Inter-area oscillations of power system

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Abstract— the limited energy resources getting depleted day by day and hence the essence of renewable energy resources in the power system is getting employed nowadays. This increases the interconnection of power system in most of the cases which in turn results in the long distant power transfers between the power grids. This type of power transfer elevates the risk of low frequency oscillations between electrical and mechanical systems in the power grid. The oscillations are caused by specifically the synchronous generators which are connected to the power grid. These are known as inter-area oscillations and are usually in the stable region but reduces significantly the power transfer capacities of the network. In rare cases the damping ratio of the control system becomes negative and as a result the oscillations go out of control which leads to the reliability of grid issues and some temporary blackouts in expanded scale.

Keywords—electromechanical, Inter-area mode oscillations, damping control model, TCSC, LQG etc.

I. Introduction

The electromechanical oscillations are of several types and they are classified based on the system components that they affects [1]. The types of electromechanical oscillations are 1) intra-plant mode oscillations 2) Oscillations in the local plant mode 3) Inter-area mode oscillations 4) Oscillations in the control mode 5) The torsional modes between the rotating plant. We will focus only on the Inter-area mode oscillations as per the objective of this paper [2]. This is most common oscillation which is observed over a large part of the network. This involves the two coherent groups of generators those are swinging at each other at a frequency of 1000 Hz or fewer than that. For this reason the variation in the tie line power may somehow become large with the frequency of oscillation approximately 0.3 Hz. This type of complex phenomenon mainly involves non-linear dynamic characteristics in between many components of the system. This particular damping characteristics is basically effected by the power strength of tie-line, the type of loads and the power which flows between the interconnection and the interaction of the loads with the generator dynamics and their control of association. When the system is lightly damped then the operation of system becomes pretty difficult.

Now, here we have considered the LQG (Linear quadratic Gaussian) damping control method for the improvement of the inter-area mode oscillation system. This technique is guaranteed to produce the minimum-phase or good-damped zeros of transmission by squaring the design plant system approximately, in order to recover the system from power failure efficiently. An order 7 MISO (multi-input single output system) controller has been formulated for a particular 138th order of a 16 machine and area of five power systems which is accumulated with a series-capacitors controlled using thyristor bridges in order to improve the damping in the critical area with the application of signal measurements employed in a global basis.

II. Modeling and Design of the System

A. Overview of the system

The damping control has the primary equipment which is the 5 area and 16 machine power system [3]. The New England and New York interconnected network is the near model of the above said system. For facilitation of the power transfer a thyristor controlled series capacitors (TCSC) is employed in between the bus number of 18 and bus number 50 of the system. By the Eigen analysis of the system the four inter area mode is depicted of which the first three are very poorly damped requires the control action of damping. The centralized TCSC controller provides the extra damping control action to every critical area mode which are of needed [4]. The most efficient control measurements are found in between the power flow signals between the bus numbers 45 and 51, 16 and 18 and 13 and 17 respectively, on the basis of modal analysis. There are certain lines in the system which carries the power from Area 3 and Area 4 to the equivalent generator which is G13 respectively.

B. *Objectives of damping control model*

The design controller must provide a least amount of damping in the steady-state after going through a sudden larger disturbance in every key interconnection. This type of least amount of damping corresponds to the settling of the inter-area oscillations within ten to fifteen seconds. The operation of the power system is widespread and behavior of the simulation models used can be uncertain. Under the given conditions a robust cont6roller must be used and the controller should have very least amount of sensitivity to various operating conditions and the component parameters of the systems. Also, the torsional vibration of the turbine generator and other resonances in the ac transmission network is minimum.

III. SIMPLIFICATION OF THE MODEL

The recent control design processes like the LQG method produces the controllers of the order which is equal to the plant order and usually very high which is assigned with the required amount of extra weights [5]. The order reduction of the model is very much required in order to simplify the design method and then make it more complex about the ultimate controller. The simplified plant which is involved in the design is a more or less appropriate approximation of the control design. The central problem is given as follows.

For a high order linear model G(s) a low order approximate model $G_{red}(s)$ needs to be developed such that normalized infinite distance between the models is significantly low. The normalized infinite difference is given by $||G(s)- G_{red}(s)||_{\infty}$.

