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An Investigation of New Control Methods to Improve Damping of Oscillations in Large-Scale Power Systems and a Proposed Control Approach Suitable for Iran Power Network

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ABSTRACT

The stability has become a very important issue in power system operation because of its effects on system performance and especially economic problems due to blackouts. On the other hand, it is essential to prevent the blackout due to the disturbances. Power oscillation is a major cause of blackouts. There are some solutions for damping the oscillations by conventional controllers such as PSSs. Nowadays, there are new solutions by WAMS (based on PMUs) in large scale networks. This paper contains some new approaches and recent research results for damping power oscillations especially for application in Iran network.

KEYWORDS: Power System Oscillations, Damping Control, Wide Area Measurement System (WAMS), Phasor Measurement Unit (PMU), Power System Stabilizer (PSS).

1. INTRODUCTION

With regard to the importance of power systems' performance continuity in electrical loads and also to the expenses the power consumers are to pay for their energy procurement, the concepts of stability and security of power systems have found a special place. There is usually a reverse relationship between economic considerations and procurement of power system security: higher levels of investments are required for more security. Therefore, all attempts to eliminate sudden faults at a power system should be performed in such a way to minimize the possibility of changing power disturbances to chief incidents such as wide-ranging blackouts. In such disturbances, power oscillations in power systems have always constituted a chief concern of different operators. With their frequency range of 0.1 to 2 Hz, electromechanical Low-Frequency Oscillations (LFO) are innately classified in power systems. Different issues have been ensued from the insufficient damping of such oscillations during the history of power systems. Electromechanical oscillations are of the following types [1]:

- Inter-plant mode oscillations;
- Local plant mode oscillations;
- Inter-area mode oscillations;
- Control mode oscillations;
- Torsional mode oscillations.

Inter-area oscillations have caused numerous separations in power systems, with many of which provoking wide-ranging blackouts in power networks. Some of the considerable events are as follows [1]:

- Detroit Edison, DE-Ontario Hydro (OH)-Hydro Quebec (HQ) in the 1960s and 1985;
- Finland, Sweden, Norway, and Denmark in the 1960s;
- Saskatchewan-Manitoba Hydro-Western Ontario in 1966;
- Italy, Yugoslavia, and Austria (1971 to 1976);
- Western Electric Coordinating Council (WECC) in 1964 and 1996;
- South eastern Australia in 1975;
- Scotland and England in 1978;
- Western part of Western Australia in 1982 and 1983;
- Taiwan in 1985;
- Ghana and Ivory Coast in 1985;
- Southern Brazil in 1975, 1980, and 1984.

In addition to above-mentioned cases, Iran Statewide Power Network has experienced oscillations [2 and 3], which have constituted main concerns voiced by relevant experts. Different methods have been used to address this problem, among the most conventional of which one may refer to designation of various stabilizers and controllers. A conventional controller to eliminate leading between electrical moment and referent's input voltage, Power System

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Stabilizer (PSS) is designed in voltage regulator of the generator, containing a gain, phase compensation blocks, a washout filter, speed of inputs, frequency, power, and output limiters [4]. Fig. 1 exhibits a generic PSS model.

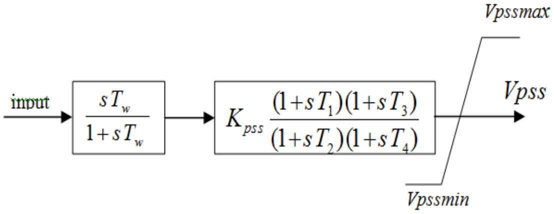


Fig. 1: conventional, simple transfer functions in PSS studies [5]

Yet, using another approach, many studies have addressed supplementary controllers through system controls and different instruments especially Flexible AC Transmission System (FACT) and High-Voltage Direct Current (HVDC) transformers. Since in this state, in which damped oscillations in power systems are focused, designed control is referred to as Power Oscillation Damper (POD) [6-13].

As application of Phasor Measurement Units (PMU) expands, Wide Area Monitoring and Measurement Systems (WAMS) have found a special place in engineering of power systems, as in estimation of electromechanical characteristics of low-frequency systems to identify oscillation modes [14]. Moreover, advanced WAMS-based stabilizer established aimed at damping of oscillation modes have been addressed in some references (as in [15]) as a Global Power System Stabilizers (GPSS).

In other words, since an identification of remote signals is made possible by inter-area oscillations, in addition to Conventional Power System Stabilizers (CPSS) which work based on local signals (such as generator velocity), a suitable controller may be designed to achieve oscillation damping using remote signals. Since this system serves based on WAMS abreast with conventional local controllers as a supplementary controller in power systems [16], some references [17 and 18] refer to is as Wide-Area Controller (WAC) and some other [19-23] as Wide-Area Damping Control (WADC), the latter of which is widely-used in this article, whose focus is on oscillation damping. Fig. 2 shows the place of this type of controlling as compared to other components of power system.

