**Mathematical modelling of Adaptive PI Controller of STATCOM for Voltage Stability**

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***Abstract –*** *In power system, voltage stability is considered as performance measurement parameter. Hence to achieve voltage stability Static Compensator (STATCOM) is used. Last few years STATCOM has been used to enhance the performance of the power system. It can regulate a systems voltage by providing fast and efficient power support. However, previously there are many different STATCOM control systems that have been studied which includes fundamental Proportional Integral (PI) controller. The experimentation approach to obtain the PI gains or studies with trade off of relevance and execution. Hence, the performance at an operating point for some control parameters may vary for same control parameter at different operating point. To improve performance of control system at different operating conditions, this paper proposes the control model which can self-adjust the control gains such that always give desired response during disturbances. Since the changes is self-governing, this gives the attach-and-play capability for STATCOM operation. The simulations results of the adaptive PI control for different operating conditions such as transmission network, load level, control gain, severe and consecutive disturbances shows excellent consistence. The conventional STATCOM perform well for same operating condition, but when it comes for system condition change proposed control method shows upper hand over previous conventional method.*

***Keywords-******Adaptive control, proportional-integral (PI) control, reactive power compensation, STATCOM, voltage stability.***

I **INTRODUCTION**

In power system, voltage stability is considered as performance measurement parameter. Hence to achieve voltage stability Static Compensator (STATCOM) is used. Reactive power exchange between the STATCOM and the transmission line can be controlled by controlling the STATCOM output voltage Vs. The operation and control of the STATCOM have been discussed in [1]–[3]. Previously, different control methods have been discussed for STATCOM control in [2]-[6]. Most of these methods focus on controller design rather than going for setting the PI controller gains. The experimentation approach to obtain the PI gains or studies with tradeoff of relevance and execution is given in [7]-[8]. Hence, the performance at an operating point for some control parameters may vary for same control parameter at different operating point. Performance of STATCOM may be undesirable as operating condition changes.

An adaptive PI control of STATCOM for voltage stability of power system network is presented in this paper. In STATCOM with conventional PI controller, control gains are already fixed. Performance of this STATCOM decreases as operating condition changes. With this adaptive PI control method, the control parameters of PI controller can be self-adjusted automatically under different operating conditions in a power system.

**II STATCOM MODEL AND CONTROL**

The corresponding equivalent circuit of the STATCOM is shown in Fig.1. In this power system, the sum of the transformer winding resistance losses and the inverter conduction losses are given by resistance Rs. Lsis the leakage inductance of the transformer. The sum of the switching losses of the inverter and the power losses in the capacitor are represented by resistance Rc.



Fig. 1. Equivalent circuit of STATCOM.

The three-phase mathematical expressions of the STATCOM can be written in the following form [9], [10]:

By using the transformation, the equations from (1) to (4) can be written as,

Where ids and iqs are the d and q currents respected to ias,ibs,and ics.K is a factor that relates the dc voltage to the peak phase-to-neutral voltage on the ac side; Vdcis the dc-side voltage; α is the phase angle for the STATCOM output voltage leads to the bus voltage; ω is the synchronously rotating angle speed of the voltage vector; Vdl and Vql represent the d and *q* axis voltage corresponding Val, Vbl, and Vcl.Since Vql=0, based on the instantaneous active and reactive power definition, (6) and (7) can be obtained as follows [2],[10].

 (6)

 (7)

Based on the above equations, the traditional control strategy for STATCOM is obtained shown in Fig. 2 [7], [8],[11].



Fig. 2. Block diagram of Traditional STATCOM PI control.

As shown in Fig. 2, the phase-locked loop (PLL) provides the basic synchronizing signal which is the reference angle to the measurement system. In voltage regulator block measured bus line voltage Vmis compared with reference voltage Vref. The voltage regulator provides the required reactive reference current of STATCOM Iqref. Here Kdis defined as the allowable voltage error when rated reactive current flow through the STATCOM[1]. .In current regulator block the STATCOM reactive current Iq and reactive reference current Iqref are compared, and the output of the current regulator is the angle phase shift of the inverter voltage with regard to the system voltage. The limiter represents the limit on the value of control considering the maximum reactive power capability of the STATCOM[2].

# **III ADAPTIVE PI CONTROL FOR STATCOM**

The proposed adaptive PI control method is given in this section so as to obtain desired response at different operating conditions without performing trial-and-error studies to control parameters for PI controllers. With adaptive PI controller the control gains can be self adjusted depending upon the disturbances so that desired response is obtained under different operating conditions.



