A Novel Robust Adaptive Dead-Zone Controller Using Non-Quadratic Lyapunov Function For FACTS

Keywords:
Power System Modeling and Control, Flexible AC Transmission Systems (FACTS), Static VAR Compensator (SCV), Dead-Zone Modification Scheme, Robust Adaptive Controller, Quadratic and Non-Quadratic Lyapunov Functions (QLF and NQLF), Disturbance, Dynamic Stability, Optimization of Controller Parameters.

Abstract:
In literature, robust adaptive control theory has been used for several purposes such as damping of growing oscillations, enhancing the system response and improving system transient stability. The novel application of robust adaptive control, presented in this paper, is the adaptive tuning and optimization of controller parameters in order to improve the dynamic stability of power systems.

The paper proposes a new robust adaptive control mechanism that implements and adopts the concept of dead-zone modification scheme for a 14th order state-space flexible AC Transmission Systems (FACTS) dynamic model. The developed controller will overcome the arising of uncertainty in system parameters, as well as, the internal and external disturbances in power systems. This is achieved by limiting the output error signal defined as the error in the load terminal voltage, within a prescribed horizontal strip (dead-zone) based on the nominal voltage tolerance, while maintaining system dynamic stability, this is considered as the main target of this work.

The model used in this application is a power network, equipped with one of the flexible AC transmission system devices, namely a static VAR Compensator (SVC), where the developed controller aims at maintaining a better dynamic performance of the system, in the presence of parameter uncertainty and usually unaccounted disturbances, whether stemming from internal or external sources.

Simulation results, obtained using MATLAB/SIMULINK, compare the output error signal while using fixed controller parameters with the use of robust adaptive control loops based on either QLF or novel NQLF. Results obtained confirm the capability of the suggested control technique, specially the controller based on NQLF, in restoring system dynamic stability as well as improving system performance in the occurrence of disturbances.
1-INTRODUCTION:
Automatic control has played a very important and vital role in the field of engineering and science especially for power system application.
During the period from 1960 to 1980 optimal control of both deterministic and stochastic systems as well as adaptive and learning control were fully investigated.
Most adaptive control schemes have shown good converge and stability in ideal case when no disturbance or noise acts on the system and when its parameter are kept constant.
From 1980 to the present time, developments in modern control systems have been significantly centered on many new control techniques.
Most adaptive control schemes have shown good converge and stability in ideal case when no disturbance or noise acts on the system and when its parameter are kept constant.
The robust adaptive control seems to be powerful techniques in practical application. It is also used for damping the growing oscillations, enhancing the speed of response and improving system transient stability as well as the control application in which the plant tends to vary its parameter with time times also some times measurements of systems variables are affected by internal/external. This controller is normally used in control of systems with unknown time varying parameters so far called "robust adaptive control schemes".
So the control system is called robust if it remains stable and achieves certain performance criteria in the presence of possible uncertainties.
This uncertainty is classified as follow:

1-Un Structured uncertainties:
Many dynamic perturbations that may occur in different parts of a system can, however be lumped into one single perturbation block $\Delta$, for instance, some unmodelled, high frequency dynamics. This uncertainty representation is referred to as "Un structured".

2-Parametric uncertainties:
In this type of uncertainty the perturbation like dynamic perturbation in many industrial control system which can caused by in accurate description of component characteristics torn and worn effects on plant component or shifting of operating points such perturbation can be represented by variations of certain parameter over some possible value ranges (complex or real). They affected the low frequency range performance and called parametric uncertainties.

3-Structured uncertainties:
In many robust design problem, it is more likely that the uncertainly scenario is a mixed case described in (1,2). The uncertainties under consideration would include unstructured uncertainties, such as unmodelled dynamics, as well as parameter variation.
The new application of robust adaptive control presented in this paper is the adaptive tuning and optimization of controller in order to improve the dynamic stability of power systems. This paper proposes a new robust adaptive control mechanism that implements and adopts the concept of dead zone modification scheme for a 14th order state space flexible AC Transmission Systems (FACTS) dynamic model.

2-FACTS MODELLING:

The model used in this application is a power network equipped with one of the flexible AC Transmission Systems (FACTS) devices namely a static compensator (SVC) as shown above.

This model consists of three modules:

2.1-AC system module:
It consists of generator system which can be represented by a generator has voltage $E_s$ and internal resistance, Transmission system which can be represented by the impedances of transmission lines, and load system which can be represented as $R$-$L$ load.

2.2-The controller module:
It consists of D-Q-Z PLL model, PI TCR voltage controller, Transport Delay filter and Feedback voltage Filter. The input of this controller is the reference voltage $V_{ref}$ and the output is the firing angle of the thyristor in the FACTS device.

