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COMPARISON OF ADAPTIVE PI AND PI CONTROL OF STATCOM FOR VOLTAGE REGULATION

S.P.ANJAN [#1] and R.M.NAGRALE [*2]

[#] *BE, EEP, M.B.E. Society's, College of Engineering, Ambajogai,India.*

[*] *P.H.D, Instrumentation, M.B.E. Society's, College of Engineering, Ambajogai,India.*

Abstract*— STATCOM can give quick and productive responsive power backing to keep up power system voltage soundness. Previously, different STATCOM control systems have been talked about including numerous utilizations of relative fundamental (PI) controllers. On the other hand, these past works acquire the PI picks up through an experimentation approach or far reac hing studies with a tradeoff of execution and relevance. Consequently, control parameters for the ideal execution at a given working point may not be powerful at an alternate working point. This paper proposes another control model taking into account versatile PI control, which can self-change the control additions amid an unsettling influence such that the execution dependably coordinates a fancied reaction, paying little respect to the change of working condition. Since the change is self -governing, this gives the attachment and-play capacity for STATCOM operation. In the reenactment test, the versatile PI control shows steady fabulousness under different working conditions, for example, distinctive introductory control increases, diverse burden leve ls, change of transmission system, continuous aggravations ,and a serious aggravation. Interestingly, the routine STATCOM control with tuned, altered PI picks up for the most part perform fine in the first framework, yet may not execute as productive as the proposed control strategy when there is a change of framework conditions.

***Index Terms*— Adaptive Control, Plug and Play, Proportional-Integral (PI) Control, Reactive Power Compensation, STATCOM, Voltage Stability.**

I.INTRODUCTION

Voltage constancy is a decisive deliberation in improving the security and consistency of power systems. The static compensator (STATCOM), a well-liked device for reactive power control based on gate turnoff (GTO) thyristors, has gained much interest in the last decade for improving power system stability. In the past, a variety of control methods have been proposed for STATCOM control. References mainly focus on the organize 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 control parameters or gains play a key factor in STATCOM performance. Presently, few studies have been carried out in the control parameter settings. In the PI controller gains are intended in a case-by-case study or trial-and-error approach with tradeoffs in performance and competence. Generally speaking, it is not possible for utility engineers to perform trial-and-error studies to find suitable parameters when a new STATCOM is connected to a system. 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. In Our project, we concentrate on the near investigation of the control systems or voltage source converter based STATCOM, comprehensively grouped into voltage control STATCOM and current control STATCOM. Under the previous, stage movement control is contrasted and the recent, considering backhanded decoupled current control and regulation of AC transport and DC join voltage with hysteresis current control . The initial two plans have been effectively executed for STATCOM control at the transmission level, for receptive force pay, and voltage bolster and are as of late being used to control a STATCOM utilized at the appropriation end. The accompanying lists are considered for examination – estimation and sign moulding necessity, execution with differing straight/nonlinear burden, absolute consonant bending (THD), DC join voltage variety and exchanging recurrence. The paper quickly portrays the notable highlights of every procedure, with their benefits and negative marks. The paper likewise underscores the decision of current control procedure, as it fundamentally influences the execution of a STATCOM.

A dynamic recreation model of the STATCOM has been produced for different control calculations in MATLAB/ SimPower System environment. Voltage strength is a discriminating thought in enhancing the security and unwavering quality of force frameworks. The static compensator (STATCOM), a famous gadget for receptive force control in light of door side road (GTO) thyristors, has increased much enthusiasm for the most recent decade for enhancing force framework soundness. Before, different control systems have been proposed for STATCOM control. References basically concentrate on the control plan instead of investigating how to set corresponding vital (PI) control picks up. In numerous STATCOM models the control rationale is executed with the PI controllers. The control parameters or increases play a key consider STATCOM execution. Quickly, couple of studies have been completed in the control parameter settings. The PI controller additions are outlined for a situation by-contextual analysis or experimentation approach with tradeoffs in execution and productivity. As a rule, it is not plausible for utility specialists to perform experimentation studies to discover suitable parameters when another STATCOM is associated with a framework. Further, regardless of the possibility that the control increases have been tuned to fit the anticipated situations, execution may be frustrating when an extensive change of the framework conditions happens, for example, when a line is redesigned or resigns from administration.

The circumstance can be far and away more terrible if such transmission topology change is because of a possibility. Accordingly, the STATCOM control framework may not perform well when for the most part required. Not quite the same as these past works, the inspiration of this paper is to propose a control system that can guarantee a brisk and steady craved reaction when the framework operation condition differs. At the end of the day, the change of the outer condition won't have a negative effect, for example, slower reaction, overshoot, or even unsteadiness to the execution. Base on this essential inspiration, a versatile PI control of STATCOM for voltage regulation is displayed in this paper. With this versatile PI control strategy, the PI control parameters can act naturally balanced consequently and alterably under distinctive unsettling influences in a force framework.

