A REVIEW ON QUANTITATIVE FEEDBACK THEORY (QFT) TO MAINTAIN POWER SYSTEM STABILITY

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Abstract: There are different practical methods which are used to maintain the power system stability but these systems are characterized by high uncertainty which makes it difficult to maintain good stability. In case of conventional methods, if plant parameter changes we cannot assure about the system performance hence it is necessary to design robust control for uncertain plant. Among the various strategies proposed to tackle this problem, Quantitative Feedback Theory (QFT) has proved its superiority.[6] QFT falls into the classical control category, and is a frequency domain design method. It is an alternative to other design methods such as root locus and H∞. From theory, through simulation, on a single machine, infinite bus system, it will be shown that the application of QFT to robust PSS design does indeed work.Other methods allow the designer to produce a design for single operating point and one has no idea how the design performs at the other operating points. QFT is a design method that allows the designer to choose a set of realistic operating points and to produce a design that includes those points. [6]

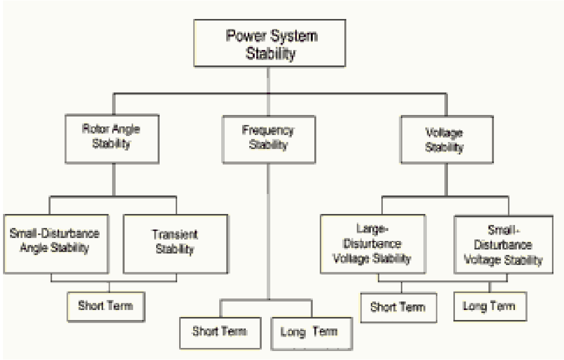
Keywords: PSS, robust controller, QFT, stability, design steps.

I. INTRODUCTION:

Power system is defined as a network of one or more gene rating units, loads and transmission lines including the associated equipment’s connected to it.Power system stability is defined as the ability of the electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded, so that practically the entire system remains intact.[7] Reliability is the overall objective in power system design and operation. To be reliable, the power system must be secure most of the time. To be secure, the system must be stable but must also be secure against other contingencies that would not be classified as stability problems e.g., damage to equipment such as an explosive failure of a cable, fall of transmission towers Present-day power systems are being operated under increasingly stressed conditions due to the prevailing trend to make the most of existing facilities. Increased competition, open transmission access, and construction and environmental constraints are shaping the operation of electric power systems in new ways that present greater challenges for secure system operation. Therefore, relays are used to detect this condition and trip generators before the damage occurs. Although tripping prevents the damage, it results in under-frequency, and possibly load interruption, and in the worst case, cascading outages and blackout.

For a reliable electric power service:-

- Steady-state and transient voltages and frequency must be held within close tolerances
- Steady-state flows must be within circuit limits
- Synchronous generators must be kept running in parallel with adequate capacity to meet the load demand
- Maintain the “integrity” of the bulk power network (avoid cascading outages).



II. WHAT IS POWER SYSTEM STABILIZER (PSS)?

Power system stabilizer (PSS) controller design, methods of combining the PSS with the excitation controller (AVR), investigation of many different input signals and the vast field of tuning methodologies are all part of the PSS topic. The basic function of PSS is to add damping torque to the generator rotor oscillations by controlling its excitation using the auxiliary stabilizing signal. To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations. Synchronous generators in electric power plants are equipped with continuously acting automatic voltage regulators (AVRs) in order to control the voltage. It is known that the AVR has a destabilizing effect on the power system stability, especially for a large interconnected power system. As a result, low frequency oscillations may continue for a long time and in some cases have serious limitations for power transfer capability. A PSS can be then used to provide additional supplementary control signals to the excitation system to damp out these oscillations The dynamic stability of a system can be improved by providing suitably tuned power system stabilizers on selected generators to provide damping to critical oscillatory modes. Suitably tuned Power System Stabilizers (PSS), will introduce a component of electrical torque in phase with generator rotor speed deviations resulting in damping of low frequency power oscillations in which the generators are participating.[3,7]

