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COMPARISON OF EXISTING LFC APPROACHES IN A DEREGULATED ENVIRONMENT

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ABSTRACT

Any power system has a fundamental control problem of matching real power generation to load plus losses, a problem called Load Frequency Control (LFC) or frequency regulation. The purpose of Load Frequency Control is tracking of load variation while maintaining system frequency and tie line power interchanges close to specified values.

With introduction of the deregulation policy to the power system operation, a lot of interests have been recently refocused on the LFC. That is because the conventional controllers are incapable of obtaining good dynamical performance, then, it comes the need for novel control strategies to maintain the reliability and eliminates the frequency error.

Recently, under deregulated organizations, several notable LFC scenarios based on classical, robust/adaptive and intelligent control theorems have been proposed. In this paper by using of obtained results, we make varies comparisons between these approaches and discuss on the main advantages and disadvantages of these methods.

I. INTRODUCTION

Main objectives of Load Frequency Control (LFC) or Automatic Generation Control (AGC) for a power system are: 1- minimizing the transient error of frequency and tie-line power, and, 2- ensuring zero steady-state errors of these two quantities. That is why the Area Control Error (ACE) for each area, in a general formulation, consists of a linear combination of tie-line error (DPtie) and frequency error (Δf),Glover and Sarma (1):

$$ACE = Dptie + Bf.Df$$

The constant Bf is called a frequency bias constant. Cohn (2) has shown that choosing Bf equal to the area frequency response characteristic, $Bf=B$, gives satisfactory performance of the interconnected system.

Two additional LFC objectives are to return the integral of frequency error and the integral of net tie-line error to zero in steady-state.

In power system industry, as the amount of electric energy using open access grows, significant technical problems such as LFC becomes challenging when implemented in a competitive, distributed control environment.

The organizational change associated with open transmission access (deregulation) can be expected to require new technical concepts, new modeling and metering.

The literature on LFC is voluminous; the brief survey that comes in this paper, refers only references that are directly related to our subject. References (2-4) give a detailed discussion of pre-open access LFC. In the pre-deregulation mode (centralized LFC), a system operator executes the LFC algorithm, which issues real power control signals to all generators in a designated geographical control area. In the deregulation environment, these system operators may be companies that own neither generation nor transmission, but control the operation of both as though they do. The effects of deregulation of the power industry on LFC have been addressed in (5-10).

In addition above two modes, there are a number of possible combinations in which centralized LFC exists in parallel with deregulated structure (hybrid LFC market), Christie and Bose (6). The Norwegian network is an example of this state, Gjerde et al (5). In this countries, as metering and communications become cheaper, the number of entities that can participate in deregulation structure will grow.

Under deregulated structure, several notable approaches based on classical, robust and intelligent control theorems have been proposed. Meliopoulous et al (7) and Christie and Bose (10) discuss several LFC scenarios and issues in power system operation after deregulation.

Following this introduction, we list some recently published papers that proposed classical, robust and intelligent based load frequency controller in section II to section IV, separately. The fifth section, makes varies comparisons between these approaches and discuss on the main advantages and disadvantages, based on obtain result in referred papers.

II. CLASSICAL APPROACHES

The conventional control strategy for LFC problem is to take the integral of the control error as the control signal. An integral controller provides zero steady- state frequency deviation but it exhibits poor dynamic performance, Kundur (11), especially in the presence of

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other destabilizing effects such as parameter variations and nonlinearities.

Among the various types of load frequency controllers, the most widely employed is the conventional Proportional Integral (PI) controller (3, 12-15).

To design a classical load frequency controller for power system, first the nominal operating conditions and then a class of linear equations or a mathematical model for system description are derived.

Having this mathematical model at hand, one can used different methods for synthesis of linear controllers. In classical control methodologies, to obtain the desired gain and phase margins, Bode and Nyquist diagrams as well as root locus are usually used. Therefore, the design procedure of classical load frequency controller is straightforward, easy and amenable for practical implementation.

Majority of these methodologies assume a rather accurate modeling of the system to be controlled. The models are commonly derived through linearization of nonlinear equations about the operating point. Analysis and synthesis are based on these models and in case of variations in model parameters; the results are no longer necessarily reliable. Although the effects of variations, in a few design methods, however, the design methods presented up to here have not been aimed at robustifying control system against these variation.

