GENETIC ALGORITHM BASED ROBUST CONTROL
FOR UPS INVERTER CONTROL

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ABSTRACT
This paper presents a new technique for designing a robust UPS inverter controller based on the concept of fixed-structure robust controller and a mixed sensitivity method. The uncertainty caused by the parameter changes of motor resistance, motor inductance and load are formulated as multiplicative uncertainty weight, which are used in the objective function in the design. Performance weight is designed based on the closed-loop objective which is normally applied in $H_\infty$ optimal control. Genetic Algorithm (GA) is adopted to solve the optimization problem and find the optimal controller. The proposed technique can solve the problem of complicated and high order controller of conventional $H_\infty$ optimal control and also retains the robust performance of conventional $H_\infty$ optimal control. Simulation results in a UPS inverter control system show the effectiveness of the proposed technique.

KEY WORDS
Fixed-Structure Robust $H_\infty$ Control, Genetic Algorithm, $H_\infty$ Control, UPS inverter

1. INTRODUCTION
In recent years, many researchers have tried to propose an effective technique to design a controller for general plants. A more recent control technique uses computational intelligence such as genetic algorithms (GA’s) in adaptive or learning control. Karr and Gentry [1], [2] applied GA in the tuning of fuzzy logic control which was applied to a pH control process and a cart-pole balancing system. Hwang and Thomson [3] used GA’s to search for optimal fuzzy control rules with prior fixed membership functions. Somyot and Manukid [4] proposed a GA based fixed structure $H_\infty$ loop shaping control to control a pneumatic servo plant. To obtain parameters in the proposed controller, genetic algorithm is proposed to solve a specified-structure $H_\infty$ loop shaping optimization problem. Infinity norm of transfer function from disturbances to states is subjected to be minimized via searching and evolutionary computation. The resulting optimal parameters make the system stable and also guarantee robust performance.

In UPS inverter, many engineers development to design a robust controller to ensure both the stability and the performance of the system under the perturbed conditions. One of the most popular techniques is $H_\infty$ optimal control in which the uncertainty and performance can be incorporated into the controller design. Unfortunately, the order of the resulting controller from this technique is usually higher than that of the plant, making it difficult to implement the controller in practice.

According to the standard procedure of robust control [5], there are many techniques for designing a robust controller in a general plant; for example, mixed sensitivity function, mu-synthesis, $H_\infty$ Loop Shaping, etc. However, controllers designed by these techniques result in a complicated structure and high order. The order of the controller depends on the order of both the nominal plant and the weighting functions. It is well known that a high order or complicated structure controller is not desired in practical work. To overcome this problem, a fixed-structure robust controller is designed. In this paper, we illustrate the design of a UPS inverter controller which can guarantee stability under the specified perturbed conditions and which also has a simple structure.

The paper is organized as follow: section 2 covers the UPS inverter modeling. In section 3, Robust $H_\infty$ Mixed-sensitivity and the proposed technique are discussed as well as GA algorithm. The design examples and results are demonstrated in section 4. And in section 5 the paper is summarized.

2. MODELING OF THE SINGLE PHASE UPS INVERTER
A well known model of UPS inverter is shown in Fig 1. The dynamic model of this UPS inverter from the modulating signal ($v_{con}$) to the output voltage ($V_c$) is given by [6].

$$G = \frac{K_{PWM}R}{LCRs^2 + LS + R}$$

where $K_{PWM} = V_d / v_{tri}$. The parameters of the UPS inverters used for the proposed design are as follow:

$V_d = 240-260$ V, $v_{tri} = 10$ V, $L = 0.2$ mH, $C = 50\mu$F, $R = 30\Omega$
3. ROBUST $H_{\infty}$ MIXED-SENSITIVITY AND THE PROPOSED TECHNIQUE

This section illustrates the concepts of the standard Robust $H_{\infty}$ Mixed-sensitivity and the proposed technique.

3.1 Robust $H_{\infty}$ Mixed-sensitivity

The cost function in the design is the infinity norm based on the concept of robust mixed-sensitivity control, which can be briefly described as follows [5].

1. In the mixed-sensitivity method, firstly, the weighting function of the plant’s perturbation and/or performance must be specified. In this paper, $W_2$ is specified for the uncertainty weight of the plant and/or $W_1$ is specified for the disturbance attenuation of the system. The cost function can be written as:

$$\begin{bmatrix} W_1 S \\ W_2 T \end{bmatrix}_{\infty} < \gamma$$ (2)

where $T$ is the plant’s complementary sensitivity function, and $S$ is the plant sensitivity function.

Assume that the plant is denoted as $P$. The controller is denoted as $K$ and the system is the unity negative feedback control. The sensitivity and complementary sensitivity function can be expressed as:

$$S = (1 + PK)^{-1}$$ (3)

$$T = I - S = PK(1 + PK)^{-1}$$ (4)

This cost function is based on frequency domain specifications. In this approach, the fitness value in PSO is based on the cost function in mixed sensitivity robust control.