III. WHAT IS THE OBJECTIVE?

In order to maintain the transient stability different approaches like, increasing of the restoring synchronizing forces or reduction in accelerating torque were achieved by various methods-reduction of transmission system reactance's, high speed fault clearing, also by enhancing the small signal stability was introduced.[1] A novel approach to capture the development of dynamic voltage instability caused by the dynamics of different power system devices, such as loads, generators, automatic voltage regulators (AVR), over excitation limiters (OXL), power system stabilizers (PSS), and on-load tap changing (OLTC) transformers using an accurate time-domain analysis was designed. To make the controller robust against parameter variations around an operating point, variations in system parameters due to the load change are translated to the uncertainty framework and are represented using Integral Quadratic Constraints (IQCs).so robust power system stabilizers for interconnected power systems by considering effects of parameter variations and interconnections from other generators was designed. The inclusion of dynamic load model significantly increases the nonlinearity of the system. The automatic voltage regulation (AVR) and power system stabiliser (PSS) design problems are coordinated for the augmentation of stability so a new robust control methodology to improve the power system transient stability and voltage regulation in interconnected power systems including dynamic loads is designed based on quantitative feedback theory .

IV. QUANTITATIVE FEEDBACK THEORY

Basics of Qft:

QFT is a frequency domain method that was developed by Horowitz [1].The Horowitz observation is that feedback is only necessary if there is uncertainty either of the dynamics or of the external signals (e.g. unmeasured disturbances). Otherwise, any behaviour can be achieved by open loop prefiltering.[2] The QFT design procedure is highly transparent because the stability and performance criteria are always visible during the design process and this makes it ideal for practical control design. Since QFT is based on the frequency response data, complex plants can be modelled. [4] The reason for using QFT is that it offers direct insight into available trade-offs between controller complexity and specifications at each step, and corrections can be made accordingly. It is an iterative process, and also allows the designer to compare different designs. System cannot always be defined exactly; there will always be tolerances either in parameter constants or operating conditions.

The specific characteristics of QFT are:

- The amount of feedback is tuned to the amount of plant and disturbance uncertainty and to the performance specifications.
- Design trade-offs at each frequency are highly transparent between stability, performance, plant uncertainty, disturbance level, controller complexity and controller bandwidth.

Achieving a successful robust design involves a number of steps:

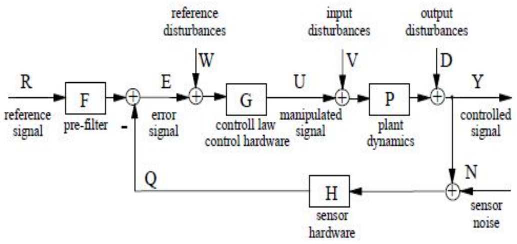
Specifications of control problems, plant model data, theoretical control system design, implementation of theoretical design, simulation and system under actual operating conditions. (Involving the nonlinear plant).

- The result is a robust design which is insensitive to plant variation.
- There is one design for the full envelope that is there is no need to verify plant's inside templates.
- Any design limitations are apparent up front.
- In comparison to other multivariable design techniques there is less development time for a full envelope design.
- One can determine what specifications are achievable early in the design process.
- One can redesign for changes in the specifications quickly.

QFT Design Problem Formulation

To execute a QFT design you are not required to identify a plant model from the data nor should you define specifications in any specific format over the whole frequency range from zero to infinity.

The quantitative feedback theory (QFT) method offers, frequency -domain based approach to handle feedback control problems with robust performance approach. In QFT the plant dynamics may be described by frequency response data, or by transfer function with mixed uncertainty models. The basic idea in QFT is to convert design specifications at closed loop and plant uncertainties into robust stability and performance bounds on open loop transmission of nominal system and then design controller by using loop shaping.[2]



The feedback system in the figure represents the plant (open loop process dynamics), controller to be designed and another transfer function known as transfer function as referred to in the manual.

According to the figure, if the controller to be designed is G(in forward path) then H could be used to denote sensor dynamics, while if the controller is H (in feedback path),G could be used to represent the actuator hardware dynamics.

Why is QFT preferred?

