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VOLTAGE STABILITY IMPROVED BY AN ADAPTIVE PI CONTROL OF STATCOM

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ABSTRACT

A system voltage instability happens once a disturbance occur within the system and increase in load demand. to beat this drawback inject reactive power in to the system Static synchronous compensator (STATCOM) will give quick and economical reactive power support to take care of grid voltage stability. Standardmanagementler for STATCOM as well as several applications of PI controller get PI gains via a trial-and-error approach provides control parameters for the best performance at a given operative purpose might not be effective at a distinct operative purpose. This project proposes a brand new management model supported adaptive PI management, which might self-adjust the management gains throughout a disturbance. associate degree adaptive managementler provides control parameters for the best performance. below varied operative conditions, like completely different initial management gains, completely different load levels, amendment of transmission network, consecutive disturbances, and a severe disturbance. The projected system is enforced in MATLAB/SIMULINK computer code surroundings

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

INTRODUCTION

Voltage stability may be a vital thought in up the protection and responsibleness of power systems. The static compensator (STATCOM), a well-liked device for reactive power management supported gate turnoff (GTO) thyristors, has gained a lot of interest within the last decade for up installation stability[1]. within the past, varied management ways are planned for STATCOM management. References [2]–[9] principally specialise in the management style instead of exploring a way to set proportional-integral (PI) management gains. In several STATCOM models, the management logic is enforced with the PI controllers. The management parameters or gains play a key consider STATCOM performance. Presently, few studies are disbursed within the management parameter settings. within the [10]-[12] PI controller gains ar designed in an exceedingly independent study or trial-and-error approach with tradeoffs in performance and potency. typically speaking, it\'s not possible for utility engineers to perform trial-and-error studies to seek out appropriate parameters once a brand new STATCOM is connected to a system. Further, although the management gains are tuned to suit the projected situations, performance could also be dissatisfactory once a substantial modification of the system conditions happens, like once a line is upgraded or retires from service[13]-[14].

The case are often even worse if such transmission topology modification is as a result of a contingency. Thus, the STATCOM system might not perform well once principally required. A few, however restricted previous works within the literature mentioned the STATCOM PI controller gains so as to higher enhance voltage stability and to avoid long standardisation. as an example, in [15]-[17] linear best managements supported the linear quadratic regular (LQR) control ar planned. This management depends on the designer’s expertise to get best parameters. In [18] an exceedingly new STATCOM state feedback style is introduced supported a zero set idea. almost like [15]-[17] the ultimate gains of the STATCOM state feedback controller still rely upon the designer’s alternative. In [19]-[21] an exceedingly fuzzy PI management methodology is planned to tune PI controller gains.

However, it is still up to the designer to settle on the particular, settled gains. In [22] the population-based search technique is applied to tune controller gains. However, this methodology typically desires a protracted period of time to calculate the controller gains. A trade off of performance and also the sort of operation conditions still needs to be created throughout the designer’s decision-making method. Thus, extremely economical results might not be forever accomplishable underneath a selected in operation condition. completely different from these previous works, the motivation of this paper is to propose an impact methodology that may guarantee a fast and consistent desired response once the system operation condition varies. In alternative words, the modification of the external condition won't have a negative impact, like slower response, overshoot, or perhaps instability to the performance.

Base on this basic motivation, associate adjustive PI management of STATCOM for voltage regulation is conferred during this paper. With this adjustive PI management methodology, the PI management parameters are often self-adjusted mechanically and dynamically underneath completely different disturbances in an exceedingly installation. once a disturbance happens within the system, the PI management parameters for STATCOM are often computed mechanically in each sampling period of time and may be adjusted in real time to trace the reference voltage. completely different from alternative management ways, this methodology will not be laid low with the initial gain settings, changes of system conditions, and also the limits of human expertise and judgment. this may build the STATCOM a "plug-and-play" device. additionally, this analysis work demonstrates quick, dynamic performance of the STATCOM in varied in operation conditions..

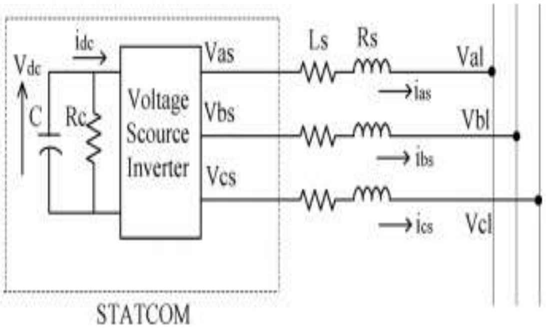


Fig.1. Equivalent circuitofSTATCOM.

STATCOM MODEL AND CONTROL

A. System Configuration

The equivalent circuit of the STATCOM is shown in Fig. 1. during this facility, the resistance R_S in series with the voltage source electrical converter represents the total of the electrical device winding resistance losses and therefore the electrical converter conductivity losses. The inductance LSthe outflow inductance of the electrical device. The resistance R_C in in shunt with the electrical device C represents the total of the switch losses of the electrical converter and therefore the power losses within the electrical device. In Fig. 1, In Fig. 1, V_{as},$V_{bs}$and $V_{cs}$are the three-phase STATCOM output voltages;V_{al} ,$V_{bl}$and V_{cl} are the three phase bus voltages; andi_{as} ,i_{bs} andi_{cs} are the three-phase STATCOM output currents [15],[23]

B. STATCOM Dynamic Model

The three-phase mathematical expressions of the STATCOM can be written in the following

$$L_s \frac{di_{as}}{dt} = -R_s i_{as} + V_{as} - V_{al} \quad (1)$$

$$L_s \frac{di_{bs}}{dt} = -R_s i_{bs} + V_{bs} - V_{bl} \quad (2)$$

$$L_s \frac{di_{cs}}{dt} = -R_s i_{cs} + V_{cs} - V_{cl} \quad (3)$$

$$\frac{d}{dt}\left(\frac{1}{2}CV_{dc}^2(t)\right) = -[V_{as}i_{as} + V_{bs}i_{bs} + V_{cs}i_{cs}] - \frac{V_{dc}^2(t)}{R_c} \quad (4).$$

By using the abc/dq transformation, the equations from (1) to (4) can be rewritten as

$$\frac{d}{dt}\begin{bmatrix} i_{ds} \\ i_{qs} \\ V_{dc} \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \omega & \frac{K}{L_s}\cos\alpha \\ -\omega & -\frac{R_s}{L_s} & \frac{K}{L_s}\sin\alpha \\ -\frac{3K}{2C}\cos\alpha & -\frac{3K}{2C}\sin\alpha & -\frac{1}{R_c C} \end{bmatrix}\begin{bmatrix} i_{ds} \\ i_{qs} \\ V_{dc} \end{bmatrix} - \frac{1}{L_s}\begin{bmatrix} V_{dl} \\ V_{ql} \\ 0 \end{bmatrix} \quad (5)$$

where i_{ds} and i_{qs} are the d and q currents corresponding toi_{as} ,i_{bs} andi_{cs}; K is a factor that relates the dc voltage to the peak phase-to-neutral voltage on the ac side; V_{dc} is the dc-side voltage; is the phase angle at which the STATCOM output voltage leads the bus voltage; ω is the synchronously rotating angle speed of the voltage vector; and $V_{dl}$and V_{ql}represent the d and q axis voltage corresponding to V_{al},$V_{bl}$and V_{cl}.Since V_{ql}=0, based on the instantaneous active and reactive power definition, (6) and (7) can be obtained as follows [23],[24]

$$p_l = \frac{3}{2} V_{dl} i_{ds} \quad (6)$$

$$q_l = \frac{3}{2} V_{dl} i_{qs}. \quad (7)$$

Based on the above equations, the traditional control strategy can be obtained, and the STATCOM control block diagram is shown in Fig.2 [10],[11],[25].

