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PSCAD ZY-Toolbox Manual for RfG

1 Introduction

Welcome to the User Manual for the PSCAD ZY-Toolbox library, designed specifically for grid code compliance within the framework of the Requirements for Generators (RfG) in Sweden. This library is tailored to assist any grid-connected party (connectee) in meeting the technical standards necessary for connecting their plant to the Swedish power grid.

A key initial step for any connectee seeking grid connection is the extraction of both self and coupling (small-signal) impedances/admittances of their plant. Accurate impedance/admittance data is crucial, as it forms the foundation for subsequent stability assessments and ensures that the plant will not adversely affect the operation of the wider power system.

The PSCAD ZY-Toolbox library streamlines this process by providing a structured and user-friendly environment for performing admittance measurements using a so called- frequency scan. This manual will guide the users through the complete workflow, including:

- **Background:** An introduction to the frequency scan technique and impedance definitions.
- **Toolbox contents:** An overview of the files provided together with the ZY-Toolbox library.
- **Library setup:** How to integrate the library into PSCAD environment.
- **Case setup:** How to integrate the plant model into PSCAD case.
- **Parameter settings:** Detailed explanation of all user-adjustable parameters.
- **Screening process:** Step-by-step instructions for running simulations and screening the required data.

- **Reporting of results:** Guidance on post-processing and using the provided template to document admittance data as part of grid code compliance in the grid-connection process.

Step-by-step instructions for configuring and using the ZY-Toolbox in PSCAD are provided in Sections 5-9. However, the manual is recommended to be read in its entirety.

Please note that while this manual covers the extraction of admittance data, the subsequent use of this data for grid stability assessment is outside the scope of both the library and this manual. For further guidance on assessing converter driven stability from frequency dependent admittance data, please see the document Vägledning omriktarstabilitet_v2.1 available within the toolbox bundle.

2 Background

2.1 Frequency scan

The PSCAD ZY-Toolbox performs a frequency scan to extract frequency-dependent admittance data of a grid connected plant. The frequency scan typically needs to cover the range 1–2500 Hz to capture relevant behaviors and dynamic characteristics. The scan is conducted in time domain using electromagnetic transient (EMT) simulation.

During the scan, the toolbox applies small single-tone voltage perturbations in series with an ideal grid voltage source contained within the Toolbox. For each perturbation frequency f_p, the voltage perturbation must be injected separately in positive and negative sequence.

The resulting current response is measured, with current defined as positive when flowing towards the plant**.** The steady-state time-domain signals are processed using the Discrete Fourier Transform (DFT) to extract the voltage and current components at the perturbation frequency.

Note: Positive current is defined as directed into the investigated plant in the impedance definition. Accordingly, positive power flow is also towards the plant, defining power consumption as positive and power production as negative.

2.2 Impedance definition

Four impedances describe the grid connected plant.

The extracted DFT components of the perturbation signals, $\hat{v}_p(f_p)$, $\hat{v}_n(f_p)$, $\hat{\imath}_a(f_p)$, represent the positive-sequence voltage perturbation, negative-sequence voltage perturbation, and the measured current response of the plant respectively. From these quantities, the small-signal impedances are defined.

The small-signal impedances describe the relationship between an injected voltage perturbation to the resulting current response at a given frequency. The positive-sequence self-impedance Z_{ap} and the negative sequence self-impedance Z_{an} relate the perturbation in each sequence at perturbation frequency f_p to the current response at the same frequency f_p. The positive-sequence coupling impedance Z_{cp} and negative-sequence coupling impedance Z_{cn} relate the perturbation in one sequence to the current response in the opposite sequence at the shifted frequency $f_p \pm 2f_1$, capturing the frequency coupling between the sequences.

The self and coupling impedances in positive and negative sequence are defined as

$$Z_{ap} = \frac{\hat{v}_p(f_p)}{\hat{\imath}_a(f_p)}, \qquad Z_{an} = \frac{\hat{v}_n(f_p)}{\hat{\imath}_a(f_p)}, \qquad Z_{cp} = \frac{\hat{v}_p(f_p)}{\hat{\imath}_a(f_p - 2f_1)}, \qquad Z_{cn} = \frac{\hat{v}_n(f_p)}{\hat{\imath}_a(f_p + 2f_1)} \quad (1)$$

where f_1 denotes the fundamental grid frequency.

For further information on coupling impedances and frequency coupling, please see the document Vägledning för omriktarstabilitet_v2.1.

Although the quantities above are expressed in terms of impedance as commonly used in converter–grid interaction and stability analysis, the PSCAD ZY-Toolbox reports the results as admittance. The corresponding impedance can be obtained as the inverse of the admittance.

3 Toolbox bundle contents

The complete ZY Toolbox bundle is made up of the folders as seen in Figure 1. The folder Automatisering contains a file that automates the frequency scan method, Toolbox the PSCAD library and resource file, Dokumentation this manual and an Excel template for reporting of results, and Interaktionsstudier contains further guidance on assessing converter driven stability as well as any other requirements.