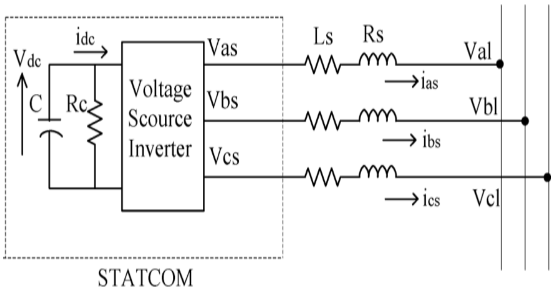

Fig. 1. Equivalent circuit of STATCOM.[26]

At the point when an aggravation happens in the framework, the PI control parameters for STATCOM can be processed consequently in every examining time period and can be adjusted in real time to track the reference voltage. 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. This paper is organized as follows. Section II illustrates the system configuration and STATCOM dynamic model. Section III presents the adaptive PI control method with an algorithm flowchart. Section IV compares the adaptive PI control methods with the traditional PI control, and presents the simulation results. Finally, Section V concludes this paper.

II. STATCOM MODEL AND CONTROL

A. System Configuration

The corresponding circuit of the STATCOM is shown in Fig. 1. In this power system, the resistance Rs in series with the voltage source inverter represents the sum of the transformer winding resistance losses and the inverter conduction losses. The inductance L_s represents the leakage inductance of the transformer. The resistance R_s in shunt with the capacitor C represents the sum of the switching losses of the inverter and the power losses in the capacitor. 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; and, i_{as} , i_{bs} and i_{cs} are the three-phase STATCOM output currents.

B. STATCOM Dynamic Model

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

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

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

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

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

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

$$\frac{d}{dt}\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dc} \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \omega & \frac{K}{L_a}\cos\alpha \\ -\omega & -\frac{R_s}{L_s} & \frac{K}{L_a}\sin\alpha \\ -\frac{3K}{2C}\cos\alpha & -\frac{3K}{2C}\sin\alpha & -\frac{1}{R_0 C} \end{bmatrix} \times \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dc} \end{bmatrix} - \frac{1}{L_s}\begin{bmatrix} V_{dl} \\ V_{ql} \\ 0 \end{bmatrix} \tag{5}$$

Where i_{ds} , i_{qs} are the d and q currents respected to I_{as} , I_{bs} and I_{cs} K is a factor that relates the dc voltage to the peak phase-to-neutral voltage on the ac side; V_{ds} is 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; V_{dl} and V_{ql} and 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, and can be obtained as follows.

$$pl = 3/2(V_{dl} i_{ds}) \qquad (6)$$

$$ql = 3/2(V_{dl} i_{qs}) \qquad (7)$$

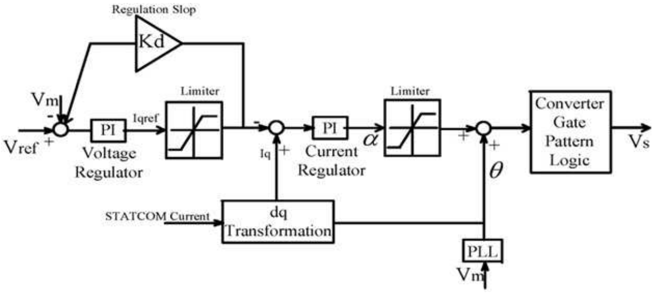

Fig. 2: Traditional STATCOM PI Control Diagram[26]

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]. 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 V_m is compared with V_{ref} and the the voltage regulator provides the required reactive reference current I_{ref} . The droop factor K_d is defined as the allowable voltage error at the rated reactive current flow through the STATCOM. The STATCOM reactive current I_q is compared with I_{ref} , 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.

III. ADAPTIVE PI CONTROL FOR STATCOM

A. Concept of Adaptive PI Control Method

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. An adaptive PI control block for STATCOM is shown in Fig. 3. the measured voltage $V_m(t)$ and the reference voltage $V_{ref}(t)$, and the q -axis reference current I_{qref} and the q -axis current are in per–unit values.

The proportional and integral parts of the voltage regulator gains are denoted by K_{p_v} and K_{i_v} respectively. Similarly, the gains K_{p_I} and K_{I_v} represent the proportional and integral parts, respectively, of the current regulator. In this control system, the allowable voltage error K_d is set to 0. The K_{p_v} , K_{i_v} and K_{p_I} , K_{I_v} can be set to an arbitrary initial value such as simply 1.0. One exemplary desired curve is an exponential curve in terms of the voltage growth, shown in Fig. 4.

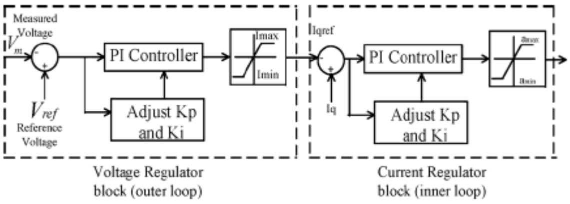

Fig.3 Adaptive PI Block For STATCOM[26]

The K_{p_v} , K_{i_v} and K_{p_I} , K_{I_v} can be set to an arbitrary initial value such as simply 1.0. One exemplary desired curve is an exponential curve in terms of the voltage growth, shown in Fig. 4, which is set as the reference voltage in the outer loop. Other curves may also be used than the depicted exponential curve as long as the measured voltage returns to the desired steady-state voltage in desired time duration.The process of the adaptive voltage-control method for STATCOM is described as follows.

