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Self Tuning Pi Controller for STATCOM for Voltage Regulation and Reactive Power Control



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Abstract:

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. 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.

Index Terms:

Adaptive control, plug and play, proportional-integral (PI) control, reactive power compensation, STATCOM, voltage stability.

I. INTRODUCTION:

The present invention generally relates to an adaptive controller for a static compensator (STATCOM) to enhance voltage stability and, more; particularly, to such an adaptive controller which dynamically adjusts proportional and integral parts of the voltage regulator gains and the current regulator gains and to improve STATCOM control in power systems. Voltage stability is a critical consideration in improving the security and reliability, for example, of power systems of public utilities and those power systems used in industry. The Static Compensator (STATCOM), a popular device for reactive power control based on gate turn-off (GTO) thyristors, has attracted much interest in the last decade for improving power system stability. In many STATCOM systems, the control logic is implemented with PI controllers. The control parameters or gains play a key factor in performance.

Presently, few studies have been, carried put on the control parameter settings. In many practices, the, PI controller gains are designed in a case-by-case study or trial-and-error. Approach with tradeoffs if performance and efficiency. Generally speaking, it is hot feasible for utility engineers to perform extensive trial-and-error studies to find suitable parameters for each new STATCOM connection. Further, even if the control gains have been tuned to fit reasonable projected scenarios, performance may disappoint when a considerable change of the system conditions occurs, such as, for example, when a transmission line upgrade cuts layer replacing an old transmission line. The response can be particularly worse if the transmission topology change is due to an unexpected contingency. Thus, the STATCOM control system may not perform well when it is needed most.

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A few, but limited, previous works in the non-patent-literature discuss the STATCOM PI controller gains in order to better enhance voltage stability and to avoid time-consuming tuning. A motivation in the art may be to design a control method that can ensure a quick and desirable response when the system operation condition varies in an expected or even an unexpected manner. The change of the external conditions; should not have; a significant negative impact on the performance. Here the negative impact may refer to slower response, overshoot, or even instability of a power system. Based on this; fundamental motivation, an adaptive control approach for STATCOM to enhance voltage stability is an object of the present invention. The present invention meets the above-identified needs by providing an adaptive control method and apparatus in which the PI control parameters are self-adjusted automatically, given different disturbances in the system. When a disturbance occurs, the PI control parameters can be computed automatically in every sampling time period and adjusted in real time to track the reference voltage.

Hence, the PI control parameters are dynamically and automatically adjusted such that the desired performance can be always achieved. The method, according to one embodiment, will not be: affected by the initial settings and is robust with respect to changes of system conditions. In this way, the STATCOM becomes a “plug and play” device. In addition, an embodiment of the present invention also demonstrates a fast, dynamic performance of STATCOM under widely varying operating conditions. An embodiment of apparatus for adaptive control for a static compensator (STATCOM) for a power system comprises a voltage regulator outer loop and a current regulator inner loop. The voltage regulator outer loop comprises a comparator for initially setting proportional and integral parts of voltage regulator gains and comparing a voltage reference value over time, to a measured bus voltage value.

The outer loop further comprises a proportional integral controller and an ‘adjustment’ circuit, responsive to the comparator, for adjusting the proportional and integral parts of the voltage regulator gain, the adjustment circuit being connected in parallel to the output of the comparator, the adjustment circuit outputting the adjusted parts to the proportional integral controller. The output of the proportional integral controller is q-axis reference current; (or just q reference current for simplicity) value input to a minimum, maximum current limiter circuit.

The current regulator inner loop comprises similar elements as the voltage regulator outer loop where the outer loop comparator compares the q-axis reference current value output of the limiter circuit with a q-axis current (or just q current for simplicity) to adjust phase angle. The DC voltage in the STATCOM is so modified to provide an exact amount of reactive power into the system to keep a bus voltage at a desired value.

II. STATCOM MODEL AND CONTROL:

The equivalent circuit of the STATCOM is shown in Fig. 1. In this power system, the resistance in series with the voltage source inverter represents the sum of the transformer winding resistance losses and the inverter conduction losses. The inductance represents the leakage inductance of the transformer.

