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Inter-Area Oscillation Damping In Power System Using Fuzzy Logic Wide Area Damping Controller

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Abstract:

Recent innovative improvements in the wide-range estimation framework (WAMS) are acknowledging brought together controls for enhancing the force frameworks solidness. The most difficult obstruction against these advances identifies with correspondence delays, which are not steady and rely on upon data framework stacking. Ignoring this inactivity could decay the damping execution of shut circle control or even corrupt the framework soundness. This paper plans a fluffy rationale wide-zone damping controller (FLWADC) to soggy the between region motions adjusting for the ceaseless idleness. The controller is focused around the fluffy rationale because of its demonstrated vigor against info signal varieties. The proposed controller has three info signs comprising of precise distinction, its subordinate, and the time inactivity, which is unequivocally decided through measured information time labels and the exact time signal at the controller area. Tenet bases of FLWADC are created such that enrollment capacities of the yield variable are as needs be moved to adjust for the time delay. A standard proving ground for element reproductions and its extended form are analyzed, and numerical confirmations are examined. To sum up the conclusions attracted the research endeavor, different sets of affectability studies are led, covering controller parameter changes, power framework reconfigurations, and moving the framework working point.

Index Terms:
Communication latency, fuzzy logic controller (FLC), inter-area oscillations, wide-area measurement system (WAMS).

Introduction:

SINCE the 1960s, low recurrence motions have been watched when huge force frameworks are interconnected by generally powerless tie lines. These motions are as a rule in the scope of 0.1–2 Hz. Motions connected with a solitary generator or a solitary plant against whatever is left of the force framework are called neighborhood modes that have frequencies in the scope of 0.8–2 Hz. In any case, between range motions with recurrence between 0.1 to 0.8 Hz show up when a gathering of generators in one region are swinging against a gathering of generators in an alternate zone. These oscillatory modes are all the more undermining to the framework steadiness since they frequently experience the ill effects of poor damping [1]. Power framework stabilizer (PSS), adaptable AC transmission frameworks (FACTS), and high voltage direct present (HVDC) advances luckily offer a Shade adaptations of one or a greater amount of the figures in this paper are accessible online incredible potential to enhance this test [2]–[4]. In this sense, it has been so far a typical practice to utilize by regional standards measured flags as input inputs of damping control circles. However, with nearby flags, one can hose generally discernible and controllable motions and the recognizable space would likely be constrained. In the writing, it is showed that if remote signs are encouraged to the controller, the framework dynamic execution can be upgraded contrasted and the generally measured signs [5]. The wide-territory estimation framework (WAMS), empowered by expansive sending of phasor estimation units (Pmus), is skilled to screen dynamic information of the force framework, for example, voltage, current, point, and recurrence. It henceforth proposes an exceptional open door in controlling force framework flow following the recognizable space gets to be more extensive with WAMS data. The accomplishments are for the most part because of time-stamped synchronous estimations appropriate anytime of a topographically spread electric system [6]. The time requested to render PMU information at the framework or provincial control focus in addition to that of exchanging charges to control gadgets is completely alluded to as the correspondence deferral or idleness. This time deferral relies on upon the correspondence framework stacking and, in criticism control circle, decreases the viability of the control framework and may even result in the complete framework shakiness [7]. As needs be, it is of basic essential to consider the dormancy amid the controller outline process. In the writing, diverse systems have been proposed to make up for the idleness. References [8]–[10] have introduced multi-operators, blended, and indicator based controllers for time-deferred frameworks.

Reference [11] has proposed a versatile phasor power motions damping controller wherein the pivoting directions are balanced for consistent remuneration of time-differing latencies. Likewise, [12] has examined direct control plan method that uses an advancement based iterative calculation with a set of straight network imbalance requirements. The strategy proposed in [12] is to acquire the ideal controller parameters, while effectively considering the transmission delay. Reference [13] has introduced a pragmatic experience on the HVDC-based damping controller consolidating the correspondence time delay. In a wide-zone power framework stabilizer for the little flag solidness was composed where a second request rough guess was utilized for the purpose of dormancy thought. Reference [15]developed strategies to consider variable deferral components in control of wide-region power frameworks. In [16], a powerful technique was proposed too for cases in which time-shifting standard limited instabilities showed up in a delay system.The principle impediment with the previously stated systems is that the control guideline is focused around a linearized framework model, and the controller parameters are tuned for some ostensible working states. Then again, qualities of force plants are characteristically nonlinear; power frameworks are alert frameworks; and their operation is of a stochastic nature.

Controller parameters that are ideal for one situated of working conditions may be incapable for different sets. To overcome such difficulties, the nonlinear progress of the force framework are considered in the controller outline strategy [17].An alternate answer for nonlinear control issues is application of fluffy rationale controllers (Flcs) [18]. FLC endures the instability, imprecision, or change of info parameters and additionally gives a chance to present master information in control standards. This sort of controller yields great results under changing working conditions and time-shifting information signals. FLC has been used as a proficient apparatus to settle power frameworks in an extensive variety of working conditions and different gadgets, for example, PSS and FACTS [19], [20]. The significant commitment of this paper is to plan a fluffy rationale wide-territory damping controller (FLWADC) for between range motions damping and constant dormancy pay. It is accepted that the controller is installed in a static synchronous arrangement compensator (SSSC) placed in a standard four-machine two-region power framework and its extended form.

