

## Verification of simulation results by providing wide compensation range and low DC link voltage characteristics using hybrid STATCOM

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### Abstract

In a three phase power transmission system, a hybrid static synchronized compensator (STATCOM) with a broad compensation range and low DC link voltage is proposed in this study. These major properties allow for a significant decrease in system expenses. Comparisons are made between capacitive coupled STATCOM, conventional STATCOM, and hybrid STATCOM. After that, a design for the system parameters is put out that takes into account the reactive power compensation range and steers clear of any potential resonance issues. The functioning of hybrid STATCOM under various voltage and current situations, including unbalanced current, voltage dip, and voltage fault, is then suggested. In order to confirm the wide compensation range, low DC link voltage characteristics, and the excellent dynamic execution of the hybrid STATCOM.

**Keywords:** Capacitive coupled static synchronous compensator (C-STATCOM), Hybrid static synchronous compensator (hybrid-STATCOM), Static synchronous compensator (STATCOM), Insulated Gate Bipolar Transistor (IGBT), Point of Common Coupling (PCC), Voltage Source Converter (VSC)

### Introduction

The majority of electrical equipment could function properly during anticipated departures from the utility's provided nominal voltage and frequency. Many electrical and electronic gadgets that are more sensitive to change in power quality than older equipment has been included into automated operations in the modern industrial facility. The problem with poor power quality is not limited to just energy efficiency and the environment; quality and supply reliability, also known as power quality and supply quality, are increasingly crucial. Electric power quality is a subject of growing concern for both electric utilities and end users. It may also be characterized as the extent to which the usage and supply of electric power impacts the functionality of electrical equipment. A power quality problem is defined as any power problem manifested in voltage, current, or frequency deviations that result in power failure or disoperation of customer or equipment from the perspective of customers. Problems mainly include voltage sag, voltage dip, voltage swell, flicker, harmonics, and power interruption. These power quality problems may cause abnormal operations of facilities or even trip protection devices. Hence, the maintenance and improvement of electric power quality has become an important scenario today. This is a very important reason for interesting in power quality which is the economic value, such that there are economic impacts on utilities, their customers, suppliers and load equipment. Recently there has been a great emphasis on revitalizing industry with more automation and more modern equipment. This usually means electronically controlled, energy efficient equipment that is often much more sensitive to deviations in the supply voltage than were its electromechanical in addition of the electrical disturbances and the resultant financial losses associated with these disturbances. Hence, the interesting in power quality became a very urgent need in modern area.

### SCOPE OF THE PROJECT

In this hybrid Static Synchronous Compensator (STATCOM) is provided to compensate the reactive power for varying the load conditions. Actually the power quality is the quality of the voltage that is being addressed in most cases. Technically, power is the rate of energy delivery and is proportional to the product of the voltage and current. It would be difficult to define the quality of this quantity in any meaningful manner. The power supply system can only control the quality of the voltage; it has no control

over the currents that particular loads might draw. Therefore, it's very useful to study the problems of the voltage quantity as power quality problems. The most power quality problems that always occur at the distribution systems are voltage sag, voltage swell and harmonics. This thesis will concern on these power problems.

**CIRCUIT CONFIGURATION OF PROPOSED METHOD**

The purpose of the Hybrid STATCOM is to provide the same amount of reactive power as the load and it is consumed but with the opposite polarity. The situation can be even worse if such transmission topology change is due to a contingency. Thus, the STATCOM control system may not perform well when mostly needed. Different from these previous works, the motivation of this paper is to propose a control method that can ensure a quick and consistent desired response when the system operation condition varies.