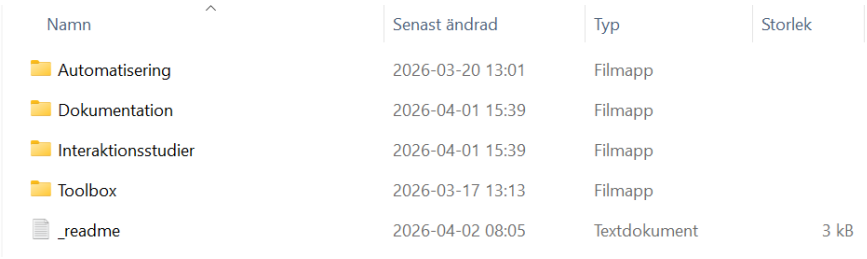


Figure 1: ZY-Toolbox bundle contents.

4 Compatibility overview

The PSCAD ZY-Toolbox library is compatible with PSCAD Version 5.0+ and any compiler.

An execution file (.exe), also referred to as an application, is provided along with the library. Instructions for using the execution file are included in this user manual. To be able to use the execution file, please ensure that all required automation packages, such as the PSCAD Automation Library, are installed. The distributed executable file is a Windows-only build and can be run on Windows systems. Native executables for other operating systems are not included in the Toolbox bundle.

5 Library setup

To set up the library, follow these steps:

1. Open the folder Toolbox containing the library and its associated files. Figure 2 illustrates the folder contents.

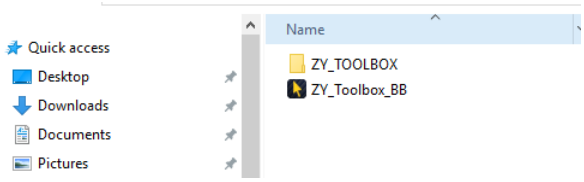


Figure 2: Toolbox folder contents.

2. Locate the file named ZY_Toolbox_BB. Open this file by either double-clicking it or by appending it to an already open PSCAD V5.0+ project. Figure 3 shows the PSCAD environment after this step.

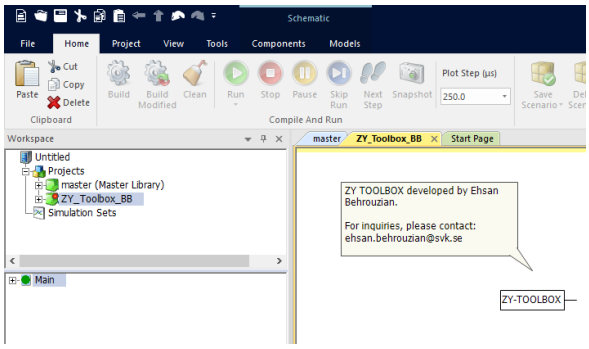


Figure 3: PSCAD environment after opening or appending the ZY-Toolbox library.

3. Click the “+” sign next to ZY_Toolbox_BB (see Figure 4) in the primary workspace pane.

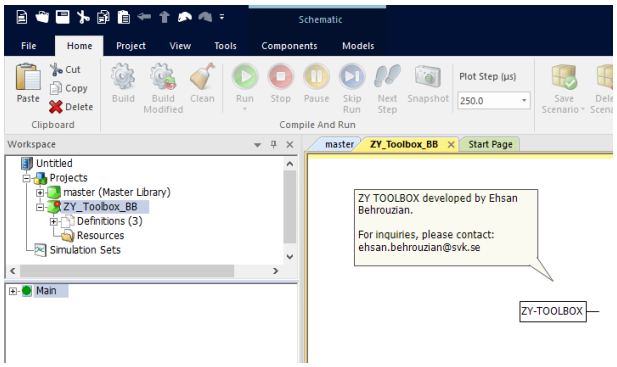


Figure 4: PSCAD environment after clicking on the “+” next to ZY_Toolbox_BB.

4. Right-click on the Resources section under ZY_Toolbox_BB, select “Add,” and then choose “Other(*.*)”. Navigate to the folder containing the library and open the subfolder named ZY_TOOLBOX (refer to Figure 5 and Figure 2).

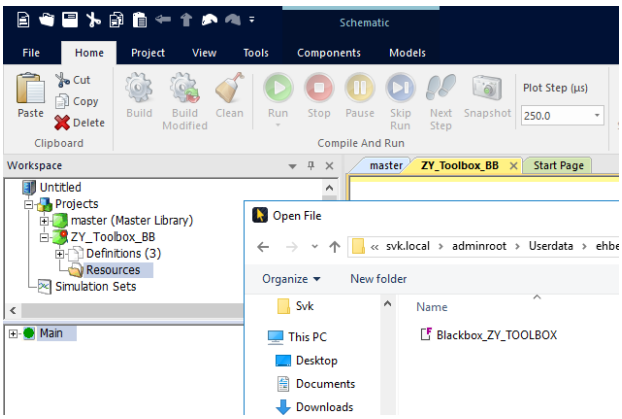


Figure 5: Process of adding the file Blackbox_ZY_TOOLBOX to the Resources.