1) The bus voltage $V_m(t)$ is measured in real time.
2) When the measured bus voltage over time $V_m(t) \neq V_{ss}$,the target steady-state voltage, which is set to 1.0 per unit (p.u.) in the discussion and examples, $V_m(t)$ is compared with V_{ss} Based on the desired reference voltage curve, K_{p_v} and K_{i_v} are dynamically adjusted in order to make the measured voltage match the desired reference voltage, and the q -axis reference current I_{qref} can be obtained.
3) In the inner loop, I_{qref} compared with the q –axis current I_q .Using the similar control method like the one for the outer loop, the parameters K_{i_I} and K_{p_I} can be adjusted based on the error. Then, a suitable angle can be found and eventually the dc voltage in STATCOM can be modified such that STATCOM provides the exact amount of reactive power injected into the system to keep the bus voltage at the desired value.

It should be noted that the current $I_{\max}$ and $I_{\min}$ and the angle $\alpha_{\max}$ and $\alpha_{\min}$ are the limits imposed with the consideration of the maximum reactive power generation capability of the STATCOM controlled in this manner. 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.

B. Derivation of the Key Equations

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.

Here, $V_{dl}(t)$ and $V_{ql}(t)$ can be computed with the transformation

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

Then, we have

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

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

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

In (10) V_{ss} is the target steady-state voltage, which is set to 1.0 p.u. in the discussion and examples; $V_m(t)$ is the measured voltage; τ = 0.01 s. The curve in Fig. 4 is one examples of $V_{ref}(t)$

If the system is operating in the normal condition, then $V_{ref}(t)$ = 1 p.u. and, thus, $V_{ref}(t)$ =1 p.u. This means that K_{p-V} and K_{i-V} will not change and the STATCOM will not inject or absorb any reactive power to maintain the voltage meeting the reference voltage. However, once there is a voltage disturbance in the power system, based on $V_{ref}(t) = V_{ss} - (V_{ss} - V_m(t))e^{-\frac{t}{\tau}}$, K_{p-V} and K_{i-V} will become adjustable and the STATCOM will provide reactive power to increase the voltage. Here, the error between $V_{ref}(t)$ and $V_m(t)$ is denoted by $\Delta V(t)$ when there is a disturbance in the power system. Based on the adaptive voltage-control model, at any arbitrary time instant t, the following equation can be obtained:

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

where Ts is the sample time, which is set to 0.000025 s here as an example.

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. Therefore, the resulting expression for the output of the discrete-time integrator block at t is,

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

Considering

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

$$\int_{t-T_s}^{t} \Delta V(t-T_s)dt$$

considering $y(t-T_s) = I_{qref}(t)$ (13) we can rewrite the (11) as

$$\Delta V(t)K_{p-V}(t) + K_{i-V}(t)$$

$$\Delta V(t)dt -$$

$$\int_t^{t+T_s} K_{i-V}(t-T_s)\int_{t-T_s}^{t} \Delta V(t-T_s)dt = I_{qref}(t+T_s)$$

$$-I_{qref}(t) \tag{13}$$

Over a very short time duration,
Considering
we can consider $K_{i-V}(t) = K_{i-V}(t-T_s)$ Hence, (13) can be
(13)
rewritten as

$$\Delta V(t)K_{p-V}(t) +$$

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

where $A = \Delta V(t) - \Delta V(t-T_s)$ Based on (12), if we can determine in ideal response the Ratio $(I_{qref}(t+T_s) - I_{qref}(t))/(\Delta V(t))$ 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

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

Since the system is expected to be stable, without losing generality,we may assume that the bus voltage will come back to1 p.u. in ,5 τ where it is the delay defined by users as shown in Fig. 4. Since $I_{qref}(t_0)$ =0 based on (15), (11) can be rewritten as

$$\Delta V(t_0)K_{p-V}(t_0) +$$

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

Where t_0 is the time that the system disturbance occurs.

Setting $K_{i-V}(\bar{t}_0)$ =0, we then have

$$K_{p-V}(t_0) = R \tag{17}$$

Setting , $K_{p-V}(\bar{t}_0)$ =0, we then have

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

Now, the ratio $mv = (K_{i-V}(t_0)) / +(K_{p-V}(t_0))$ can be considered as the ideal ratio of the values of $K_{p-V}(t)$ and $K_{i-V}(t)$ after fault. Thus, (15) can be rewritten as

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

Here, k_V can be considered as the steady and ideal ra $(I_{qref}(t+T_s) - I_{qref}(t)) / (\Delta V(t))$ Based on the system bus capacity and the STATCOM rating, $\Delta V_{\max}$ can be obtained, which means any voltage change greater than $\Delta V_{\max}$ cannot come back to 1 p.u. Since we have $-1 \le I_{qref}(t) \le 1$, we have the following equation:

$$\frac{\Delta V(t_0)}{\Delta V_{\max}} = k_V$$

$$\times \frac{\Delta V(t_0)K_{p-V}(t_0) + K_{i-V}(t_0)\int_{t_0}^{t_0+5\tau} \Delta V(t)dt}{R} \tag{20}$$

Based on (16), (19), and (20), k_v can be calculated by (21)

$$k_V = \frac{R\times\Delta V(t_0)}{(K_{p-V}(t_0)\Delta V(t_0) + K_{i-V}(t_0)\int_{t_0}^{t_0+5\tau} \Delta V(t)dt)\times\Delta V_{\max}} \tag{21}$$

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

$$\Delta V(t)K_{p-V}(t) + mvK_{p-V}(t)\int_{t}^{t+T_s} Adt = k_v \times \Delta V(t) \tag{22}$$