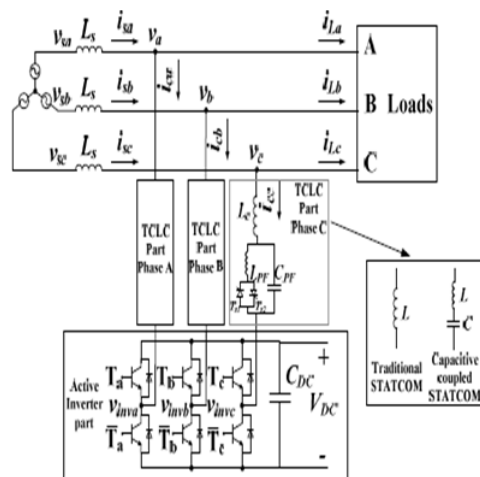


Figure 1: Circuit Diagram

In other words, the change of the external condition will not have a negative impact, such as slower response, overshoot, or even instability to the performance. Base on this fundamental motivation, an adaptive PI control of STATCOM for voltage regulation is presented in this paper. With this adaptive PI control method, the PI control parameters can be self-adjusted automatically and dynamically under different disturbances in a power system given operating point may not be effective at a different operating point.

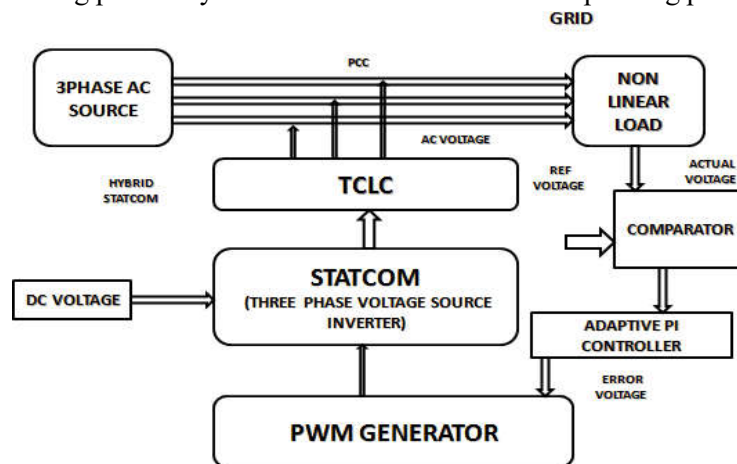


Figure 2. Block diagram of Hybrid STATCOM device

This paper proposes a new control model based on adaptive PI control, which can self-adjust the control gains during a disturbance such that the performance always matches a desired response, regardless of the change of operating condition. Since the adjustment is autonomous, this gives the plug-and-play capability for STATCOM operation. In the simulation test, the adaptive PI control shows consistent excellence under various operating conditions, such as different initial control gains, different load levels, and change of transmission network, consecutive disturbances, and a severe disturbance. In contrast, the conventional

STATCOM control with tuned, fixed PI gains usually perform fine in the original system, but may not perform as efficient as the proposed control method when there is a change of system condition.

### TCLC part control

Different with the traditional SVC control based on the traditional definition of reactive power. It is used to improve the response time. The TCLC part control is based on the instantaneous p-q theory. The TCLC part is mainly used to compensate the reactive current with the controllable TCLC part impedance. The TCLC part impedance can be calculated with ohm's law in terms of the RMS value of the load voltage and the reactive current. It can be calculated in real time. The trigger signals to control the TCLC part can be generated by comparing the firing angle, which is the phase angle of the load voltage. The firing angle of the each phase can differ if the unbalanced loads are proposed control algorithm, the reactive power of each phase is compensated and the active power can be basically balanced, so that DC – link voltage can be maintained at a low level even under unbalanced load compensation.

### Active inverter part control

In this proposed control strategy, the instantaneous active and reactive current id-iq method is implemented for the active inverter part to improve the overall performance of hybrid STATCOM under different voltage and current conditions, such as balanced or unbalanced, voltage dip and voltage fault. Specifically, the active inverter part is used to improve the TCLC part characteristics by limiting the compensating current to its reference value. So that the mistuning problem, the resonance problem and the harmonic injection problem can be avoided.

The reference value contains reactive power, unbalanced power and current harmonic components. By controlling the compensating current to track its reference current. The active inverter part can compensate for the load harmonics current and improve the reactive power compensation ability and dynamic performance of the TCLC part under different voltage conditions.

### CONTROL STRATEGY OF HYBRID-STATCOM

As illustrated in the previous section, the output voltage of Hybrid STATCOM is controlled in such a way that the phase angle between the inverter voltage and the line voltage  $\delta$  is dynamically adjusted so that the Hybrid STATCOM generates or absorbs the desired reactive power at PCC point. Hence, the phase angle control between the voltage of PCC and the source voltage is the main principle of Hybrid STATCOM control. The aim of such control scheme is to maintain constant voltage magnitude at the point of the load under system disturbances figure.3 shows the direct PI control for hybrid STATCOM.