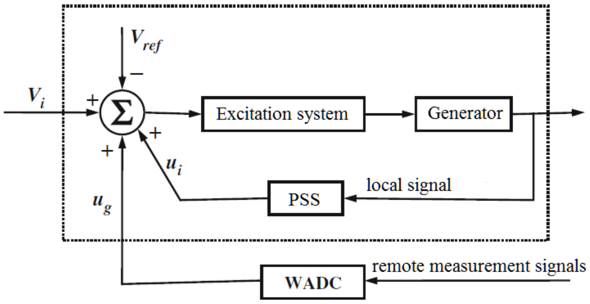


Fig. 2: Wide-Area Damping Control (WADC) and Wide-Area Controller (WAC) alongside PSS

Although such controls are differently designed and implemented, the issue of power system oscillation damping is addressed in all of them. Increasing number of such studies in the recent year is indicative of its importance and researchers' focus on introduction of new techniques using modern technologies. As Iran Statewide Power Network has experienced a number of oscillations and WAMS is implemented therein [24], appropriate solutions can be suggested to resolve existing problems. In addition to addressing newly conducted research in both inside and outside of Iran, this study is intending to compare and juxtapose current methods and approaches in order to propose an approach to improve Iran Statewide Power Network's oscillations.

2. Different Control Methods for Oscillation Damping

In this section, different kinds of control methods to improve power system oscillation damping, especially in new research, are reviewed.

2.1. Methods Based on Configuration of Conventional Stabilizers

Importance of application and configuration of power systems stabilizers is so high that methods for calculation of prices of ancillary services are proposed in new articles. In [25], for instance, a method for calculation of price of PSS's impact on Small Signal Stability Index (SSSI) is suggested through defining the index as to damping of the most critical system mode.

The reference [26] expresses a method to identify electromechanical modes for the IEEE 39-bus system, damping ratio of oscillation modes before and after retuning through phase compensation [27 and 28]. Fig. 1 demonstrates impacts of retuning in terms of percentage. This is observed that retuning has made a 50 to 373 percent improvement in damping of oscillation modes. This improvement may be, however, changed as operation conditions alter.

Modes	Damping ratio before retuning (percentage)	Damping ratio after retuning (percentage)	Impact of retuning (percentage)
1	-5.56	4.24	176
2	-6.53	3.42	152
3	-4.29	3.75	187
4	1.24	5.86	373
5	4.68	8.24	76
6	1.76	7.98	353
7	2.89	6.28	117
8	6.4	10.37	62
9	3.47	6.82	97
10	5.16	7.76	50

Table 1: investigation of retuning impacts on damping of oscillation modes of the IEEE 39-bus system using findings of the [26]

In the [29], a method was presented to retune existing stabilizers for desired modes that extracts an open-loop transfer function from the present stabilizer for the whole system using PMU-obtained measurement amounts. For this function, afterwards, new stabilizers are designed for damping the modes in question using the classic method. Accordingly, then, new parameters of stabilizers are determined. Although, this method cannot ensure that no interference happens among performances of stabilizers.

Impacts of inaccurate configurations in power system stabilizers of Iran Statewide Power Network on oscillation damping are addressed in the [3], where behaviors of the Network in case of disturbances in both absence and presence of PSS are examined. This research has taken into account the complete model of network generator with relevant excitation systems. In order to investigate oscillations, response of the network after fault occurrence in t=1 sec. in Aliabad-Esfarayen inter-area and outgo of his line in t=1.1 sec. is studied. Diagrams for rotor angel (in terms of degrees) in different states are exhibited for Shirvan and Nishabour Power Plants in Khorasan as well as Neka Power Plant in Mazandaran. Figures 3, 4, and 5 display above quantities after occurrence of fault with/without network stabilizers in configured/misconfigured states. This is witnessed that when stabilizers are not well controlled, rotor angel oscillates—the oscillation which is lowly damped in such a way that it is still in the network even after 100 seconds. The important point is that inaccurate configuration of PSS neither improves damping nor leads the network to stability. Comparing figures, this is seen that addition of manufacturing units with active, relatively-configured stabilizers can improve oscillation damping. Consequently, appropriate configurations particularly in such large-scale systems as Iran's Network are of paramount importance. Modification of operation conditions and network's operating points are also seminal, being able to allow for reduction in impacts made by stabilizers.

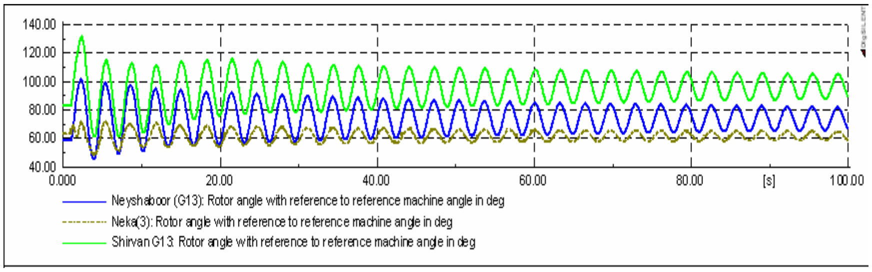


Fig. 3: diagram for rotor angel simulation in three Iranian power plants after occurrence of an event in which stabilizers were inactive [3]