5. Select the file Blackbox_ZY_TOOLBOX. If the file is successfully attached, the PSCAD environment will appear as shown in Figure 6. If the file is not properly linked, it will be displayed in red, as illustrated in Figure 7. If you encounter any issues with file attachment, ensure that the file paths are correct and that all required files are present in the specified directories. Once these steps are completed, the library is fully set up and ready for use.

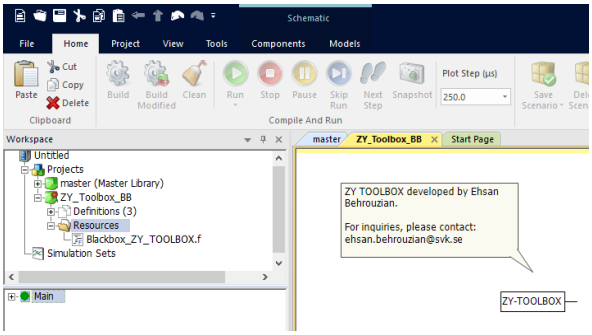


Figure 6: Blackbox_ZY_TOOLBOX file is successfully linked to the Resources.

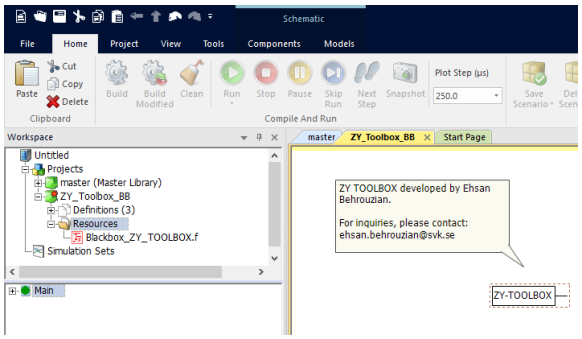


Figure 7: Blackbox_ZY_TOOLBOX file is not successfully linked to the Resources.

6 Case setup

Begin this step by creating a PSCAD case that includes the plant model and all associated components, such as filters, step-up transformers, and other relevant equipment, up to the grid connection point where the admittance screening will be conducted. Once complete, add the case to the workspace projects.

For demonstration purposes in this manual, a wind park model is used as an example. This model has already been developed in a PSCAD case named test_Pmax_Q0, which is added to the workspace as illustrated in Figure 8. The model comprises an aggregated wind park and a step-up transformer. It is designed up to the 230 kV grid connection point, where the screening will be conducted. Please note that the grid itself is modeled

within the ZY-Toolbox; therefore, it does not need to be included in the plant model.

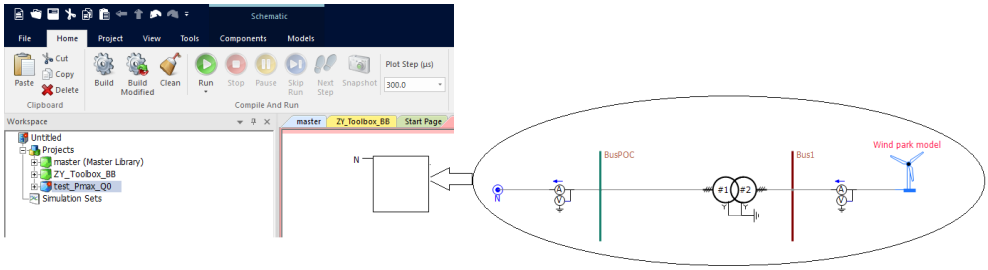


Figure 8: Case setup process by adding the plant PSCAD case to workspace.

Once both the library and the plant case are set up, copy the ZY-Toolbox library and paste it into the project case. Connect the Toolbox to the plant model as shown in Figure 9.

Note: All libraries, including the ZY-Toolbox library, must be placed above all cases in the PSCAD workspace (see Figure 9). If the library is placed below the case, it may not be automatically loaded into the case each time the workspace is opened.

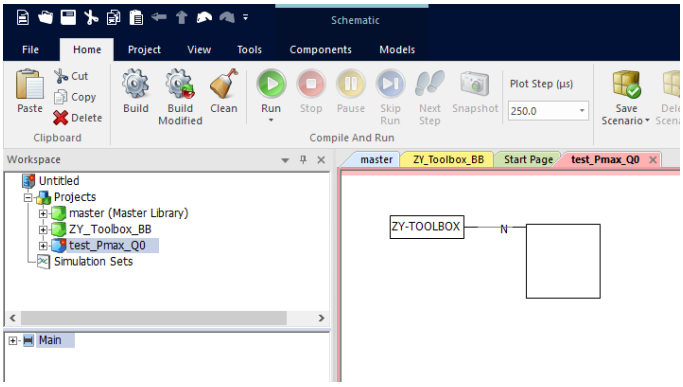


Figure 9: Adding ZY-Toolbox to the case and connecting it to the plant. Note that inside the Workspace ZY_Toolbox_BB is located above the test_Pmax_Q0.

Please ensure that the case and library are stored within the same folder, and save the workspace configuration as shown in Figure 10. In this example, the workspace is saved with the name Workspace. Additionally, the example is further developed by adding several other cases intended for different operating points.