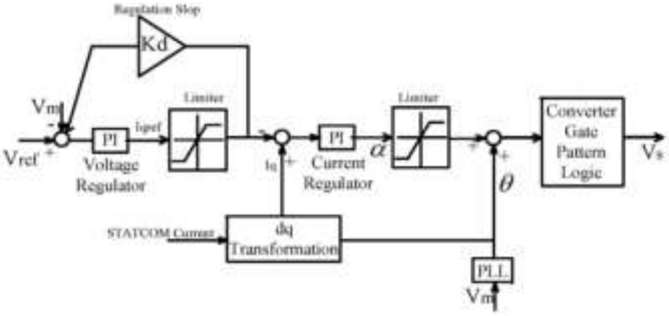


Fig. 2. Traditional STATCOM PI control block diagram.

As shown in Fig. 2, the phase-locked loop (PLL) provides the essential synchronizing signal that is that the reference angle to the measuring system. Measured transit line voltage is compared with the reference voltage , and therefore the transformer provides the specified reactive reference current . The droop issue k_d is outlined because the allowable voltage error at the rated reactive current flow through the STATCOM. The STATCOM reactive current $I_q$is compared withI_{qref},, and therefore the output of the present regulator is that the angle part shift of the electrical converter voltage with relation to the system voltage. The electrical circuit is that the limit obligatory on the worth of management whereas considering the most reactive power capability of the STATCOM.

ADAPTIVE PI CONTROL OF STATCOM

A.Idea of the planned adjustive PI management technique

The STATCOM with mounted PI management parameters might not reach the specified and acceptable response within the facility once the ability system operative condition (e.g., hundreds or transmissions) changes. associateadjustive PI management technique is conferred.

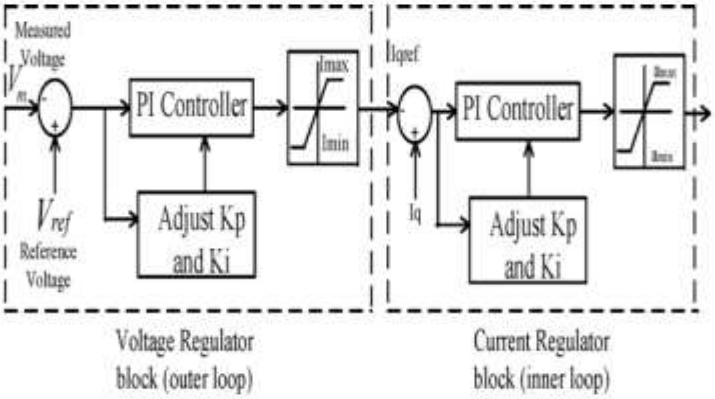


Fig. 3. Adaptive PI control block for STATCOM

during this section so as to get the specified response and to avoid activity trial-and-error studies to search out appropriate parameters for PI controllers once a replacement STATCOM is put in in an exceedingly facility. With this adjustive PI management technique, the propellant self-adjustment of PI management parameters is complete. associateadjustive PI management block for STATCOM is shown in Fig. 3. In Fig. 3, the measured voltage and therefore the reference voltage,and the q-axis reference current and therefore the q-axis current square measure in per–unit values. The proportional and integral components of the transformer gains square measure denoted by $k_{p-v}$and k_{i-v}, severally. Similarly, the gains and represent the proportional and integral components, severally, of the present regulator. during this system, the allowable voltage errork_d is set to zero. The k_{p-v},$k_{i-v,}$$k_{p-i}$and k_{i-i}can be set to associate capricious initial price like merely one.0. One exemplary desired curve is associate graphical record in terms of the voltage growth, shown in Fig. 4, that is ready because the reference voltage within the outer loop. alternative curves may additionally be used than the delineate graphical record as long because the measured voltage returns to the specified steady-state voltage in desired time period. {theprocess|the technique} of the adjustive voltage-control method for STATCOM is represented as follows.

1) The bus voltage $v_m(t)$is measured in real time.

2) Once the measured bus voltage over time , the target steady-state voltage, that is ready to 1.0 per unit (p.u.) within the discussion and examples, $v_m(t)$is compared with v_{nn}. supported the specified reference voltage curve, $k_{p-i}$and $k_{i-i}$are dynamically adjusted so as to create the measured voltage match the specified reference voltage, and therefore the q-axis reference current is obtained.

3) Within the inner loop, I_{qref} is compared with the q-axis current I_q. exploitation the similar management technique just like the one for the outer loop, the parameters $k_{p-i}$and $k_{i-i}$is adjusted supported the error. Then, an appropriate angle is found and eventually the dc voltage in STATCOM is changed specified STATCOMprovides the precise quantity of reactive power injected into the system to stay the bus voltage at the specified price.

It ought to be noted that the present and $I_{max}$and I_{min} the angle $\alpha_{max}$and α_{min}square measure the bounds obligatory with the thought of the most reactive power generation capability of the STATCOM controlled during this manner. If one in every of the most or minimum limits is reached, the most capability of the STATCOM to inject reactive power has been reached. Certainly, as long because the STATCOM size has been befittingly studied throughout designing stages for inserting the STATCOM into the ability system, the STATCOM mustn't reach its limit unexpectedly

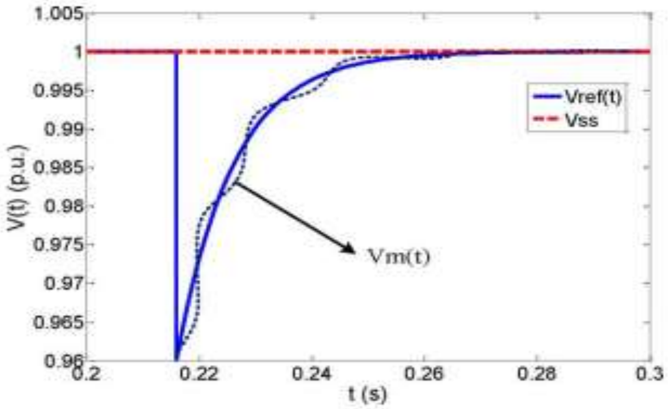


Fig. 4.Reference voltage curve.

B.Derivation of the Key Equations

Since the inner loop management is analogous to the outer loop management, the mathematical technique to mechanically regulate PI controller gains within the outer loop is mentioned during this section for illustrative functions. the same analysis is applied to the inner loop.

Here, $v_{dl}(t)$and $v_{ql}(t)$ can be computed with the d-q transformation

$$\begin{bmatrix} V_{dl}(t) \\ V_{ql}(t) \\ 0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_{al}(t) \\ V_{bl}(t) \\ V_{cl}(t) \end{bmatrix}. \quad (8)$$

Then, we have

$$V_m(t) = \sqrt{V_{dl}^2(t) + V_{ql}^2(t)}. \quad (9)$$

Based on $v_m(t)$, the reference voltage$v_{ref}(t)$, is set as

$$V_{\mathrm{ref}}(t) = V_{ss} - (V_{ss} - V_m(t))e^{-\frac{t}{\tau}}. \quad (10)$$

Based on the adaptive voltage-control model, at any arbitrary time instant t, the following equation can be obtained:

$$\Delta V(t) K_{p\_V}(t) + K_{i\_V}(t) \int_t^{t+T_s} \Delta V(t) dt = I_{qref}(t + T_s) \quad (11)$$

where$T_s$is the sample time, which is set to 2.5×10^{-5}s here as an example.