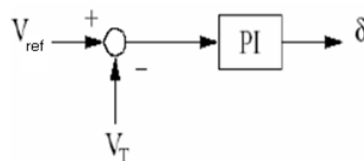


Figure 3. Direct PI control for Hybrid STATCOM

The controller input is an error signal obtained from difference of the reference rms voltage and the rms value of the terminal voltage measured. The controller processes the error signal and generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage. Such error is processed traditionally by a PI controller, or by any other controllers.

STATCOM can provide fast and efficient reactive power support to maintain power system voltage stability. In the literature, various STATCOM control methods have been discussed including many applications of proportional-integral (PI) controllers. However, these previous works obtain the PI gains via a trial-and-error approach or extensive studies with a tradeoff of performance and applicability. Hence, control parameters for the optimal performance at a given operating point may not be effective at a different operating point. This paper proposes a new control model based on adaptive PI control, which can self-adjust the control gains during a disturbance such that the performance always matches a desired response, regardless of the change

of operating condition. Since the adjustment is autonomous, this gives the plug-and-play capability for STATCOM operation.

The voltage regulator block is a outer loop and current regulator block is a inner loop. Both regulators are used to adjust the  $K_p$  and  $K_i$  gain. In the simulation test, the adaptive PI control shows consistent excellence under various operating conditions, such as different initial control gains, different load levels, and change of transmission network, consecutive disturbances, and a severe disturbance. In contrast, the conventional STATCOM control with tuned, fixed PI gains usually perform fine in the original system, but may not perform as efficient as the proposed control method when there is a change of system conditions.

In the past, various control methods have been proposed for STATCOM control. Mainly focus on the control design rather than exploring how to set proportional- integral (PI) control gains. In many STATCOM models, the control logic is implemented with the PI controllers.

The current regulator is used to regulate the current. For this diagram PI controller act as a current regulator. The control parameters or gains play a key factor in STATCOM performance. Presently, few studies have been carried out in the control parameter settings. The PI controller gains are designed in a case-by-case study or trial-and-error approach with tradeoffs in performance and efficiency. Generally speaking, it is not feasible for utility engineers to perform trial-and-error studies to find suitable parameters when a new STATCOM is connected to a system

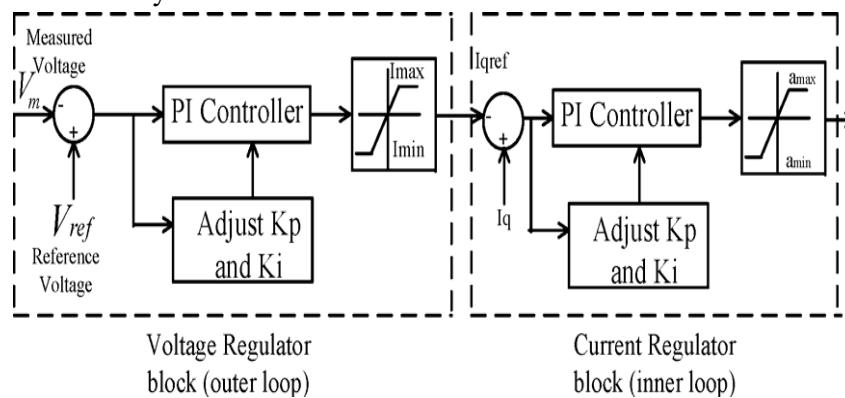


Figure 4. Adaptive PI Controller in Hybrid STATCOM

Further, even if the control gains have been tuned to fit the projected scenarios, performance may be disappointing when a considerable change of the system conditions occurs, such as when a line is upgraded or retires from service. The situation can be even worse if such transmission topology change is due to a contingency. Thus, the STATCOM control system may not perform well when mostly needed. The adaptive PI controller in hybrid STATCOM for current regulator is shown in figure 4.