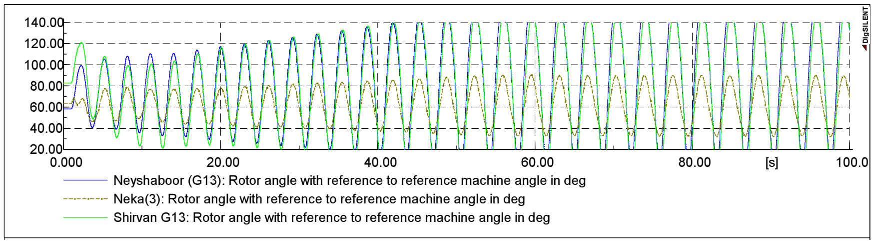


Fig. 4: diagram for rotor angel simulation in three Toos, Shirvan, and Neka Power Plants after occurrence of an event in which PSS was activated, but improperly configured [3]

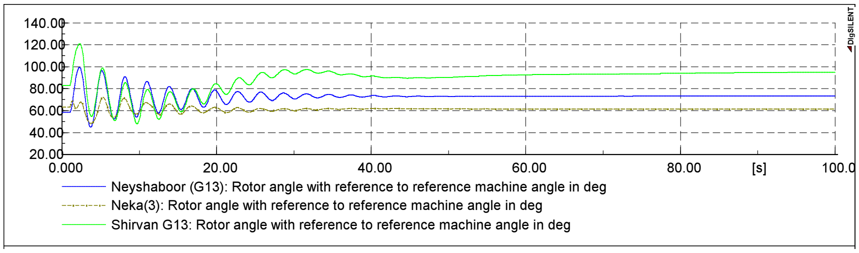


Fig. 5: network's response with PSS being activated in Toos, Shirvan, and Neka Power Plants where parameters were relatively configured [3]

2.1.1. Configuration of Existing Stabilizers with Optimization Methods

In some articles, existing stabilizers are configured with optimization methods. Through expense functions, which are mainly defined based on amounts of oscillations, configurations that minimize such oscillations are found and expressed to be applied in controllers. The reference [30], for example, found the optimized parameters for a 612 MW Korean Power Plant using time simulation. It examined, moreover, the related model and efficiency of its parameters' configurations. This plan has, although, not used remote signals for power system.

Using cultural algorithm, the reference [31] drew upon configuration of multi-machine power system stabilizers, comparing the results with genetic algorithm. It indicated that cultural algorithm is sooner to arrive at the final response. In addition to displaying simulation results, this reference used a conventional index for expression of system oscillations known as the Integral of the Time Multiplied Absolute Error (ITAE), as defined in equation 1:

$$\mathrm{ITAE} = \int_0^t \sum_{i=1}^{n} t|\Delta\omega_i|\, dt \qquad (1)$$

Where, t is time and $\boldsymbol{\Delta\omega_i}$the amount of velocity changes of the generator *i*. In fact, the area under oscillation curve with time weighted coefficient is taken into consideration in order to prevent from a reduction in oscillations' significance as they protract to become damped. Therefore, the configurations which minimize the function are the desirable response. Since duration of the calculations in this method is some minutes, its online application seems unlikely.

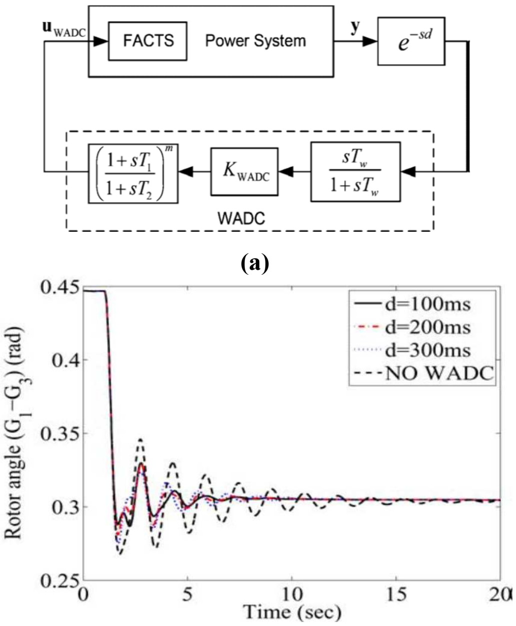
2.2. Designing New Controllers

Aimed at stabilizing power system, both application of modern equipment such as those working based on HVDC and FACTS and classic methods as well as utilization of new control methods like resistant and adaptive methods are addressed in different research, to which are referred in this section.

2.2.1. Classic Controllers for Oscillation Damping

The reference [20] presets an approach for classical designation of WADC for power system in which remote signal delays are considered. This study applies a leading-lagging control and designs a WADC control for desirable performance of FACTS instruments after extraction of a linear model based on signals appropriate for power system and sufficient reduction of its ranking by classic method. As shown in Fig. 6a, this reference considers a structure similar to conventional power stabilizers. Regarding a special block, the reference considers signal delays for required margin based on Linear Matrix Inequalities (LMI) method.

As observed in in Fig. 6b, the four-machined simulation system, response of performance of the closed-loop system is better than the condition where no control exists. Thus, this response is changed with consideration of signal delays. Considering some contingencies of the power system, this reference shows efficiency of design control by nonlinear simulation of several systems. Constant impedance model is applied in this work; while, uncertainty ensued from this issue may overshadow dynamic efficiency of the control process with regard to load diversity in the power system. In addition, impacts of multiple time-varying delays (related to different signals) are disregarded in the reference [20] in inter-area oscillations damping designation.



