AN ADAPTIVE FUZZY LOGIC CONTROLLER FOR POWER OSCILLATION DAMPING BY STATCOM WITH ENERGY STORAGE

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Abstract- This paper offers with the outline of an adaptive power oscillation damping (POD) controller for a static synchronous compensator (STATCOM) outfitted with vitality stockpiling. That is done the use of a signal estimation technique taking into account a changed recursive least square (RLS) calculation, which allows a fast, particular, and versatile estimation of the low-recurrence electro-mechanical motions from locally measured signals over the span of power machine unsettling influences. The proposed methodology is successful in developing the damping of the system on the frequencies of interest, also inside the instance of system parameter instabilities and at various association purposes of the compensator. To begin with, the assessment of enthusiastic and receptive vitality infusion into the quality contraption could be played out the utilization of a simple four-system machine adaptation. A control procedure that improves dynamic and responsive force infusion at different association variables of the STATCOM will be inferred utilizing the rearranged model. Small signal analysis of the element execution of the proposed control system could be executed. The efficiency of the proposed oversee way to deal with offer power oscillation damping regardless of the association component of the instrument and which is near to the present system parameter instabilities will be set up through simulation and experimental outcomes.

Index Terms- POD, STATCOM, signal estimation technique, RLS and Small signal analysis.

I. INTRODUCTION

Static synchronous compensator (STATCOM) increases the stability of an ac power system. It can be applied at distribution level to overcome power quality problems and even at transmission level for voltage control and power oscillation damping (POD) [1]–[3]. It typically applied only for injection of reactive power, by combining the STATCOM with an energy storage connected to converter’s dc-link, a more flexible control of the transmission system can be achieved [4], [5]. In U.K a STATCOM with energy storage is already installed for voltage and power flow control [6]. The introduction of wind energy and other distributed generation will pave the way for more energy storage into the power system and auxiliary stability enhancement function is possible from the energy sources [7]. Because injection of active power is used temporarily during transient, incorporating the stability improvement function in systems where active power injection is mainly used for other purposes [8] can be impressive. Low-frequency electromechanical oscillations (of range of 0.2 to 2 Hz) are most common in the power system and are of concern of secure operation of the system, especially in a transmission system that is weak [9]. Hence, FACTS controllers, both in series and shunt configuration, have been majorly used to increase stability of the power system [1]. Using reactive power injection, the first swing stability and POD can be obtained by varying the voltage at the point of common coupling. The drawback of the shunt configuration for this kind of applications is that the PCC voltage must be regulated within limits (typically between ±10% of the rated voltage), and this reduces the amount of the compensator’s damping. Moreover, the amount of injected reactive power needed to vary the PCC voltage depends on the short circuit impedance of the grid seen at the point of connection. On the other hand, injection of active power, affects the PCC-voltage angle (transmission lines are effectively reactive) without altering the voltage magnitude significantly.

The control of STATCOM with energy storage (named hereafter as E-STATCOM) for power system stability improvement has been discussed in the literature [10]–[12]. Typically the effect on dynamic performance of E-STATCOM based on its location is not considered. The performance is majorly affected by the location when injection of active power is used against POD. Moreover, the typical control strategy of the device for POD available in the literature is similar to the one utilized for power system stabilizer (PSS) [9], where a series of wash-out and lead-lag filter links are used to generate the control input signals. This kind of control strategy is effective only at the operating point where the design of the filter links is optimized, and its speed of response is limited by the frequency of the electromechanical oscillations. A modified recursive least square (RLS)-based estimation algorithm as described in [13], [14] will be used to extract the required control.
In this paper, a control strategy for the E-STATCOM when used for POD will be investigated. Because of the selected local signal quantities measured in the system, the control strategy includes the injection of active and reactive power to provide uniform damping in the power system at different locations. It will be shown that the implemented control algorithm is robust against system parameter uncertainties. For this, a fuzzy logic controller and recursive least square (RLS)-based estimation algorithm will be used.

II. MODELLING OF CONTROLLER

The power system model is simplified to the study of the impact of the ESTATCOM with the power system. The approximations system has the investigated system it has the two areas where each area has the synchronous generator.