In the controller reduction method the same procedure is applied. The Schur balanced model reduction is employed for the controller reduction. The objectives of the reduction are computing the mth order reduced model such that $G_{red}(s) = C_{red}(sI-A_{red})$^(-1) $*B_{red} + D_{red}$ from an kth order full model such that G(s) = C(sI-A)^(-1)*B + D so that,

$||G(s)- G_{red}(s)|| \leq 2*\mathrm{sum}(\sigma j)$, where j= m+1(1)k…(1)

Here, σj = Hankel singular values of G(jw) that is the square roots of the eigenvalues in their observability and controllability matrix.

σj = sqrt(λi(PQ))…………………………………………..(2)

Here, λi(PQ) is the ith highest eigenvalue of the PQ and the P and Q are the solutions of the given equalities of Lyapunov.

PA^(T) + AP + BB^(T) = 0 (the controllability equation of matrix)

QA + A^(T)Q + C^(T)C = 0 (the observability equation of the matrix)

Where, A,B,C and D are state space matrix of the transfer function model G(s) and the state space matrices of the reduced order matrix G_{red} are A_{red}, B_{red}, C_{red} and D_{red} respectively. In cases where more than 1000 numbers of state variables are involved the numerical techniques need to be employed as the analytical techniques like Krylov subspace-based technique will not going to work.

A. *Model reduction notes*

The realistic representation of the system with additional damping controller includes washouts and delay in signal transmission blocks. The chosen blocks are

V1(s) = 10s/(1+10s) (washout TF)

V2(s) = 1/(1+0.1s) (TF of delay in signal transmission)

The time constants can be adjusted by the designer of the previous filters according with the real disturbance caused typically by the measurement noises and adverse modes. Now, the performing model reduction on the plant which incorporates these types of blocks proves not sufficient for correctly approximating all the frequency ranges. This approach as given in this work reduces the order of the plant G0 without using the washout and the transmission delays and then the blocks V1 and V2 are merged to an equivalent reduced order G0bar. The order is also increased for the extra amount of blocks and the controller design will have the necessary information about the properties of signal delay and washout characteristics.

B. *LQR design primary requirements*

The standardized description of the plant and output are given by the following state space equations.

xbar = Ax + Bu + Γw

y = Cx + v

Here, x is the nth dimensional state vector and u is the mth dimensional vector inputs and y is output of q-dimensional vector of outputs. Also, the plant is very much assumed to be strictly linear, proper, time-in variant observable and controllable system. The w and v mentioned above in the equations are respectively the process noise and sensor noise inputs which are assumed to have no correlation or coefficient of variation with the Gaussian noise process matrixes W and V. The particular LQG control problem then obtains the optimal control of u(t) that minimizes the quadratic index as given below.

J = Lim(T→∞) E/T{∫ (0 to T) [z^(T)Qz +u^(T)Ru] dτ

Here, z is the representation of either x or the linear combination of the states. In practice certain output quantities are penalized instead of full state feasibility purposes. The matrixes Q and R are chosen taking into account the weighting parameters such that Q^(T) =Q≥0 and R^(T) = R>0. In most of the cases Q and R are the diagonal matrixes.

For solving the LQG problem a separation principle is needed. This way the problem is subdivided into two sub problems which are very much independent to each other. There is another way in which either the Kalman filter is designed in ay that LQR robustness characteristics are reclaimed at the input of the plant or designing the LQR in a way that Kalman filter robustness properties are reclaimed at the output.

The primary points of LTR procedure are

1) The inputs and the outputs of the plants must be at least equal. Now, in order to apply the LTR the hypothetical inpts must be included in the system to make the system square and least phase system. The total recovery can be follwed at the particular plant input but not in the plant output.

2) The artificial outputs need to included to make the system square and least phase system. But, the recovery can be applied only to the plant output but not to the input of the plant.

In both of the cases the plant is assumed to be minimum phase or least phase system for applying the full recovery. For the case of non-minimum phase system the exact same procedure may be used but only for partially recovering the required robustness properties for a specific frequency range.