The design of controllers via QFT offers some advantages over other control design methods like H∞ LQG/LTR, Q- parameterization etc. The designer can see the trade-offs between specifications and controller design. Since QFT uses uncertainty as one of the design criteria, variations in the parameters of the model describing the system will result in a design that is robust stable.

QFT design operates in the frequency domain, and as such, all that is needed to do a successful design is the frequency response of the plant. Thus plants whose frequency responses are known can be controlled without developing an analytical model. In some cases, it may be impossible to find an analytical model, and this is where QFT is most powerful.

But an essential understanding of how QFT works is necessary to produce successful designs. Controllers obtained from the design process are often simple and can be synthesised in either analog or digital form. The simplicity and low cost of the designed controllers makes QFT a suitable design method for industrial control and processes.

The QFT approach can handle single-input single-output (SISO) and multi input multi-output (MIMO), linear and nonlinear, time varying and time invariant systems.

In contrast to other robust control techniques, QFT:

- Provided design transparency
- Enables the user to assess quantitatively the cost of feedback
- Uses the phase information in the design process.

The QFT design can be broken down into the following steps:

- Converting time domain specifications to frequency domain specifications.
- Generating plant sets.
- Generating the templates.
- Selecting nominal plant.
- Generating stability bounds.
- Generating tracking bounds.
- Grouping the bounds.
- Intersecting the bounds.
- Loop shaping i.e. designing the controller.
- Pre-filter design.

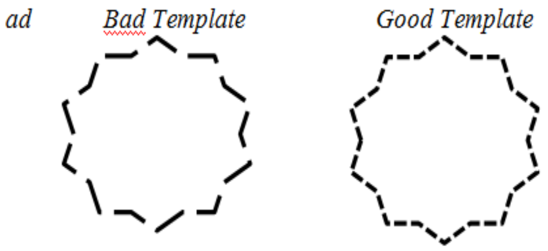
Terms of QFT

Templates

The plot of magnitude verses phase of plant sets for various frequencies is defined as template.

In control design most important thing is to have accurate information regarding the plant dynamics. Because QFT involvesfrequency-domain arithmetic, its design procedure requires the plant dynamics only in terms of its frequency response.The term template is used to denote the collection of an uncertainplant's frequency responses at a given frequency. The use oftemplates frees you from the need to have any particular plant modelrepresentation.

A generic illustration of “good” and “bad” grid choices are illustrated in Fig.



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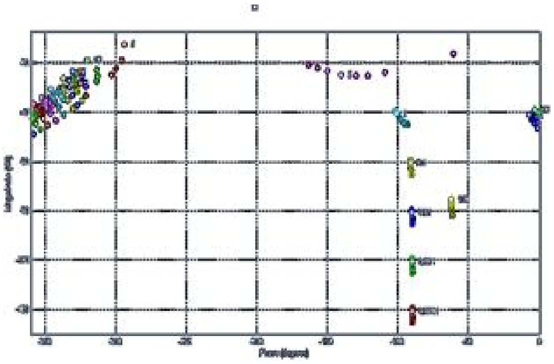


In general, there are no rules for obtaining a reasonable approximation of the boundary from the structure of the parametric uncertain plant. However, for specific cases, such as transfer functions with coefficients belonging to known intervals or with coefficients related to the uncertain parameters in a linear or multi-linear fashion. The algorithms for computing bounds require input data in terms of frequency responses (templates) rather than in terms of numerator/denominator transfer functions.

Choosing Frequencies

In any QFT design, you have to select a frequency array for computing templates and for computing bounds. An important question, for which there is no definite global answer, is how to select this array from the possible range between zero and infinity.

Fortunately, for engineering design we need only a small set. This can be found with, at the most, a few iterations. The basic rule is that for the same specification, the bounds will change only with changes in the shape of the template. Therefore, you should look for frequencies where the shape of the template shows significant variations compared to those at other frequencies. In certain problems, analysis of a completed design may indicate that you did not meet some specification over a small frequency range. This can happen only at a range for which you do not have a frequency in the array and obviously did not compute a bound there. This is what we mean by the need for iteration. In such a case, select a new frequency within this range, re-compute bounds and then augment the design as necessary.