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

$$K_{p-I}(t) = \frac{k_I \times \Delta I_q(t)}{(\Delta I_q(t) + m_I \times \int_{t}^{t+T_s} Bdt)} \tag{23}$$

$$K_{i-V}(t) = mv\times K_{p-V}(t) \tag{24}$$

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:

$$K_{p-V}(t) = \frac{k_v \times \Delta V(t)}{(\Delta V(t) + mv\times \int_{t}^{t+T_s} Adt)} \tag{25}$$

$$K_{i-I}(t) = m_I \times K_{p-I}(t) \tag{26}$$

where $\Delta I_q(t)$ is the error between $I_{qref}(t)$ and I_q , k_I is the steady state and Ideal ratio which is given as $(\alpha(t+T_s) - \alpha(t) - \alpha(t)) / (\Delta I_q(t))$,and $\alpha(t)\theta$ is the angle of the phase shift of the inverter voltage with respect to the system voltage at time t; m_I is the ideal ratio of the values of $K_{p-V}(t)$ and $K_{i-V}(t)$ after fault; and B is equal to $\Delta I_q(t) - \Delta I_q(t - T_s)$

Note that the derivation from (10)–(26) is fully reversible so that it ensures that the measured voltage curve can follow the desired ideal response, as defined in (10).

C. Flowcharts of the Adaptive PI Control Procedure

Fig. 5 is the flowchart of the adaptive PI for control for STATCOM of the block diagram of Fig. 3. The bus voltage over time $V_m(t)$ is sampled according to a desired sampling rate. Then the comparison between $V_m(t)$ and V_{ss} should take place. Different conditions for this is given as- If $,V_m(t) = V_{ss}$ then there is no need to change any parameter of system. $K_{p-V}(t)$, $K_{i-V}(t)$, $K_{i-I}(t)$ and $K_{p-I}(t)$ It means

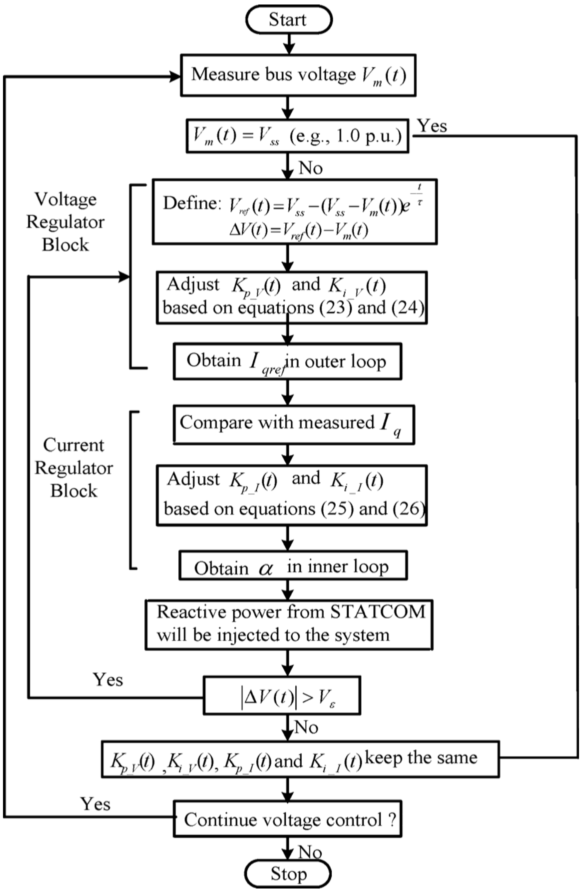

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Fig. 5. Adaptive PI control algorithm flowchart.[26]

that the power system is working smoothly. If second condition , $V_m(t) \neq V_{ss}$ then adaptive PI control begins to start the working.

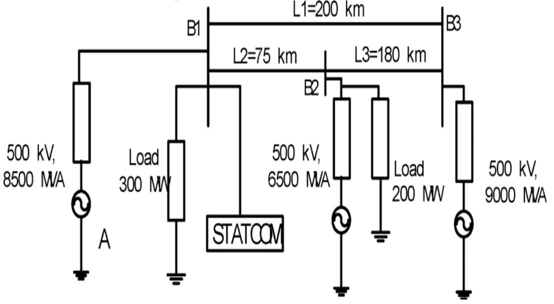

Fig. 6. Studied system.[26]

The measured voltage is compared with $V_{ref}(t)$, the reference voltage defined in (10). Then, $K_{p-V}(t)$ and $K_{i-V}(t)$ are adjusted in the voltage regulator block (outer loop) based on (23) and (24), which leads to an updated $I_{qref}(t)$ via a current limiter as shown in Fig. 3.Then, the I_{qref} is compared with the measured q-current I_q .

The control gains $K_{p-I}(t)$ and $K_{i-I}(t)$ are adjusted according to (25) and (26). Then, the phase angle is determined and passed through a limiter for output, which essentially decides the reactive power output from the STATCOM. Next, if $|\Delta V(t)|$ is not within a tolerance threshold V_ε ,which is a very small value such as 0.0001 p.u., the voltage regulator block and current regulator blocks are re-entered until the change is less than the given threshold V_ε . Thus, the values for Thus, the values for $K_{p-V}(t)$, $K_{i-V}(t), K_{i-I}(t)$ and $K_{p-I}(t)$ are maintained.