All of the conventional control schemes of LFC have an intrinsic problem that the increase in the frequency feedback gains results in the instability of the LFC loop, which restricts the control range of frequency droop.

III. ROBUST/ADAPTIVE APPROACHES

In power system, there are some deviations and uncertainties due to changes in system parameters and characteristics, load variation, and also, due to errors in modeling and linearizing. In robust control approaches, our objective is to design load frequency controller to not only meet nominal stability and nominal performance requirements, but also guarantee the "robust stability" and "robust performance" in power system on LFC problem, Bevrani (16).

The coming deregulation will increase the severity of the problem. Under this conditions, fixed controllers, such as conventional PI controllers, which are adequate under the designed condition, may fail to maintain the performance of the system at acceptance levels for other operating points.

Recently, several authors applied the concept of robust control theorems to the solution of LFC problem. But large model order, uncertain connections between subsystems, broad parameter variations and elaborate organizational structure preclude direct application of standard robust control methodologies. Due to the complexity of actual uncertainties in power systems, such pre-formatted descriptions are often either unavailable, or overly conservative.

Now, we refer to some references that are related to application of robust control theorems on the LFC problem.

Siljak (17) proposes a Linear-Quadratic (LQ) synthesis framework and a full state-feedback controller in each subsystem, while Calovic (18) presents a decentralized model, much in the same spirit, and with several refinements.

(19-27), use the optimal control techniques to improve the transient response and to achieve better performance. In these approaches, either the feasibility for implementation is still to be established or no systematic methodology is recommended for the proper choice of the equivalent dynamics for the closed-loop system.

Ha (28) shows the application of robust fuzzy sliding mode technique to the LFC problem. Stankovic et al (29), addresses analysis and design issues in LFC by using Quantitative Feedback Theory (QFT).

Several authors (30-32) applied the concept of Variable Structure Systems (VSS) to design of load frequency controllers. The complexity of VSS and the associated chattering problem may be the reason these controllers were not fully appreciated in LFC applications. Furthermore, controllers based on the state equation of the linearized model may require estimates of inaccessible state variables. Observers can be designed for this, but it would involve the additional cost of data telemetering.

Ha and Trih (33) present a variable structure-based approach to the LFC problem in electric power generation systems. This approach combines the salient features of both variable structure and fuzzy systems to achieve high-performance and robustness.

Various adaptive control techniques (34-38) were proposed for dealing with parameter variations. Recently, there are also publications in applying a Riccati Equation approach to the stabilization of uncertain linear system (34, 39) to the LFC design. All the proposed methods with consideration of robustness are based on the state-space approach.

Fixed gain controllers are designed at nominal operating conditions and fail to provide best control performance over a wide range of operating conditions. Adaptive controllers with gain adjusting gain settings have been proposed for LFC (35-37, 40). Talaq and Basri (41), shows an adaptive fuzzy gain-scheduling scheme for conventional PI and optimal load frequency controllers.

Ngamroo et al (42) propose a robust control strategy for LFC by using a solid-state phase shifter based on H-inf control design. Feliachi (43) uses H-inf strategy to solution of LFC problem, and, Bevrani (44) designs a Kharitonov's theorem-based load frequency controller.

Bevrani (45), (46) shows the μ-based load frequency controllers. These approaches consider the influence of not only load changes but also parameter variations with and without generation rate constraints, in modeling procedure

The main capability of above method is in possibility of controller design based on a "more compete" model of system which considers uncertainties, too. This fact is of great importance knowing that power systems have a variable structure and are subject to type of uncertainties and disturbances.

IV. INTELLIGENT APPROACHES

In the deregulated environment independent generators and utility generators may or may not participate in the LFC of the power system. For the purpose of evaluating the performance of such system, a flexible method has been developed and implemented. On the other hand, due to complexity and multivariable condition of the power system, classical and nonflexible LFC based on ACE signal do not give good results and therefore don't represent good enough solutions. Centralized information structure and knowledge of all system parameters are technically very difficult and economically unjustified due to geographical distribution and a large number of real system elements.