Different from these previous works, the motivation of this paper is to propose a control method that can ensure a quick and consistent desired response when the system operation condition varies. In other words, the change of the external condition will not have a negative impact, such as slower response, overshoot, or even instability to the performance. Base on this fundamental motivation, an adaptive PI control of STATCOM for voltage regulation is presented in this paper. With this adaptive PI control method, the PI control parameters can be self-adjusted automatically and dynamically under different disturbances in a power system. When a disturbance occurs in the system, the PI control parameters for STATCOM can be computed automatically in every sampling time period and can be adjusted in real time to track the reference voltage

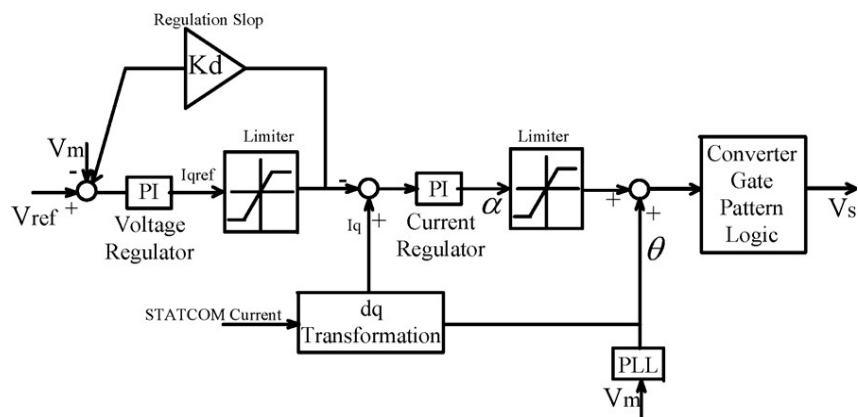


Figure 5. Adaptive PI controller in Hybrid STATCOM for current regulator

Different from other control methods, this method will not be affected by the initial gain settings, changes of system conditions, and the limits of human experience and judgment. This will make the STATCOM a “plug-and-play” device. In addition, this research work demonstrates fast, dynamic performance of the STATCOM in various operating conditions.

The adaptive PI control for STATCOM is compared with the conventional STATCOM control with pretuned fixed PI gains to verify the advantages of the proposed method. The results show that the adaptive PI control gives consistently excellent performance under various operating conditions, such as different initial control gains, different load levels, and change of the transmission network, consecutive disturbances, and a severe disturbance.

In contrast, the conventional STATCOM control with fixed PI gains has acceptable performance in the original system, but may not perform as efficient as the proposed control method when there is a change of system conditions. Future work may lie in the investigation of multiple STATCOMs since the interaction among different STATCOMs may affect each other. Also, the extension to other power system control problems can be explored.

### Hybrid STATCOM Parts

Voltage Source Converter is the core component of the Hybrid STATCOM. Voltage Source Converter is a power electronic device that converts the direct voltage to alternating voltage, and combined by six transistors, usually IGBT or GTO types. Such that the six transistors form a single level converter. A Hybrid STATCOM can be built by single or multilevel VSCs. The converted AC voltage is injected into the power system and introduces a voltage difference between the VSC and the point of connection with the power system. This voltage difference results in proper current that is injected into the power system. Active and reactive power can be injected independently in the power system.

### Energy storage

The purpose of energy storage is to maintain the DC side voltage of VSC. It can be capacitor or DC source, e.g. battery. Traditional STATCOM only has DC capacitor thus, only reactive power can be injected to the power system by STATCOM, whereas both active and reactive power can be injected to the power system by STATCOM if DC source is used.

### Filter

As the Pulse Width Modulation (PWM) technique is used in Voltage Source Converter.

The output voltage of Voltage Source Converter has switching ripple, which bring harmonics into the current injected to the power system. These harmonics will affect the voltage quality of the power system. Therefore, a relatively small reactor is installed between Voltage Source Converter and the point of the system which the Hybrid STATCOM is connected to filter those harmonics in the current. This can be L filter, LC filter and LCL filter.

Additional important part for the Hybrid STATCOM is the controller. The controller executes the calculation of the correct output voltage of Voltage Source Converter, which leads to proper shunt compensation current. The control process affect usually on the trigger pulse.