In this system, the distinct-time measuring device block in situ of the measuring device block is employed to form a strictly discrete system, and therefore the Forward-Euler methodology is employed within the discrete-time measuring device block. Therefore, the ensuing expression for the output of the discrete-time measuring device block at t is

$$y(t) = y(t - T_s) + K_{i\_V}(t - T_s) \times T_s \times \Delta V(t - T_s) \quad (12)$$

Where y(t)=Ki_v(t)$\int_t^{t+T_s} \Delta V(t)dt; y(t - T_s) = K_{i\_}v(t - T_s) \int_{t-T_s}^{t} (t - T_s)dt$

$y(t - T_s) = I_{qref}(t),$

$$\begin{aligned} &\Delta V(t) K_{p\_V}(t) + K_{i\_V}(t) \int_t^{t+T_s} \Delta V(t) dt \\ &- K_{i\_V}(t - T_s) \int_{t-T_s}^{t} \Delta V(t - T_s) dt \\ &= I_{qref}(t + T_s) - I_{qref}(t). \end{aligned} \quad (13)$$

Over a very short time duration , we can consider Ki_v(t)= Ki_v(t-T_s).Hence, (13) can be rewritten as

$$\Delta V(t) K_{p\_V}(t) + K_{i\_V}(t) \int_t^{t+T_s} A dt = I_{qref}(t + T_s) - I_{qref}(t) \quad (14)$$

Where A=ΔV(t)-ΔV(t-Ts).Based on(12),if we can determine in ideal response the ratio (Iqref(t+Ts)- Iqref(t))/(ΔV(t)) and the ideal ratio ($K_{i\_}v(t)$)/($K_{p\_}v(t)$) ,the desired $K_{p\_}v(t)$ and ($K_{i\_}v(t)$) can be solved.

Assume at the ideal response, we have

$$I_{qref}(t + T_s) - I_{qref}(t) = R \times \Delta V(t). \quad (15)$$

Since the system is anticipated to be stable, while not losing generality, we tend to could assume that the bus voltage can come to 1p.u.in 5τ ,where 5τ is that the delay outlined by users as shown in Fig. 4. Since $I_{qref}(t_0) = 0$based on (15), (11) will be rewritten as

$$\Delta V(t_0) K_{p\_V}(t_0) + K_{i\_V}(t_0) \int_{t_0}^{t_0+5\tau} \Delta V(t) dt = R \times \Delta V(t_0) \quad (16)$$

Where to is the time that the system disturbance occurs.Setting Ki_$Iv(t_0^-)$,we then have

$$K_{p\_V}(t_0) = R. \quad (17)$$

Setting $K_{i\_V(t_0^-)} = 0$,we then have

$$K_{i\_V}(t_0) = \frac{\Delta V(t_0) \times R}{\int_{t_0}^{t_0+5\tau} \Delta V(t)dt}. \quad (18)$$

Now, the ratio $m_v - K_{i\_V(t_0)}/K_{p\_V(t_0)}$ can be considered as the ideal ratio of the values of $K_{i\_V(t_0)}$ and $K_{p\_V(t_0)}$ after fault.

Thus, (15) can be rewritten as

$$I_{qref}(t+5\tau) - I_{qref}(t) = k_V \times \Delta V(t_0). \quad (19)$$

Here, kv can be considered as the steady and ideal ratio $\left(I_{ref}(t+T_s) - I_{qref}(t)\right)/(\Delta v(t))$

Based on the system bus capability and therefore the STATCOM rating, Δv_max will be obtained, which implies any voltage amendment larger than Δv_max cannot come to one p.u. Since we\'ve got-1 $\leq I_{qref}(t) \leq 1$, we have the following equation:

$$\frac{\Delta V(t_0)}{\Delta V_{\max}} = k_V \times \frac{\Delta V(t_0) K_{p\_V}(t_0) + K_{i\_V}(t_0) \int_{t_0}^{t_0+5\tau} \Delta V(t)dt}{R}. \quad (20)$$

Based on (16), (19), and (20), kv can be calculated by (21), shown at the bottom of the page.

In order to exactly calculate the PI controller gains based on (14), we can derive

$$k_V = \frac{R \times \Delta V(t_0)}{\left(K_{p\_V}(t_0)\Delta V(t_0) + K_{i\_V}(t_0) \int_{t_0}^{t_0+5\tau} \Delta V(t)dt\right) \times \Delta V_{\max}}. \quad (21)$$

$$\Delta V(t) K_{p\_V}(t) + m_V K_{p\_V}(t) \int_t^{t+T_s} A dt = k_V \times \Delta V(t). \quad (22)$$

Therefore, $K_{p\_V(t)}$ and $K_{i\_V(t)}$ can be computed by the following equations:

$$K_{p\_V}(t) = \frac{k_V \times \Delta V(t)}{\left(\Delta V(t) + m_V \times \int_t^{t+T_s} A dt\right)} \quad (23)$$

$$K_{i\_V}(t) = m_V \times K_{p\_V}(t). \quad (24)$$

Therefore, based on (23) and (24), $K_{p\_V(t)}$ and $K_{i\_V(t)}$ can be adjusted dynamically.

Using a similar process, the following expressions for current regulator PI gains can be obtained:

$$K_{p\_I}(t) = \frac{k_I \times \Delta I_q(t)}{\left(\Delta I_q(t) + m_I \times \int_t^{t+T_s} B dt\right)} \quad (25)$$

$$K_{i\_I}(t) = m_I \times K_{p\_I}(t) \quad (26)$$

Where$\Delta I_q(t)$is the error between I_{qref} and I_q, is that the steady $\left(\alpha(t+T_s - \alpha(t))\right)/\left(\Delta I_q(t)\right)$and ideal quantitative relation ,and is that the angle of the part shift of the electrical converter voltage with relation to the system voltage at time t ;mI is that the ideal quantitative relation of the values of $K_{p\_I(t)}$ and $K_{i\_I(t)}$ after fault; and is equal to $\Delta I_q(t) - \Delta I_q(t - T_s)$.

Note that the derivation from (10)–(26) is absolutely reversible in order that it ensures that the measured voltage curve will follow the specified ideal response, as outlined in (10)

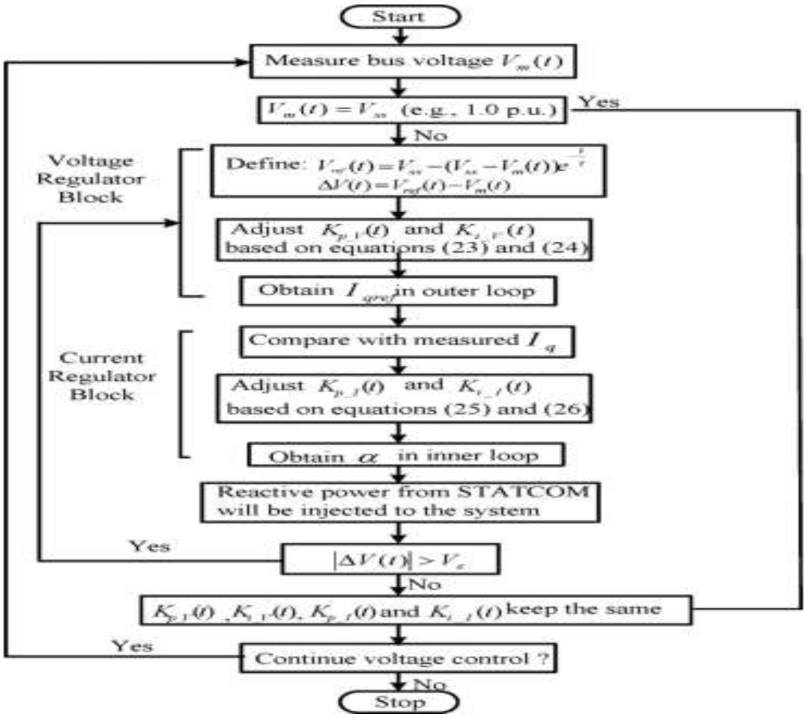


Fig. 5. Adaptive PI control algorithmflowchart

C. Flowcharts of the Adaptive PI Control Procedure

Fig.5 is an exemplary flowchart of the projected accommodative PI management for STATCOM for the diagram of Fig. 3.