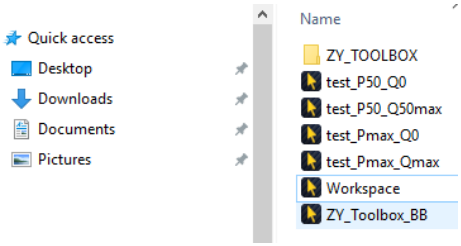


Figure 10: Library and cases are saved in the same folder and the whole workspace is saved with the name Workspace.

6.1 Case set up important considerations

Output channel configuration:
It is strongly recommended to disable all output channels in the plant model, except for those used by the Toolbox (izy and vzy inside the ZY-Toolbox). This helps prevent the storage of unnecessary data and ensures optimal processing speed.

Project settings parameters:
The simulation time step is the only parameter in the project settings that requires user configuration. Simulation time step is usually set by the model provider. Users should always verify the simulation time step against the specifications provided in the plant model documentation to ensure correct functionality.

Note: simulation time step should typically range between 1 and 50 µs. It is advisable not to exceed this range. For optimal screening accuracy, use any simulation time steps of 1, 2, 4, 5, 8, 10, 16, 20, 25, 32, 40, or 50 µs.

The remaining parameters in the Project Settings are automatically configured by the automation file; therefore, no manual adjustment by the user is required.

Case Naming Conventions:
To ensure proper execution of .exe files, avoid using spaces in case names. Instead, use underscores (_) as separators if needed. Special characters, like ‘åÅ’ ‘äÄ’ ‘öÖ’, should not be used. Also note that the case names must not start with numeric characters.

ZY-Toolbox library per case:
Each project case must contain only one ZY_Toolbox_BB library. Including multiple libraries within a single project is not permitted.

PNI is not allowed:
The plant model must not be distributed across multiple cases e.g., using

Parallel Network Interface (PNI). All components and associated items of the plant model must be contained within a single, independent case.

7 Parameter settings

The next step is to set the parameters of the ZY-Toolbox library for each case. To access the parameter menu, right-click on the ZY-Toolbox library and choose “Edit Parameters…”. Figure 11 displays the Configuration parameters for the ZY-Toolbox.

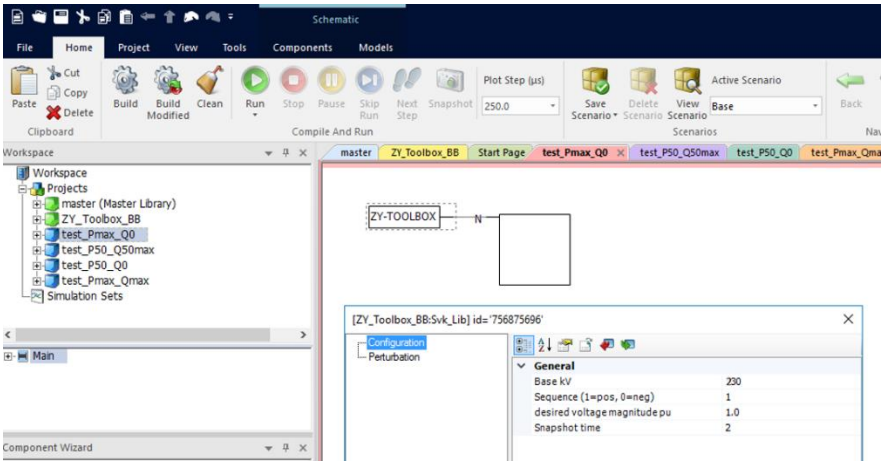


Figure 11: ZY-Toolbox Configuration parameters.

Base (kV):
This parameter specifies the base voltage level at the intended connection point to the grid. The default value is 230 kV. The base voltage must be between 0.69 and 800 kV.

Sequence:
This parameter specifies the sequence component of applied perturbations and the corresponding sequence data to be extracted. Users explicitly select either positive-sequence or negative-sequence. 1 denotes positive sequence, 0 negative sequence.

snapshot time (s):
Set this parameter to the desired snapshot time in seconds. The snapshot time should be set sufficiently long to ensure the plant reaches a steady-state at the specified operating point. The screening process will start after the snapshot time. The snapshot time must have a value between 0.1 and 50 s. The correct settings for snapshot time can be determined through trial and error while determining the desired voltage magnitude as described in the procedure below.

desired voltage magnitude (pu):
This parameter allows the user to define the actual voltage level at the intended grid connection point. The default value is set to 1 pu, which means the voltage at the connection point will match the Base (kV). For the default settings, this corresponds to 230 kV. This parameter is limited to the range of 0.5 to 1.5 pu. To further clarify how this parameter can be used, consider the following example.

Assume the wind park model, previously referenced, operates in grid voltage control mode. The desired operating condition is maximum active power output with zero reactive power at the 230 kV connection point.

Figure 12 illustrates the process for setting the required operating point.

1. The system's Base kV is set to 230 kV.
2. The snapshot time is initially configured to a high value of 50 s to delay the start of the screening process.
3. The voltage magnitude (pu) at the connection point is controlled by the setpoint vset, which is adjusted using the provided slider.