The synchronous generators are modeled as voltage sources of constant magnitude \((V_{g1}, V_{g2})\) and dynamic rotor angles \((\delta_{g1}, \delta_{g2})\) behind a transient reactance \((X'_{d1}, X'_{d2})\). The transmission system consists of two transformers represented by their equivalent leakage reactance \((X_{el}, X_{e2})\) and a transmission line with equivalent reactance \((X_{l1} = X_{l1} + X_{l2})\). For analysis purpose, the electrical connection point of the converter along the transmission line is expressed by the parameter \(\alpha\) as

\[
\alpha = \frac{X_1}{(X_1 + X_2)} \quad (1)
\]

Where

\[
X_1 = X'_{d1} + X_{e1} + X_{l1}
\]

\[
X_2 = X'_{d2} + X_{e2} + X_{l2}
\]

The control of the E-STATCOM consists of an outer control loop and an inner current control loop, as shown in Fig. 2. The outer control loop, which can be an ac voltage, dc-link voltage or POD controller, sets the reference current for the inner current controller. The generic measured signal \(Y_{m}\) depends on the type of outer loop control. The control algorithm is implemented in dq-reference frame where a phase-locked loop (PLL) [15] is used to track the grid-voltage angle \(\theta_g\) from the grid-voltage vector \(g_v\). By synchronizing the PLL with the grid-voltage vector, the \(d\) and \(q\) components of the injected current \((i_{d}^{\text{inj}} \text{ and } i_{q}^{\text{inj}})\) control the injected active and reactive power, respectively. In the notation in Fig. 2, the superscript “*” denotes the corresponding reference signals.

![Fig. 3. Equivalent circuit for two machine system with STATCOM](image)

For the system in Fig. 3, the change in active power output from the generators due to injected active and reactive power from the E-STATCOM is calculated as in

\[
\begin{align*}
\Delta P_{g1, p} &\approx -\Gamma p1 P_{inj} \\
\Delta P_{g2, p} &\approx (1 - \Gamma p2) P_{inj}
\end{align*}
\]

\[
\begin{align*}
\Delta P_{g1, q} &= \frac{V_{g1} V_{g2} s (\delta_{g1} - \delta_{g2}) a (1-a)}{E_g C} Q_{inj} \\
\Delta P_{g2, q} &= \frac{V_{g1} V_{g2} s (\delta_{g1} - \delta_{g2}) a (1-a)}{E_g C} Q_{inj}
\end{align*}
\]

Where \((\Delta P_{g1, p}, \Delta P_{g2, p})\) and \((\Delta P_{g1, q}, \Delta P_{g2, q})\) represent the change in active power from the corresponding generators due to injected active power and reactive power, respectively. \(\Gamma_p, P_{inj}\) and \(Q_{inj}\) are given by

\[
\begin{align*}
\Gamma_p &\approx \left[ (1-a) V_{g1} V_{g2} + a (\delta_{g1} - \delta_{g2}) \right] E_g C \\
P_{inj} &\approx E_{go} i_{d}^{\text{apm}} \\
Q_{inj} &\approx - E_{go} i_{q}^{\text{apm}}
\end{align*}
\]

The equation (2) and (3) used to get the power output from the generators injected from the active and the reactive power for the converters location. The initial steady-state PCC voltage magnitude \(E_p\) and generator rotor angles \((\delta_{g10}, \delta_{g20})\) correspond to the operating point where the converter is in idle mode.

III. POD CONTROLLER

POD controller consists of Phase Locked Loop(PLL) block, RLS estimator and Fuzzy Logic controller. In this section PLL and Fuzzy Logic controller are discussed, RLS estimator will be discussed in next section. The Block diagram of POD controller is shown in Fig.4.

![Fig. 4. Block diagram of the POD controller](image)
A. Phase Locked Loop

The PLL (3ph) block models a Phase Lock Loop (PLL) closed-loop control system, which tracks the frequency & phase of a sinusoidal three-phase signal by using an internal frequency oscillator. The control system adjusts the internal oscillator frequency to keep the phases difference to 0. The figure shows the internal diagram of the PLL.

The three-phase input signal is converted to a dq0 rotating frame (Park transform) using the angular speed of an internal oscillator.

![Fig.5. Block diagram of PLL](image-url)

The quadrature axis of the signal, proportional to the phase difference between the abc signal & the internal oscillator rotating frame, is filtered with a Mean (Variable Frequency) block. A Proportional-Integral-Derivative (PID) controller, with an optional automatic gain control (AGC), keeps the phase difference to 0 by acting on a controlled oscillator. The PID output, corresponding to the angular velocity, is filtered & converted to the frequency, in hertz, which is used by the mean value.

B. Fuzzy Logic Controller

Fuzzy logic gives a totally exceptional, unorthodox approach to procedure a control bothers. This technique makes a forte of what the machine need to do in inclination to hoping to comprehend the way it works. You can in any case offer regard for taking care of the issue as opposed to attempting to form the system scientifically. This almost constantly closes in quicker, modest arrangements.