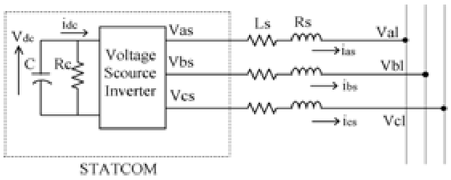

Fig. 1. Equivalent circuit of STATCOM.

Based on the above equations, the traditional control strategy can be obtained, and the STATCOM control block diagram is shown in Fig. 2. As shown in Fig. 2, the phase-locked loop (PLL) provides the basic synchronizing signal which is the reference angle to the measurement system. Measured bus line voltage is compared with the reference voltage, and the voltage regulator provides the required reactive reference current. The droop factor is defined as the allowable voltage error at the rated reactive current flow through the STATCOM. The STATCOM reactive current is compared with, and the output of the current regulator is the angle phase shift of the inverter voltage with regard to the system voltage. The limiter is the limit imposed on the value of control while considering the maximum reactive power capability of the STATCOM.

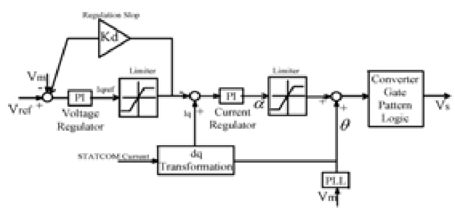

Fig. 2. Traditional STATCOM PI control block diagram.

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III. ADAPTIVE PI CONTROL FOR STATCOM:

The STATCOM with fixed PI control parameters may not reach the desired and acceptable response in the power system when the power system operating condition (e.g., loads or transmissions) changes. An adaptive PI control method is presented in this section in order to obtain the desired response and to avoid performing trial-and-error studies to find suitable parameters for PI controllers when a new STATCOM is installed in a power system. With this adaptive PI control method, the dynamical self-adjustment of PI control parameters can be realized. If one of the maximum or minimum limits is reached, the maximum capability of the STATCOM to inject reactive power has been reached. Certainly, as long as the STATCOM sizing has been appropriately studied during planning stages for inserting the STATCOM into the power system, the STATCOM should not reach its limit unexpectedly. Since the inner loop control is similar to the outer loop control, the mathematical method to automatically adjust PI controller gains in the outer loop is discussed in this section for illustrative purposes. A similar analysis can be applied to the inner loop. An adaptive PI control block for STATCOM is shown in Fig. 3.

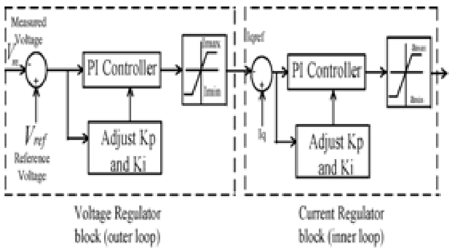

Fig. 3. Adaptive PI control block for STATCOM.

In this system, the discrete-time integrator block in place of the integrator block is used to create a purely discrete system, and the Forward-Euler method is used in the discrete-time integrator block.

IV. SIMULATION RESULTS:

In the system simulation diagram shown in Fig. 4, a 100-MVAR STATCOM is implemented with a 48-pulse VSC and connected to a 500-kV bus. This is the standard sample STATCOM system in Matlab/Simulink library, and all machines used in the simulation are dynamical models. Here, the attention is focused on the STATCOM control performance in bus voltage regulation mode.

In the original model, the compensating reactive power injection and the regulation speed are mainly affected by PI controller parameters in the voltage regulator and the current regulator. The original control will be compared with the proposed adaptive PI control model.

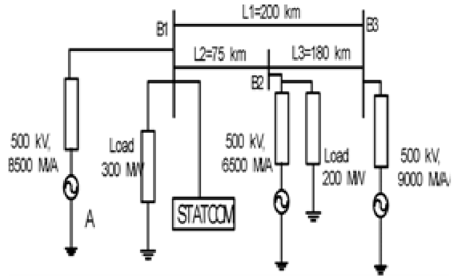

Fig. 4. Studied system.