To begin the simulation:

1. Set the reference active power to its maximum value.
2. Achieve zero reactive power by incrementally tuning the vset parameter using trial and error while maintaining maximum active power production during the simulation run. Adjust the snapshot time to appropriate value.

Through this approach, a voltage magnitude of 0.99 pu is in this example identified as optimal, meeting the target operating point. A snapshot time of 10 seconds allows the model to reach steady state. In general, this procedure should be applied when simulating voltage control to achieve desired reactive power transfer.

Figure 13 displays the final Configuration parameter settings.

Note: The configuration settings for positive- and negative-sequence are identical for each operating point.
Note: Based on the example above, the plant will not be able to control the voltage if it attempts to regulate it at the connection point to the toolbox, as this point is connected to an infinite source. In such a case, a practical workaround would be to add a small inductance—approximately 10% of the output filter or transformer inductance—to enable controllability with only a negligible impact on the plant impedance.

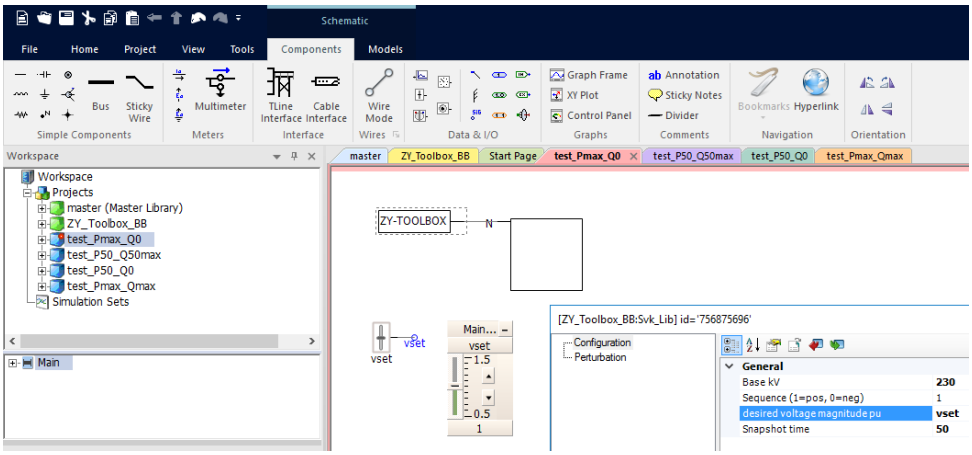


Figure 12: Process of finding correct settings for snapshot time and desired voltage magnitude.

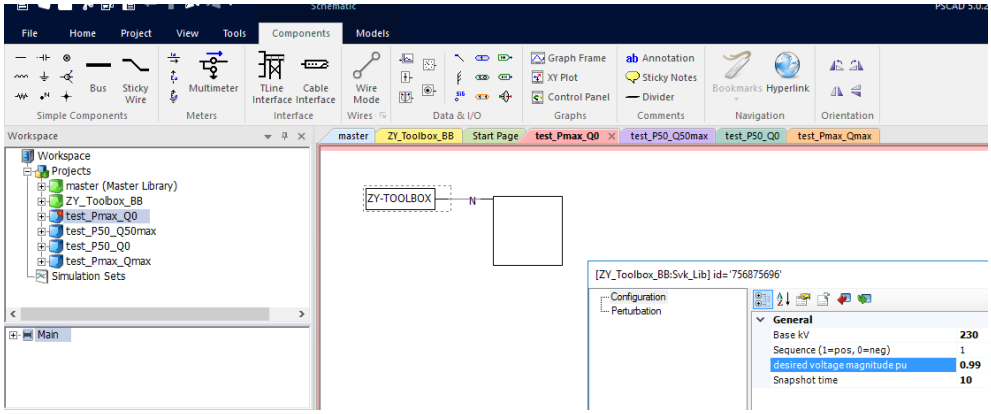


Figure 13: Final parameter settings for snapshot time and desired voltage magnitude.

The next set of parameters are adjusted under the tab Perturbation shown in Figure 14.

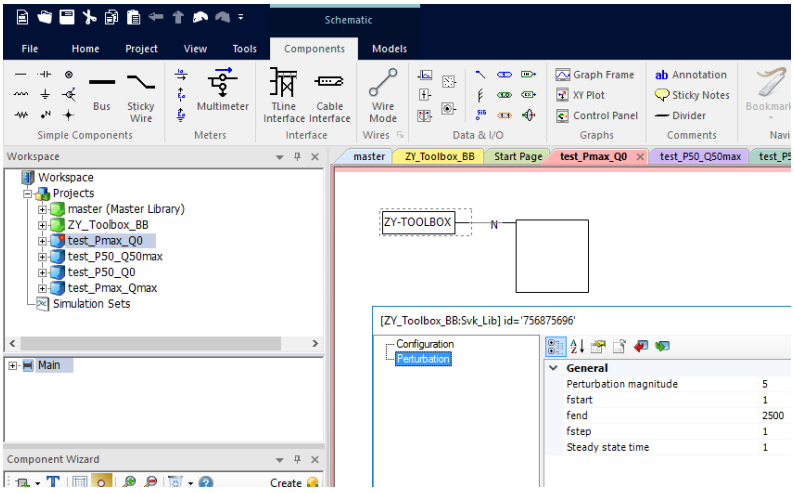


Figure 14: ZY-Toolbox perturbation parameters.

