GUI Tool for Analysis of Nonlinear Control System

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***Abstract*— In practice, all systems can be classified either as linear or nonlinear systems. However, linear, time-invariant system if examined in detail is always found to be nonlinear to some extent. Powerful and user-friendly mathematical tools are available for linear system analysis, whereas no such tool is available for nonlinear analysis. This paper presents a useful GUI tool *'nonlintools'*, based on MATLAB. It helps to study, analysis and design of nonlinear control systems. The simulation software tool discussed in this paper aims to provide control engineers a tool that simplify the design steps for nonlinear control systems. The package can also be used as a teaching aid at both under and postgraduate level of control engineering education. The tool comprises of two sections – study of describing functions and stability analysis using describing function method.**

***Index Terms* — Nonlinear control system, Describing function, Limit cycle, MATLAB**

I. OVERVIEW OF THE TOOL

The proposed '*nonlintools*' is developed using GUIDE platform of MATLAB 6.5. GUIDE is Graphical User Interface Develepoment Environment. The *'nonlintools'* comprises of two basic parts. ---

1. Study of behavior of describing functions of various types of nonlinear elements.
2. Stability analysis of nonlinear control systems using describing function method.

Purpose of the tool is to provide user-friendly platform for the analysis of nonlinear control systems. Any user with just the primary knowledge of describing function method can use this tool very effectively. It reduces the development time of the designer to a great extent. It can be effectively utilized as a teaching aid also.

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The main window of the tool can be opened by typing the command '*nonlintools'* on MATLAB command window. User can select any one option for further analysis.

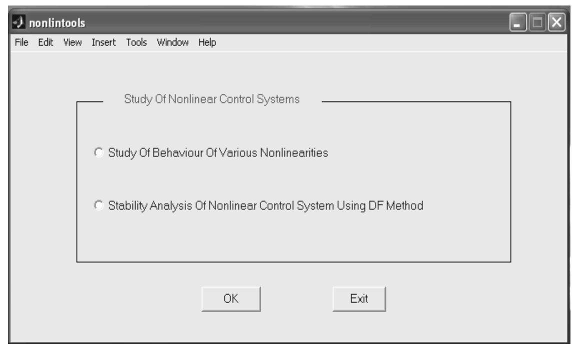

Fig. 1 Main selection window of nonlintool

II. STUDY OF THE BEHAVIOUR OF VARIOUS TYPES OF NONLINEAR ELEMENTS

Unlike to the transfer function, G(s) of the linear element, the describing function (DF), $K_N(X,\omega)$ changes with the different input value. It is important to understand the behavior of DF with changing values of input amplitude. Various types of common nonlinear elements like -- amplifier with saturation and dead zone, ideal relay, relay with dead zone and hysteresis, backlash etc., are considered. This portion of the package is primarily helpful in the teaching of nonlinear elements. This section helps the user to get acquainted with the behavior of nonlinear elements before proceeding with the stability analysis. $X \rightarrow Kn(X)$ graph is used to demonstrate the characteristics of selected element. The graph shows the changes in describing function against different values of input X. The user has to simply select the type of nonlinear element from the toolbar menu. After providing input amplitude range and corresponding parameter value i.e. saturation limit, dead zone, hysteresis etc., the tool generates and displays the corresponding $X \rightarrow Kn(X)$ plot. Study of this plot will make it clear for the user that how the particular nonlinearity will behave for the given input. The GUI is developed in such a manner that if the user fails to enter any necessary input, it will generate an 'Error Dialog Box' asking the user to enter that particular value before evaluating.

Also the GUI displays the name of the nonlinearity along with its DF, so that the user may correlate easily to the graph. The users can also enter multiple parameter values for nonlinearity and compare the same on a single graph.

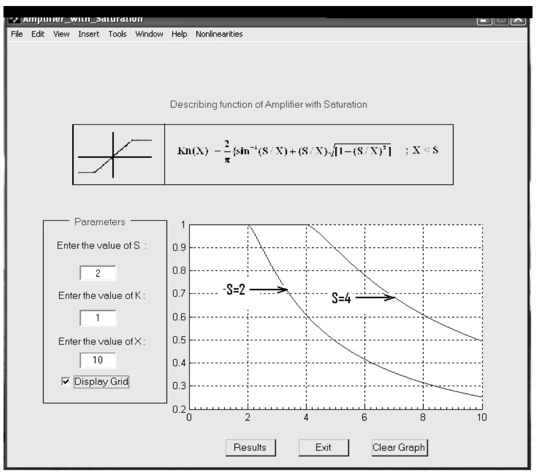

Fig. 2 K_N (X) Plot of Amplifier with Saturation Type nonlinearity

Thus the user can have a comprehensive knowledge of the behavior of all major nonlinear elements.