In the normal fluffy based damping controllers, where the transmission postponement is disregarded, signs displaying the between range wavering data are utilized as the controller information signals. While, in the proposed FLWADC, an extra flag meaning the time deferral of input signs is encouraged to the controller too. This sign is measured by PMU information time labels and the facilitated general time (UTC) at the controller area. Contingent upon the estimations of this sign, yield enrollment capacities are moved in a way that adjusts for the impact of the time delay. Notwithstanding the base case numerical reenactment, the strength of the planned FLWADC is explored in the circumstances of controller parameters changes, power framework reconfiguration, and working point moves. This peculiarity offers the proposed FLWADC for reasonable applications. Whatever remains of the paper is illustrated as takes after. Segment II shows the configuration methodology and execution of the routine FLWADC barring the time postponement impact. Segment III uncovers the effect of time defers in the execution of ordinary FLWADC. In Section IV, the strong FLWADC with time delay remuneration is outlined and its execution is confirmed. Area V introduces the affectability investigation. The paper is closed in Section VI.

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II. CONVENTIONAL FLWADC WITHOUT LATENCY COMPENSATION:

This section is to demonstrate the ability of FLC in damping inter-area oscillations with using an SSSC and WAMS signals in an ideal condition, i.e., no time delay of remote signals.The two-area four-machine benchmark test system, shown in Fig. 1, is utilized as the study test bed and its parameters are specified in [1].

The simulation platform is in Matlab/Sim-Power Systems toolbox [21]. Here, the SSSC is placed in the tie line between two areas to control the power flow in the tie line between buses 8 and 9 and damp the inter-area oscillations. However, the optimal location of SSSC in practical and large power systems is vital point and requires comprehensive studies.

The SSSC offers 10% compensation in the steady state and has a dynamic range of variation from 1% to 20%. SSSC is a well-known series connected FACTS controller based on voltage source converter (VSC). Fig. 2 illustrates SSSC connection to the transmission line and its control structure [22].

Indeed, SSSC is an advanced type of controlled series compensation and controls the power flow and mitigates the oscillation, albeit by a proper controller design. Fig. 2 also displays themain control system of SSSC. It can be observed that , as one of reference signals required for the control system, is the desired magnitude of the series reactive voltage and determines the reactive power exchange for series compensation.

By injecting the series voltage, namely , SSSC provides a variable reactance, , in series with transmission line and adjusts the effective line reactance. Therefore, SSSC offers an active means for the reactive power compensation as well as power oscillation damping. The variable reactance realized by SSSC is expressed as (1) where denotes the line current and is obtained by (2) [23]:

$$X_q = \frac{V_q}{i_L} \tag{1}$$

$$V_q = V_{q\mathrm{Ref}} + \Delta V_q . \tag{2}$$

In steady state, and are constant. While during dynamic conditions, the series injected voltage is modulated to damp the system oscillations.

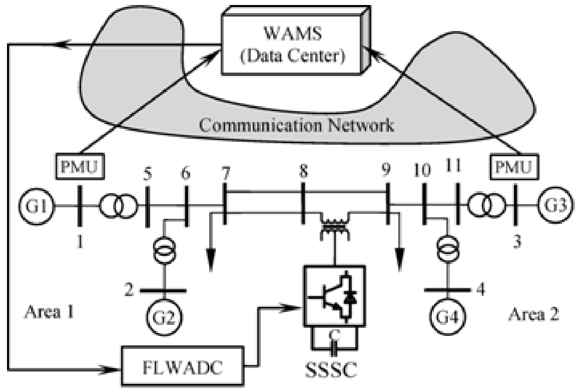

Fig. 1. Two-area four-machine power system with SSSC.

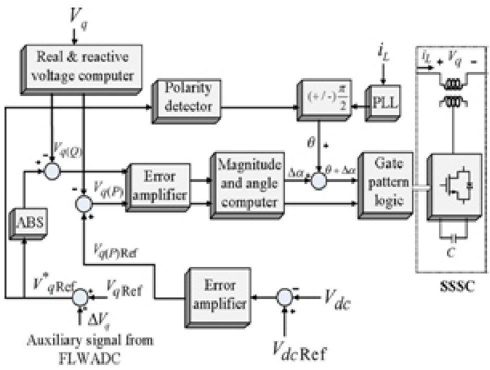

Fig. 2. Block diagram of SSSC control system..

One of fundamental issues in designing wide-area based damping controllers is the selection of feedback signals (which is directly dependant to the locations of PMUs) to achieve the best modal observability and optimal oscillation damping. Generally speaking, a PMU device measures the real - time three-phase voltage and current quantities. The PMU then computes the three- phase phasor values, the sequence components, the system frequency, as well as the rate of change of frequency and renders these data to the control center [24]. Although the PMU computed frequency and its rate of change are based on the local voltage measurement, there are several methods which let us calculate the generator speed through PMU measurements [25]–[27]. Frequency is a key indicator for the system stability and generation/demand balance. This parameter or its derivatives, such as rotor speeds and their rate of change, are usually employed as the damping controller feedback signals [1], [5], [12]. To this end, buses associated with G1 and G3 are assumed to be equipped with PMUs and its derivative are chosen as global feedback signals. However, in large power systems with hundreds of units and buses, a PMU

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placement study that maximizes the dynamic information would be in essence.Another important subject in implementing the FACTS de-vice's damping controller is identifying the best location for ap-plying auxiliary damping signal to provide an effective damping of oscillations and to minimize the interactions between FACTS power flow and damping controllers. In [28], an example of ap-plying the damping controller signal to the DC or AC voltage reference of FACTS was given. A method was developed to analyze the relative effect and to avoid the negative interactions between damping controller and other control loops. It has been shown that applying the damping controller signal to DC voltage reference of FACTS device causes a significant destructive interaction on its other control loops.