(a)

(b)

Fig. 6: WADC for FACTS instruments: (a) structure, (b) system response [20]

2.2.2. Adaptive Controllers for Oscillation Damping

The reference [16] expresses general structure of the Fig. 7 for adaptive control-based stabilizers. In this general structure, real output of the system is used for parameter identification/estimation of the system and, accordingly, for determination of relevant parameters and controller.

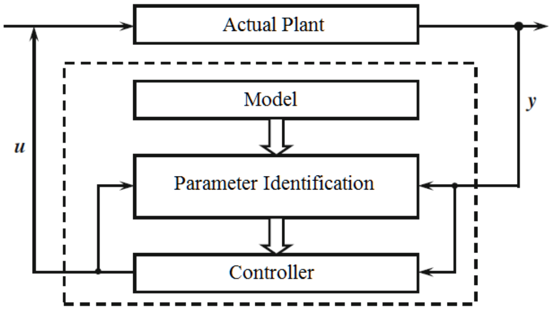


Fig. 7: general structure of adaptive control

Investigating the problems confronted by conventional stabilizers such as the time-consuming process of retuning and uncertainties of optimized performance in different work points, the reference [32] made attempts to overcome such problems by a suitable Proportional-Integral (PI) adaptive control law. Authors of this study enhanced the Improved Simple Adaptive Control (ISAC) in a Model Reference Adaptive Control (MRAC) mode, as shown in the Fig. 8. Moreover, relationship diagram between designed stabilizers along with other system components including AVR and the generator connected to infinite bus are presented in the Fig. 9.

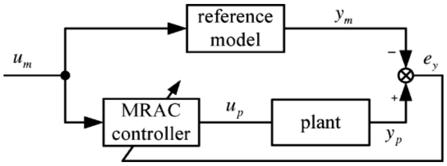


Fig. 8: MRAC structure [32]

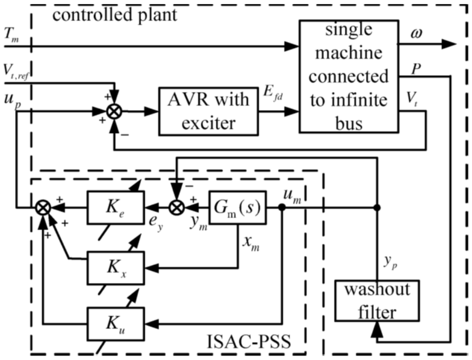


Fig. 9: model reference adaptive stabilizer [32]

Aimed at improvement of oscillations damping, the [33] used WAMS data as controller input, in which delays resulting from PMU information measurement and development, which are transmitted by telecommunication systems, are taken into account. In this study, the related adaptive control structure is designed and operated to control one of FACTS instruments in order to improve inter-area oscillations, as formed in the equation 2.

$$G_c(s,T_d) = K(T_d)\frac{1+T_1(T_d)s}{1+T_2(T_d)s}\frac{1+T_3(T_d)s}{1+T_4(T_d)s}\frac{T_w s}{1+T_w s} \tag{2}$$

This transfer function is much similar to stabilizers common in power systems including gain (k), lagging/leading block, and a washout filter block. The main difference of this controller is dependency of its entire parameters (save for time constant of the washout filter) to delay time parameter (T_d), based on which transfer function parameters are tuned and, thus, this control is adaptive. The amount of delay is dependent on PMU measurement and calculation speed and also on information transmission speed in pertinent telecommunication contexts that may maximally change up to 150 milliseconds. Fig. 10 shows the performance structure of damping controller and information transmission therein.

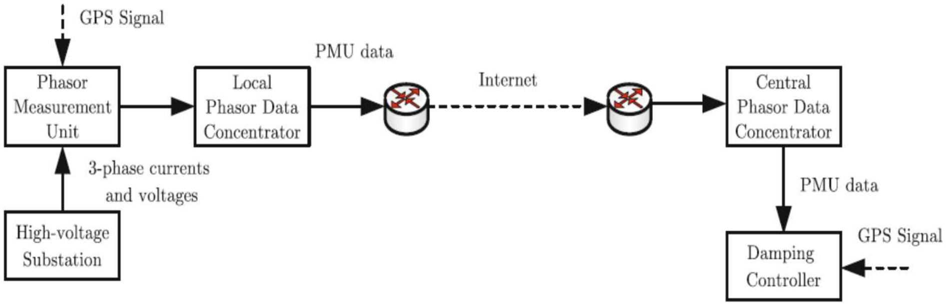
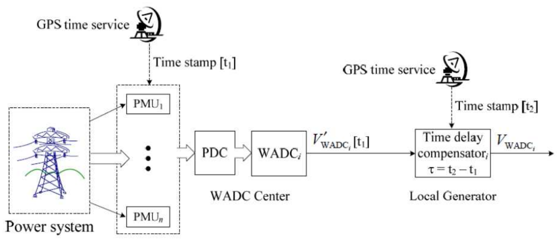
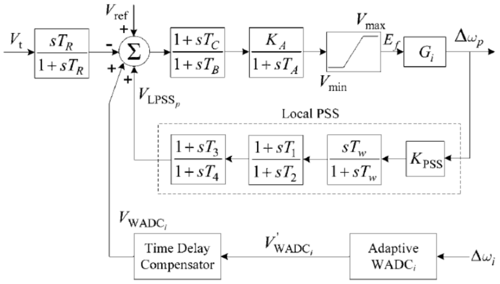


Fig. 10: a design for damping control and information transmission therein [33]

The reference [34] considers WAMS remote signals for measurement and transmission of input signals in the control system. It uses the Subspace System Identification Technique (SIT) to find a low-ranked model for the power system. Using the suggested plan, it then follows online WADC tuning in an adaptive manner. This study pays attention to system uncertainties and compensation of delays ensuing from remote signals. This reference uses a linear model for power system to apply intended controls and, as observed in the Fig. 11, control process of the wide-area is performed by a structure similar to a conventional Local PSS (LPSS) with a delay compensator, which, together with local stabilizers, are applied to the system. This study has ignored the changes ensuing from system contingencies and probable nonlinear behaviors in the power system.