Perturbation magnitude (%):
The ZY-Toolbox enables users to specify the perturbation magnitude as a percentage (%) of the fundamental base voltage. The default perturbation magnitude is set to 5%. A value between 0.1 and 10% can be chosen.

fstart (Hz):
Specify the desired starting frequency. The default value is 1 Hz. The starting frequency must lie between 1 and 2500 Hz.

fend (Hz):
Specify the desired ending frequency. The default value is 2500 Hz. The ending frequency must lie between 1 and 2500 Hz and needs to be greater than fstart.

fstep (Hz):
Specify the desired incremental frequency step. Steps are applied linearly. The default step size is 1 Hz. For optimal screening accuracy, use any frequency step of 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1 or 5 Hz. Other frequency steps can be chosen but the Toolbox will warn users of non-optimal frequency step.

Note: Simulations need to cover the frequency range specified in the project-specific requirements provided by Svenska kraftnät, which is normally 1–2500 Hz. For exact requirements, see the project-specific documentation (Insamlingsmall_kraftparksmodul_RfG.xlsx).

Steady state time (s):
Specify the time required for the plant to reach a steady state after applying the perturbation. The default steady state time is 1 second but may be specified as any value between 0.1 and 1000 s.

Note: Apart from the parameter adjustments described above, no modifications should be made within the ZY-Toolbox library.

8 Creating simulation sets

After configuring all cases and setting the parameters, users must create simulation sets. Utilizing simulation sets enables parallel execution of multiple cases, thereby significantly accelerating the simulation process. The number of cases that can be assigned to each set depends on both the number of CPU cores available on the user's computer and the user's PSCAD license.

It is assumed that users are familiar with the concept of simulation sets; therefore, only a brief recommendation is provided here. Users are

encouraged to assign cases to each set thoughtfully to maximize CPU utilization and overall simulation efficiency. In general, it is recommended to group similar cases within the same set - for example, cases with similar frequency ranges and steady-state durations. This approach is beneficial because a simulation set will only proceed to the next set once all cases in the current set have completed. As a result, the total simulation time for a set is determined by the case that takes the longest to finish (often due to a higher number of screening points).

By grouping cases with similar expected runtimes, users can ensure that all cases within a set complete at approximately the same time, minimizing idle CPU time and maximizing efficiency.

Note: Creating at least one simulation set is essential for the process to function correctly. The execution file will fail if no simulation set is defined, even if there is only a single case.

9 Execution

Once all project cases are provided with Toolbox parameters and simulation sets have been prepared, save them in the project workspace and close PSCAD. The screening process can be performed using the execution file provided with the library. Proceed with the following steps:

Locate and open ZY_Toolbox_automation.exe in the folder Automatisering (Windows refers to the file as an Application). Double-click the file to open it. Figure 15 shows the window that will appear.

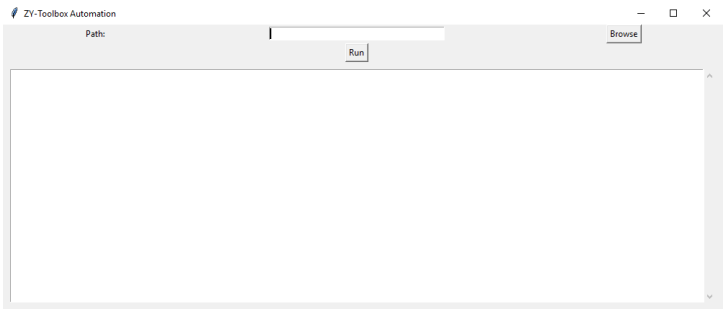


Figure 15: ZY-Toolbox automation window at start.

Select the PSCAD Workspace Folder
Click on the “Browse”-button and navigate to the folder containing the PSCAD workspace. The default directory is the location of the executable (.exe) file.

Run the PSCAD simulation
Click “Run”.

Note: At the start of the simulation, all project case subfolders within the workspace directory (if present) are deleted to ensure a clean environment. Any previous simulation runs will have stored their results in the subfolders as .csv files. If retention of these subfolders is required, make sure to create a backup in advance.

The program launches PSCAD, loads the specified workspace, adjusts various parameter settings, and initiates the simulation. After running the executable file, the only required action is to wait and allow the computer sufficient time to complete a predefined sequence of tasks. If no unexpected issues arise, the process should complete successfully. During this period, do not interrupt the operation, or open, modify, or move any files or folders within the workspace directory, as this may disrupt the process and compromise the results.

During the process, progress can be monitored within the PSCAD environment or through the automation window to estimate the remaining simulation time. The automation window indicates the screening status by showing the most recently processed frequency for each case within the current simulation set. An example is illustrated in Figure 16.