Fig. 3. Adaptive PI control block for STATCOM

An adaptive PI control block for STATCOM is shown in Fig. 3. the measured voltage Vm(t) and the reference voltage Vref(t), and the *q* -axis reference current Iqref(t) and the *q* -axis current are in per–unit values.

The proportional and integral gains of the voltage regulator block are represented by Kp\_V and Ki\_V respectively. Similarly, the gains Kp\_I and Ki\_I represent the proportional and integral gains of the current regulator block.Fig. 4 shows the reference voltage curve.



Fig. 4. Reference voltage curve

The proposed adaptive PI control method of STATCOM is described as follows.

1. The bus voltage Vm(t) is measured in real time.
2. After measuring the bus voltage Vm(t) over time, the Vm(t) is compared with target steady state voltage Vss. Kp\_V and Ki\_V are automatically adjusted so that measured voltage Vm(t) matches the desired reference voltage curve.The voltage regulator block provides required q-axis reference current Iqref .
3. In current regulator block Iqref and actual q-axis current Iq are compared. Gains Kp\_I and Ki\_I are automatically adjusted based on error similar to voltage regulator block. Desired angle alpha represented by α can be obtained and dc voltage in STATCOM can be adjusted so as inject desired reactive power to maintain bus voltage at required level.

Here Imin and Imax and the angle αmin and αmax gives the limits on maximum reactive support provided by STATCOM.

 By using d-q transformation Vdl(t) and Vql(t) can be obtained.

Reference voltage Vref(t) can be calculated using Vm(t)

 (10)

Here, Vss is target steady state voltage which is set to 1 p.u. and τ = 0.01 s.

Under normal operating condition Vm(t)=1 p.u. and Vref(t)=1p.u. So control gains will not change. Here ∆V(t) is error between Vm(t) and Vref(t).

 ∆V(t)=Vref(t)-Vm(t)

From voltage regulator block at any instant t following equation is obtained.

Here Ts represents the sampling time set to 2.5×10-5 sec.

Resulting expression for the output of the discrete-time integrator block using Forward-Euler method at any instant t is,

Assuming Iqref(t) we can write equation (11) as,

For very short duration of time, we consider

 so equation (13) can be rewritten as

Where,

Based on equation (12) if we find out ideal response ratios of and the required Kp\_V and Ki\_V can be calculated.

Assuming ideal response we have,

Assuming bus voltage will come back to 1 p.u. in 5. Since Iqref(t0)=0 from equation (15) and equation(11) we can write,

Here t0 is the time at which system disturbance occurs.

Considering, We have

Considering, We have

Ratio can be considered as required ideal ratio for finding ideal gains Kp\_V and Ki\_V. so from equation (15) we can write,

Kv is considered as ideal ratio of .

Here ∆Vmax depends upon STATCOM rating.

Using equations (16), (19) and (20) kv can be calculated as shown in equation (21)

From equation (14) we can write,

So Kp\_V and Ki\_V can be calculated from following equations

Therefore from equations (23) and (24) control gains can be adjusted dynamically.

Similarly, for current regulator block PI control gain can be calculated dynamically.

Here, Fig. 5 shows the Flowchart for adaptive PI control method.

**V CONCLUSION**

Measure bus voltage Vm(t)

Vm(t)=Vss  (e.g. 1.0 p.u)

 Yes

 No

Define Vref(t)=Vss-(Vss-Vm(t)) ∆V(t)=Vref(t)-Vm(t)

Adjust Kp\_v(t) and Ki\_v(t)

Obtain Iqref in outer loop

Compare with measured Iq

Adjust Kp\_I(t) and Ki\_I(t)

Adjust α in inner loop

Reactive power from STATCOM will be injected to the system

 Yes

 No

Kp\_v(t) , Ki\_v(t), Kp\_I(t) and Ki\_I(t) keep the same

Continue voltage control ?

 Yes

 No

Fig. 5 shows the Flowchart for adaptive PI control method.

In the simulation, STATCOM with proposed adaptive PI controller is examined under different operating conditions. Results thus obtained are compared with the STATCOM with traditional PI controller. The results shows that the proposed adaptive PI controller gives excellent response under different operating conditions as the control parameters are modified automatically based on the disturbances.

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