1.The accommodative PI management method begins at begin. The bus voltage over time $V_m(t)$ is sampled in line with a desired rate. Then $V_m(t)$ is compared with V_{ss}.If $V_m(t) = V_{ss}$, then there is no reason to alter any of the known parameters $K_{p\_V(t)}$, $K_{i\_V(t)}$, $K_{p_I(t)}$and $K_{i\_I(t)}$.The power system is running swimmingly. On the opposite hand, if $V_m(t) \neq V_{ss}$, then accommodative PI management begins.

2.The measured voltage is compared with V_{ref}, the reference voltage outlined in (10). Then, $K_{p_V(t)}$and area unit adjusted within the transformer block (outer loop) supported (23) and (24), that results in associate updated I_{qref} via a current electrical circuit as showninFig.3

3.Then, the $I_{qref}$is compared with the measured q-currentI_qThe management gains $K_{p_I(t)}$and $K_{i_I(t)}$area unit adjusted supported (25) and (26). Then, the phase α is decided and felt a electrical circuit for output, that basically decides the reactive power output from the STATCOM.

4.Next, if $|\Delta V(t)|$is not at intervals a tolerance threshold V_ϵ, which may be a terribly tiny price like 0.0001 p.u., the transformer block and current regulator blocks area unit re-entered till the amendment is a smaller amount than the given threshold V_ϵ. Thus, the values $K_{p\_V(t)}$, $K_{i\_V(t)}$, $K_{p_I(t)}$and $K_{i_I(t)}$are maintained

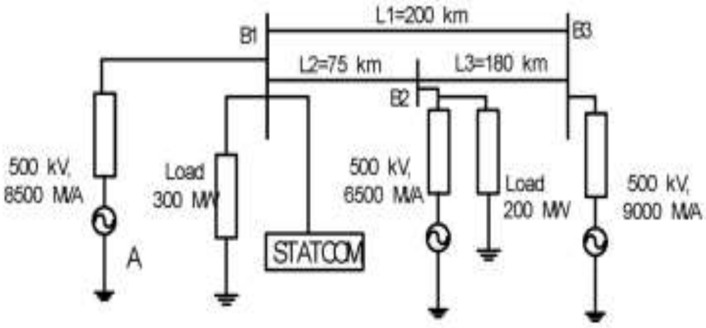


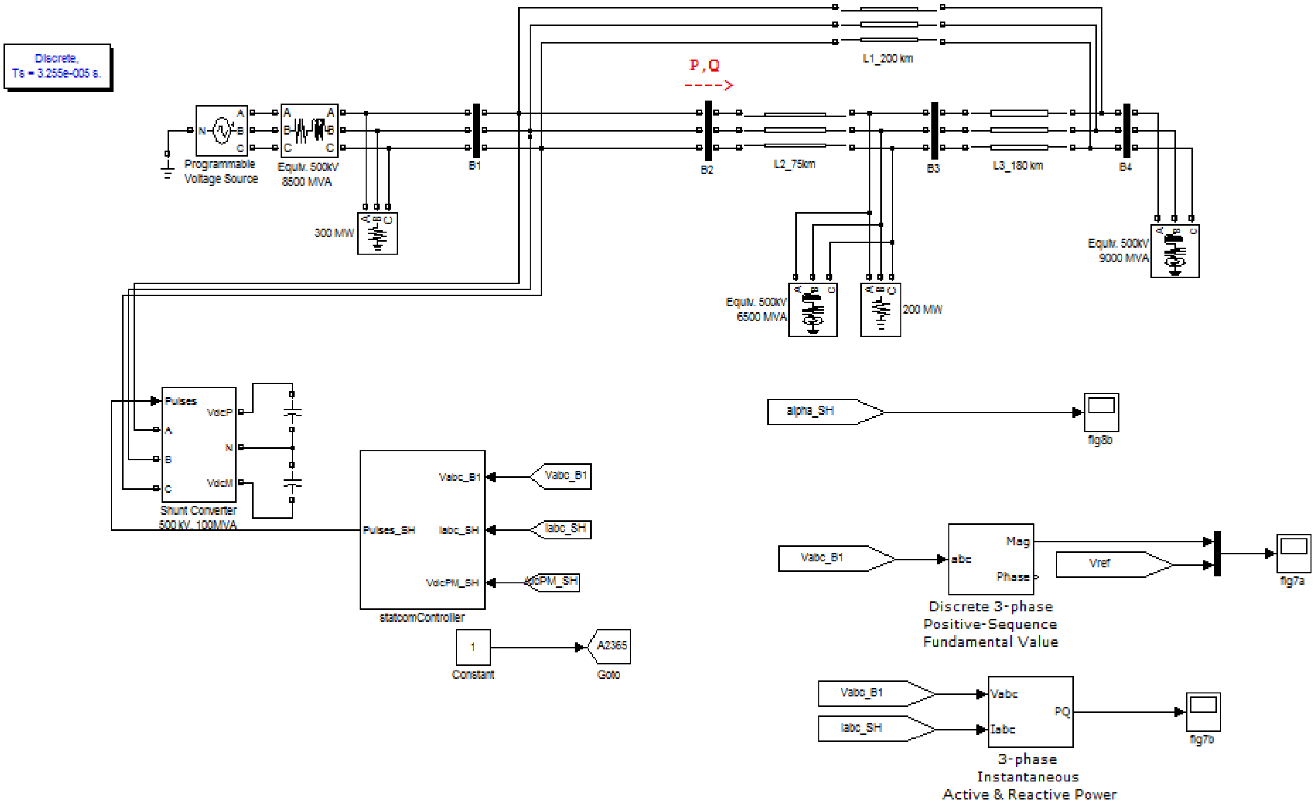
Fig. 6. Studied system

If there is the necessity to unceasingly perform the voltage-control method, that is typically the case, then the method returns to the measured bus voltage. Otherwise, the voltage-control method stops (i.e., the STATCOM management is deactivated).

SIMULATION RESULTS

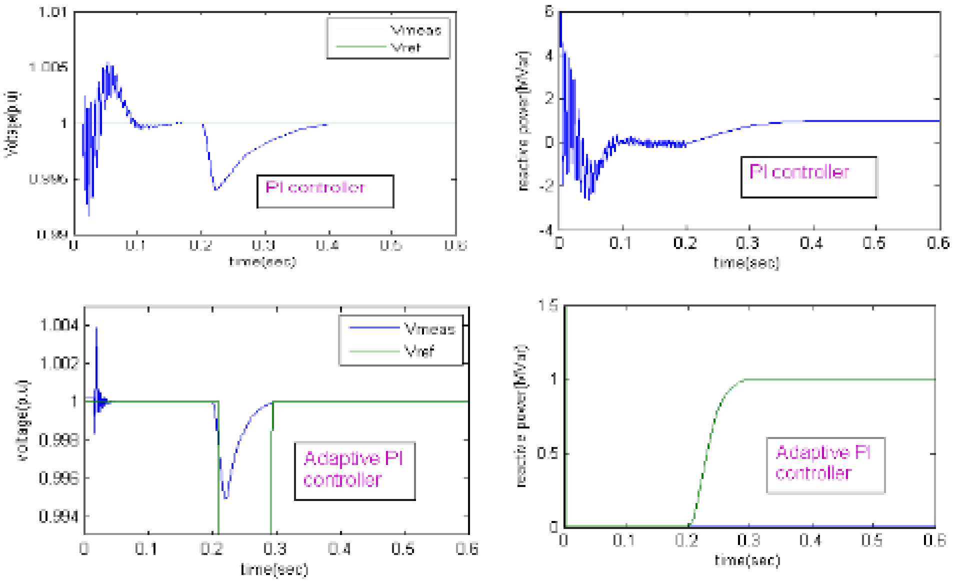
A.System Data

In the system simulation diagram shown in Fig. 6, a 100-MVAR STATCOM is enforced with a 48-pulse VSC and connected to a 500-kV bus. this can be the quality sample STATCOM system in Matlab/Simulink library, and every one machines utilized in the simulation square measure kinetic models. Here, the eye is concentrated on the STATCOM management performance in bus voltage regulation mode. within the original model, the compensating reactive power injection and therefore the regulation speed square measure chiefly suffering from PI controller parameters within the transformer and therefore the current regulator. the first management are compared with the planned adjustive PI management model. Assume the steady-state voltage,v_{ss} =1.0 p.u.



