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DESIGN OF ROBUST STATCOM CONTROLLER USING LOOP SHAPING TECHNIQUE WITH DIFFERENTIAL EVOLUTION

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Abstract: **In this paper, design of a fixed parameter robust STATCOM controller using Loop-shaping procedure is presented. A simple loop shaping method which yields a fixed parameter robust controller has been found suitable to provide good damping characteristics. The graphical loop shaping procedure used in designing a robust STATCOM controller can be significantly improved by embedding some optimization procedure in it. The objective function of the design problem is formulated to include closed loop responses. In this Thesis, a latest evolutionary computational technique called Differential Evolution (DE) has been employed to find the fixed parameter robust controller parameters. DE algorithm and Matlab is used to determine the controller parameter and system stability.**

Keywords: **STATCOM, Differential evolution, MATLAB, Loop Shaping Technique**.

I. INTRODUCTION

Demand of electrical power is continuously rising at a very high rate due to rapid industrial development. To meet this demand, it is essential to raise the transmitted power along with the existing

transmission facilities. The objective is to make the best use of the transmission asset, and to maximize the loading capability. Stability of power system has been a major concern in system operation. Design of a fixed parameter robust STATCOM controller using Loop-shaping procedure is presented. As STATCOM controller has been design to provide good damping characteristics. Such control strategies, have been investigated [1-2].

A simple loop shaping method which yields a fixed parameter robust controller has been found suitable to provide good damping characteristics [3]. The graphical Loop-Shaping method involves error and trial method. So, designing a controller can be quite complicated for a higher order system. The graphical loop shaping procedure used in designing a robust STATCOM controller can be significantly improved by embedding some optimization procedure in it. The objective function of the design problem is formulated to include closed loop responses. The optimization techniques based on derivative information would fail and search method would only work [4]. The local search methods such as simplex method will only give local optimization solutions. The global optimization techniques would be most suitable to solve such optimization problem. The evolutionary computational methods [5] are the ones which provide global optimal or near global optimal solution.

In this paper, a latest evolutionary computational technique called Differential Evolution (DE) has been employed to find the fixed parameter robust controller parameters.

Differential Evolution (DE) based robust control design greatly reduces the computational effort compared to the manual graphical technique. Hence it is very suitable for solving the optimization problem arising out of controller design

II. POWER SYSTEM MODEL

A single machine infinite bus system with a STATCOM installed at the midpoint of the transmission line. The dynamics of the generator is expressed in terms of the second order electromechanical swing equation and internal voltage equation. These are,

$$\dot{\delta} = \omega_b \omega$$

$$\dot{\omega} = (P_m - P_e - D\omega)/M$$

$$\dot{E_q'} = (-E_q + E_{fd})/T_{do}' \qquad (1)$$

$$\dot{E_{fd}} = -\frac{1}{T_A}E_{fd} + \frac{K_A}{T_A}(V_{to} - V_t)$$

Here, ω and δ are the generator speed and rotor angle while e_q' and E_{fd} represents the generator internal voltage and field voltage, P_m and P_e is the input and output power, D and M represents damping and inertia coefficients.

The VSC generates a controllable AC-voltage source $v_o(t) = V_o\sin(\omega t-\Phi)$ behind the leackage reactance. The voltage difference between the STATCOM – bus AC voltage $v_L(t)$ and $v_o(t)$ produces active and reactive power exchange between the STATCOM and the power system, Which can be controlled by adjusting the magnitude V_o and the phase Φ. The dynamics relation between the capacitor voltage (V_{dc}) and current (I_{dc}) in the STATCOM circuit are expressed as [6].

$$\frac{dV_{dc}}{dt} = \frac{I_{dc}}{C_{dc}} = \frac{c}{C_{dc}}[I_{Lod}\cos\Phi + I_{Loq}\sin\Phi] \qquad (2)$$

Where, c=mk and k is the ratio between ac and dc voltage, m is the modulation index and Φ is the phase angle. I_{Lod} and I_{Loq} are the direct and quadrature axes components of STATCOM current I_{Lo}. The output voltage phasor is

$$\overline{V_0} = CV_{dc}(\cos\Phi + j\sin\Phi) \qquad (3)$$

Where, V_0 is the output voltage and V_{dc} is the voltage across dc capacitor

III. ROBUST CONTROLLER DESIGN USING LOOP SHAPING

Loop shaping is a graphical procedure to design a proper controller C satisfying robust stability and performance criteria. .The basic idea of the method is to construct the loop transfer function, L=PC to satisfy the robust performance criterion approximately and then to obtain the controller from the relationship C=L/P.

