

NYQUIST PLOT

A Nyquist plot is a graphical representation used in control engineering. It's essentially a fancy way to analyze a system's stability, performance and frequency response.

What it plots:

- It plots the complex behavior (both magnitude and phase) of a system in response to varying frequencies.
- Imagine a system like an amplifier for sound. A Nyquist plot would show how much the amplifier boosts the volume (magnitude) and how much it delays the sound (phase) at different musical tones (frequencies)

STEPS TO PLOT :

- We start with a mathematical description of the system (transfer function).
- We feed this function with different frequencies one by one.
- At each frequency, we calculate two things:
 - magnitude: How much the system amplifies the signal at that frequency.
 - Phase: Any delay the system introduces to the signal.
- These magnitude and phase values are then plotted as a point on a graph.
- As we sweep through all frequencies, we end up with a smooth curve or path on the graph - this is the Nyquist plot.

What it tells us:

- The main purpose is to assess stability. A stable system won't go out of control.
- The plot's path and its interaction with a specific point (**usually -1 on the horizontal axis**) tells us if the system is stable or not.
- If the path **doesn't encircle that point**, the system is likely **stable**.
- If the path **encircles the point**, the system might be **unstable**.

Why do we use nyquist plot:

1. Stability Check:

The primary purpose of the nyquist plot is to assess the stability of the control system. The Nyquist plot helps visualize if the system's response (magnitude and phase) **encircles a critical point(-1+0j)**. **No encirclement indicates stability.**

2. Performance:

It is measured by parameters such as gain margin and phase margin.

3. Visualization of Frequency Response:

It provides a visual picture of how the system responds to different frequencies.

4. Model validation check:

Nyquist plot can be used to validate mathematical models of control system. By comparing experimental nyquist plots with theoretical predictions, engineers can verify the accuracy of their models and identify any discrepancies that may require further investigation.

5. Robustness analysis:

It refers to the ability of a system to perform effectively in the presence of uncertainties and disturbances.

Comparison of root locus,polar plot and nyquist plot

| Feature | Root Locus | Polar Plot | Nyquist Plot |
|-------------------------|--|--|--|
| What it Analyzes | Movement of system poles with parameter change | Magnitude and phase at a single frequency | Magnitude and phase across a range of frequencies |
| Strengths | Easy to interpret for basic stability analysis (single-input, single-output systems) | Quick visualization of magnitude and phase at a specific frequency | Combines stability and frequency response analysis - Handles time delays effectively - Can be used with Bode plots for more comprehensive analysis |
| Weaknesses | Limited view of frequency response | Only analyzes one frequency at a time | Can be complex for high-order systems |
| Purpose | Analyze closed-loop stability | Understand frequency response | Analyze stability and performance |
| Best Used For | Basic stability analysis - Designing for desired performance | Understanding behavior at a specific operating point | Detailed stability and frequency response analysis-Gain and phase margin calculation |
| Application | Commonly used for feedback control system design and analysis | Primarily employed in filter design | Widely utilized in stability analysis and controller design |

Working of nyquist plot

1. **Frequency Response:** The Nyquist plot is based on the frequency response of a system. This response shows how the system behaves at different frequencies when subjected to inputs.
2. **Complex Plane:** In a Nyquist plot, the frequency response is represented in the complex plane. Each point on the plot corresponds to a specific frequency, where the real part of the frequency response is plotted on the horizontal axis and the imaginary part is plotted on the vertical axis. And its location represents the magnitude and phase of the system's response at that frequency.
3. **transfer function:** The Nyquist plot is obtained by plotting the complex values of the transfer function of the system at different frequencies. The transfer function is the ratio of the output to the input of a system in the frequency domain.
4. **Mapping the points:** As the frequency varies, the complex values of the transfer function are plotted on the complex plane, creating a set of points that form a curve. This curve is known as the Nyquist curve.
5. **Stability Analysis:** The Nyquist plot provides valuable information about the stability of the system. According to the Nyquist stability criterion, if the Nyquist plot encircles the critical point $(-1, 0)$ in the complex plane in a counterclockwise direction (for a stable system), the system is stable. If it encircles the point in a clockwise direction (for an unstable system), the system is unstable.

Applications of nyquist plot

1. **Control Systems Design and Analysis:** Engineers use Nyquist plots to analyze the stability and performance of feedback control systems. By examining the Nyquist plot, they can determine the stability margins, such as phase margin and gain margin, which are crucial for ensuring stable system operation. Nyquist plots also help in designing compensators and controllers to achieve desired system behavior.
2. **Electrical Engineering:** Nyquist plots are used in the design and analysis of electrical circuits and systems, such as amplifiers, filters, and feedback systems. They help engineers understand the frequency response characteristics of these systems and ensure stability and performance specifications are met.

3. **Communications Systems:** In communication systems, Nyquist plots are used to analyze the stability and performance of modulation and demodulation processes. They help in understanding the effects of channel impairments, such as noise and distortion, on the transmitted signals.
4. **Signal Processing:** Nyquist plots are employed in digital signal processing (DSP) for analyzing the stability and performance of digital filters and control systems. They aid in designing filters with desired frequency response characteristics and evaluating their stability.
5. **Aerospace and Automotive Systems:** Engineers in aerospace and automotive industries use Nyquist plots for designing flight control systems, autopilots, and vehicle stability control systems. These plots assist in ensuring stable and reliable operation of aircraft and vehicles under various operating conditions.

What are the limitations of the Nyquist plot

One of the main limitations is that it can only be used for linear systems. Nonlinear systems do not have a well-defined frequency response, and therefore, the Nyquist plot cannot be used for their analysis.

Nyquist plot can be used for systems with multiple input and output

Yes, Nyquist plots can indeed be used for systems with multiple inputs and outputs (MIMO systems), but the interpretation becomes more complex compared to single-input single-output (SISO) systems. In MIMO systems, each input-output pair can have its own Nyquist plot, and the overall stability of the system is determined by analyzing the behavior of all input-output pairs simultaneously.

Nyquist plots are applied to MIMO systems:

1. **Multiple Input-Output Pairs:** In a MIMO system, there can be multiple input-output pairs, each representing a distinct control path or signal pathway within the system. For each input-output pair, a Nyquist plot can be generated based on the transfer function relating the input signal to the output signal.

2. **Interpretation of Encirclements:** When analyzing Nyquist plots for MIMO systems, the critical point $(-1, 0)$ in the complex plane is still significant for stability assessment. The system is stable if and only if all the Nyquist plots for all input-output pairs encircle the critical point in a counterclockwise direction. Encirclements in the opposite direction indicate instability.
3. **Consideration of Interactions:** MIMO systems can exhibit interactions between input-output pairs, meaning changes in one input may affect multiple outputs and vice versa. These interactions can complicate the analysis of Nyquist plots since the stability of one input-output pair may be influenced by the behavior of other pairs. Engineers need to consider these interactions when interpreting Nyquist plots for MIMO systems.
4. **Robustness Analysis:** Nyquist plots for MIMO systems can also be used for robustness analysis, examining how variations in system parameters or uncertainties affect stability across all input-output pairs simultaneously. Robust stability analysis techniques, such as μ -analysis, are often employed to assess the robustness of MIMO systems based on Nyquist plots.
5. **Controller Design:** Nyquist plots for MIMO systems play a crucial role in controller design, allowing engineers to design controllers that stabilize all input-output pairs simultaneously while meeting performance specifications. Controller synthesis techniques tailored for MIMO systems, such as H^∞ control or μ -synthesis, often utilize Nyquist plots as part of the design process.