B.Response of the Original Model

In the original model,k_{p-v} =12, k_{i-v} =3000,k_{p-i} =5, k_{i-I} =40. Here, we have a tendency to keep all of the parameters unchanged. The initial voltage supply, shown in Fig. 6, is 1 p.u., with the voltage base being 500 kV. during this case, if we have a tendency to set 1, then we have the initial $m_v$calculated as m_v =770.8780.
Voltage base being 500 kV. In this case, if we set R=1, then we have the initial mV calculated as mV= 770.8780. Since,in this case, $\Delta V(t_o) = \Delta V_{max}$ and k_V =84.7425, based on(23)–(26), we have



(b)

Fig. 7. Results of (a) voltages and (b) output reactive power using the same network and loads as in the original system.

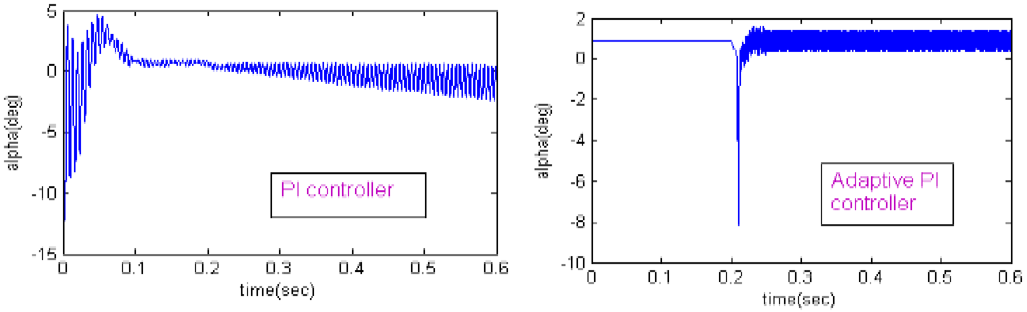


Fig. 8. Results of using the same network and loads as in the original system

$$K_{p\_V}(t)=\frac{84.7425\times\Delta V(t)}{\left(\Delta V(t)+770.8780\times\int_t^{t+T_s}A\,dt\right)} \tag{27}$$

$$K_{i\_V}(t)=770.8480\times K_{p\_V}(t) \tag{28}$$

$$K_{p\_I}(t)=\frac{57.3260\times\Delta I_q(t)}{\left(\Delta I_q(t)+2.3775\times\int_t^{t+T_s}B\,dt\right)} \tag{29}$$

$$K_{i\_I}(t)=2.3775\times K_{p\_I}(t). \tag{30}$$

Based on (27)–(30),theadjustive PI system is designed, and therefore the results square measure shown in Figs. 7 and 8, severally. Observations square measure summarized in Table I. From the results, It is obvious that the adjustive PI management are able to do faster response than the first one. the mandatory reactive power quantity is that the same whereas the adjustive PI approach runs quicker, because the voltage will. Set ωt=α+θ , where α is that the output angle of this regulator, and is that the reference angle to the mensuration system.

In the STATCOM, it is that decides the management signal. Since θ could be a terribly giant worth (varying between 0 to 2Π), the ripples of within the scale shown in Fig.8 will not have an effect on the ultimate simulation results.

Note that there is a awfully slight distinction of 0.12 MVar within the volt-ampere quantity at steady state in Table I, that ought to be caused by process roundoff error. the explanation is that the sensitivity of dVAR/dV is around 100 MVar/0.011 p.u. of voltage. For simplicity, we have a tendency to might assume that sensitivity could be a linear perform. Thus, once the voltage error is 0.00001 p.u., Var is 0.0909 MVar, that is within the same vary because the 0.12-MVar match. Thus, it is affordable to conclude that the slight volt-ampere distinction in Table I is as a result of spherical Δvar⁄Δvoff error within the dynamic simulation that perpetually offers small ripples on the far side fifth digits even within the final steadystate

C. Amendment of PI management Gains

During this state of affairs, the opposite system parameters stay unchanged whereas the PI managementler gains for the first control square measure modified to k_{p-v},$k_{i-v,}$$k_{p-i}$and $k_{i-i} = 1$. The dynamic management gains, that square measure freelance of the initial values before the disturbance however rely upon the post fault conditions, square measure given as

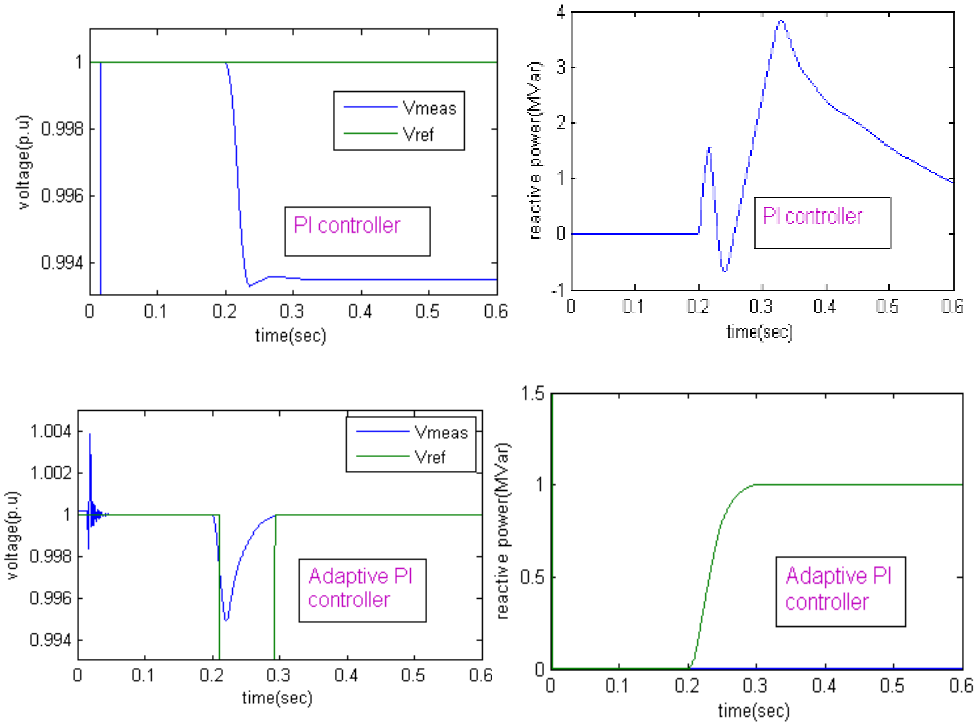
$$K_{p\_V}(t) = \frac{80.1632 \times \Delta\mathrm{V}(t)}{\left(\Delta\mathrm{V}(t) + 732.3115 \times \int_t^{t+T_s} \mathrm{A}dt\right)} \tag{31}$$

$$K_{i\_V}(t) = 732.3115 \times K_{p\_V}(t) \tag{32}$$

$$K_{p\_I}(t) = \frac{47.4959 \times \Delta\mathrm{I}_q(t)}{\left(\Delta\mathrm{I}_q(t) + 1.8232 \times \int_t^{t+T_s} \mathrm{B}dt\right)} \tag{33}$$

$$K_{i\_I}(t) = 1.8232 \times K_{p\_I}(t). \tag{34}$$

supported (31)–(34), the adjustive PI management model is designed, and therefore the results square measure shown in Figs. 9 and 10, severally. From Fig. 9(a), it is discovered that once the PI management gains square measure modified to completely different values, the first management model cannot create the bus voltage come back to to 1 p.u., and therefore the STATCOM has poor response. The reactive power cannot be multiplied to tier to satisfy the necessity. However, with adjustive PI management, the STATCOM will answer disturbance absolutely as desired, and therefore the voltage will come back to to 1 p.u. quickly at intervals 0.1 s. Fig. 9(b) conjointly shows that the reactive power injection cannot be endlessly multiplied within the original management to support voltage, whereas the adjustive PI management performs as desired.