Fuzzy logic is a very powerful method of reasoning when mathematical formulations are infeasible and input data are imprecise. These above problems are encountered in many control applications in which we know, how the system is behaving but find it difficult to express the derived behavior in terms of mathematical model are in analytical formula. In this case fuzzy logic is a powerful tool for designing the control system accurately. In the block diagram shown, the controller is between a pre-processing block and a post-processing block.

![Fig.6. Block diagram of Fuzzy Controller](image-url)

IV. RLS Algorithm

As described in the introduction, effective power oscillation damping for various power system operating points & E-STATCOM locations require fast, accurate, and adaptive estimation of the critical power oscillation frequency component. This is achieved by the use of an estimation method based on a modified RLS algorithm. One can compute filtered output, filter error and filter weights for given input and desired signals using RLS adaptive filter algorithm.

![Fig.7. Block diagram of RLS filter](image-url)

A. Dialog Box and Parameters of RLS Algorithm

The Filter length is used to enter the length of the FIR weights vector. Forgetting factor (0 to 1) is the exponential weight factor in the range of 0 & the value of 1 of infinite memory. Initial value to specify forgetting factor is the dialog box to enter the value of the forgetting factor in the block parameter of the RLS filter dialog box. Select input port to specify the forgetting factor of λ input port. Filter weights is used to specify the values of the FIR filter weights. Initial input variance estimate has the initial value of 1/p(n). Adapt port is the check box to enable the adapt input port. Reset port is the check box to enable to reset the input port. Output filter weights is the check box to export the filter weights from port.

![Fig.8. Dialog box of RLS filter](image-url)
B. RLS Set of Rules

The Recursive least squares (RLS) adaptive clear out is a set of rules which recursively reveals the filter out coefficients that limit a weighted linear least squares cost function referring to the enter alerts. The RLS algorithms are recognized for their tremendous performance whilst running in time varying environments but on the price of an expanded computational complexity and a few balance issues. On this algorithm the filter out tap weight vector is updated the use of following equation,

\[ w(n) = wT (n-1) + \text{okay}(n) \text{ en-1}(n) \]
\[ \text{okay}(n) = u(n) / (\lambda + X T (n) u(n)) \]
\[ u(n) = w\lambda - 1 (n-1) X(n) \]

in which \( \lambda \) is a small tremendous consistent very near, but smaller than 1. The filter out output is calculated by

\[ Yn-1(n) = wT (n-1) X (n) \]
\[ \text{en-1}(n) = d(n) - yn-1(n) \]

V. SIMULATION RESULTS

The POD controller described in earlier Section is here verified via MATLAB simulation using the well known two-area four-machine system in Fig.9.

The implemented system is rated 20/230 kV, 900 MVA and the parameters for the generators and transmission system together with the loading of the system are given in detail in [9].

The system is initially operating in steady state with a transmitted active power, 400 MW from area 1 to area 2. A three-phase fault is applied to the system on one of the transmission lines between buses as shown in fig.11.

Fig.9. Simplified two-area four machine power system.

Injected active and reactive power with E-STATCOM connected at bus. Active power injection (top) and reactive power injection (bottom); Total transmitted power (bottom most).
Due to the applied disturbance, a poorly damped oscillation is obtained after the fault clearing; the performance of the E-STATCOM following the fault at three different scenarios is shown in Fig. 12. Graph shows Active power, reactive power and Total Transmitted power.

Injected active and reactive power with E-STATCOM and POD controller connected at bus. Active power injection (top) and reactive power injection (bottom); total transmitted power is the below graph.

Because of a good choice of signals for controlling both active and reactive power injection, effective power oscillation damping is provided by the E-STATCOM irrespective of its location in the line.

Measured transmitted active power output following a three-phase fault with E-STATCOM connected to POD using fuzzy controller by only P injected (blue solid), only Q injected (green solid), both P and Q injected (magenta solid).

V. CONCLUSION

This project has the energy storage application equipped with the shunt-connected STATCOM for power oscillation damping (POD). The POD controller designed on Fuzzy Logic is used based on the Recursive Least Square (RLS) algorithm. The advantages of the RLS over the signal techniques used to get the filters have been highlighted. The ability of E-STATCOM to enhance system security and stability over the electrochemical oscillations of disturbances has been shown. The robustness of the control algorithm has been verified via the simulation.

REFERENCES

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