From the results, it is obvious that the adaptive PI control can achieve quicker response than the original one. The necessary reactive power amount is the same while the adaptive PI approach runs faster, as the voltage does. The results are shown in figs. 5(a), 5(b), 5(c) and 5(d). From the results, it is obvious that the adaptive PI control can achieve quicker response than the original one. The necessary reactive power amount is the same while the adaptive PI approach runs faster, as the voltage does.

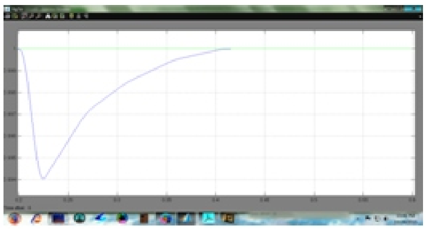

Fig. 5(a) Voltage profile using the Original control

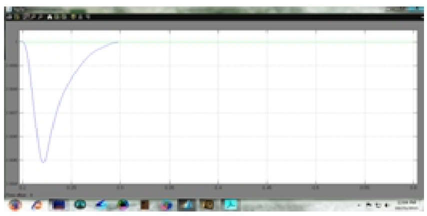

Fig 5(b) Voltage profile using the Adaptive control

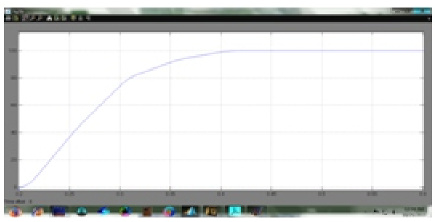

Fig 5(c) output reactive power with Original control

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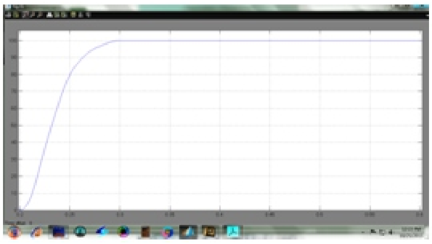

Fig 5(d) output reactive power with Adaptive control

The results are shown in Figs 6(a), 6(b), 6(c) and 6(d). It can be observed that when the PI control gains are changed to different values, the original control model cannot make the bus voltage get back to 1 p.u., and the STATCOM has poor response. The reactive power cannot be increased to a level to meet the need. However with adaptive PI control, the STATCOM can respond to disturbance perfectly as desired and the voltage can get back to 1 p.u. quickly within 0.1s and the reactive power injection cannot be continuously increased in the original control to support voltage, while the adaptive PI control performs as desired.

Fig 6(a) Voltage profile using the Original control

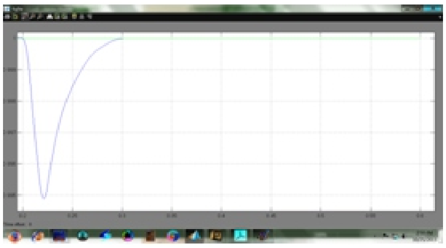

Fig 6(b) Voltage profile using the Adaptive control

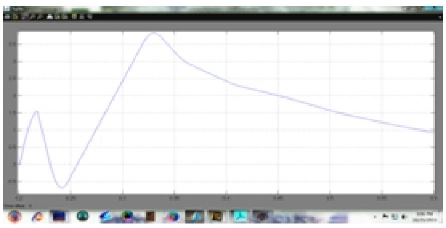

Fig 6(c) output reactive power with Original control

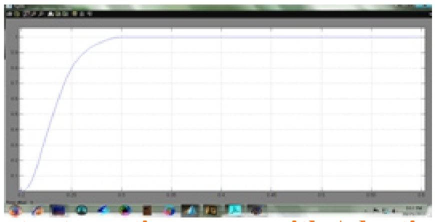

Fig 6(d) output reactive power with Adaptive control

The results are shown in Figs 7(a), 7(b), 7(c) and 7(d).