3.2 Fixed Structure Robust Control

GA is used to solve the Robust $H_{\infty}$ Mixed-sensitivity problem, which is difficult to solve analytically. The $K(p)$ is a structure-specified controller. The structure of the controller is specified before starting the PSO optimization process. In most cases, this controller has simple structures such as PI, PID or lead-lag configuration. A set of controller parameters, $p$, is evaluated to maximize the objective function. Lead-lag controller is investigated as a fixed-structure controller. The controller structure is expressed in (5). $x_1$, $x_2$ and $x_3$ are parameters that will be evaluated.

$$K(x) = \frac{x_1 s + x_2}{s + x_3}$$ (5)

The controller parameters set is

$$x = [x_1 \ x_2 \ x_3]$$ (6)

In our proposed technique, the fitness function is

$$fitness \ function = \left\| W_1 G K(x) \right\|_{\infty} - G K(x)\right\|_{\infty}$$ (7)

3.3 Genetic Algorithm

Our proposed technique uses GA to solve the optimization problem in (7). GA is well known as a biologically inspired class of algorithms that can be applied to any nonlinear optimization problem. This algorithm applies the concept of chromosomes, and the operations of crossover, mutation and reproduction [5]. At each step, called generation, fitness values of all chromosomes in population are calculated. Chromosome, which has the maximum fitness value (minimum cost value), is kept as a solution in the current generation and passed to the next generation. The new population of the next generation is obtained by performing the genetic operators such as crossover, mutation, and reproduction. Crossover randomly selects a site along the length of two chromosomes, and then splits the two chromosomes into two pieces by breaking them at the crossover site. The new chromosomes are then formed by matching the headpiece of one chromosome with the tailpiece of the other. Mutation operation forms a new chromosome by randomly changing value of a single bit in the chromosome. Reproduction operation forms a new chromosome by just copying the old chromosome. Chromosome selection in genetic algorithm depends on the fitness value. High fitness value means high chance to be selected. Operation type selection; mutation, reproduction, or crossover, depends on the pre-specified operation’s probability.
Fig. 2. Genetic Operations (a) Crossover (b) Reproduction and (c) Mutation.

The genetic algorithm which has the maximum fitness is the answer of this optimization.

4. DESIGN EXAMPLE AND RESULT

A UPS inverter is used to illustrate the effectiveness of the proposed technique. In this example, the system of the output voltage control of the UPS inverter has the parameters at the nominal plant as follows: $V_d = 240-260$ V, $\nu_{ref} = 10$ V, $L = 0.2$ mH, $C = 50 \mu$F, $R = 30 \Omega$. The specification of perturbation used for the design is shown in Table 1. As seen in the table, the reasonable tolerance and changes in system parameters are specified.

Table 1 Parameters UPS inverter changing in the design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal Value</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C$</td>
<td>50 $\mu$F</td>
<td>$\pm30%$</td>
</tr>
<tr>
<td>$R$</td>
<td>30 $\Omega$</td>
<td>$\pm30%$</td>
</tr>
<tr>
<td>$L$</td>
<td>0.2 mH</td>
<td>$\pm30%$</td>
</tr>
</tbody>
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To specify the uncertainty weight, the plots of several multiplicative plant perturbations are shown, and then the transfer function which has a higher amplitude than all of uncertainty models is specified as the uncertainty weight. Fig. 3 shows the plot of uncertainty weights. The uncertainty weight can be specified as:

$$W_i = \frac{0.8 s + 800}{s + 0.001}$$ (8)

Performance weights can be selected properly by the well-known concept shown in [6]

$$W_2 = \frac{0.7104s^2 + 1.793 \times 10^5s + 1.199 \times 10^7}{s^2 + 1690s + 1.493 \times 10^7}$$ (9)

The Robust $H_\infty$ Mixed-sensitivity controller obtained by this method is:

$$K_\infty = \frac{6.258 \times 10^5s^3 + 1.475 \times 10^5s^2 + 1.631 \times 10^7s^2 + 1.68 \times 10^7s + 9.343 \times 10^7}{s^3 + 5.131 \times 10^6s^2 + 1.316 \times 10^8s^2 + 3.882 \times 10^9s^2 + 2.677 \times 10^{10}s^2 + 9.343 \times 10^{10}s + 1.933 \times 10^{11}}$$ (10)

The structure of the controller is selected as lead-lag which has the structure as (5). The GA parameters are selected as: $x_1 \in [0,20]$, $x_2 \in [0,100]$, $x_3 \in [0,20]$, population size $= 100$, crossover probability $= 0.7$, mutation probability $= 0.25$, and maximum generation $= 150$.

When running the GA for 82 iterations, an optimal solution is obtained as shown in Fig. 4.

By the proposed technique, the optimal lead-lag controller is evaluated as follows.

$$K(x) = \frac{0.0019858s + 19.486}{s + 0.00072222}$$ (11)

The infinity norm obtained by the evaluated controller is 0.5546 which is less than 1. Consequently, since this norm is less than 1, then the system is robust according to the concept of mixed sensitivity robust control. A conventional mixed sensitivity controller is also designed for comparison. In the conventional technique, the order of the final controller is 5.
Fig. 4. Convergence of solution of the proposed technique.

Fig. 5 The output response of $H_\infty$ Mixed-sensitivity controller at the perturbed condition when there is disturbance ($0.1u(t)$) entered in the input system.

Fig. 6 The output response of proposed controller at the perturbed condition when there is disturbance ($0.1u(t)$) entered in the input system.

5. CONCLUSION

This paper proposes a new technique to design a fixed-structure robust controller for UPS inverter. The proposed technique uses Genetic Algorithm is then adopted to find the final optimal controller. As seen in the results, the stability margin obtained from the proposed controller is almost the same as that of $H_\infty$ Mixed-sensitivity controller. The effectiveness of the proposed controller is also verified by the time domain responses under the conditions of both parametric uncertainties and input disturbance.

Cleary, the order of the conventional technique controller is very high and its structure is very complicated. Thus, the advantage of simple structure can be obtained by the proposed technique. The step responses of both proposed and conventional technique at nominal conditions are shown in Fig. 5 and Fig. 6. This figure shows that the output response from the proposed controller is almost the same as the conventional robust controller. Cleary, both the proposed and conventional controllers are robust.
REFERENCES