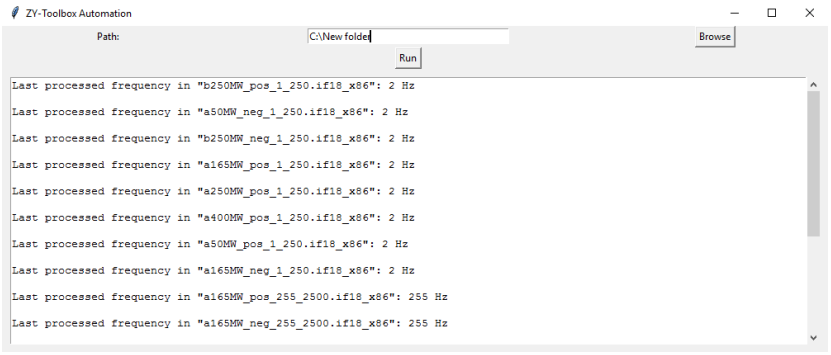


Figure 16: ZY-Toolbox automation window during the process.

After the start of the process, please wait until the PSCAD simulation is finished. When the first “Success” window appears (see Figure 17), it indicates that the simulation has finished. PSCAD will then be closed automatically.

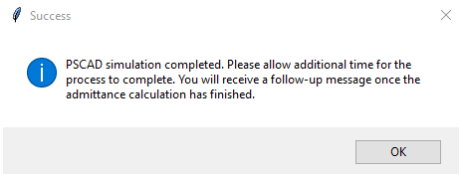


Figure 17: First “Success” window will be shown once the PSCAD simulation is finished.

Please wait a little longer until another window titled “Success” appears, indicating the completion of the admittance calculations (Figure 18). Before selecting OK and closing the window, verify the automation window (Figure 16) to ensure that the final processed frequency matches the expected value in all cases.

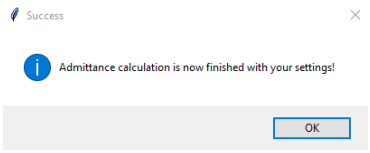


Figure 18: Second “Success” window will be shown once the admittance calculation is finished.

10 Results

After the completion of the simulation and admittance calculation, navigate to the workspace folder and find the subfolders corresponding to each case project. An example of this is illustrated in Figure 19. Within these subfolders, locate the .csv file named Admittances. Open this file to verify that both self and coupling admittances are included. Figure 20 illustrates an example of the saved data displayed in Excel. In this data, f_p represents the frequency in hertz (Hz). Y and Y_c denote the self and coupling admittances, respectively, measured in siemens (S).
Similarly, $ph(Y)$ and $ph(Y_c)$ correspond to the phase angles of the self and coupling admittances, expressed in degrees.

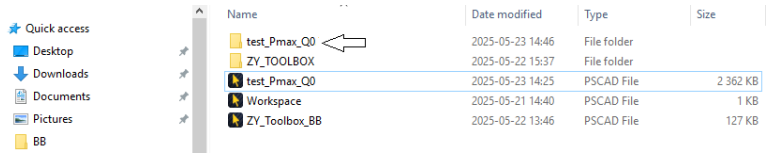
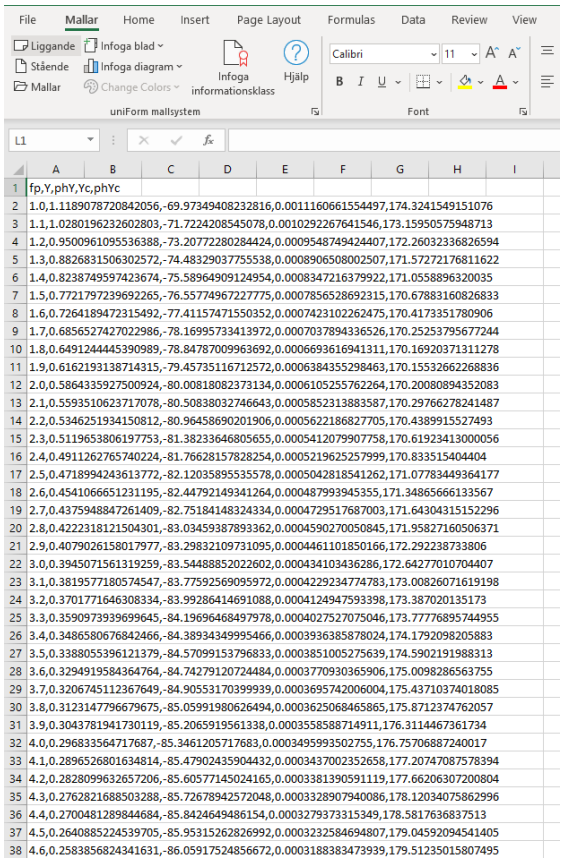


Figure 19: Workspace folder containing subfolder test_Pmax_Q0 with the results corresponding to test_Pmax_Q0 project case.