IV. CONTROLLING THE INTER-OSCILLATIONS

The Linear Quadratic Gaussian (LQG) technique is employed to improve the inter area oscillations of the system which has the synchronous generators connected to the infinite bus. The LQG model is reduced by the 9^{th} order transfer function design of the plant. When it is required to further reduce the controller size then the damping ratios of inter- area modes are reduced. A non-linear MATLAB simulation for a time interval of 50 secs is presented below in which the Inter area oscillations and the power flow for uncontrolled system and controlled with LQG controller is represented in the same graph. From the graphs it is clear that with controlled action the oscillations of the system reduces over time and the power flow is stabilized. Initially the controlled response is oscillatory with some amount of distortion but over time that oscillation reduces and the flat line is observed close to after 50 secs.

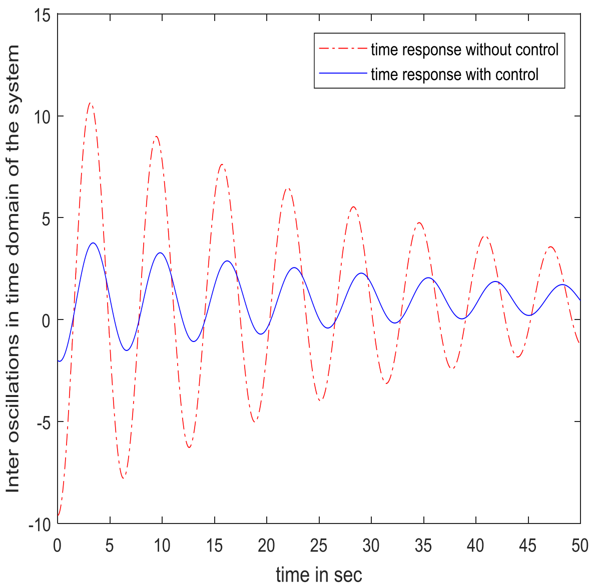

Fig 1: The time domain simulation (Dot-dashed line: Uncontrolled, Solid line: Controlled)

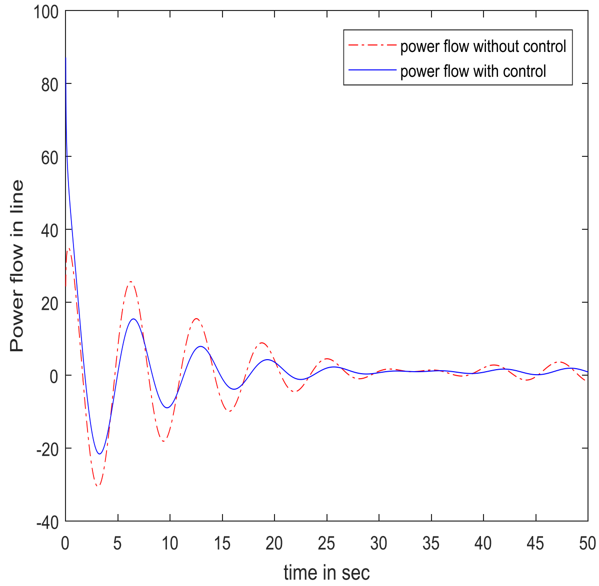

Fig 2: The power flow simulation (Dot-dashed line: Uncontrolled, Solid line: Controlled)

V. CONCLUSION

This paper presents the brief design of the concepts of inter-area oscillations in the power system and its effects on the network which can be minimized using the LQG/LTR formulation in the system. The practical controller structure of the 7^{th} order TCSC employed system which represents an equivalent model of the actual large order (138^{th}) system meets the requirement efficiently. This proposed technique also provides the future scope of the LTR system framework where the design system sustains the good robustness characteristics that is very much needed for the frequency range. It is expected to have some variety or uncertainty in the actual non-linear full model than our proposed simplified lower order model.

ACKNOWLEDGMENT

A particular thanks must be given to the authors of the books provided in the reference section. In the books the design concepts of LQG systems about improvement of the inter-area oscillation power drop is described in details. The MATLAB codes of the design are not included in this study for limiting the paper length within convenient size.

REFERENCES