. (a) (b)

Fig. 9. Results of (a) voltages and (b) output reactive power with changed PI control gains.

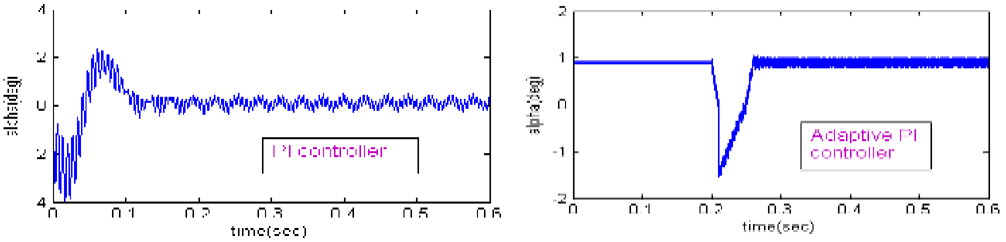


Fig. 10. Results of α with changed PI control gains

D. Amendment of Load

In this case, the original PI controller gains are kept, which means k_{p-v},=12,$k_{i-v,} = 3000$ $k_{p-i} = 5$and k_{i-i} =40.However, the load at Bus B1 changes from 300 to 400 MW. during this case, we will have the given dynamic management gains by

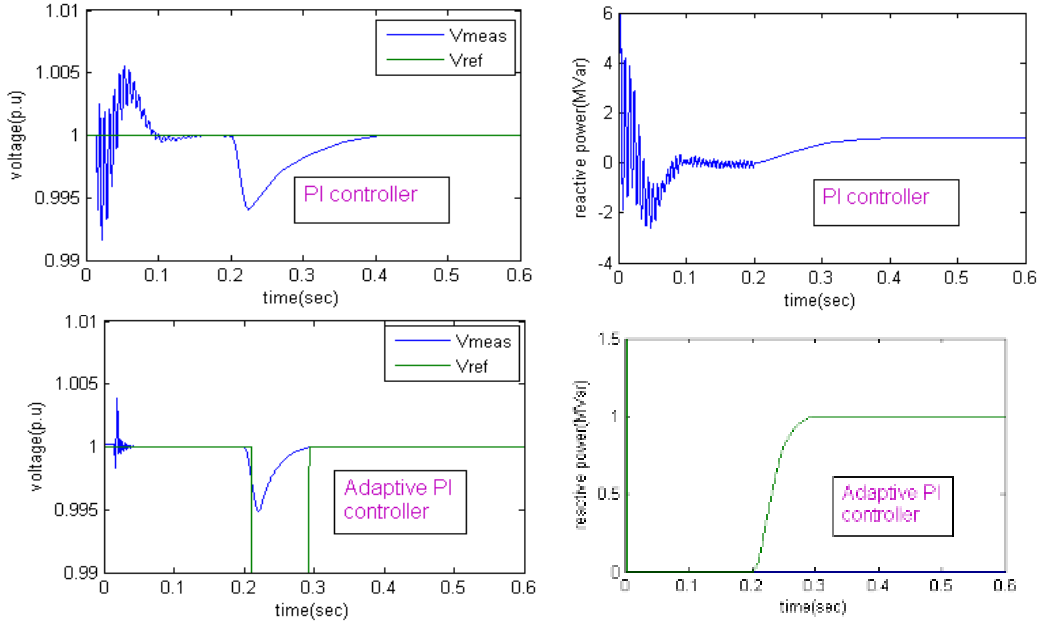
$$K_{p\_V}(t) = \frac{93.3890 \times \Delta V(t)}{\left(\Delta V(t) + 187.5579 \times \int_t^{t+T_s} A dt\right)} \quad (35)$$

$$K_{i\_V}(t) = 187.5579 \times K_{p\_V}(t) \quad (36)$$

$$K_{p\_I}(t) = \frac{8.1731 \times \Delta I_q(t)}{\left(\Delta I_q(t) + 13.1652 \times \int_t^{t+T_s} B dt\right)} \quad (37)$$

$$K_{i\_I}(t) = 13.1652 \times K_{p\_I}(t). \quad (38)$$

Based on (35)–(38), the adjustive PI management model is designed for automatic reaction to a amendment in hundreds. The results square measure shown in Figs. 11 and 12. Table II shows some key observations of the performance.



(b)

Fig. 11. Results of (a) voltages and (b) output reactive power with a change of load.

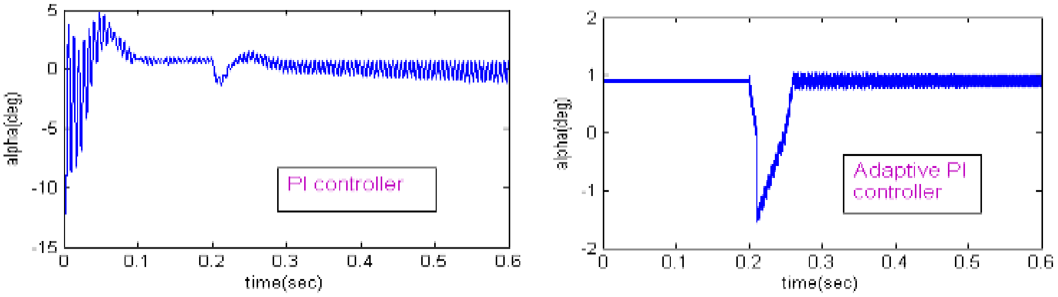


Fig. 12. Results of α with a change of load.

E. Amendment of Transmission Network

During this case, the PI controller gains stay unchanged, as within the original model. However, line one is shifted at 0.2 s to represent a unique network which might correspond to regular transmission maintenance. Here, we have

$$K_{p\_V}(t) = \frac{18.3245 \times \Delta V(t)}{\left(\Delta V(t) + 286.9512 \times \int_t^{t+T_s} A dt\right)} \quad (39)$$

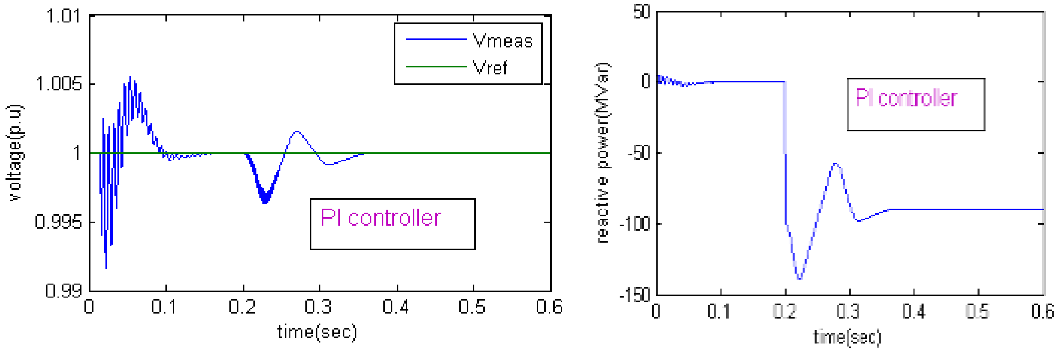
$$K_{i\_V}(t) = 286.9512 \times K_{p\_V}(t) \quad (40)$$