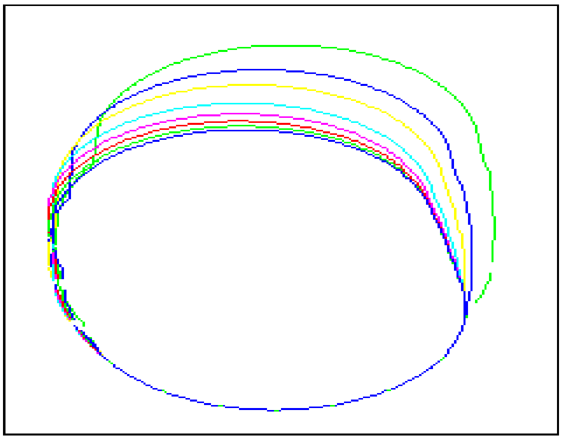
Choosing the Nominal Plant

In order to compute bounds, you will have to designate one plant element from the uncertain set as the nominal plant (if there is no uncertainty the fixed plant is the nominal one). This is required in order to perform QFT design with a single nominal loop. If the plant is described with a non-parametric uncertainty model with disk uncertainty, the nominal plant is already determined. However, we have a choice when the uncertain set corresponds to parametric uncertainty. As long as the set satisfies the assumptions on the uncertainty model given in continuous time, we may choose any plant case. Pick the most convenient plant for design. Note that the nominal plant index is an integer.

Robust Stability Bounds

Given the plant templates, QFT converts closed-loop magnitude specifications into magnitude and phase constraints on a nominal open-loop function. These constraints are called QFT bounds.

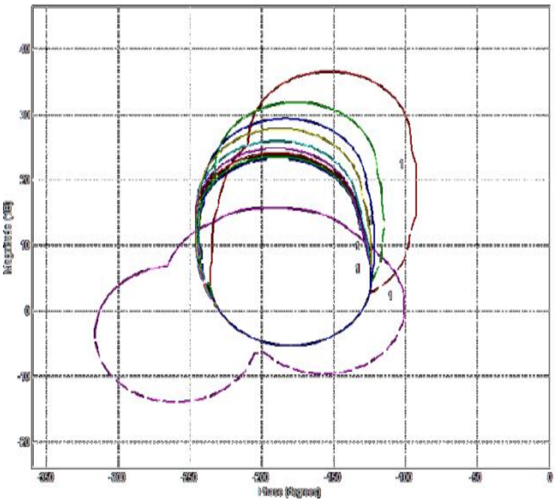
The bounds are calculated by moving each plant template around the Nichols Chart to satisfy the control specification. At each point, the nominal plant is marked on the Nichols Chart. This is done by hand. The computer generates the bounds by solving a quadratic inequality at each design phase. Figure shows the bounds that are generated.



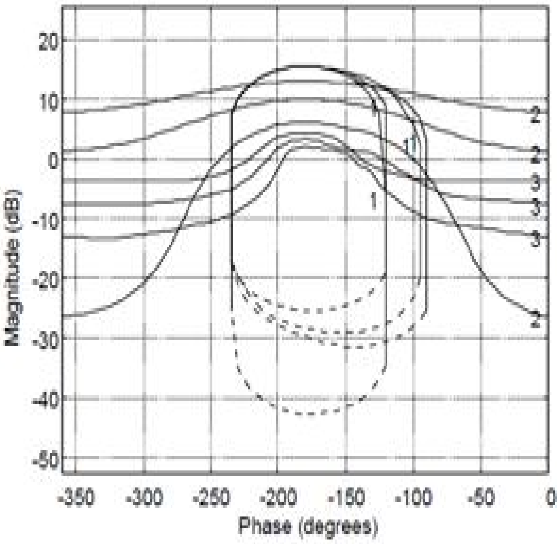
Tracking Bounds

Function based on upper and lower limit curves tracking bounds are generated at various frequencies and different plant sets. Tracking bounds are generated by using MATLAB QFT command.