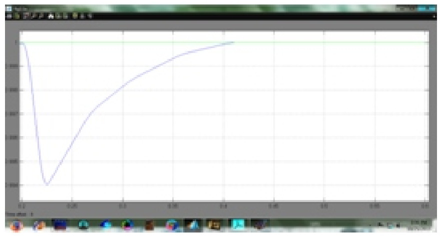

Fig 7(a) Voltage profile using the Original control

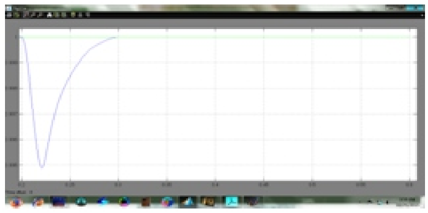

Fig 7(b) Voltage profile using Adaptive control

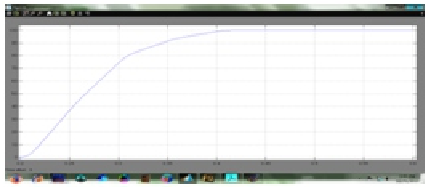

Fig 7(c) output reactive power using Original control

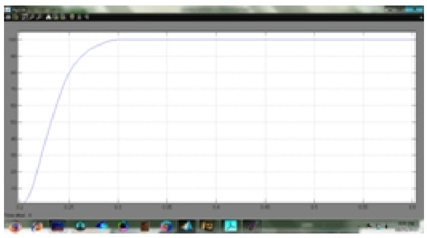

Fig 7(d) output reactive power using Adaptive control

The results are shown in Figs 8(a), 8(b), 8(c) and 8(d). Note that the STATCOM absorbs VAR from the system in this case. Here, the disturbance is assumed to give a voltage rise at (substation A) from 1.0 to 1.01 p.u.; meanwhile, the system has a transmission line removed which tends to lower the voltages.

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The overall impact leads to a voltage rise to higher than 1.0 at the controlled bus in the steady state if the STATCOM is not activated. Thus, the STATCOM needs to absorb VAR in the final steady state to reach 1.0 p.u. voltage at the controlled bus. Also note that the initial transients immediately after 0.2 s lead to an over absorption by the STATCOM, while the adaptive PI control gives a much smoother and quicker response.

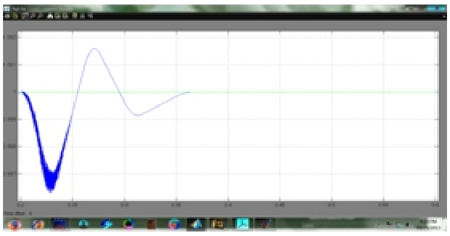

Fig 8(a) Voltage profile using Original control

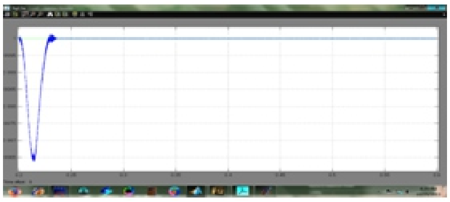

Fig 8(c) Voltage profile using Adaptive control

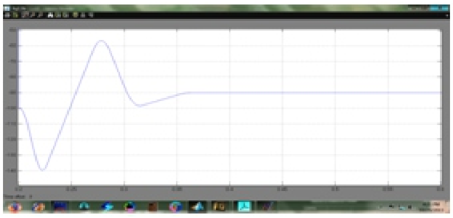

Fig 8(b) output reactive power using Original control

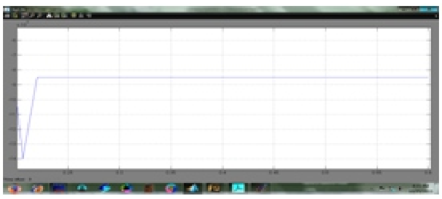

Fig 8(d) output reactive power using Adaptive control

The results are shown in Figs9(a), 9(b), 9(c) and 9(d). It is apparent that the adaptive PI control can achieve much quicker response than the original one, which makes the system voltage drop much less than the original control during the second disturbance.

