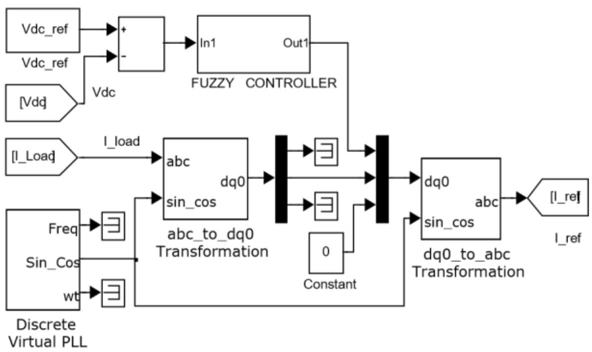


Fig.3 Block diagram of the reference current extraction and Dc-bus voltage regulation through SRF method.

IV. Fuzzy Logic Controller (FLC)

Shunt The disadvantage of PI controller is its inability to react to abrupt changes in the error signal, ε, because it is only capable of determining the instantaneous value of the error signal without considering the change of the rise and fall of the error, which in mathematical terms is the derivative of the error signal, denoted as Δε. To solve this problem, Fuzzy logic control as it is shown in Fig 4 is proposed. The determination of the output control signal, is done in an inference engine with a rule base having if-then rules in the form of

if ε *is......and* $\Delta\varepsilon$ *is.......,then output is.......*

With the rule base, the value of the output is changed according to the value of the error signal ε, and the rateoferror Δε. The structure and determination of the rule base is done using trial-and-error methods and is also done through experimentation.

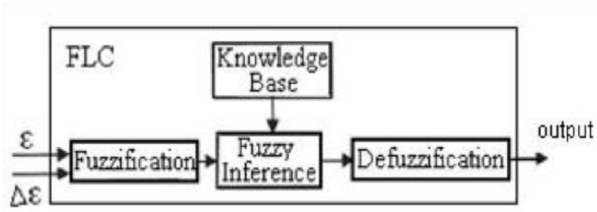


Fig.4 Basic representation of the fuzzy logic controller (FLC)

The MATLAB/SIMULINK implementation of the fuzzy controller for one phase is shown in figure 5.

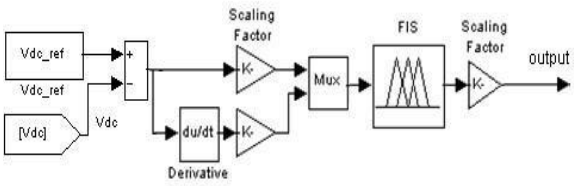


Fig.5 SIMULINK model of the fuzzy logic controller (FLC)

All the variables' fuzzy subsets for the inputs ε and Δε are defined as (NB, NM, NS, Z, PS, PM, PB). Taking into account of the coverage, sensitivity, robustness of universe, the fuzzy subsets of the membership functions use "Z"- shaped membership function in the left, triangular membership function in the middle, and "S"-shaped membership function curve in the right [8]. The membership functions and the universes of the inputs are illustrated in Figure 6. For the output variable, the fuzzy subsets of the membership functions have a triangular shape only as it is illustrated in Figure 7. The fuzzy control rule is illustrated in the tables I.

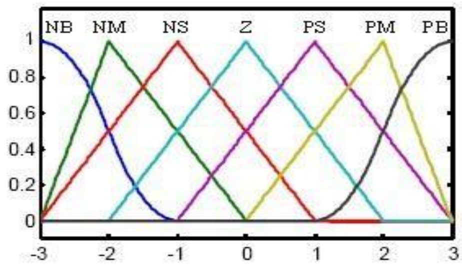


Fig.6 Membership function curves of the inputs ε and Δε

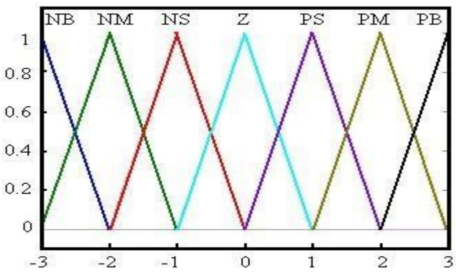


Fig.7 Membership function curves of the output

V. Simulation Results and Discussion

The proposed system configuration of Fig.1 has been simulated by Simulink of Matlab as it is shown in Fig. 8.