III. Stability Analysis of Nonlinear Control System Using DF Method

For a given linear control system, various stability analysis methods such as Routh Hurwitz stability criterion, Nyquist stability criterion, root locus, etc., are available. In similar way the DF method is one of the methods for stability analysis of nonlinear control system, which works in the frequency domain. The fundamental approach is to plot the polar plot of the linear part of the plant, and investigate its intersections with the locus of $-\frac{1}{K_N(X)}$ plot. The widest use of describing functions is in stability investigations and prediction of limit cycles in nonlinear control systems. Limit cycle means self sustained oscillations of fixed frequency and amplitude. The characteristic equation of a system with a nonlinear element having its describing function K_N (X) is given as,

$$-\frac{1}{K_N(X)} = G(s)H(s)$$

For feedback with, H (s) =1and s=jω

$$-\frac{1}{K_N(X)} = G(j\omega)$$

If G(jω) curve encloses all the entire $-\frac{1}{K_N(X)}$ curve, then the system is absolutely unstable. If there is no intersection between the loci and polar plot as well if the polar plot does not enclose the $-\frac{1}{K_N(X)}$ curve, then the system is stable. If there is an intersection than the limit cycle generates and stability of the limit cycle is required to check. The basic steps in the DF method are as follows:

1. Get the polar plot of the linear part.
2. Find $-1/K_N(X)$ from the $K_N(X)$ of a given nonlinearity and plot it on the same graph taking different values of X.
3. Find out whether the limit cycle exist or not by finding the intersection of both the graphs.
4. Calculate the value of frequency ω and Amplitude X of the limit cycle.

Performing all the above-mentioned steps manually is a time consuming task. Probabilities of making a mistake increases manifold in manual method. The suggested tool performs all above steps with the help of MATLAB file and directly generates the end results. The simulation package is developed in view to reduce the analysis time. The GUI environment provides user-friendly platform.

The user has to enter the coefficients of the numerator and denominator of the transfer function of the linear part in the vector form in the given space i.e. [a_3 a_2 a_1 a_0]. Also the user can specify the frequency range and the step size over which they want to plot the polar plot. Then the user has to select the type of nonlinearity and the GUI will ask input parameters corresponding to that particular nonlinearity. Here also the user can specify the amplitude range and step size to plot the $-\frac{1}{K_N(X)}$ plot. In case the user fails to enter any of the required input parameters, the GUI will generate an 'Error Dialog Box' asking the user to enter that particular data.

After entering the linear and nonlinear parameters, the tool generates and displays the corresponding plots. Study of these plots convey about the stability condition of the system. This will be very helpful for the stability analysis and the design of nonlinear control system.

In the entire tool, a typical menu bar is being added at the top of the GUI. The menu bar provides all necessary functionalities to the users. With the menu bar the user can :-

(1) Open another MATLAB file
(2) Save a particular simulation result
(3) Print the simulated result and graph
(4) Undo, Redo, Cut, Copy, Paste etc.
(5) Change the figure and axes properties
(6) Insert figure toolbar, Camera toolbar etc.
(7) Zoom In, Zoom Out, Pan , Rotate 3D , etc.

IV. CASE STUDY

In this example a typical nonlinear control system as shown in Fig. 3 is considered to perform '*nonlintools'*. The system consists of relay with hysteresis type nonlinearity. The linear part has one pole at zero.

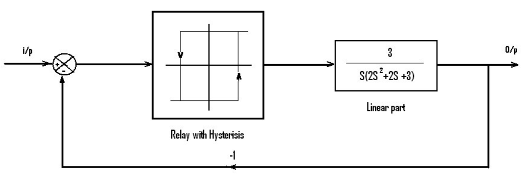

Fig. 3 Typical nonlinear control system

On pressing the corresponding button for the plots the tool calculates and plots the graphs on same plane. Thus the users can reduce the time for manual plotting of polar and $-\dfrac{1}{K_N(X)}$. Also, the user can change the input parameters of either linear or nonlinear part in steps and compare with the previous results on same graph and that check the effect of changing parameter on overall system.

The comparative study of nonlinear system with a linear gain of 4 and 6 is carried out. The result is shown in fig. 4. This way one can compare the performance very easily. This comparative study makes the designing of the system very easy for engineers. Thus the user can find out the effect of parameters of linear and nonlinear part the system on behavior of entire system within a matter of minutes.

Thus the stability of control system can be checked. The tool provides visualization of the effect of different parameters on the behavior of the system in very user-friendly way.

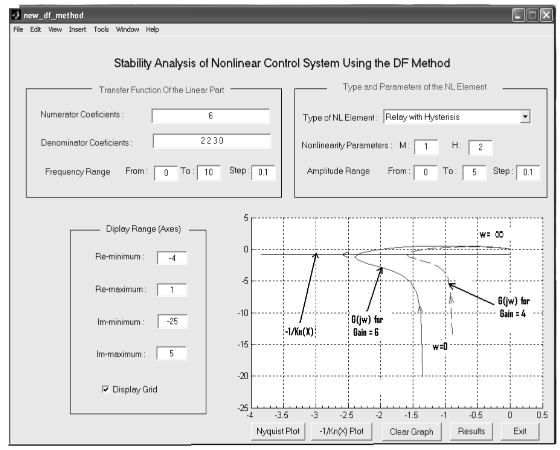

Fig. 4 Result for the system discussed in case study

V. CONCLUSION

In this paper a powerful and new simulation tool is presented for nonlinear control system analysis. The tool would greatly facilitate the simulation of nonlinear systems. The tool is expected to be useful in designing of nonlinear control systems along with the behavior study of nonlinear elements. The tool can accept any of the common nonlinearities along with linear system of any order. The tool uses new generation of GUIs developed in MATLAB, which will greatly enhance the user's experience with the tool. A case study of relay with hysteresis displays that the simulation tool is simple yet very effective. User learning time would be very small and simulation results are in line of the theoretical facts.

The tool development is under process and further facilities to find the frequency and amplitude of limit cycle is planned. This will further enhance the effectiveness as a designing tool.

VI.REFERENCES

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