This issue is examined here as well and it is found that applying the auxiliary damping signal to AC voltage reference of SSSC yields better results than the other signals as they are decoupled. In this study, the output of FLWADC is thus utilized to modulate and consequently adjusts to yield a proper damping of inter-area oscillations. Change of results in moving the active power between areas 1 and 2 up and down and consequently adjusting the accelerating and decelerating areas according to the equal area criterion. Thus, the proper control of during power swing situations will reduce the overall amplitude of oscillations. In [29] and [30], the contribution to power oscillations damping and stability enhancement by SSSC is addressed in detail. The developed FLWADC is designed based on Mamdani inference engine [18]. The fuzzification process, defuzzification, rule base, and inference engine are essential parts of fuzzy controller which are clarified in the following.

A. Fuzzification:

Fuzzification involves mapping crisp input parameters, namely and , to fuzzy variables. This process exe-cutes a membership grade to translate the numeric values of inputs into linguistic values. Fuzzy sets for input parameters and output variables are designed by studying the behavior of FLWADC input signals in different situations, particularly before and after faults.Doing so, the membership functions for inputs and output of FLC are obtained, as depicted in Figs. 3 and 4. Note that through a trial and error process with various functions, it was found that triangular membership function leads to a better damping effect for small angle deviations; thus, it is adopted for both input and output variables. In Figs. 3 and 4, the symbols are defined as NB: negative big, NM: negative medium, Z: zero, PM: positive medium, PB: positive big, N: negative, and P: positive.

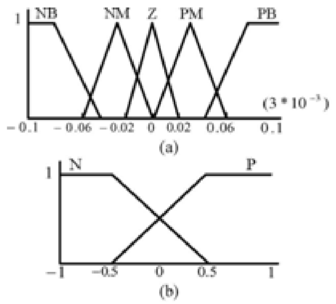

Fig. 3. Membership functions of fuzzy controller inputs: (a) and (b) .

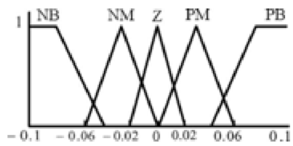

Fig.4. Membership functions of fuzzy controller output.

B. Rule Base and Inference Engine:

The fuzzy control strategy is realized by the inference engine that is a rule base including all possible combinations of inputs and proper outputs for each of them. In this section, 10 rules covering all combinations of membership functions shown in Figs. 3 and 4 are extracted for the conventional FLWADC. For the sake of illustration, the procedure of rule extraction is de-scribed in the following. Referring to Fig. 1, consider a combination in which corresponds to PM and lies within P membership function. This information means that is greater than and their difference is ascending too.

Thus, the SSSC injected reactance should be capacitive in order to increase the active power flow from area 1 toward area 2. This situation is called deceleration control of the system and its opposite point is acceleration control in which the SSSC injected reactance is inductive in order to reduce the active power flow at the location of SSSC. Based on above explanations, the rules in terms of input parameters, i.e., and , are outlined as follows:

- If is PM and is P, then the output is PB.

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- If is PB and is P, then the output is PB.
- If is NM and is P, then the output is Z.
- If is NB and is P, then the output is NM.

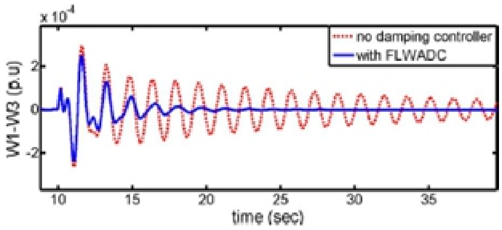

Fig.5. Rotor speed difference between G1 and G3, without time delay.

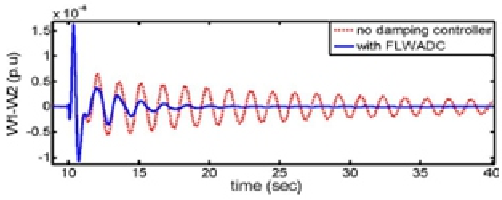

Fig. 6. Rotor speed difference between G1 and G2, without time delay.

- If w is PM and is N, then the output is Z.
- If w is PB and is N, then the output is PM.
- If w is NM and is N, then the output is NB.
- If w is NB and is N, then the output is NM.
- If w is Z and is P, then is the output PB.
- If w is Z and is N, then is the output NB.

C. Defuzzification:

Here, it is intended to generate a crisp numeric value, which is used as a control input for power system, based on outputs of fuzzy rules. Once the input variables are fuzzified and sent to the fuzzy rule base, the output of the rule base is then aggregated and defuzzified.Aggregationmeans all of the output fuzzy sets are added in a logical way. Then, a crisp control signal is accordingly produced. Centroid technique, as one of the commonly used defuzzification methods, is adopted in this paper. In this technique, the control signal is

$$\Delta u(k) = \frac{\sum_{i=1}^{n} F_i S_i}{\sum_{i=1}^{n} F_i} \qquad (3)$$

Where is the membership grade and is the membership function singleton position.

D. Simulation Results:

For the sake of simulation, it is assumed that in the system shown in Fig. 1, a three-phase to ground fault occurs on bus 8 and lasts for 200 ms. This fault stimulates oscillation of the system. Figs. 5 and 6 show the rotor speed difference between G1 and G3 and the rotor speed difference between G1 and G2 as well as their damping behavior in two situations of with and without FLWADC. The inter-area oscillation is measured by rotor speed difference of G1 and G3 and the local oscillation is measured by rotor speed difference of G1 and G2.

As shown in Figs. 5 and 6, in the case without FLWADC, the system experiences severe fluctuations with very low damping. However, the supplementary controller of FLWADC leads to an effective damping of oscillations after the event of fault.

