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Design of Robust STATCOM Controller Using Loop Shaping Technique with Differential Evolution: A Review

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Abstract: **This paper review, the design of a fixed parameter robust STATCOM controller using Loop-shaping procedure. 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 paper, 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 (ωt-Φ) 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 .

B. Key operators for differential evolution

As a member of the EA family, DE shares many common features with the EA.

a) ***Initial population***

DE is a parallel search method using a population of N parameter vectors for each generation G , the population P^G is composed of X_i^G ,i=1,2,3,………N. The initial population P^{Go} can be chosen randomly under uniform probability distribution. If there is nothing known about the problem to be optimized :

$$X_i^G = X_{i(L)} + rand_i\,[0,1].(X_{i(H)} - X_{i(L)}) \qquad (6)$$

Where, $X_{i(L)}$ and $X_{i(H)}$ are the lower and higher boundaries of d-dimensional vector X_i is

$$X_i = [X_{j,i}] = [X_{1,i}, \ldots\ldots\ldots X_{d,i}]^T$$

b) Encoding

Although there are floating number encoding methods are available, binary encoding scheme is still the most commonly used method for most Evolutionary algorithm. Binary encoding is based on limited binary integers and therefore its disadvantage is that ability to effectively represent variables possible of tacking values of different magnitudes, where for large valued parameters many bits may not be significant in final results.

DE tackles the disadvantages on binary encoding by using floating point numbers to encode parameter variables.

c) Mutation

The objective of mutation is to enable search diversity in the parameter space as well as to direct the existing object vectors with suitable amount of parameter variation in a way that will lead to a better result at a suitable time. It keeps the search robust and explores new areas in the search domain.

For real parameter optimization, mutation is the process of adding a randomly generated number to one or more parameters of an existing object vector. In DE, the mutation vectors the mutation vectors are generated by adaptively scaling and correlating the output of output of pre-defined, multivariate probability distribution. The DE mutation of a vector is achieved by adding the weighted difference 0f two randomly selected vectors as

$$X_i^{G+1} = X_i^G + f_1 .(X_{r1}^G - X_{r2}^G) \qquad (7)$$

Where, G represents the G_{th} generation r1≠r2≠i and r1,r2 are randomly selected integers within the population size N , i.e. r1,r2 ϵ{1,2,……………N}.

The mutation vector defined in this equation does not have any information of the original vector X_i^G. The difference defined by randomly selected $(X_{r1} - X_{r2})$ has zero mean and scale factor f_1 only changes the scale without introducing bias into the search process.

d) Crossover

Crossover or Recombination is the main operator Genetic Algorithm (GA) and a complementary process for Differential Evolution (DE). Crossover aims at reinforcing prior successes by generating child individuals out of existing individuals or object parameters.

The basic recombination process is a discrete recombination. The crossover constant CR is used to determine if the newly generated individual is to be recombined. The resulting expression of the mutation and crossover processes are given in eq. below as:

$$X_i^{G+1} = X_i^G + f_2 .(X_{r3}^G - X_i^G) + F.(X_{r1}^G - X_{r2}^G) \quad (8)$$

Where, the randomly generated integer r1≠r2≠r3≠i, F is the mutation constant, f2 controls the crossover constant. f2 can take from [0,1] and remain constant throughout evolution process. Generally with a population size of 20d (d is the problem dimension) F=0.8 and f2=0.5 appear to be reasonably good value to start a DE process. It can be seen that f2=1 is the discrete recombination model with CR=1 and f2=0 represents mutation only model.

e) Selection

After the Mutation and Crossover operator, all trial vectors $u_{i,G+1}$ have found. The trial vector $u_{i,G+1}$ are compared with the individual vector $X_{i,G}$ for selection into the next generation. The selection operator is listed in the following description:

$$X_{i,G+1} = u_{i,G+1} , \text{ if } f(u_{i,G+1}) > f(X_{i,G}) ,$$

$$X_{i,G+1} = X_{i,G} , \text{ if } f(u_{i,G+1}) \leq f(X_{i,G}), i=1,2\ldots\ldots N \quad (9)$$

If the objective function value of trial vector is better than the value of individual vector, the trial vector will be chosen as the new individual vector $X_{i,G+1}$ of next generation. On the contrary, the original individual vector $X_{i,G}$ will be kept as the individual vector $X_{i,G+1}$ in the next generation.

C. DE advantages

According to price the main advantages of DE include:

- Fast and simple for application and modification.
- Effective global optimization capability.
- Parallel processing nature.
- Operating on floating point format with high precision.
- Efficient algorithm without sorting or matrix multiplication.
- Effective on integer, discrete and mixed parameter optimization.
- Operates on flat surfaces.
- Ability to handle non-differentiable, noisy and/or time dependent objective functions.
- Ability to provide multiple solutions in a single run and effective in non-linear constraint optimization problems with penalty functions.
- Self – referential mutation operation.

IV. CONCLUSION

In this review, the current status of power system stability enhancement using STATCOM is discussed. Design of the STATCOM controller is discussed using two techniques. 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.

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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