(a)



(b)

Fig. 11: structure of wide-area damping controller: (a) general relations, (b) linearized model [23]

2.2.3. Damping the oscillations with Robust Model Controls

Since power systems are subject to ever-changing conditions, their controls should be robust. The robustness means efficiency of the controller against power system uncertainty. In some references, damping control is formulated under norm optimization problems. H^{∞} and H^{2} norms are minimized in a proper manner under Linear Matrix Inequalities (LMI) to achieve desirable and stable behaviors. Both centralize and decentralized control structures are used. For instance, different control structures and responses proposed in [35] are useful for Wide-Area Control Systems (WACS) by Phasor Measurement Units (PMUs) synchronized to assure confident performance by interconnected power systems.

Reference [11] tried to control power oscillations damping (POD) using a large-scale photovoltaic system. It, therefore, considered the Linear Quadratic Gaussian (LQG) control method for a power system with $(t)\phi$ uncertainty and unity-covariance Gaussian white noise process named as $w(t)$ as the Fig. 12, in which remote measurement signal delays are regarded. In this plan, $\zeta(t)$ is the uncertainty output and $\xi(t)$ the input resulting from the uncertainty model which are examined by the following relations in a linear manner.

$$\Delta x = A_1\Delta x(t) + B_1\Delta u(t) + B_2\xi(t) + B_2 w(t)$$
$$\Delta y(t) = C_2\Delta x(t) + D_2\xi(t) + D_2 w(t)$$
$$\zeta(t) = C_1\Delta x(t) \qquad (3)$$

In this reference, the controller degree achieved by reduction methods is minimized by maintaining frequency behavior features and performance of closed-loop is validated by power system nonlinear simulations. In addition, robustness of the relevant controller is evaluated after different system operation modes are examined.

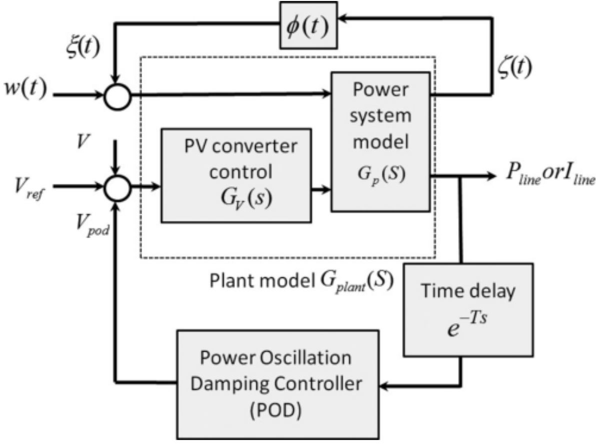


Fig. 12: general relations of POD control for large-scale photovoltaic system [11]

[36] examines LQG control using Kalman Filter based on Fig. 13, in which system state space matrixes (A, B, C), Error L feedback matrix, and v and w noises are considered. The important point is that weighted coefficients are determined in control design target function based on system modes. The modes whose damping is to be improved are of higher importance in designs and, thus, they are called Modal Linear Quadratic Gaussian control (MLQG). In said control design, a flowchart is presented in which network contingencies (generator outputs, lines, and power transformers) and even cessation of control signal are investigated in order to improve robustness.

Moreover, POD damping control structure is operable using HVDC lines in centralized and decentralized modes, which are shown for instance in Fig. 14 as signal relations in two plans for a power system with five areas [37].