TABLE I
DELAY VALUES IN VARIOUS COMMUNICATION LINKS [32]

Communication link	Associated delay (ms)
Fiber-optic cables	100-150
Digital microwave links	100-150
Power line (PLC)	150-350
Telephone lines	200-350
Satellite link	500-700

III. IMPACT OF TIME DELAY ON THE CONVENTIONAL FLWADC PERFORMANCE

In the preceding section, it was revealed that an ideal FLWADC (ignoring time delay) can effectively damp inter-area and local oscillations in power systems. However, this is not the case in the real world where we have communication delays in WAMS signals. That is, the feedback input signals are received at the controller station after a while and the control command applies in the system after a time interval. This section intends to illustrate how a conventional FLWADC responds in the presence of time delays.

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First, brief reviews on communication links used in WAMS along with their typical time delays are presented; then, the simulation results are given.

A. Communication Links Communication links employed in WAMS include both wired (telephone lines and fiber-optics) and wireless (satellites and microwave links) options. Delays associated with the specified links act as a fundamental indicator to the amount of time-lag happening before the action is commenced. The followings are among the communication options for WAMS:

• Telephone lines: The main advantage of telephone lines is that they are easy to install and also cost-effective to use.

• Fiber-optic cables: The benefits of utilizing fiber-optics include its immunity to RF & atmospheric interference, and its considerable bandwidth that can be used by the utilities for other telecommunication needs [31]. In spite of high investment cost, fiber-optic cables are nowadays quite standard and broadly deployed by utilities.

• Satellites: The disadvantages of using a satellite are its high cost, narrow bandwidth, and associated link delays.

• Microwave links: Microwave links have been used by utilities to a great extent. These links are considered as a better option compared to leased lines, since they are easy to set up and are highly reliable. Signal fading and multipath propagation are the main disadvantages of microwave links. High-speed data rate capability and noise immunity of digital microwave links makes them a more suitable choice than analog microwave links to serve the needs of utilities [32].

Table I indicates the typical values of time delays in various communication links. Also, practical experiences and statistics of PMU deployments could provide other useful data for the sake of simulation and performance analysis of WAMS [32].

B. Latency Computation From Time-Stamp Information The phasor data concentrator (PDC), or super PDC, is used to communicate remote signals from PMUs to the control center.

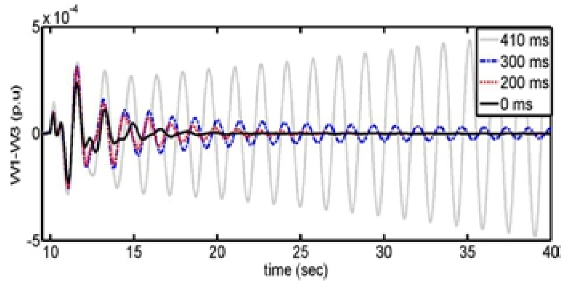

Fig. 7. Impact of time delay on conventional FLWADC performance (interarea oscillations).

The global positioning system (GPS) renders an exact timing pulse. By exploiting the GPS signal, the WAMS precise time synchronization is accomplished. The main task for PDC is to synchronize the measurements of entire PMUs and to send the data every 20 ms to the control center. In the case of congestion in one or more communication lines, the PDC waits until completing the data of all PMUs. Hence, the total delay of delivering the WAMS data for control center applications is the latency of most congested line plus the time needed for synchronization. Once the PDC has gathered the data from all channels, it starts sending the data to the control center at a much faster rate (1kHz max) until it clears the back-log. More likely the damping controller is not located at the control center; thus, a fraction of data are sent toward the controller location. The total latency of received data is calculated by subtracting the local time at the control center or the damping controller location from the instant of origin at the PMU locations [33].

C. Simulation Results The simulations in previous section are repeated again with considering the latency in feedback signals and the conventional FLWADC. Based on Table I, three different amounts of latency are considered: 200, 300, and 410 ms. Simulation results are shown in Fig. 7. It can be seen that with an increase in the time delay of remote signal, the conventional FLWADC performance diminishes more and more. Fig. 7 shows that with the time delay of 300 ms, the inter-area oscillations are not damped well, while the system is still stable. However, for the time delay of 410 ms, the system becomes unstable. Based on simulation results, for longer time delays, the controller does not damp the oscillations and the destructive action of the controller can even make the system unstable.

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IV. ROBUST FLWADC WITH LATENCY COMPENSATION

When the time delay was considered in remote feedback signals, the FLWADC could not effectively damp the oscillations. Furthermore, in latencies more than a certain value (about 400 ms), the controller even destabilized the system after the fault. In this section, the FLWADC is redesigned with the purpose of compensating the destructive effect caused by time delays. Accordingly, in addition to the inputs of conventional FLWADC, another signal indicating the latency of feedback signals till the SSSC location is fed to the controller. To compensate for the effect of time delay, rule bases of the proposed robust FLWADC are devised in a way that the membership function of the output variable is shifted as a function of the remote signal latency.

The crucial issue that the designer should consider is the amount of output membership function shift with respect to the amount of delay in remote feedback signals. If the shift is inconsistent, the controller cannot compensate for the destructive effect of the latency and would work improperly. Generally, the process of membership function establishment is a heuristic but uncomplicated endeavor and mainly depends on the experience and knowledge of controller designer. For each input and output signal of a fuzzy controller, a real-number interval as the universe of discourse is readily defined by the help of observation or simulation tools.

The universe of discourse of each fuzzy variable is then quantized into a number overlapping fuzzy sets [18]. The number of sets is an odd number and depends on the sensitivity of the output with respect to the input variation and the range of corresponding universe of discourse. A preprocessing study and simulation stage would be an effective solution for the membership function establishment. In the designed FLWADC in this paper, it is assumed that the signal latency lies within 0 to 700 ms which absolutely covers the practical cases [32]. Hence, the proposed rule-base has practical merits and could be of interest for the practitioners of real systems.