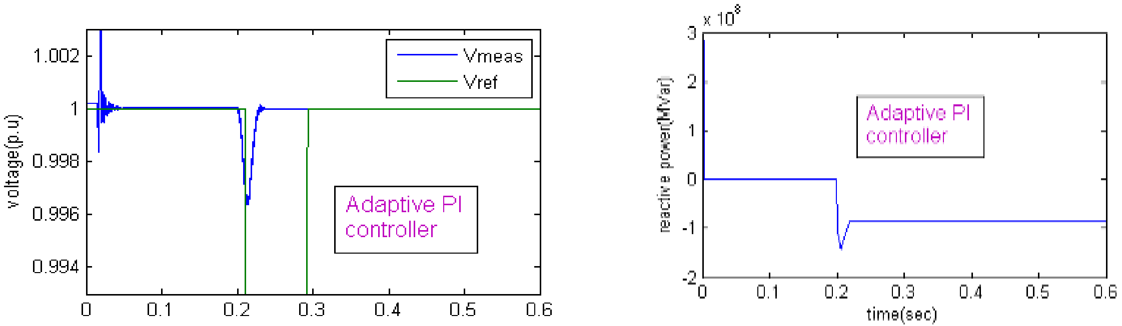
$$K_{p\_I}(t) = \frac{41.4360 \times \Delta I_q(t)}{\left(\Delta I_q(t) + 412.0153 \times \int_t^{t+T_s} B dt\right)} \quad (41)$$

$$K_{i\_I}(t) = 412.0153 \times K_{p\_I}(t). \quad (42)$$

Based on (39)–(42), the adjustive PI management model is designed to mechanically react to changes within the transmission network.The results are shown in Figs.13 and 14.

Note that the STATCOM absorbs volt-ampere from the system during this case. Here, the disturbance is assumed to allow a voltage rise at (substation A) from 1.0 to 1.01 p.u.; meantime, the system features a line removed that tends to lower the voltages. the general impact results in a voltage rise to on top of 1.0 at the controlled bus within the steady state if the STATCOM is not activated. Thus, the STATCOM has to absorb volt-ampere within the final steady state to achieve 1.0 p.u. voltage at the controlled bus. conjointly note that the initial transients forthwith when 0.2 s cause associate degree over absorption by the STATCOM, whereas the adjustive PI management offers a way drum sander and faster response, as shown in Fig. 13





(a) (b)

Fig. 13. Results of (a) voltages and (b) output reactive power with a change of transmission network.

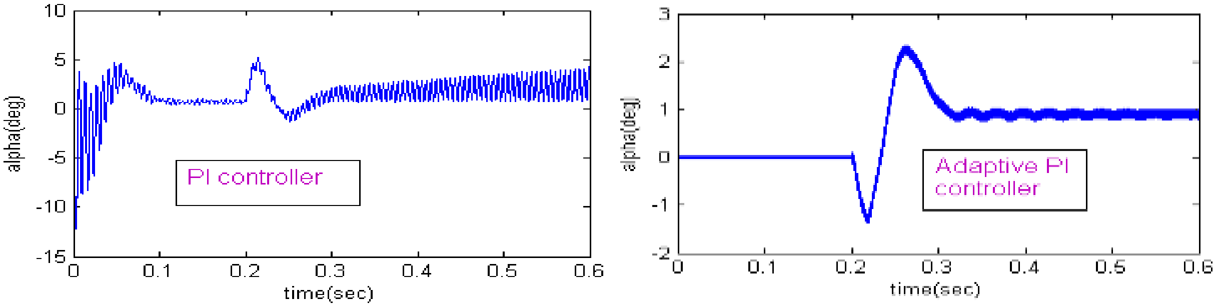


Fig. 14. Results of α with a change of transmission network.

F.Two Consecutive Disturbances

During this case, a disturbance at 0.2 s causes a voltage decrease from 1.0 to 0.989 p.u. and it happens at station A. After that, line one is shifted at 0.25 s. The results square measure shown in Figs. 15 and 16. From Fig. 15, it is apparent that the adjustive PI management are able to do a lot of faster response than the first one, that makes the system free fall a lot of but the first management throughout the second disturbance. Note in Fig. 15(a) that the most important free fall throughout the second disturbance event (startingat 0.25s) with the first management is 0.012 p.u., whereas it is 0.006 p.u. with the planned adjustive management. Therefore, the system is a lot of sturdy in responding to consecutive disturbances with adjustive PI management

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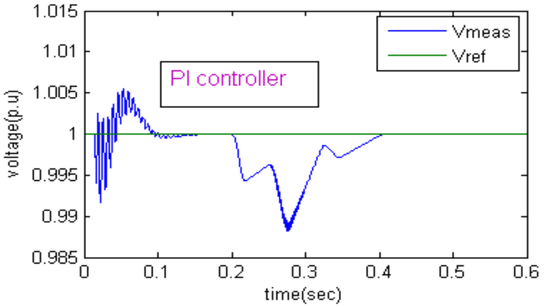
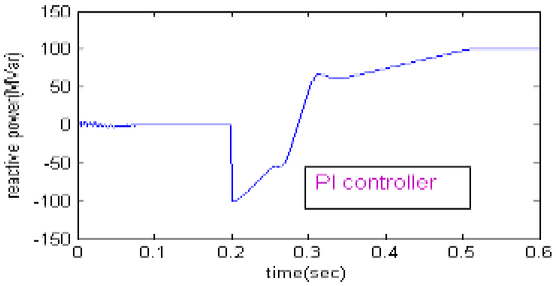
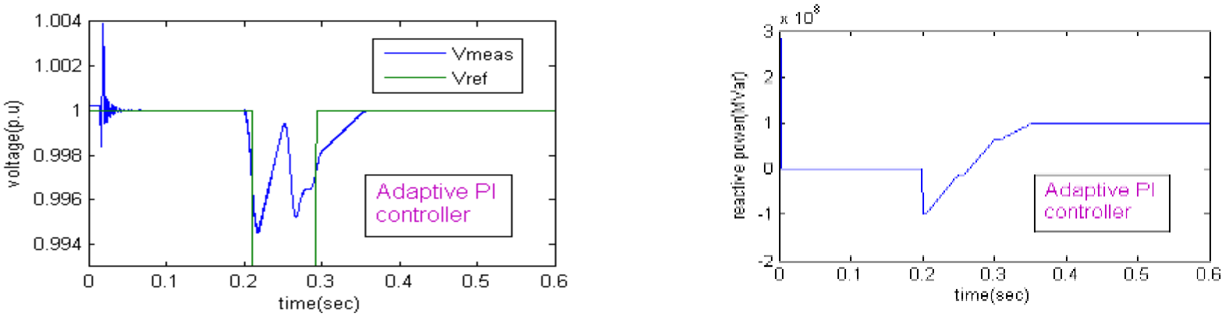






(a) (b)

Fig. 15. Results of (a) voltages and (b) output reactive power with two consecutive disturbances.