Artificial intelligent techniques have been successfully applied to the LFC problem with rather promising results (47-50).

Bevrani et al (49) and Bevrani (50), design load frequency controllers using the neural networks with back-propagation algorithm in supervised learning mode. In order to greatest response and fast activity, Teshnehlab and Watanabe (51) has proposed Flexible Neural Networks (FNNs) based load frequency controller with dynamic neurons that have wide ranges of variation. Reference (51), gives a detailed discussion of FNNs.

The application of Artificial Neural Networks (ANNs) in control of complex system has been a subject of extensive studies in the past decade. As we know, the ANNs are based on the biological nervous systems. Learning algorithms cause the adjustment of the weights so that the controlled system give the desired response. There is a strong relationship between the training of ANNs and adaptive control. Therefore, increasing the flexibility of structure induces a more efficient learning ability in the system, which in turn causes less iteration and better error minimization. To obtain the improved flexibility, teaching signals and other parameters of ANNs (such as connection weights) should be related to each other.

Bevrani et al (49) have used a sigmoid unit function, as a mimic of the prototype unit, to give a flexible structure to the neural network. For this purpose, authors introduce a hyperbolic tangential from of the sigmoid unit function, with a parameter that must be learned, to fulfill the above-mentioned goal.

The proposed load frequency controller in reference (49), act as a self-tuning controller, that, it can learn from experience, in the sense that connection weights and SFPs are adjusted on-line; in other words this controller should produce ever-decreasing tracking errors from sampling by using FNNs.

V. COMPARISON

The classical PI controller is simple for implementation but generally gives large frequency deviations and robust stability and robust performance is not reachable using these controllers.

Despite the promising results achieved by adaptive controllers (34-38, 40), the control algorithms are complicated and require on-line system model identification. The adaptive control strategies usually require satisfaction of the perfect model-following conditions or explicit parameter identification.

For some design methods, for example the adaptive controller design proposed in (38), it is not easy to extend the method to a general multi-area system.

. It is shown that in comparison with conventional integral and also variable structure controllers, the responses with the proposed controllers in (9, 44-46) are more robust to load disturbances and parameter variations even in the presence of governor dead band and generation physical constraints.

Papers (9, 45-46, 49-50) consider a simple distribution company and its suppliers as shown in Fig. 1. In this example the distribution company (DISCO) buys firm power from one-generation company (GENCO 2) and enough power from other generation company (GENCO 1) to supply its load and support the LFC task. Transmission company (TRANSCO 1) delivers power from GENCO 1. TRANSCO 1 is also contracted to deliver power associated with the LFC problem.

In the structure proposed the DISCO are to be responsible for tracking the load and hence performing the load frequency control task by securing as much transmission and generation capacity as needed. Connections of the DISCO to other companies are considered as disturbances (d1).

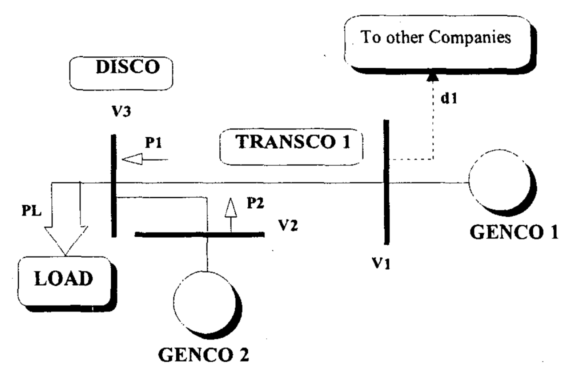

Fig. 1. A distribution company and its suppliers

In robust design approaches that are shown in (9, 45-46), it is possible; we use the physical understanding of power system for procedure design. Also it is possible to more pay attention on interconnections between areas. Usually, in the most scenarios, the interconnection among some areas is considered as the channels of disturbances.

Therefore, it has been important to suppress the transmission of disturbances by some coordinated control of governor system so far.

By using structured singular values, the stability condition for the overall system can be stated as to achieve a sufficient interaction margin and a sufficient gain and phase margin defined in classical feedback theory during each area control design.