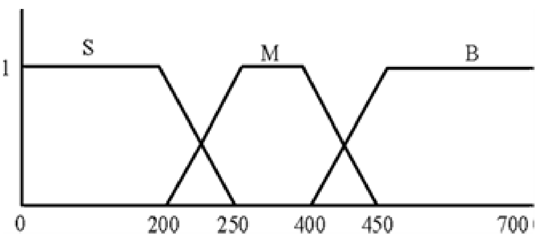

Fig.8. Membership functions of the third input variable for robust FLWADC.

The membership functions associated with the third input are given in Fig. 8. As it can be seen, the amount of latencies is divided into three intervals (S: small, M: medium, and B: big); thus, three membership functions are introduced for the latency. The rule base of the robust FLWADC is designed so as if the latency is small, the amount of shift will be small and so on. To clarify the problem and how the new input (latency value) is considered in the designing process of FLWADC, some graphs are represented in Fig. 9. In this figure, a hypothetical oscillatory signal of is assumed. Fig. 9(a) illustrates signal at the PMU location, i.e., before transmission. Let us call it signal (a). Fig. 9(b) and (c) displays the same signal at SSSC location with two different time delays, call them signals (b) and (c). In the conventional FLWADC, where the latency is overlooked, signal (b) at the SSSC controller is handled as the original signal (a). Hence, at , it is conceived that is PB and is P and the controller output signal is adopted based on the second rule as PB (see Section II-B). However, at , the original signal (a) has the following values: is PB and is N. Thus, the sixth rule with the output of PM should has been chosen. This point is the origin of controller malfunction demonstrated in the preceding section. For a longer latency, the received signal (c) is depicted in Fig. 9. At is NM and is P associated with the original signal, while is Z and is N are those perceived at the SSSC location. This analysis is the basis for how new rules are developed to compensate for the time delay. Table II outlines the rule base of the delay-compensated FLWADC.

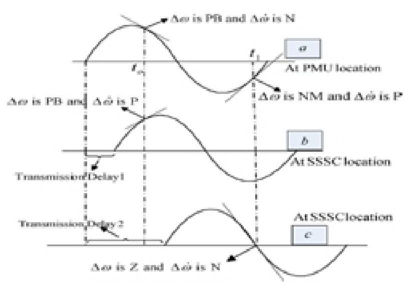

Fig. 9. Hypothetical oscillatory signal of

TABLE II
RULE BASE OF DELAY-COMPENSATED FLWADC.

Time Delay	$\Delta\dot{\omega}$ \ $\Delta\omega$	NM	NB	Z	PM	PB
S	P	NB	NM	Z	PM	PB
	N	NB	NM	Z	PM	PB
M	P	NM	Z	Z	PB	PB
	N	NB	NB	Z	Z	PM
B	P	Z	PM	Z	PM	PM
	N	NB	NB	Z	NM	Z

In the following, the performance of the proposed robust FLWADC is demonstrated. The system situation and the fault stimulating the oscillations are the same as Section II; however, various time delays are considered in the feedback signals. Simulation results of both rotor speed difference between G1 and G3 and rotor speed difference between G1 and G2 are shown in Figs. 10 and 11. As observed in Figs. 10 and 11, unlike the conventional FLWADC which makes the system unstable with 410 ms time delay in remote feedback signals, the proposed new FLWADC preserves the system stability even with larger values of the latency. The new FLWADC effectively compensates the destructive effect of time delay and damps both inter-area and local oscillations.

The structure of the proposed robust FLWADC is very similar to the other fuzzy logic-based damping controllers used in FACTS and PSSs applications. The only difference is that the membership functions associated with outputs are shifted in order to compensate for the latency of remote feedback signals. Thus, the proposed controller has practicality merits and can be designed for operation of various-type controllers in real power systems with multiple areas and several oscillating frequencies. In such cases, it is necessary to design amulti-stage (multi-band) FLWADC similar to a conventional multi-band damping controller [34], [35]. Each of the bands can be used for a special oscillation mode and finally the outputs of the bands are summed.

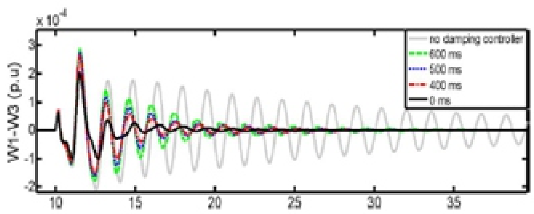

Fig. 10. Rotor speed difference between G1 and G3 damping with new FLWADC and various time delays.

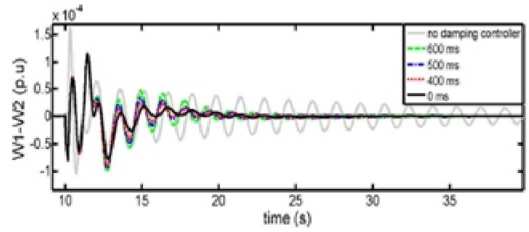

Fig. 11. Rotor speed difference between G1 and G2 damping with new FLWADC and various time delays.

up and passed through a final limiter producing the stabilizer output. This subject is investigated in the following where the performance of the proposed FLWADC is disclosed in a system with three areas and two interarea oscillation modes.

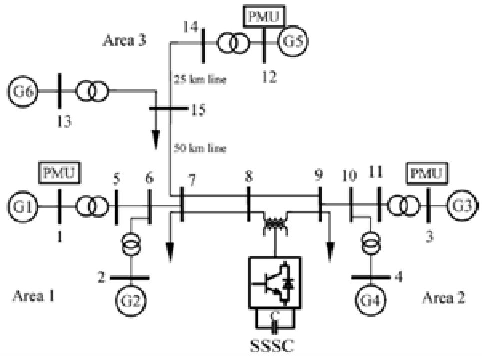

Fig. 12. Schematic diagram of the three-area test system with SSSC.