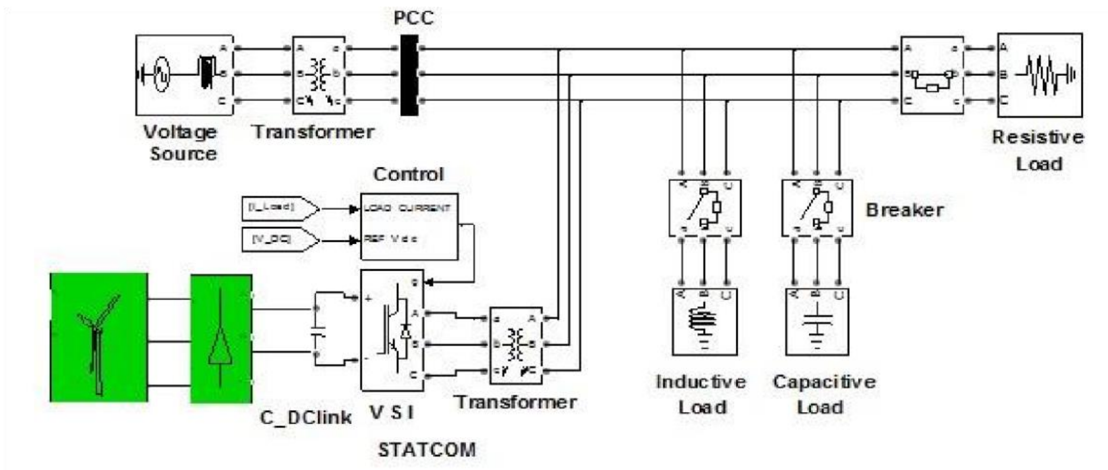


Fig.8 MATLAB/SIMULINK model for the studied system configuration

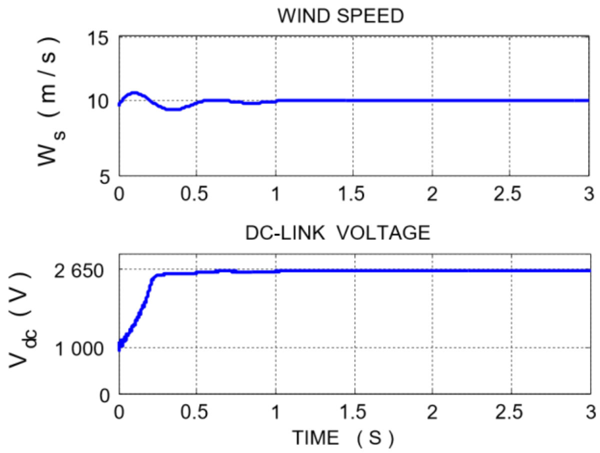
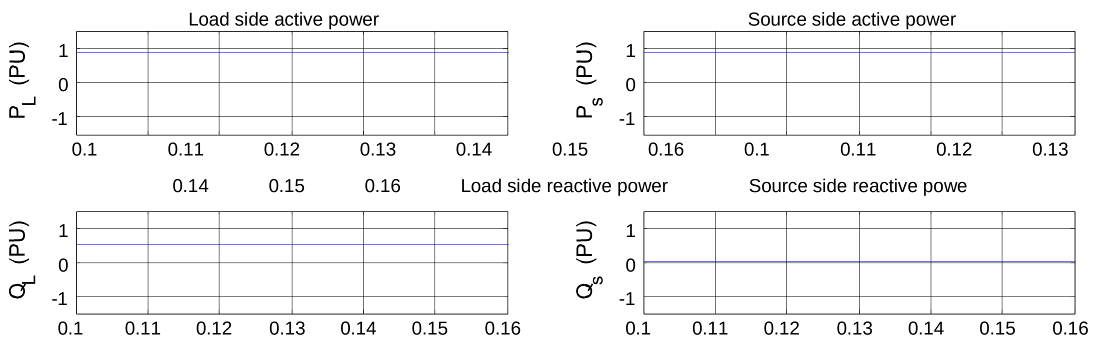