**SIMULATION RESULT**

Simulation shows the proposed circuit diagram having the input terminal and the components **connections** are given to the output terminals of each and every scope.

Simulation diagram for control scheme

The purpose of energy storage is to maintain the DC side voltage of voltage source converter. The voltage at the point of common coupling with the load and source voltage are equal the reactive power exchange is zero and the STATCOM does not generate and absorb reactive power. When is greater than the hybrid STATCOM shows an inductive terminal connected to its terminal. It is a FACTS device and it is connected in shunt with the FACTS. It works as controllable current source. The shunt capacitive compensation is used to improve the power factor. Whenever an inductive load is connected to the transmission line power factor lags because of lagging load current. To compensate shunt capacitors connected with draws current leading the source voltage.

The reactive power compensation for large industrial load and HVDC transmission line and substation are shown in simulation diagram.

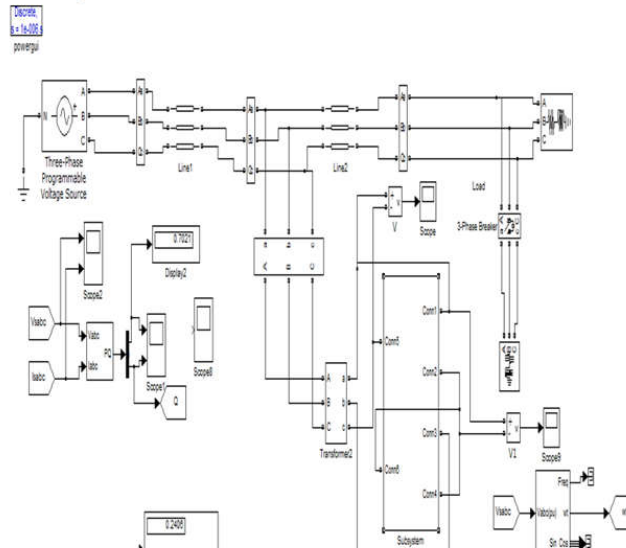


Figure 6. Simulink diagram for reactive power compensation

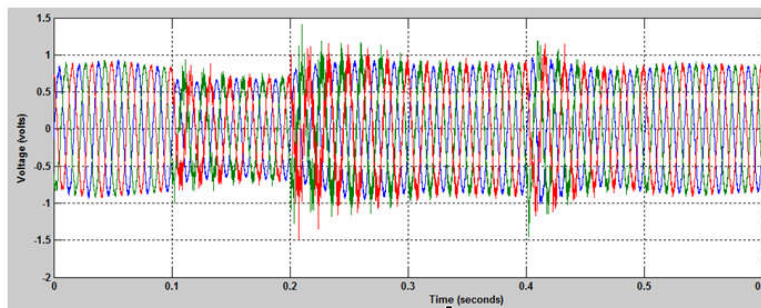