The studied two-area benchmark system is expanded here to a three-area power system, shown in Fig. 12. A detailed description of the modified system including its excitation system and network parameters were given by [36]. The rotor angle oscillation modes of the modified system, obtained by Eigen value analysis, consist of five oscillation modes: three local and two interarea modes [36]. The inter-area mode 1 is characterized by having a higher frequency (0.78 Hz) than mode 2 (0.46 Hz). Mode 1 consists of generators of area 1 (G1 and G2) swinging against those of area 3 (G5 and G6). While, mode 2 consists of generators of area 2 (G3 and G4) swinging against those of areas 1 and 3 (G1, G2, G5, and G6). Like before, in the modified system, the power oscillation damping can be achieved by properly modulating the SSSC injected voltage. A simple two-stage FLWADC is proposed which is represented in Fig. 13. It is evident that to damp out multimode oscillations, a suitable supplementary signal containing both modes of oscillations is necessary.

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In order to modulate the SSSC reactance for damping two inter-area oscillation modes, any signal with adequate modal observability of inter-area oscillations, such as inter-area tie-line powers or voltage angle differences between buses in different areas, could be used as the feedback signal. The modal analysis of the interconnected system, the PMU historical recordings, and the system practitioners' experiences could be valuable sources in this regard.

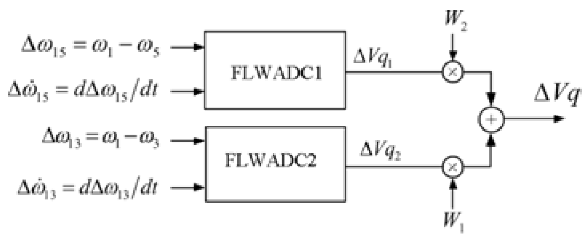

Fig. 13. Two-stage FLWADC designed for three-area power system.

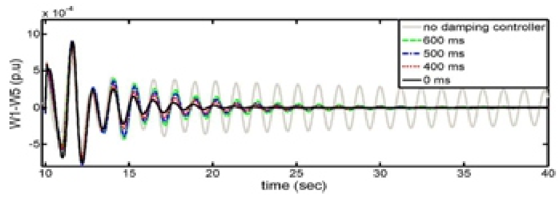

Fig. 14. Rotor speed difference between G1 and G5 (mode 1) damping with two-stage FLWADC and various time delays.

Here, for damping the inter-area mode 1 (0.78 Hz), FLWADC1 is used whose inputs and also, FLWADC2 is employed to damp out the oscillation mode 2 (0.46 Hz) with inputs and . The membership functions and rule base of both damping controllers are as Figs. 3 and 4 and Table II. Note that in Fig. 13, the aggregated damping signal is obtained according to (4). Weighting factors and are chosen as inversely proportional to the normalized damping ratio of their dominant mode obtained from the Prony analysis ( ) [34]: (4) Similar to the preceding study, it is assumed that a three-phase self-clearing fault occurs at bus 8 and lasts for 200 ms. The SSSC located at the tie line between buses 8 and 9 is equipped with the proposed two-stage FLWADC. The simulation is repeated with respect to various time delays associated with remote feedback signals as well as a case with no damping controller. The time response of generating units' rotor speeds are illustrated in Figs. 14 and 15. As observed in these figures, the robust FLWADC successfully damps out both oscillation modes 1 and 2 through effective compensations of the destructive effect caused by feedback signal latencies.

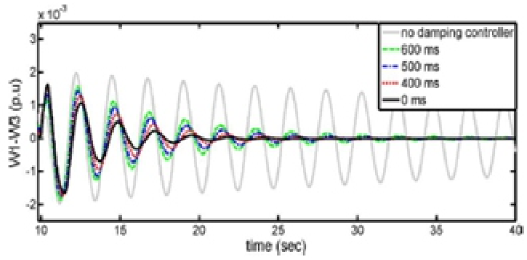

Fig. 15. Rotor speed difference between G1 and G3 (mode 2) damping with two-stage FLWADC and various time delays.

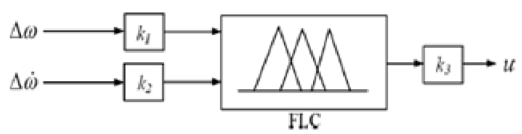

Fig. 16. Main structure of FLWADC with input and output scaling factors.

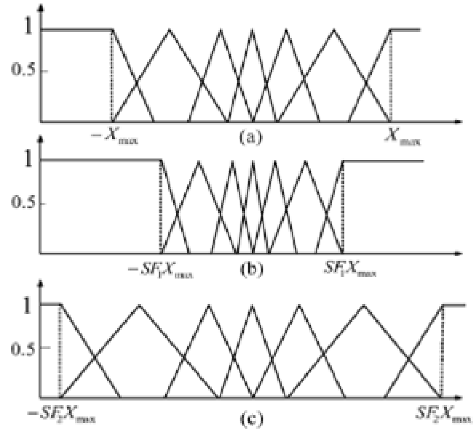

Fig. 17. Changes in the output membership functions: (a) original and normalized, (b) compact, and (c) expanded.

V. SENSITIVITY ANALYSIS:

In this section, the performance of the proposed robust FLWADC is investigated by a set of studies when parameterschange or the system travels to a new operating point.

A. Changes in the Controller Parameters:

In designing the fuzzy controller, by modifying the scaling factors (SFs) associated with a certain parameter, the controller's working range with a satisfactory performance might decrease or increase.