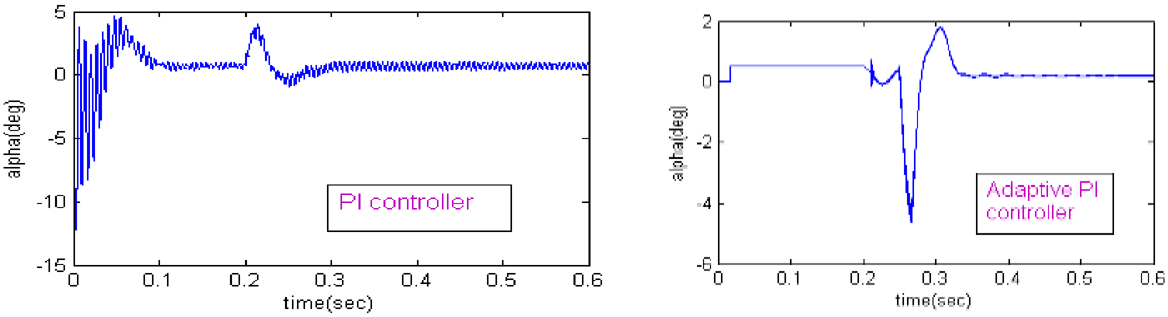
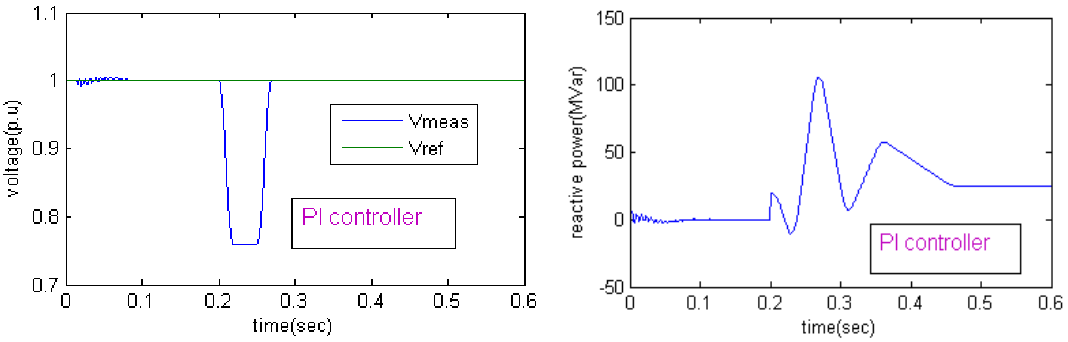
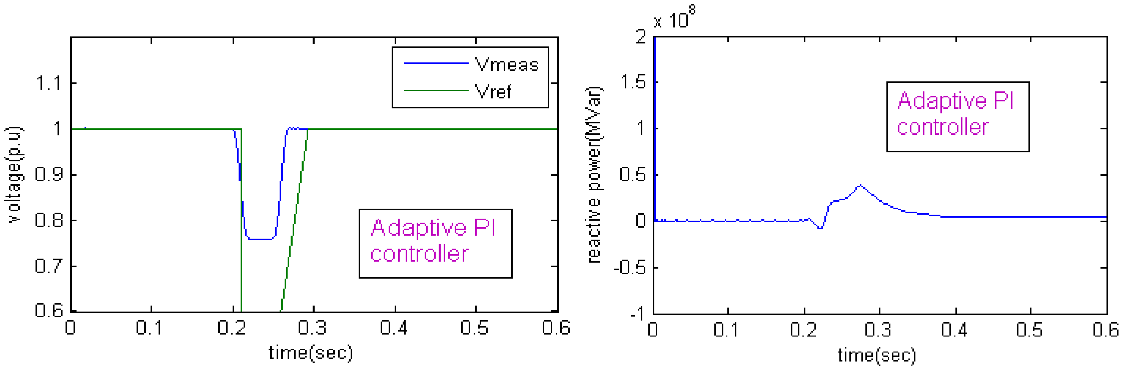


Fig. 16. Results of α with two consecutive disturbances

G. Severe Disturbance

During this case, a severe disturbance at 0.2 s causes a voltage decrease from 1.0 to 0.6 p.u. and it happens at station A. After that, the disturbance is cleared at 0.25 s. The results square measure shown in Figs. 17 and 18. as a result of the limit of STATCOM capability, the voltage cannot come back to to one p.u. when the severe free fall to 0.6 p.u. when the disturbance is cleared at 0.25 s, the voltage goes back to around 1.0 p.u. As shown in Fig. 17(a) and therefore the 2 insets, the adjustive PI management will bring the voltage back to 1.0 p.u. a lot of faster and drum sander than the first one. a lot of vital, the Q curve within the adjustive management (Q_{max} = 40 MVar) is way but the Q within the original management Q_{max} =118 MVar).





(b)

Fig. 17. Results of (a) voltages and (b) output reactive power in a severe disturbance

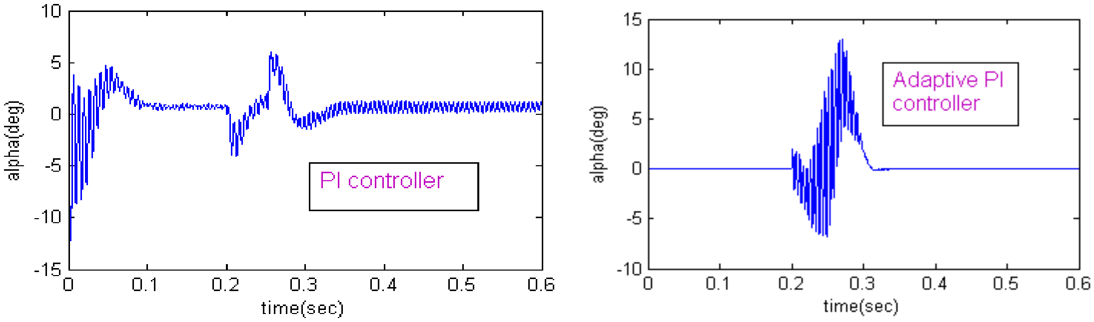


Fig. 18. Results of alpha in a severe disturbance

TABLES

TABLE I
PERFORMANCE COMPARISON FOR THE ORIGINAL SYSTEM PARAMETERS

	Original Control	Adaptive Control
Lowest Voltage After Disturbance	0.9938 p.u.	0.9938 p.u.
Time(Sec) When V=1.0	0.4095 sec	0.2983 sec
ΔT To Reach V=1.0	0.2095 sec	0.0983 sec
Var Amount At Steady State	97.76 MVar	97.65 MVar
Time To Reach Steady State Var	0.4095 sec	0.2983 sec

TABLE II
PERFORMANCE COMPARISON WITH A CHANGE OF LOAD

	Original Control	Adaptive Control
Lowest Voltage After Disturbance	0.9949p.u.	0.9949p.u.
Time(Sec) When V=1.0	0.4338 sec	0.3125 sec
Δt To Reach V=1.0	0.2338 sec	0.1125 sec
Var Amount At Steady State	93.08MVar	92.72MVar
Time To Reach Steady State Var	0.4338 sec	0.3125 sec

TABLE III
PERFORMANCE COMPARISON WITH CHANGED TRANSMISSION

	Original Control	Adaptive Control
Lowest Voltage After Disturbance	0.9954p.u.	0.9954p.u.
Time(Sec) When V=1.0	0.4248 sec	0.2744 sec
Δt To Reach V=1.0	0.2248sec	0.0744 sec
Var Amount At Steady State	-82.92MVar	-85.02MVar
Time To Reach Steady State Var	0.4248 sec	0.2744 sec

CONCLUSION

In the literature, varied STATCOM management strategies are mentioned together with several applications of PI controllers. However, these previous works acquire the PI gains via a trialand-error approach or in depth studies with a exchange of performance and relevance. Hence, management parameters for the optimum performance at a given in operation purpose might not forever be effective at a special in operation purpose. to handle the challenge, this paper proposes a replacement management model supported adaptational PI management, which may self-adjust the management gains dynamically throughout disturbances in order that the performance forever matches a desired response, regardleof the modification of in operation condition. Since the adjustment is autonomous, this provides the "plug-and-play" capability for STATCOM operation. within the simulation study, the planned adaptational PI management for STATCOM is compared with the traditional STATCOM management with pretuned mounted PI gains to verify the benefits of the planned technique. The results show that the adaptational PI management provides systematically wonderful performance below varied in operation conditions, like totally different initial management gains, totally different load levels, modification of the transmission network, consecutive disturbances, and a severe disturbance. In distinction, the traditional STATCOM management with mounted PI gains has acceptable performance within the original system, however might not perform as economical because the planned management technique once there\'s a modification of system conditions.

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