Figure 7: Three phase load voltage

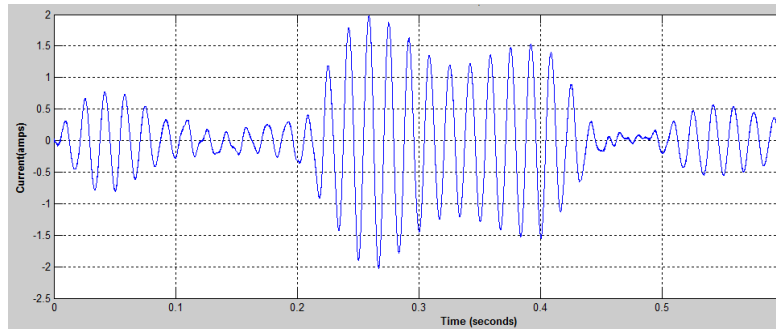


Figure.8: Opposite harmonics injected in pcc

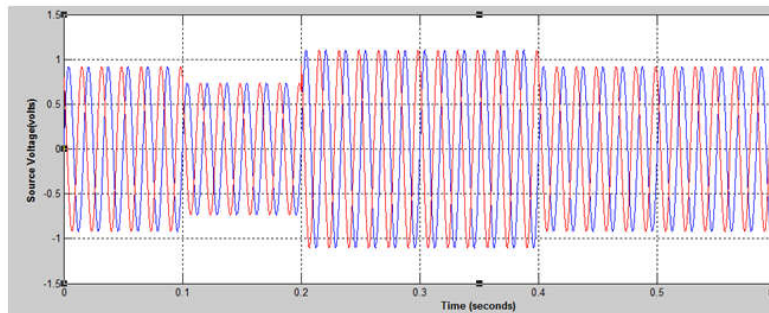


Figure9: Three phase source voltage

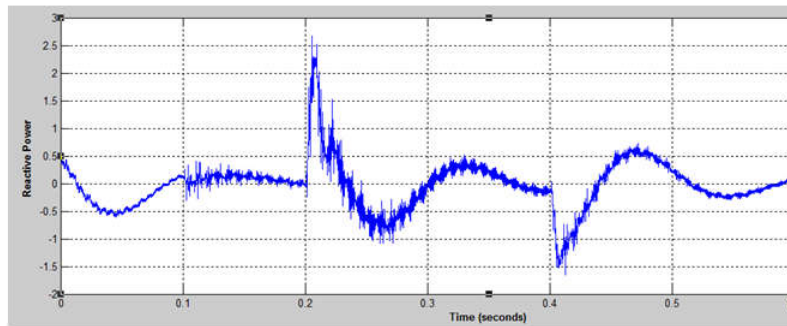


Figure 10: Reactive power Injection

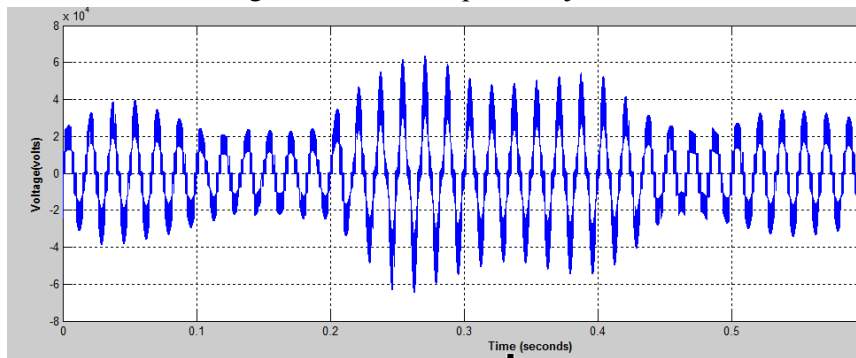


Figure 11:Multi level inverter output voltage

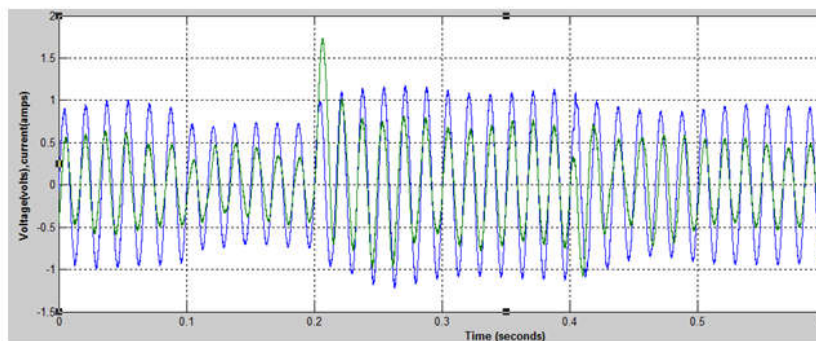


Figure 12: Voltage and current waveform after compensation

## APPLICATIONS

- Reactive power compensation in transmission
- Line current and voltage harmonics mitigation in power transmission line.

## CONCLUSION

To demonstrate the benefits of the suggested approach, the simulation research compares the proposed adaptive PI control for STATCOM with the traditional STATCOM control with pretuned fixed PI gains. The findings demonstrate that the adaptive PI control consistently provides excellent performance under a variety of operating conditions, including varying initial control gains, varying load levels, changing transmission network conditions, multiple consecutive disturbances, and a severe disturbance, and compensating for reactive power.

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