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In Fig. 16, and are the input SFs and is the output SF. Technically, and change the sensitivity of controller with respect to input signals and can adjust the FLC gain. One vital issue, commonly studied in wide-area damping controller design, is the impact of controller gain, , on the damping performance [12]. This subject is scrutinized here. Fig. 17 shows the normalized original triangular membership functions of the output variable and the scaled shapes as well. Fig. 18 shows the conventional FLWADC performance when latency exists in the signals. Simulations show the damping of inter-area oscillations for two values of . The delay margin, defined as the maximum delay of feedback signals in which

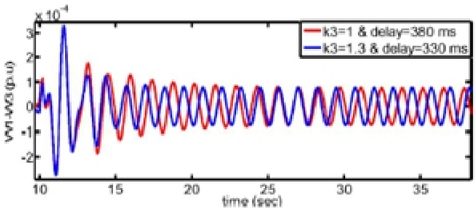

Fig. 18. Impact of on the conventional FLWADC performance when remote feedback signals have latency.

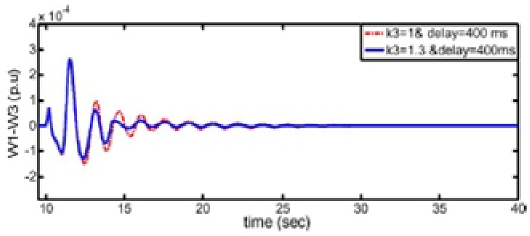

Fig. 19. Impact of on the robust FLWADC performance when remote feedback signals have 400 ms delay

the system stability is preserved, is under study in Fig. 18. As shown, with the increase of from 1 to 1.3, the controller performance deteriorates since a lower amount of time delay is tolerable for the system.

This conclusion is the direct opposite of the preceding section and reveals the importance of latency consideration in the design process of controller. Finally, the impact of increasing on the performance of the delay-compensated FLWADC is explored. Simulation results are shown in Fig. 19. Based on this figure, with 400 ms time delay, increasing from 1 to 1.3 improves the damping of inter-area oscillations..

B. Changes in the System Operating Point:

As discussed in Section IV, the robust FLWADC rule base is written in a way that, with respect to the amount of time delay in input signals, the output membership functions are accordingly shifted. As seen in Fig. 9, the oscillation time period (or synonymously frequency,) is the crucial factor in shifting the output membership functions. When the system operating point transitions to a new set, the frequency of inter-area oscillations changes. Consequently, the rule base devised in previous situation might not work effectively.

This issue is probed here. To change the operating point of the standard two-area system, a severe contingency is considered and one of the 220m tie lines connecting two areas is switched off. Other parameters and the fault characteristics remain unchanged. Simulation reveals that with this reconfiguration, becomes 0.35 Hz from the past value of 0.66Hz. Inter-area oscillations associated with this case study are shown in Fig. 20, where different values of time delays are considered as well. Also, Fig. 20 depicts the system behavior when no controller is assigned to the SSSC.

It is deduced that, when no damping controller exists, the system becomes unstable after the event of the fault. This observation is while the system tolerates the fault in the past operating point. However, when a damping controller is added to SSSC, the system stability is guaranteed even for long time delays in the feedback

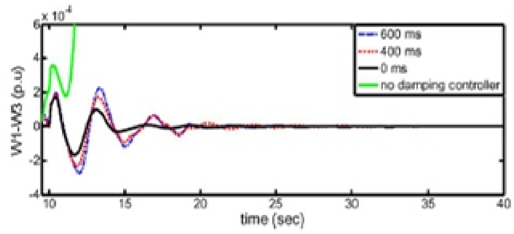

Fig. 20. Damping performance of the robust FLWADC in the new working point.

signals. Other simulations with various operating points verify as well the satisfactory of the proposed robust FLWADC.

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CONCLUSION:

This paper examined the capability of FLC in damping between zone and nearby motions through a SSSC gadget found in one of tie lines interfacing diverse force frameworks. It was demonstrated that an ordinary FLWADC does not work tastefully and may even destabilize the force framework when the info signs have expansive latencies. Thus, considering the sign time postpones in the outline procedure of FLWADC is a crucial attempt in true applications.

It was showed too that when FLC is embraced for the controller gadget and the time deferral exists in the got signals, the guideline bases are connected in a wrong way. In such a circumstance, moving the enrollment capacities of the yield variable is a compelling strategy and legitimately makes up for the time delay. Reproductions results with affect ability examination uncovered that the execution of the proposed inertness remunerated FLWADC is exceptionally vigorous in multi mode motions and against changing the controller addition or the force framework working point.

REFERENCES:

[1] P. Kundur, Power System Stability and Control. New York: Mc-Graw- Hill, 1994.

[2] X. Yang and A. Feliachi, “Stabilization of inter-area oscillation modes through excitation systems,” IEEE Trans. Power Syst., vol. 9, no. 1, pp. 494–502, Feb. 1994.

[3] E. V. Larsen, J. J. Sanchez-Gasca, and J. H. Chow, “Concepts for design of FACTS controllers to damp power swings,” IEEE Trans. Power Syst., vol. 10, no. 2, pp. 948–956, May 1995.

[4] M. Xiao-Ming, Z. Yao, G. Lin, and W. Xiao-Chen, “Coordinated control of inter-area oscillation in the China southern power grid,” IEEE Trans. Power Syst., vol. 21, no. 2, pp. 845–852, May 2006.

[5] X. Xie, J. Xiao, C. Lu, and Y. Han, “Wide-area stability control for damping interarea oscillations of interconnected power systems,” IET Gen. Transm. Distrib., vol. 153, no. 5, pp. 507–514, Sep. 2006.

[6] Real-Time Application of Synchrophasors for Improving Reliability, North American Electric Reliability Corporation, Oct. 2010.

[7] H. Wu et al., “The impact of time delay on robust control design in power systems,” in Proc. IEEE PES Winter Meeting, 2002, vol. 2, pp. 27–31.