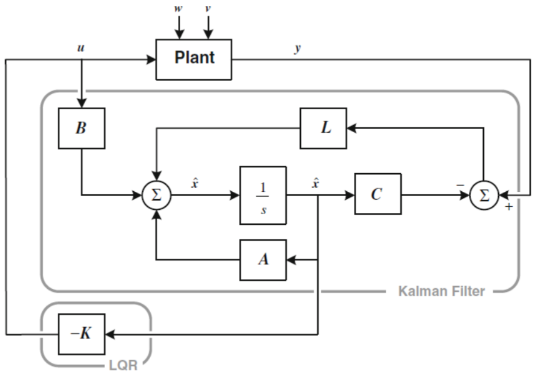
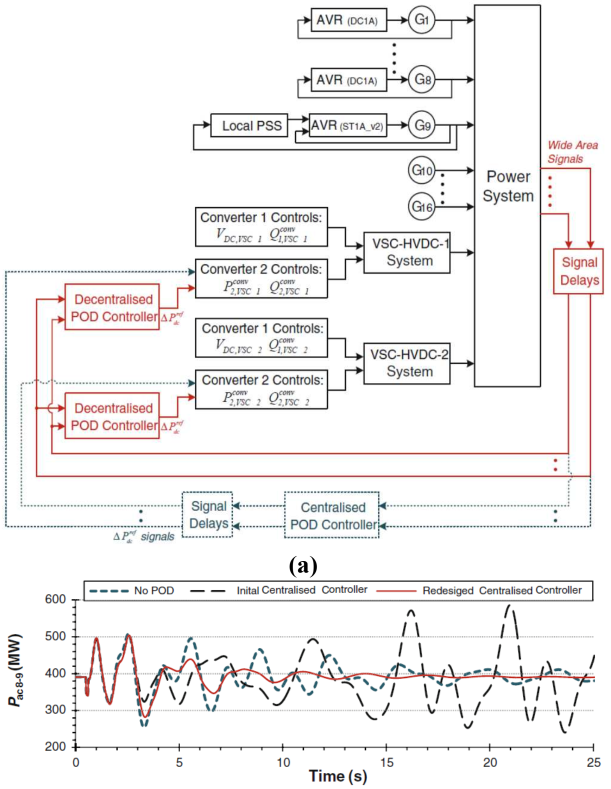


Fig. 13: LQG standard structure used in damping improvement of modes in MLQG design [36]



(a)

(b)

Fig. 14: WAMS-based damping control with HVDC for a sample network: (a) signal relations, (b) an oscillation control simulation sample [37]

In this power system, two HVDS lines are used for inter-area relations and attempt are made to, utilizing delayed large-scale system signals, design and operate the damping control for inter-area modes so as to apply ΔP_{dc}^{ref} signals as control signals for power change amount of each HVDC systems. In this reference, however, designs are made on the basis of system linear model and special values analysis, and uncertainties ensuing from system nonlinear behaviors are not discussed. It, on the other hand, tries to apply the effects of events on system mode translocations and, thus, finding critical modes.

The next point is the delay of signals whose impacts are higher in centralized than decentralized control. In the reference [9], its impact on damping coefficient of vacillatory modes of a power system, for whose damping a similar controller with MLQG is designed, was evaluated, as shown in the Fig. 15. This is indicative of a considerable impact of signal delays on control target, since damping coefficient is significantly decreased as this delay is expanded. In addition, this reference compares the mode with the one in which no damping control is considered. For instance, signal delays higher than 771 milliseconds result in inefficiency of damping controller so that the damping coefficient is decreased—even less than the condition in which no damping control is considered. Consequently, robustness of control against signal delays should be considered in designs. Of course, one of the next certainty performance threats of this control is loss of feedback signals, for which the controller is designed in Multi Input/Single Output (MISO) manner.

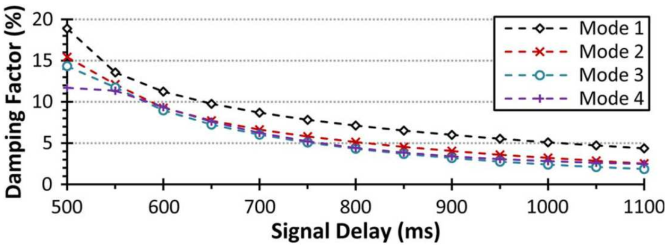


Fig. 15: reduction of damping coefficient with increased signal delays for damping control designed for a sample power system [9]

Contingency aspect of MLQG damping control is also investigated. For instance, performance of closed-loop for above-said power system was studied in different performance conditions and HVDC operation. In the Fig. 16, loci of power system modes were obtained to examine their location as to damping areas. This figure, which is obtained for a sample system, indicates that some system modes such as mode 2 may have very low damping under certain conditions. Such investigations are carried out as per the system linear model, and the system may be subject to more threats under nonlinear performance.

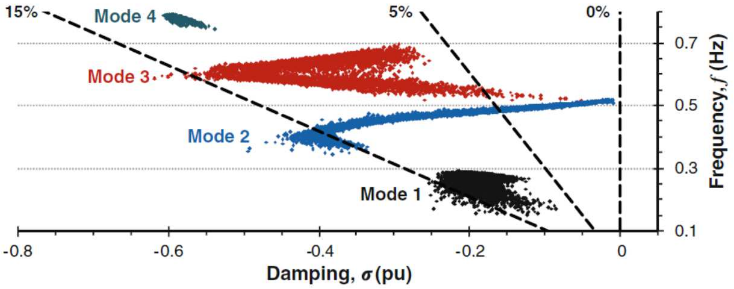


Fig. 16: loci of sample system modes under different conditions [38]

In addition to constant changes in network performance, one of the most prevalent indeterminacies and uncertainties of the power system is load model that has significant impacts on stability and is required for designation of a robust control. This is more evident for behavioral model of mechanical loads like motors. In the [39], its effect on system stability especially in the presence of robust and non-robust controllers was examined. It concluded that conventional controllers and stabilizers (PSS/PODC) show appropriate behavior with constant impedance model which is usually considered in common dynamic studies. They, however, may fail to produce desirable damping in confrontation with dynamic loads whose number in large-scale power systems may be considerable. Therefore, this reference suggested to utilize Robust Power Oscillation Damping Control (RPODC) in order to make sure of desirable damping. Fig. 17 indicates above issue in comparison with amount of damping moment.