If there is the need to continuously perform the voltage-control process, which is usually the case, then the process returns to the measured bus voltage. Otherwise, the voltage-control process stops (i.e., the STATCOM control is deactivated).

IV. SIMULATION RESULTS

A. System Data

In the system simulation diagram shown in Fig. 6, a 100-MVAR STATCOM is implemented with a 48-pulse VSC and connected to a 500-kV bus. This sample of STATCOM system is already available in matlab.[10]–[12].

Here, the attention is focused on the STATCOM control performance in bus voltage regulation mode. In the PI STATCOM control 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.

Assume the steady-state voltage, V_{ss} = 1.0 p.u. In Sections IV-B, C, and F, a disturbance is assumed to cause a voltage drop at 0.2 s from 1.0 to 0.989 p.u. at the source (substation A). Here, the 0.989-p.u. voltage at substation A is the lowest voltage that the STATCOM system can support due to its capacity limit. The third simulation study in Subsection IV-D assumes a voltage drop from 1.0 to 0.991 under a changed load. The fourth simulation study in Subsection IV-E assumes a disturbance at 0.2 s, causing a voltage rise from 1.0 to 1.01 p.u. at substation A under a modified transmission network.

In Subsection IV-F, a disturbance at 0.2 s causes a voltage decrease from 1.0 to 0.989 p.u. occurring at substation A. After that, line 1 is switched off at 0.25 s. In Subsection IV-G, a severe disturbance is assumed with a voltage sag of 60% of the rated voltage. When the fault clears, the voltage gets back to around 1.0 p.u.

In all simulation studies, the STATCOM immediately operates after the disturbance with the expectation of bringing the voltage back to 1.0 p.u. The proposed control and the original PI control are studied and compared.

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 keep all of the parameters unchanged.The initial voltage source, shown in Fig. 6, is 1 p.u., with the voltage base being 500 kV. In this case, if we set R=1, then we have the initial m_V calculated as m_V = 770.8780. Since,in this case, $\Delta V(t_0) = \Delta V_{\max}$ and k_V = 84.7425, based on (23)–(26), we have

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

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

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

$$K_{i-I}(t) = 2.3775 \times K_{p-I}(t) \tag{30}$$

Based on (27) to (30) the adaptive PI control system can be designed,and the results are shown in Fig. (7) to (15), respectively.Observations are summarized in Table 1. 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. Set $\omega t = \alpha + \theta$, where α is the output angle of the current regulator,and θ

is the reference angle to the measurement system. In the STATCOM, it is !t that decides the control signal. Since θ is a very large value, the ripples of α in the scale shown in Fig. 13,14 and 15.will not affect the final simulation results.Note that there is a very slight difference of 0.12 MVar in the var amount at steady state in Table 1, which should be caused by computational roundoff error.The reason is that the sensitivity of dVAR/dV is around 100 MVar/0.011 p.u. of voltage.

Table I Performance Comparison For The Original System Parameters

PARAMETERS	PI CTRL	ADAPTIVE CTRL
Lowest Voltage After Disturbance	0.9938p.u.	0.9938p.u.
Time(Sec) At V=1.0	0.4095 sec	0.2983 sec
At To Reach V=1.0	0.2095 sec	0.0983 sec
Var Amount At Steady State	97.76MVar	97.65MVar
Time To Reach Steady State Var	0.4095 sec	0.2983 sec