[8] H. Ni, G. T. Heydt, and L. Mili, “Power system stability agents using robust wide area control,” IEEE Trans. Power Syst., vol. 17, no. 4, pp. 1123–1131, Nov. 2002.

[9] Y. Zhang and A. Bose, “Design of wide-area damping controllers for interarea oscillations,” IEEE Trans. Power Syst., vol. 23, no. 3, pp. 1136–1143, Aug. 2008.

[10] B. Chaudhuri, R. Majumder, and B. C. Pal, “Wide-area measuremen based stabilizing control of power system considering signal transmission delay,” IEEE Trans. Power Syst., vol. 19, no. 4, pp. 1971–1979, Nov. 2004.

[11] N. R. Chaudhuri, S. Ray, R. Majumder, and B. Chaudhuri, “A new approach to continuous latency compensationwith adaptive phasor power oscillation damping controller (POD),” IEEE Trans. Power Syst., vol. 25, no. 2, pp. 939–946, May 2010.

[12] W. Yao, L. Jiang, J. Y. Wen, and S. J. Cheng, “Delay-dependent stability analysis of the power systemwith a wide-area damping controller embedded,” IEEE Trans. Power Syst., vol. 26, no. 1, pp. 233–240, Feb. 2011.

13] J. He, C. Lu, X.Wu, P. Li, and J.Wu, “Design and experiment of wide area HVDC supplementary damping controller considering time delay in China southern power grid,” IET Gen. Transm. Distrib., vol. 3, no. 1, pp. 17–25, Jan. 2009.

[14] D. Dotta, A. S. Silva, and I. C. Decker, “Wide-areameasurement-based two-level control design considering signals transmission delay,” IEEE Trans. Power Syst., vol. 24, no. 1, pp. 208–216, Feb. 2009.

[15] S.Wang, X. Meng, and T. Chen, “Wide-area control of power systems through delayed network communication,” IEEE Trans Control Syst. Technol., vol. 20, no. 2, pp. 495–503, Mar. 2012.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

[16] S. Xu and J. Lam, "Improved delay-dependent stability criteria for time-delay systems," IEEE Trans. Autom. Control, vol. 50, no. 3, pp. 384–387, Mar. 2005.

[17] M. Zarghami, M. L. Crow, and S. Jagannathan, "Nonlinear control of FACTS controllers for damping inter-area oscillations in power systems," IEEE Trans. Power Del., vol. 25, no. 4, pp. 3113–3121, Oct. 2010.

[18] M. E. El-Hawary, Electric Power Applications of Fuzzy Systems. New York: IEEE Press, 1998.

[19] C. T. Leondes, Fuzzy Theory Systems: Techniques and Applications.London, U.K.: Academic, 1999.

[20] T. Hiyama, "Rule-based stabilizers for multi-machine power system," IEEE Trans. Power Syst., vol. 5, no. 2, pp. 403–411, May 1990.

[21] Hydro-Quebec,, Sim Power Systems User's Guide. Natick, MA, Math-Works, 2008.

[22] R. M. Mathur and R.K.Varma, Thyristor-Based FACTS Controllers forElectrical Transmission Systems. New York: IEEE Press and Wiley Interscience, Feb. 2002.

[23] N. G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible Ac Transmission System. NewYork: IEEE Press, 2000.

[24] A. G. Phadke, "Synchronized phasormeasurements in power systems," IEEE Comput. Appl. Power, vol. 6, no. 2, pp. 10–15, Apr. 1993.

[25] K. Mei, S. M. Rovnyak, and C.-M. Ong, "Clustering-based dynamic event location using wide-area phasor measurements," IEEE Trans Power Syst., vol. 23, no. 2, pp. 673–679, May 2008.

[26] P. Tripathy, S. C. Srivastava, and S. N. Singh, "A divide-by-differencefilter based algorithm for estimation of generator rotor angle utilizing synchrophasor measurements," IEEE Trans. Instrum. Meas., vol. 59, no. 6, pp. 1562–1570, Jun. 2010.

[27] E. Ghahremani and I. Kamwa, "Dynamic state estimation in power system by applying the extended Kalman filter with unknown inputs to phasor measurements," IEEE Trans. Power Syst., vol. 26, no. 4, pp. 2556–2566, Nov. 2011.

[28] L. Zhang et al., "Interaction assessment of FACTS control by RGA for the effective design of FACTS damping controllers," IET Gen. Transm. Distrib., vol. 153, no. 5, pp. 610–616, Sep. 2006.

[29] H. F. Wang, "Static synchronous series compensator to damp power system oscillations," Elect. Power Syst. Res., vol. 54, no. 2, pp. 113–119, May 2000.

[30] I. Ngamroo and W. Kongprawechnon, "A robust controller design of SSSC for stabilization of frequency oscillations in interconnected power systems," Elect. Power Syst. Res., vol. 67, no. 3, pp. 161–176, Dec. 2003.

[31] Radio Subcommittee of IEEE Power System Communications Committee, "Analog/digital microwave considerations for electric/gas utilities," IEEE Trans. Power Del., vol. 8, no. 3, pp. 798–815, Jul. 1993.

[32] B. Naduvathuparambil, M. C. Valenti, and A. Feliachi, "Communication delays in wide area measurement systems," in Proc. 34th Southeastern Symp. Syst. Theory, Mar. 2002, pp. 118–122.

[33] P. Korba, R. Segundo, A. Paice, B. Berggren, and R. Majumder, "Time Delay Compensation in Power System Control," European Union Patent EP08 156 785, May 2008.

[34] R. Grondin, I. Kamwa, L. Soulieres, J. Potvin, and R. Champagne, "An approach to PSS design for transient stability improvement through supplementary damping of the common low frequency," IEEE Trans. Power Syst., vol. 8, no. 3, pp. 954–963, Aug. 1993.

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