Fig. 9. wind speed and DC-link voltage regulation



Load side current

Source side current

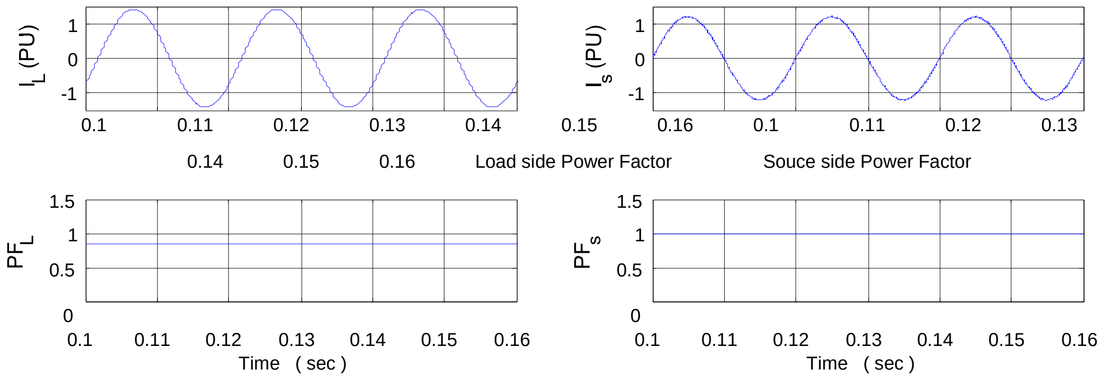


Fig.10 line Current, active power, reactive power and power factor in source and load sides for inductive load for steady state condition.

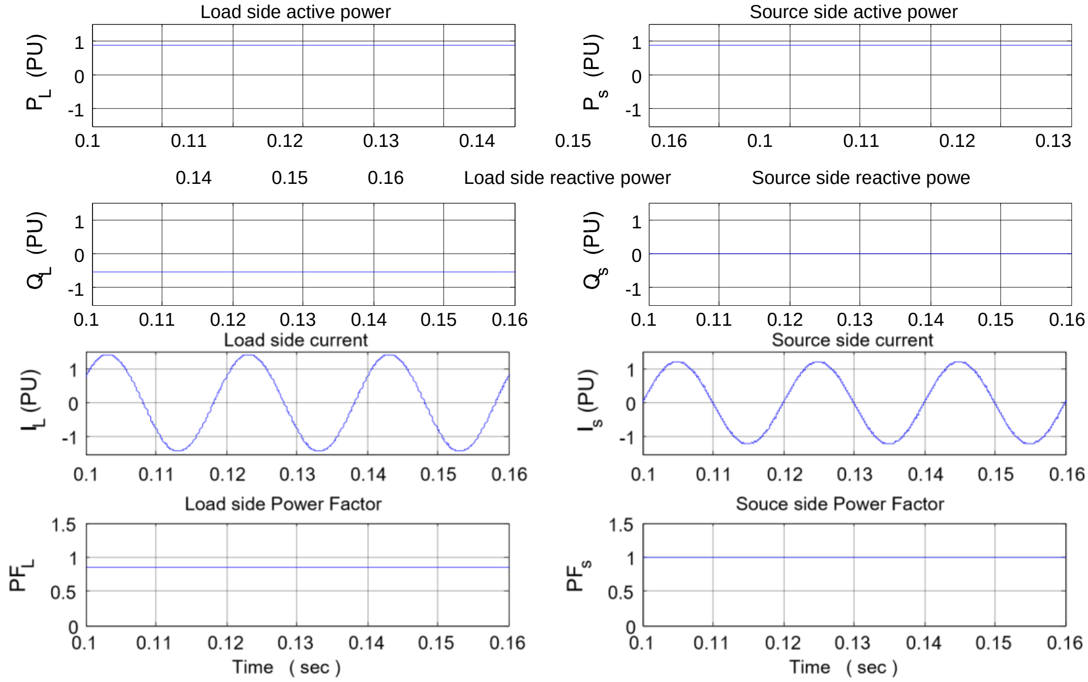


Fig.11 line Current, active power, reactive power and power factor in source and load sides for capacitive load for steady state condition.