Internal stability of the plants and properness of C constitute the constraint of the method. Condition on L is such that PC should not have any pole-zero cancellation. A necessary condition for robustness is that either orboth$|W_1|$,$|W_2|$ must be less than 1 [8].

If we select a monotonically decreasing function W_1 satisfying the other constraints on it. It can be shown that at low frequency the open loop transfer function L should satisfy,

$$|L| > \frac{|W_1|}{1-|W_2|} \qquad (4)$$

While, for high frequency,

$$|L| < \frac{1-|W_1|}{|W_2|} \approx \frac{1}{|W_2|} \qquad (5)$$

At high frequency |L| should roll-off at least as quickly as |P| does. This ensures the properness of C. The general feature of open loop transfer function is that the gain at low frequency should be large enough and |L| should not drop –off too quickly near the cross over frequency to avoid internal instability.

A. Introduction to Differential Evolution

Differential Evolution (DE) is a relatively new evolutionary algorithm (EA) developed by Price and Storn in 1994-1996 [10].DE is a stochastic direct search optimization method. It is generally consider as an accurate, reasonably fast robust optimization method.

The main advantages of DE are its simplicity and therefore easy use in solving optimization problems requiring a minimization process with real valued and multi objective functions. The most important characteristics of DE is that it uses the differences of randomly sampled pairs of object vectors to guide the mutation operation instead of using probability distribution functions as other EA_s .

IV. IMPLEMENTATION OF ROBUST CONTROLLER USING DE

The generator angular speed deviation Δω is selected as plant output, while the input is STATCOM voltage modulation index m. The value of nominal plant transfer function is given.

Problem: The problem is posed as multivariable constrained optimization problem to find the controller. So, we have to find out the values of parameters of controller.

The decision variable vector is x= $[b_2\ b_1\ b_0\ a_1\ a_0\ k_d]$.

Solution: The nominal plant transfer function taken from [7] is given as follows:

$$P(s) = \frac{0.2104s^2(s+100.827)(s-0.234)}{(s+99.17)(s+1.10)(s+0.05)(s^2+0.68s+21.63)} \qquad (6)$$

The controller structure is chosen as,

$$C(s)=\frac{b_2s^2+b_1s+b_0}{a_2s^2+a_1s+a_0} \qquad (7)$$

Where, the coefficients b_2, b_1, b_0 and a_1, a_0 are the unknown controller parameters which are to be find out using Differential Evolution algorithm. a_2 can be set as 1.

The Performance requirements are as follows**:**

A. Robust stability index (J_B)

For the robust stability index the weighting function $W_1(s)$, the stable transfer function which bounds the plant perturbation is chosen so that $\| W_1S\|_\infty < 1$.

A Butterworth filter satisfies all the properties for $W_1(s)$ and is written as

$$W_1(s)=\frac{k_d f_c^2}{s^3+2s^2f_c+2sf_c^2+f_c^3} \qquad (8)$$

W_1 is a real, rational, stable and minimum phase function.
Where, k_d is taken as one of the decision variable for the optimization of objective function.
$f_c = 0.1$
$W_2(s)$, fixed stable transfer function used as weighted structured uncertainty in the plant is chosen as, [7]

$$W_2(s) = \frac{0.9s^2+15s+27}{s^2+5s+31} \qquad (9)$$

The condition for robust stability bound at low frequency say 10^{-2} to 10^{-1} is,

$$|L| > \frac{|W_1|}{1-|W_2|} \qquad (10)$$

And for high frequency say 10^2 to 10^3 is,

$|L| < \frac{1}{|W_2|}$ (11)

The robust stability index (J_B) is expressed as,

$J_{Bi} = 0$ if bound is satisfies

$J_{Bi} = 1$ otherwise

i= 1, 2, 3,……………….N and N is no. of frequency points in bode plot of L(jω).