2.3-FACTS module (FC-TCR):
It consists of fixed capacitor and a thyristor controlled reactor (FC-TCR) its firing angle is controlled by the controller module to vary the output in order to meet system compensation. The output is the artificial rotating susceptance denoted by $b_{TCR}$.
3-The Mathematical expression:

In this section a plant is controlled adaptively and the corresponding controller and reference model are described by the following equation:

\[
Y_p(t) = a_p y_p(t) + u(t) + v(t) \quad \text{plant}
\]

\[
U(t) = \theta(t) y_p(t) + r(t) \quad \text{controller}
\]

\[
Y_m(t) = -a_m y_m(t) + r(t) \quad a_m > 0 \quad \text{reference}
\]

Where:

- \( Y_p \): output of the plant
- \( Y_m \): output of the model
- \( r \): bounded reference input
- \( v \): bounded disturbance
- \( \phi \): parameter error

Also \( e_1 \) is the output error denoting the difference between the outputs of the plant and reference model

\[
e_1 = y_p - y_m
\]

\[
\phi = \theta - \phi \quad \text{where} \quad \theta = -a_p - a_m \quad \text{is a constant value of the control parameter} \quad \theta \quad \text{for which the plant transfer function is equal to that of the model}
\]

\[
e_1(t) = -a_m e_1(t) + \phi(t) y_p(t) + v(t)
\]

\[
\phi(t) = -e_1(t) y_p(t) \quad \text{for ideal case}
\]

so two cases were presented:

1- For ideal case:

In which \( v_d(t) = 0 \) \quad (no disturbances)

\[
e_1(t) = -a_m e_1(t) + \phi(t) y_p(t) \quad \text{--------------------------}\rightarrow (1)
\]

\[
\phi(t) = -e_1(t) y_p(t) \quad \text{--------------------------}\rightarrow (2)
\]

By using quadratic Lyapunov function, the ideal adaptive law using \( e_1 \) signal in the absence of any disturbance

\[
V_1(e_1, \phi) = \frac{1}{2} e_1^2 + \frac{1}{2} \phi^2 \quad \text{--------------------------}\rightarrow (3)
\]

By taking the time derivative

\[
V_1(e_1, \phi) = e_1 e_1 + \phi \phi \quad \text{--------------------------}\rightarrow (4)
\]

By substitutes with equation (4) leads to

\[
V_1 = e_1[-a_m e_1(t) + \phi(t) y_p(t)] + \phi(-e_1 y_p(t))
\]

\[
V_1 = -a_m e_1^2 + e_1 \phi(t) y_p - e_1(t) \phi y_p
\]
\[ V_1 = -\alpha m e_1^2 < 0 \] \quad (5)

2-Perturbed case:
In which \( v_d(t) \neq 0 \)
\[ \phi = \theta = -e_1 y_p \]
\[ V_1(e_1, \phi) = -\alpha m e_1^2 + e_1 \nu < -\alpha m \left| e_1 \right| - (V_d/\alpha_m) \]

4-Control technique:
There are several techniques used in order to obtain a robustness in the Model Reference Adaptive Control (MRAC) in the presence of a disturbance.
This technique can be listed as follow:
1-\( \sigma \) modification.
2-\( e \) modification.
3-Dead zone modification.
In this paper a Dead zone modification technique is used in which this technique is considered among the nearest one to the practical case as the error is limited between minimum and maximum levels or in the error magnitude is restricted to a performance tolerance after which the computational process is terminated.
\[ \phi = \theta = 0 \]
\[ \left| e \right| < \{ V_d/\alpha_m \} \]
but in case of an error signal is greater than the tolerance limit due to any disturbance or noise the adaptation control is carried out according to:
\[ \phi = \theta = -e_1 y_p \]
\[ \left| e \right| > \{ V_d/\alpha_m \} \]
5-Program Algorithm:

In this section a program algorithm is shown for the steps of the dead zone method technique which describes the way in which the

- Choose the system to be run (1, 2, 3, 4, 5).
- Choose the disturbance step Es.
- Choose the kind of controller (fixed-quadratic-non quadratic).
- Determine the DZ limit.

- The error value is estimated by equ:

\[ e_1v = v - vr \]

- Error is compared by DZ limit (tol)

So two cases are presented:

1- For \( |e| < \text{DZ} \) the controller is off where \( \Phi = 0 = \theta \)

2- For \( |e| > \text{DZ} \) the controller is on where \( \Phi = 0 = -e_1y_p \)

The controller will be on and begin to change in plant parameter robustly in order to meet the reference model parameter until the difference between them will be within a certain limit the controller stop working.
6-Simulation Results:

The aim of this section is to design a robust controller used to improve the dynamic response of the system when subjected to disturbances. A step disturbance $E_s$ is used in this simulation.

The time response in the absence of control action is displayed as shown in figure (1). This response has ( %) maximum overshoot and settling time of about (1 second).

When the control input is activated a remarkable improvement in the voltage difference response ($V - V_r$) is obtained.

The control action will force the error signal to the desired dead zone limit.

The maximum overshoot of the system with controller (as shown in figure 2) is reduced to ( %) in addition to the settling time is reduced to 0.25 (second) which is less than the without controller case.

![Figure 1: Time response with no control action.](image)

**FIGURE (1)**

![Figure 2: Time response with control action.](image)

**FIGURE (2)**