Consideration of controller robustness is very paramount in large-scale networks, since development of an accurate load model in such networks has always been difficult and complex, which can become more sophisticated in such underdevelopment, large-scale networks as that of Iran.

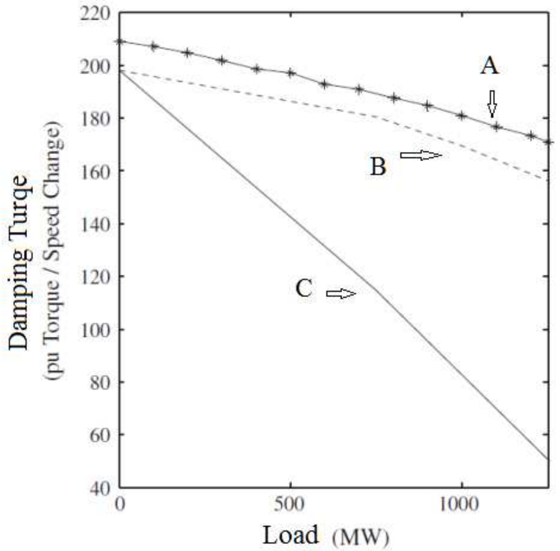


Fig. 17: comparison of system damping moment in three states: (a) PRODC robust controlling in the presence of dynamic load, (b) conventional PODC stabilizer in confrontation with constant impedance model, and (c) conventional PODC stabilizer in confrontation with dynamic load model [39]

2.2.4. Stabilizers and Damping on the Basis of other Methods

There are several stabilization methods based on intelligent algorithms such as fuzzy and neural network. As an example, the reference [40] presents a method to design proportional plus derivative output feedback power system stabilizer (PDPSS) and change it into fuzzy logic system stabilizer (FLPSS), illustrating its efficiency through time simulations in a multi-machine power system linear model. The reference [41], also, presents a predicting control for damping oscillations of a wide-ranging power system. It evaluates the power system mode space model based on measured WAMS signals in a periodic manner and accordingly presents required control parameters for different operational conditions.

3. The Approach Suggested for Iran's Power Network

Iran's statewide power network has experienced oscillations [2 and 3], which have constituted main concerns voiced by relevant experts and operators. Different attempts have been made to extract oscillatory modes and the reasons thereof. This is on the verge of a significant advancement by installation and development of a statewide measurement and monitoring system using PMU. Conditions of the network are tried to be examined in this section using the data registered in the Iran Center for Monitoring Phasor Data with a rate of 25 samples per second.

3.1. Case Study

To investigate dynamic behavior of Iran's Network, responses of this network after an event in two different times, i.e., one summer day and one winter day, are presented. This event related to deactivation of the only Iran's nuclear power plant due to internal technical problems happened in 5 Jan. 2014 and 30 June 2014. To make better comparisons of the network's responses, passing power from one of the 400 kilowatt lines at EG916 Chaghadak Station in the vicinity of the power plant is investigated. The power plant is supposed to be deactivated in t=1 sec. Figures 18 and 19 exhibit the changes of this quantity for the first and second event, respectively. At the first glance, comparisons show that damping speed of the network's oscillations is lower and vacillatory ranges are higher in the summer day.

Comparisons were made using Fast Fourier Transform (FFT) in the Fig. 20 for the range 0.1 to 2 Hz. This is observed that nuclear power plant deactivation provoked different vacillatory modes in two winter and summer working points. Although there are shared modes, the number of unshared modes between the two responses is more.

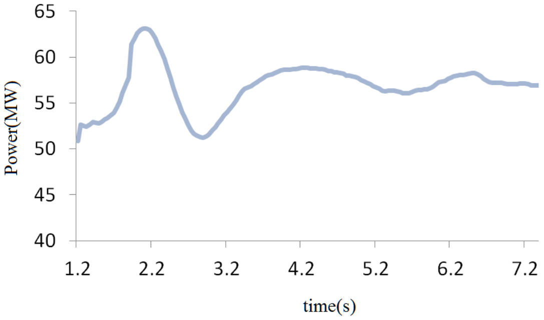


Fig. 18: response of Iran's Network to the event in a winter day

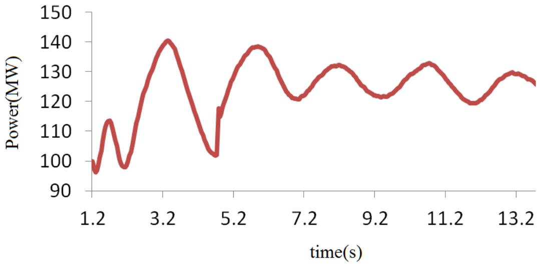


Fig. 19: response of Iran's Network to the event in a summer day

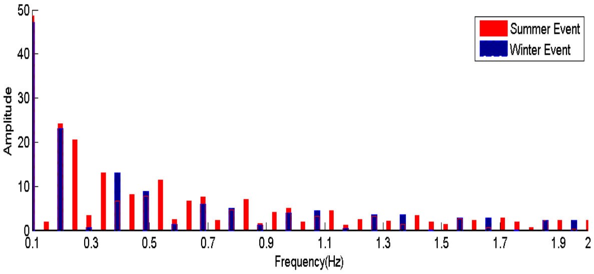


Fig. 20: Fast Fourier Transform (FFT) and comparison between Network's responses

As observed, an event which has occurred in two wholly different working points in Iran's power system has created significantly different responses with various oscillations in one error respecting frequency, scopes, and damping amounts. Though this article does not intend to analyze causes of this event, the difference may have its roots in various reasons such as difference in load level, network voltage, performance of controlling instruments, and their interplays. Certainly, this difference results in considerable uncertainly in prediction of system performance. Therefore, the controls which are designed using instantaneous performance data and based on prediction of system performance may confront serious challenges under such conditions. According to the Fig. 19, changes in nonlinear system behavior are so are so quick that make challenging adaptive control for further coordination thereto.