However, in robust design approaches, some trial and error is also required. For example, in the case of using the H-inf and μ for LFC design, there is problem of how to choose the weighting functions to represent parameter variations and performance requirements, Bevrani (45), and how to choose the matrices Q, R and ε in the case of using the Riccati equation, Wang et al (39).

Simulation results demonstrate the considerable advantages of robust load frequency controllers over other conventional controllers. From the simulation results in (9, 44-46) for deregulated structure is shown in fig. 1, it can be seen that robust controllers have shown better performance than PI controller in analyzed cases. The overshoots are smaller and the time needed for reaching wanted value is shorter. Moreover, the responses of the system employing the proposed controllers are shown as being rather insensitive to parameter changes and speed governor dead band. Other advantages of these controllers have been illustrated in (9, 44-46) and for that reason it was not presented in this paper.

In classical and robust/adaptive load frequency controller design, the state vector for the entire system should be made available for the generation of local feedback control signals. This requirement may be met if the system state vector is observable from area measurements. However, even if the observability condition is satisfied, the resulted controllers with appropriately designed observers are normally quite complicated and these approaches are not suitable for a large power system where the total number of the state variable is large, and, that is why in some applications, artificial intelligent techniques are better candidates.

The salient feature of artificial intelligent techniques is that they provide a model-free description of control systems and do not require model identification.

Table 1 summarizes the basic advantages and disadvantages of these three classes of controllers. We must note that robust control techniques can be comparable to each other so. It was investigated that under a wide spectrum of uncertainties and disturbances, the H-inf and μ approaches, in addition to maintaining, insane satisfactory performance. Via these two methods, the uncertainties are directly introduced to the synthesis; however, the H-inf based design is to some extent, conservative and μ-based hardly gives low-order controllers.

Simple controllers and controller synthesis is the main advantage of Kharitonov's method, however, this method cannot fulfill the performance requirements as efficient as H-inf and μ controllers.

TABLE 1:
Comparisons between classical and modern approaches

Approaches	Advantages	Disadvantages
Classical Approaches	Easy synthesis, Simple controller and ntroller realization, Less time consumption.	Not guaranteed stability and rformance robustness, because of synthesis based on nominal nditions, Extremely dependent upon the minal operating point as well as ected type of model, Difficult or not efficient in the te space framework, Impossible applicable to large-le power system, Move to instability by increasing quency feedback gain.
Robust and Adaptive Approaches	Possible consideration of certainties and deviations *), Simultaneous satisfactory bility and performance(R), Good ACE minimization, Possibility of using the ysical understanding of wer system in design cedure (R), Insensitivity to parameter anges.	High-order result controller (R), Synthesis is rather difficult and e-consuming, Difficult or impossible applicabl large-scale power system, Difficulty in choosing of ighting functions and equations' rameters, Complexity and chattering blem in VSS (A**).
Intelligent Approaches	Good ACE minimization, Simple synthesis, Easy applicable to larger e systems, Model-free property.	High realization expenditure.

* R: Robust, ** A: Adaptive

To summarize, Kharitonov's theory for straightforward synthesis and simple resulting controller, H-inf theory for flexibility in achieving satisfactory performance and low degree of controller, and μ -theory for applicability to structured uncertainties are of interest.

On the other hand, limitation in application of Kharitonov's synthesis is not negligible. Further more, each of these approaches have advantages and disadvantages over one another that are summarized in table 2.

TABLE 2:
Comparisons between robust approaches

Approaches	Advantages	Disadvantages
Kharitonov's Approach	Simplicity of method, Low degree of ntroller.	Limitation in application to me type of models, Weaker, from a rformance viewpoint, Impossible or difficult plicable to larger size stems.
H-inf Approach	Relatively low degree controller.	Difficulty in determination weighting functions, Synthesis conservatism cause of considering certainties in the structured form).
μ-Approach	Non conservative and curate treatment (because considering uncertainties the structured form), Stability and performance ustness under a wider ge of load variation.	Difficulty in determination weighting functions, High degree of controller.

VI. CONCLUTION

This paper classifies the existing load frequency controller design approaches in a deregulated environment to classic, robust/adaptive and intelligent categories.

Then it makes varies comparison between these categories and discusses on the their main advantages and disadvantages.

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