GROUPING OF BOUNDS



Intersection of bounds



Loop Shaping[5]

It isthe process of designing a nominal open loop transfer function. Loop shaping is the design method where it is attempted to choose a controller such that loop transfer function obtains the desired shape. The nominal loop is the product of the nominal plant and the controller (to be designed). The nominal loop has to satisfy the worst case of all bounds. It is the key design step and it consists of shaping of the open loop function to set the boundaries given by the design specifications.

Design (Pre filter shaping)

If the feedback system involves tracking of reference signals, the using the pre-filter in addition to the controller embedded within the closed loop system gives the best result. Pre-filter shaping is done using

Pshape with the generic call. The input arguments are the same as used in computing bounds.
The input arguments are:

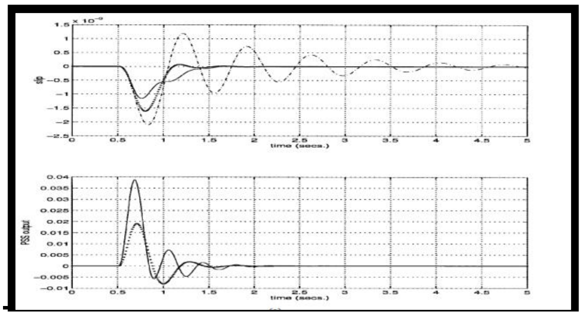
- w is the frequency array where frequency response is to be computed.
- wbds is another frequency array, a subset of W where margin bounds are computed.
- ws is an upper and lower magnitude bound on the closed-loop transfer function.
- P is the frequency response set of the plant.
- R is the disk radius in a multiplicative uncertain plant.
- G and H are the frequency response of the other functions in the loop.
- NumF0 and denF0 are initial values for the pre-filter in descending powers of S.

PSS design based on conventional QFT

Designing a PSS properly greatly enhances the overall performance of the system, but some of the designs are valid only for the designed operating point. Therefore, tuning a PSS becomes a difficult task due to the constantly changing dynamic behavior of the system. The most popular form of PSS used is the conventional lead compensation power system stabilizer. It offers ease of use and is readily implemented as an analogue circuit. Irrespective of the design technique of PSS, it is necessary to recognize the nonlinear nature of the power system and to extend the power transfer limits by damping rotor oscillations. The change in operating conditions can be represented as a parametric variation in the linearized model of the power system.[4] Such uncertainty can be handled by Quantitative Feedback Theory. The frequency response completely specifies the transfer function, which in turn uniquely determines the step response. Thus only the magnitude is considered when creating a bound on the frequency domain. The beauty of QFT lies in the fact that design can be done based solely on frequency response measurements. QFT design is useful in PSS design as where:

- Stability plays a significant role in safety regulations.
- The magnitude of uncertainties is typically very large.

In QFT a feedback is used for achieving the desirable system performance despite having plant uncertainties and disturbances. The QFT design procedure, which is usually applied to MISO systems, involves three basic steps of (i) computation of QFT bounds (ii) design of controllers and (iii) analysis of the design. The conventional PSS has been tuned to maximize damping. Hence, an increase in the gain results in a reduction in the damping of the nominal plant.However, it should be noted that any increase in the gain does not necessarily improve robustness. Hence, proper choice of the gain is very important.



System response to 5% step disturbance at the voltage reference input of the AVR ------- no controller , ……… conventional , _______ QFT based . for different values of P Q and Xe.for wide range.

It can be seen that QFT gives almost accurate result than the other controllers.

CONCLUSION:

In case of conventional methods, if plant parameter changes we cannot assure about the system performance hence it is necessary to design robust control for uncertain plant. Among the various strategies proposed to tackle this problem, Quantitative Feedback Theory (QFT) has proved its superiority. In QFT a feedback is used for achieving the desirable system performance despite having plant uncertainties and disturbances The performance of the resulting robust fixed gain PSS, established in terms of dominant pole region constraints, becomes acceptable over wide range of operating conditions. The conventional lead compensator type of PSS, can be simply retuned using the appropriate method to achieve enhanced Performance using QFT.

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