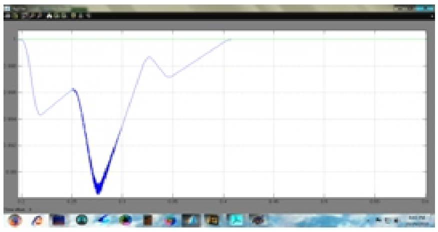

Fig 9(a) voltage profile using Original control

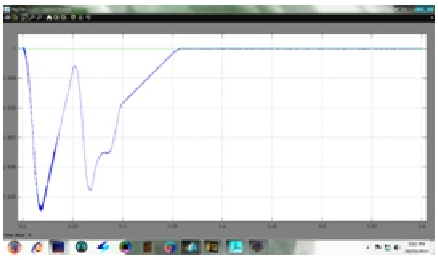

Fig 9(b) voltage profile using Adaptive control

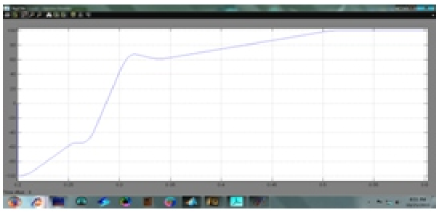

Fig 9(c) output reactive power using original control

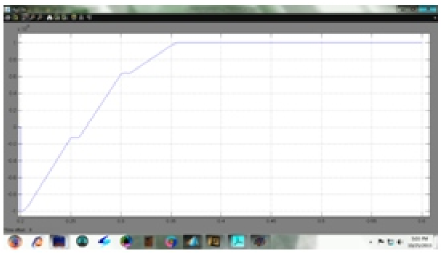

Fig 9(d) Reactive power output using Adaptive control

The results are shown in Figs 10(a)-10(d). Due to the limit of STATCOM capacity, the voltage cannot get back to 1 p.u. after the severe voltage drop to 0.6 p.u. After the disturbance is cleared at 0.25 s, the voltage goes back to around 1.0 p.u. As shown in Fig 6.7(a) and the two insets, the adaptive PI control can bring the voltage back to 1.0 p.u. much quicker and smoother than the original one. More important, the Q curve in the adaptive control (Q_max= 40 MVar) is much less than the Q in the original control (Q_max=118 MVar).

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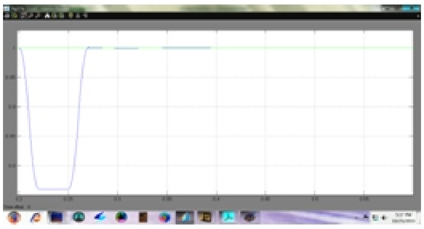
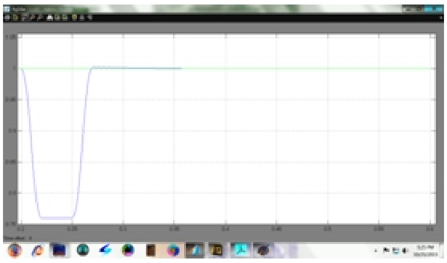
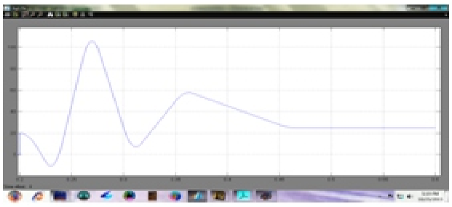


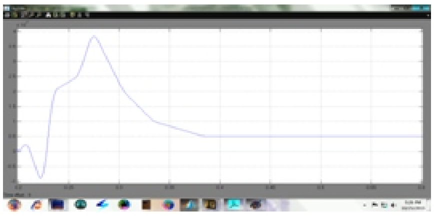
Figs 10(a) Voltage Profile using Original Control



Figs 10(b) Voltage Profile using Adaptive Control



Figs 10(c) Reactive Power using Original Control



Figs 10(d) Reactive Power using Adaptive Control

V. CONCLUSION:

Various STATCOM control methods have been discussed including many applications of 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 always be effective at a different operating point. It proposes a new control model based on adaptive PI control, which can self-adjust the control gains dynamically during disturbances so 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 study, the proposed 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.

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