B. Stability index (J_S)

The stability of closed loop system is simply by solving the roots of characteristics polynomial and then checked whether all the roots lie in the left side of the complex plane means if, roots of (1+L) < 0 then system is stable. Otherwise, system is unstable. The stability index (J_s) is defined as,

$J_s = 0$ if stable

$J_s = 1$ otherwise

The Objective function J is expressed as following,

$$J = \sum_{i=1}^{N} r_i J_{Bi} + r_0 J_s \quad (4.7)$$

Where, r_i and r_0 are penalties associated with the respective index. r_i and r_0 are such that their sum is unity i.e. $r_i + r_0 = 1$. If, N = 30 and if r_i is taken as 0.6 while r_0 is taken as 0.4 then,

$r_i = r_1 + r_2 + \ldots\ldots\ldots\ldots r_{50} = 0.6$ and $r_0 = 0.4$.

An m-file using MATLAB has been written to calculate the objective function using the weighted sum of the performance functional J_B and J_s.

Various simulation studies (4.2) indicate that the DE based robust loop shaping designed controller is best when the gain margin is 7.94 dB(0.186 rad/sec) and Phase margin as 32 deg(6.43 rad/sec). The controller

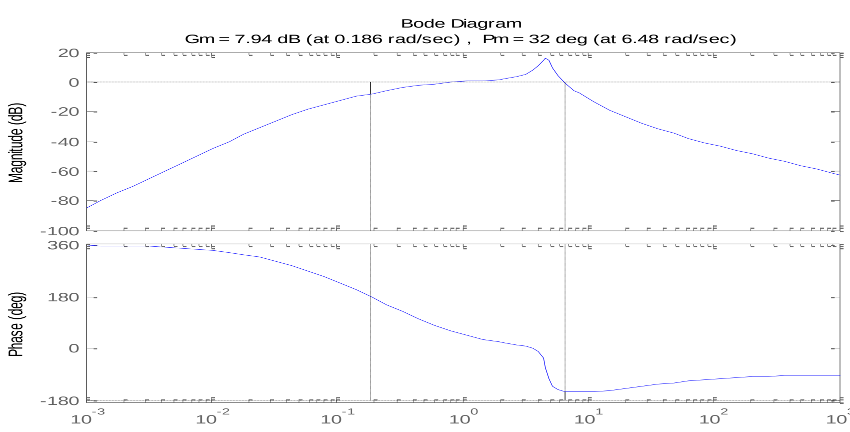
$C(s) = \frac{3.5213s^2+99.047s+145.273}{s^2+0.8401s+0.1112}$ (12)

and

$W_1(s) = \frac{0.003f_c^2}{s^3+2s^2f_c+2sf_c^2+f_c^3}$ (13)

Where, f_c is taken 0.1.

The db magnitude plots relating to W1 and W2 which were employed to arrive at this controller is shown in fig 1.



From above fig, it is clear that the system is stable because the values of phase margin and gain margin are positive.

V. CONCLUSION

A differential evolution procedure has been employed to design a loop shaping based robust STATCOM controller. The automatic loop shaping using differential evolution minimizes trial and error procedure. Simulation studies indicate that DE based robust loop shaping provide better results.

VI. LIST OF SYMBOLS

δ is the rotor angle

$T_{do,}$ is open circuit time constant

ω is the generator speed

e_q is the generator internal voltage

E_{fd} is the field voltage

Pm is the generator input power

Pe is the generator output power

M, D is the inertia& damping coefficient

V_t is the generator terminal voltage

V_{to} is the reference voltage

K_A is the exciter gain

T_A is the time constant

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