3.2. A Robust Control Approach for Iran's Network

According to above points, paying attention to uncertainties of Iran's network appears to be of essential importance, particularly since Iran is a developing country with developing networks in which different changes are made in structures and operation methods. According to the analyses made by the [38], robust control approach seems to be more effective in this system. Moreover, as per the discussions made in [39] respecting the impacts of load model on Iran's network, necessity of a robust approach in damping control designs seems to be high. In this approach, although, uncertainty models are firstly to be extracted that the relevant control against them is robust. These models can be extracted on the basis of different network contingencies or structural and operational parameters. In this regard, for instance, the uncertainty modeling approach presented in [42] may be adopted. On the other hand, control designation in this approach may be performed with consideration of measurement signal uncertainties, including signal delays whose modeling is feasible in robust control. In robust approach, thus, remote WAMS signals can be adopted to control network's oscillation damping.

The next advantage offered by this approach is that uncertainty models can contain uncertainties of tunings of other control instruments like conventional stabilizers. WADC can be designed in such a robust way to prevent reduction of WADC's efficiency if tuning values of other controllers are changed. Therefore, problems related to Iran's network stabilizers can be eliminated as cited in other sections of the reference [3].

3.3. Proposed Procedure for Designing WADC

In order to utilize remote WAMS signals, firstly the signals whose vacillatory modes are more evident are selected as feedbacks. Then, after the network's controllable instruments that have the highest effects on system oscillations are determined, a nominal model of the network is considered and required power system's uncertainty model is extracted. Then, after robust control is designed be means of different methods such as LMI, efficiency of designed WADC is evaluated in power system's nonlinear simulation. Fig. 21 exhibits the stages for this designation. Certainly, this initial WADC should be examined and procured in the practical implementation stage.

4. Conclusions

According to the points referred to in the present article, the issue of oscillation is one of the most important topics in power networks that has always threatened secure operation of networks. Researchers have applied different methods to address this issue. Among such research especially in the recent years, utilization of WAMS measurement systems has been widely adopted whereby signals are used to identify and control oscillation damping particularly in inter-area oscillations. However, utilization of these signals is subject to some problems due to delays in transmission, reception, and analysis. On the other side, power systems confront different performance conditions and constraints including small disturbances (such as load change and its dynamic behavior model) and large disturbances (like faults and deactivation of main components).

This article examined Iran's power network, investigating the network's responses in real events based on WAMS data. In this regard, robustness of the network's controls was considered as essential due to Iran's network being underdevelopment and changing conditions of the network. This approach is of higher importance regarding control of power oscillations, since it has always been a key concern for operators because of its occurrence background in the network. Also, with regard to commissioning of WAMS system in Iran's network, this is likely that nature of oscillations is firstly identified and then power paths, where oscillations are better observable, are recognized. Finally, wide-area damping control is designed and operated for improvement of networks' oscillations using different methods especially robust control based on PMU signals.

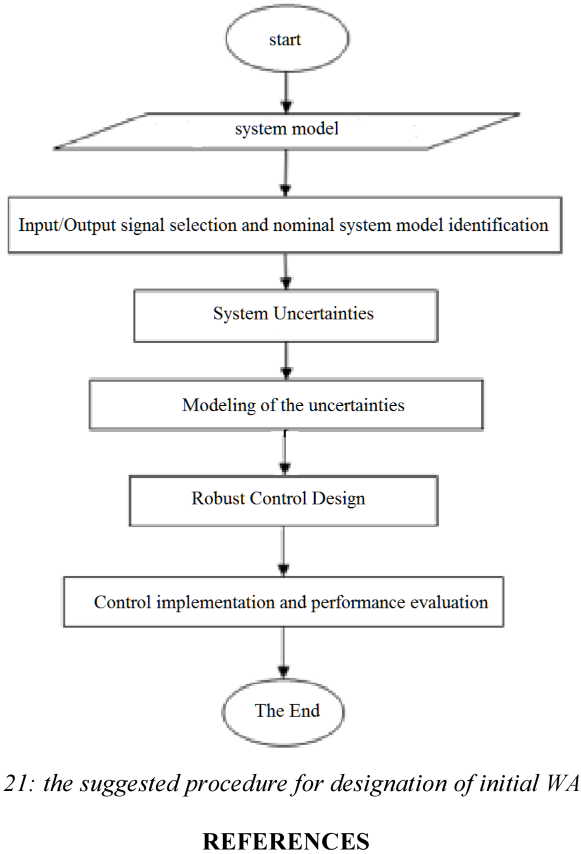


Fig. 21: the suggested procedure for designation of initial WADC

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