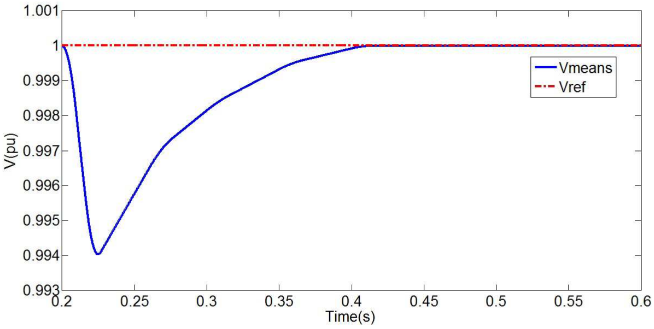

Fig. 7: Results of voltage using PI control

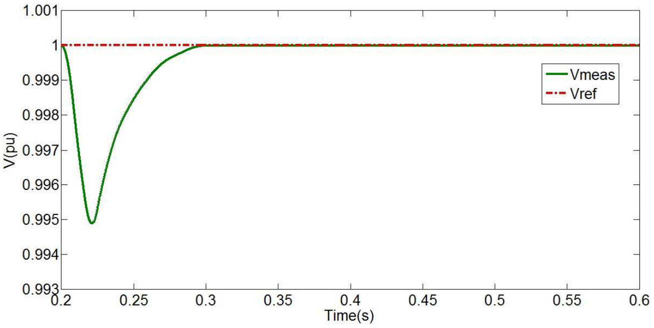

Fig. 8: Results of voltage using Adaptive PI control

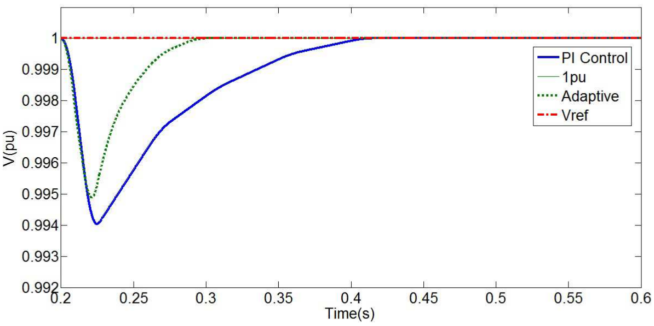

Fig. 9: Results comparison of voltage between PI and Adaptive PI control

For simplicity, we may assume that $\Delta Var / \Delta V$ sensitivity is a linear function. Thus, when the voltage error is 0.00001 p.u., Δ Var is 0.0909MVar,which is in the same range as the 0.12-MVar mismatch. Thus, it is reasonable to conclude that the slight Var difference in Table I is due to roundoff error in the dynamic simulation which always gives tiny ripples beyond 5th digits even in the final steady state.

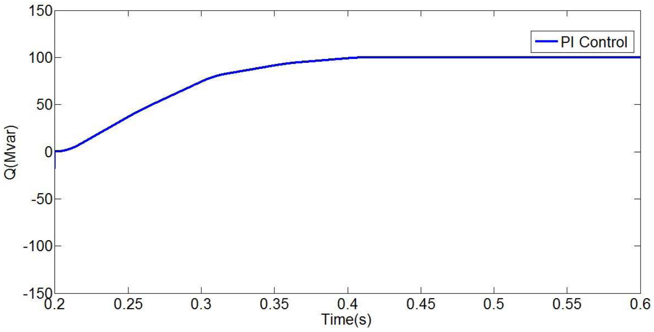

Fig. 10: Results of Q using PI control

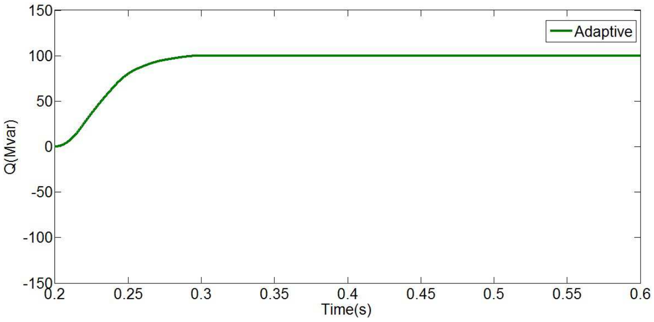

Fig. 11: Results of Q using Adaptive PI control

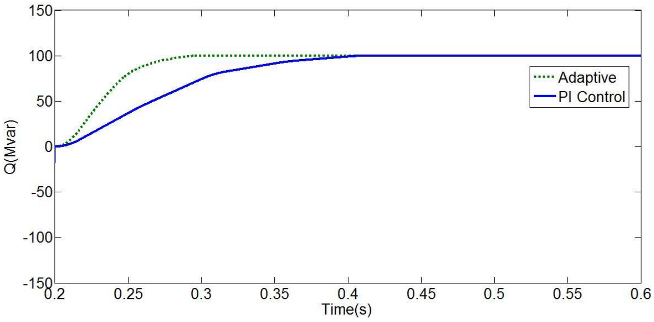

Fig. 12: Results comparison of Q between PI and Adaptive PI control

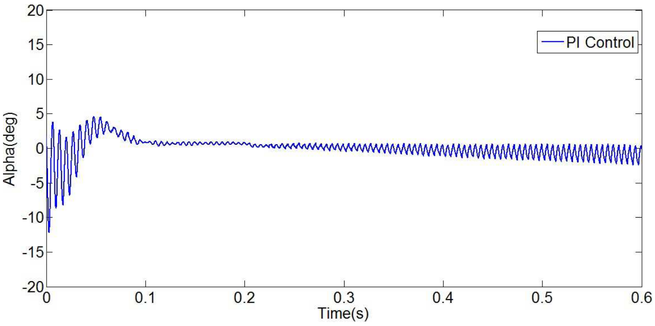

Fig. 13: Results of α using PI control

TABLE II: Performance Comparison For Change In Load System Parameters

PARAMETERS	PI CTRL	ADAPTIVE CTRL
Lowest Voltage After Disturbance	0.7140	0.7140 p.u.
Time(Sec) At V=1.0	0.4350	0.3750 sec
ΔT To Reach V=1.0	0.1676	0.0786 sec
Var Amount At Steady State	78.208	78.126Mvar
Time To Reach Steady State Var	0.4350	0.3750 sec