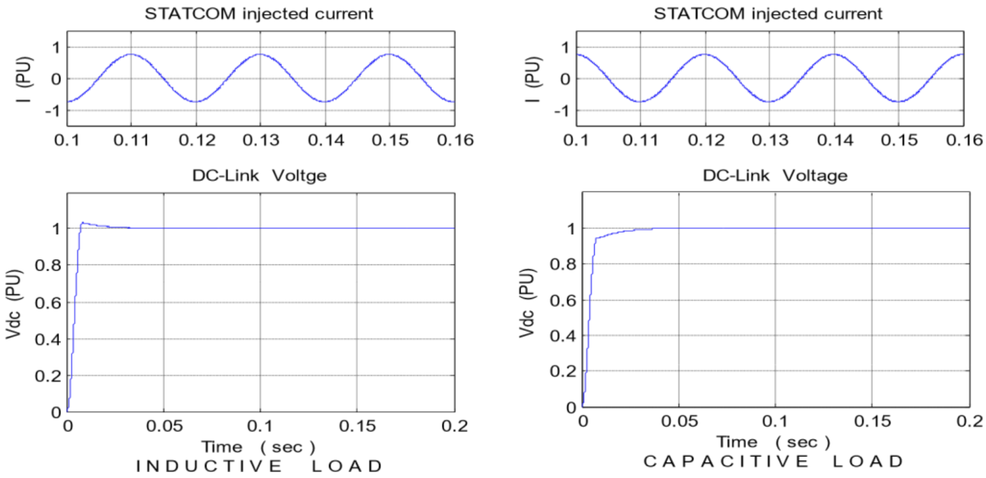


Fig.12 STATCOM injected current and DC_bus voltage regulation for capacitive and inductive load for steady state condition.

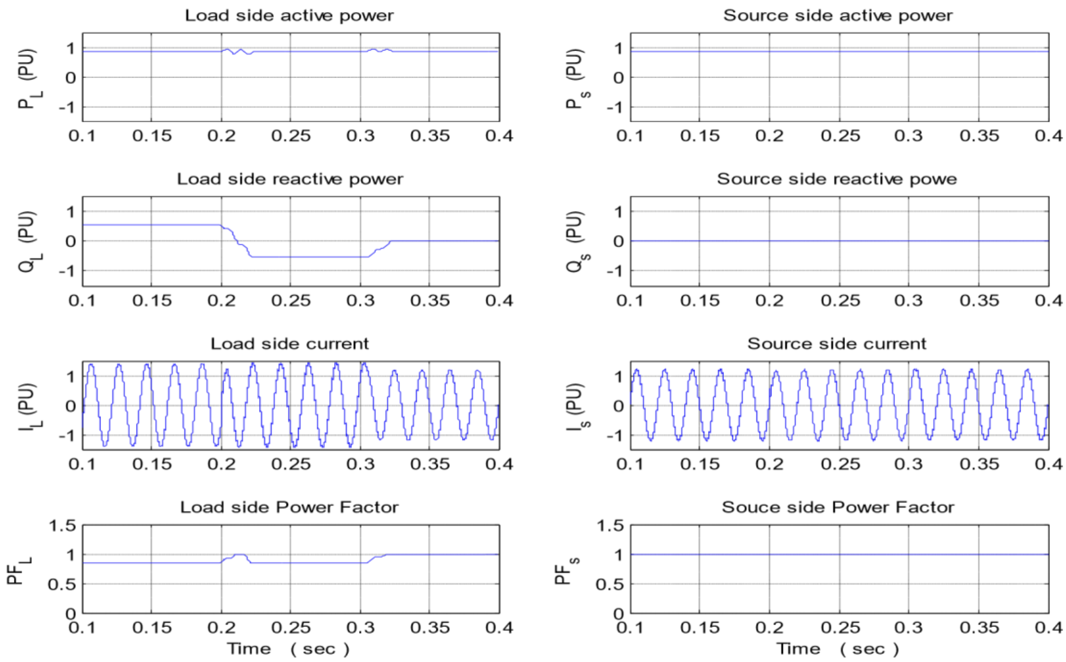


Fig.13 line Current, active power, reactive power and power factor in source and load sides for inductive and capacitive load for transient state condition.

The first task of this simulation is to evaluate the performance of the proposed fuzzy controller in steady state condition. For the sake of simplicity and clarity, only one phase is shown. Figures 10 and 11 show line Current, active power, reactive power and power factor in source and load sides for inductive and capacitive load. Figure 12 shows STATCOM injected current and DC_bus voltage regulation for capacitive and inductive load. From these figures, it is clear that STATCOM has compensated reactive power by injecting the adequate reactive current. For inductive load (Fig.10), a current of amplitude 0.76 pu and phase of -90.08° has been injected to compensate a reactive power of 0.5292 pu which makes the source current passes from 1.42 pu and -32° to 1.20 pu and -0.03° and the power factor from 0.8483 to 1. For capacitive load (Fig. 11), a current of amplitude 0.76 pu and phase of 90.08° (Fig. 13) has been injected to compensate a reactive power of -0.5292 pu which makes the source current passes from 1.42 pu and 32° to 1.20 pu and 0.03° and the power factor from 0.8483 to 1. In these two cases, the regulation of the DC-bus has remained unchanged and stable (Fig. 13).

The second task of this simulation is to evaluate the performance of the proposed fuzzy controller in transient state condition. In this case, the STATCOM is compensating the reactive power at the PCC under sudden load changing condition. Figure 13 shows the dynamic response of the STATCOM when the load changes suddenly from inductive to capacitive then to resistive. The inductive load is switched to capacitive load at t =0.2 sec and then removed at t= 0.3sec to remain only a resistive load. It is clear from Figure 13 that the STATCOM succeeded in compensating the reactive power demand of the load with fast dynamics and with minimum overshoot. Wind power seems to be the favorable clean energy source of the future. So, to optimize its use we have proposed a direct coupling of wind turbine with the Static Synchronous Compensator (STATCOM). From the results obtained, it is proven that by using the proposed PMSG-STATCOM system, wind power can be efficiently extracted by wind turbine and injected into the grid by STATCOM which has two functions; the first is feeding the linear or non linear load with harmonic voltage mitigation capability and second injecting the surplus power into the mains.

VI.Conclusion

The problems of reactive compensation and the power quality appear in power system, when the balance between supply and demand of reactive power is lost. These problems result a large financial losses and cause equipment's disfunction. . The more efficient the controller, the better it can reduce customer losses and the repair and maintenance costs associated with the distribution system. This work is about (FLC) for DCbus voltage controller of a STATCOM. The main purpose of (STATCOM) is to regulate the voltage and correct the power factor at the point of common coupling by injecting reactive into the transmission line for unity power factor. The DCbus voltage is also regulated by using, an appropriate direct component of current. The proposed scheme combined the SRF identification method and FLC. One of the major advantages of this scheme is being less sensitive to the system parameters variation; in addition, it is characterized by a negligible response time. The results of this paper show that the FLC has fast dynamic response, high accuracy of tracking the DC-voltage reference.

Wind power seems to be the favorable clean energy source of the future. So, to optimize its use we have proposed a direct coupling of wind turbine with the Static Synchronous Compensator (STATCOM). From the results obtained, it is proven that by using the proposed PMSG-STATCOM system, wind power can be efficiently extracted by wind turbine and injected into the grid by STATCOM which has two functions; the first is feeding the linear or non linear load with harmonic voltage mitigation capability and second injecting the surplus power into the mains.

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