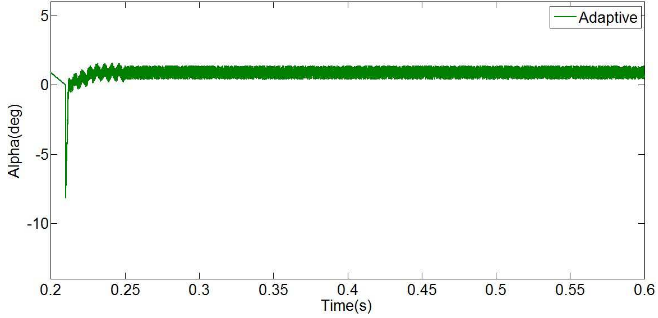

Fig. 14: Results of α using Adaptive PI control

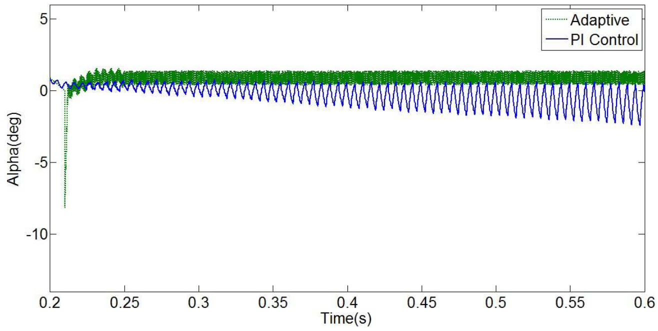

Fig. 15: Results comparison of α between PI and Adaptive PI control

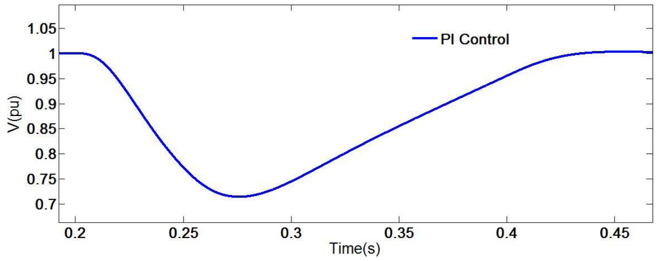

Fig. 16: Results of voltage using PI control

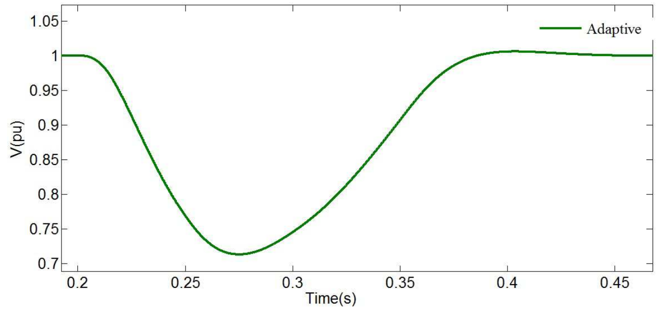

Fig. 17: Results of voltage using Adaptive PI control

B. Change Of Load

For previous example, when the voltage error is 0.00001 p.u., Δ Var is 0.0909 MVar, which is in the same range as the 0.12-MVar mismatch.so, it is reasonable to conclude that the slight Var difference in Table 2 is due to round off error in the dynamic simulation. When we change the load 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 is changed.In this case, we have the given dynamic control gains by equ.as per above example.the adaptive PI control model can be designed for automatic reaction to a change in loads. The results are shown in Fig. from (16) to (23). and Table 2 shows a few key observations of the performance.From the data shown in Table 2. it is obvious that the adaptive PI control can achieve a quicker response than the original one.This can be easily observed through comparison only.

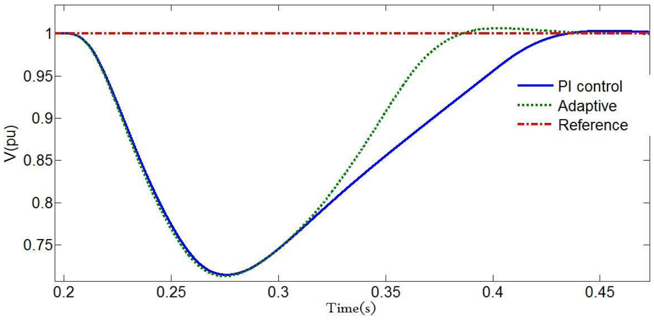

Fig. 18: Results comparison of voltage between PI and Adaptive PI control

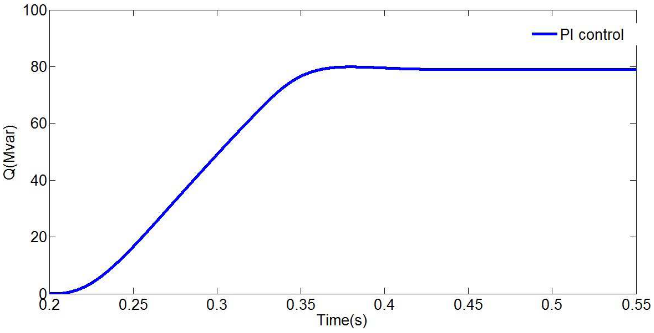

Fig. 19: Results of Q using PI control

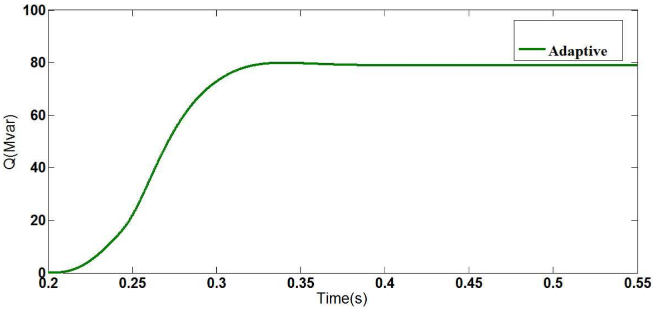

Fig. 20: Results of Q using Adaptive PI control

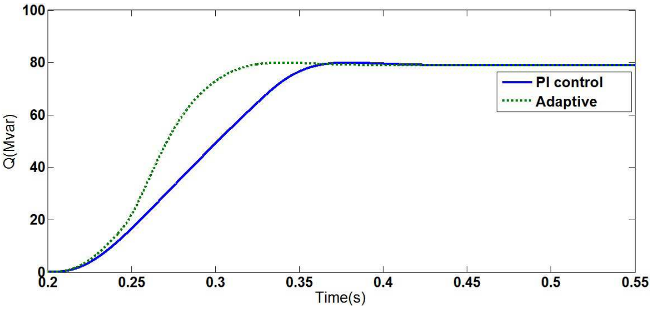

Fig. 21: Results comparison of Q between PI and Adaptive PI control

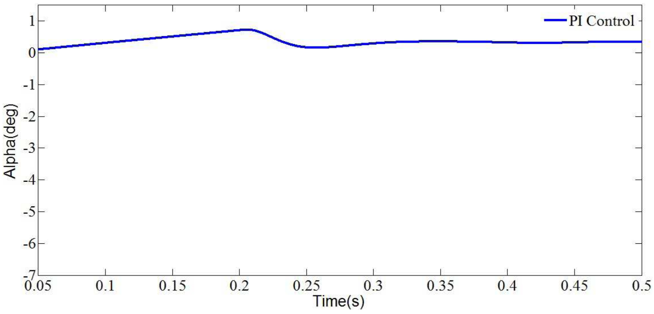

Fig. 22: Results of α using PI control

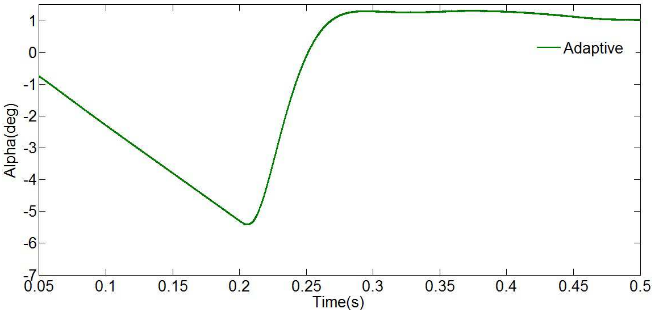

Fig. 23: Results of α using Adaptive PI control

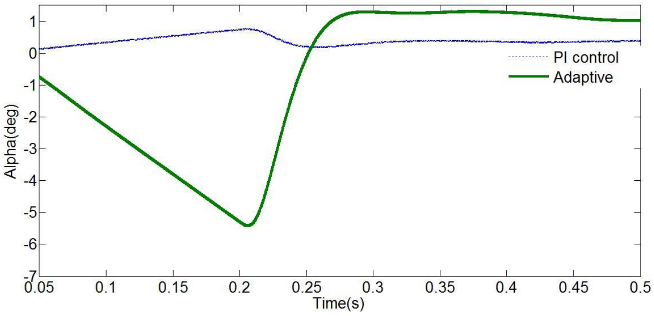

Fig. 24: Results comparison of α between PI and Adaptive PI control

Conclusion And Future Work

In the literature, various STATCOM control methods are given with its different applications of PI controllers. However, these work take trial and error method to find PI control gain parameter. Hence, these parameters are not so much effective to the operating point. So,to address these challenge,this project proposes a new control model based on adaptive PI control with its comparison, 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 PI STATCOM control.The results show that the adaptive PI control gives consistently excellent performance under various operating conditions, with the help of two different examples.only by changing the load conditions you can also observe the change by changing such as different initial control gains,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 adaptive PI control method when there is a change of system conditions.With respect to settling time .gain. harmonics, power factor and reactive power also adaptive PI control method for STATCOM is more effective than PI control of STATCOM.

Future work may lie in the investigation of multiple STATCOMs since the interaction among variouse STATCOMs may affect each other. Also, the extension to other power system control problems can be explored. We can also move towards the fuzzy controller whose results can matches with the required response in shorter time period.And concept of voltage regulation, reactive power improvement,transient period imitating, indirect control of power factor improvement and various power quality aspects are also proposed.

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Shilpa P. Anjan received her B. E. degree in Electrical Electronics and Power (EEP) from M.B.E. Society’s, College of Engineering, Ambajogai, India,in 2014, and pursuing M.E. degree in Control System Engineering from M.B.E. Society’s, College of Engineering, Ambajogai, India. Currently,She is a Professor in the Department Electrical Electronics and Power of Engineering at M.B.E. Society’s, College of Engineering, Ambajogai, India. Also, she is University Gold medalist from Babasaheb Ambedkar Marathwada university. Her area of interest covers power system ,control system.
E-mail: shilpaanjan@gmail.com

Ravindrakumar M. Nagarale received his B. E. degree in Instrumentation Technology from P.D.A.College of Engineering, Gulbarga, India, in 1990, and M.E. degree in Instrumentation Engineering fromS.G.G.S Institute of Engineering and Technology, Vishnupuri, Nanded, India, in 2006. Currently, he is a Associate Professor in the Department of Instrumentation Engineering at M.B.E. Society’s, College of Engineering, Ambajogai, India. Also, he is Research Scholar at S.G.G.S Institute of Engineering and Technology, Vishnupuri, Nanded - 431606, India. He has published about 10 refereed journal and conference papers. His research interest covers Sliding mode control, and Computational intelligent based sliding mode control. He is a member of ISTE .
E-mail: rmnagarale@yahoo.com