	A	B	C	D	E	F	G	H	I
1	fp,Y,phY,Yc,phYc								
2	1.0,1.1189078720842056,-69.97349408232816,0.0011160661554497,174.3241549151076								
3	1.1,1.0280196232602803,-71.7224208545078,0.0010292267641546,173.15950575948713								
4	1.2,0.9500961095536388,-73.20772280284424,0.0009548749424407,172.26032336826594								
5	1.3,0.8826831506302572,-74.48329037755538,0.0008906508002507,171.57272176811622								
6	1.4,0.8238749597423674,-75.58964909124954,0.0008347216379922,171.0558896320035								
7	1.5,0.7721797239692265,-76.55774967227775,0.0007856528692315,170.67883160826833								
8	1.6,0.7264189472315492,-77.41157471550352,0.0007423102262475,170.4173351780906								
9	1.7,0.6856527427022986,-78.16995733413972,0.0007037894336526,170.25253795677244								
10	1.8,0.6491244445390989,-78.84787009963692,0.0006693616941311,170.16920371311278								
11	1.9,0.6162193138714315,-79.45735116712572,0.0006384355298463,170.15532662268836								
12	2.0,0.5864335927500924,-80.00818082373134,0.0006105255762264,170.20080894352083								
13	2.1,0.5593510623717078,-80.50838032746643,0.0005852313883587,170.29766278241487								
14	2.2,0.5346251934150812,-80.96458690201906,0.0005622186827705,170.4389915527493								
15	2.3,0.5119653806197753,-81.38233646805655,0.0005412079907758,170.61923413000056								
16	2.4,0.4911262765740224,-81.76628157828254,0.0005219625257999,170.833515404404								
17	2.5,0.4718994243613772,-82.12035895535578,0.0005042818541262,171.07783449364177								
18	2.6,0.4541066651231195,-82.44792149341264,0.0004879939455355,171.34865666133567								
19	2.7,0.4375948847261409,-82.75184148324334,0.0004729517687003,171.64304315152296								
20	2.8,0.4222318121504301,-83.03459387893362,0.0004590270050845,171.95827160506371								
21	2.9,0.4079026158017977,-83.29832109731095,0.0004461101850166,172.292238733806								
22	3.0,0.3945071561319259,-83.54488852022602,0.0004341034362686,172.64277010704407								
23	3.1,0.3819577180574547,-83.77592569095972,0.0004229234774783,173.00826071619198								
24	3.2,0.3701771646308334,-83.99286414691088,0.0004124947593398,173.387020135173								
25	3.3,0.3590973939699645,-84.19696468497978,0.0004027527075046,173.77776895744955								
26	3.4,0.3486580676842466,-84.38934349995466,0.0003936385878024,174.1792098205883								
27	3.5,0.3388055396121379,-84.57099153796833,0.0003851005275639,174.5902191988313								
28	3.6,0.3294919584364764,-84.74279120724484,0.0003770930365906,175.0098286563755								
29	3.7,0.3206745112367649,-84.90553170399939,0.0003695742006004,175.43710374018085								
30	3.8,0.3123147796679675,-85.05991980626494,0.0003625068465865,175.8712374762057								
31	3.9,0.3043781941730119,-85.20659195613338,0.0003558588714911,176.3114467361734								
32	4.0,0.2968335647176 87,-85.3461205717683,0.0003495993502755,176.75706887240017								
33	4.1,0.2896526801634814,-85.47902435904432,0.0003437002352658,177.20747087578394								
34	4.2,0.2828099632657206,-85.60577145024165,0.0003381390591119,177.66206307200804								
35	4.3,0.2762821688503288,-85.72678942572048,0.0003328907940086,178.12034075862996								
36	4.4,0.2700481289844684,-85.84246494861 54,0.0003279373315349,178.5817636837513								
37	4.5,0.2640885224539705,-85.95315262826992,0.0003232584694807,179.04592094541405								
38	4.6,0.2583856824341631,-86.05917524856672,0.0003188383473939,179.51235015807495								

Figure 20: Admittance excel file containing both self and coupling admittances.

11 Reporting of results

As part of the grid connection process, frequency dependent admittance data describing the connecting power electronic interfaced plant are to be submitted to Svenska kraftnät using the Excel template provided with this library. The ZY-Toolbox library can assist connectees in acquiring this data. In the provided ZY-Toolbox folder, first open folder Dokumentation and then the file Mall_Leverans_av_Admittansdata.

The first sheet, Ref_Driftfall, describes a set of operating conditions which may or may not be relevant to the connecting plant (see Figure 21). The specified parameters include active and reactive control modes, active and reactive power flow (pu), and the desired voltage magnitude at the ZY-toolbox connection point (pu). The parameters are given either as predefined value sets or as quantities to be adjusted manually. Where multiple options are specified (e.g. separated by “/”), all relevant combinations across the parameters shall be evaluated as separate simulation cases. For example, if only row 2 is relevant to the connecting plant, a total of 2 × 3 = 6 operating points should be investigated.

For reactive control mode, the voltage level at which the control is applied must also be specified by replacing the “X” with the correct value.

	A	B	C	D	E	F
1		**Reglermod aktiv**	**Reglermod reaktiv**	**Aktiv effekt (pu)**	**Reaktiv Effekt (pu)**	**Önskad spänningsmagnitud (pu)**
2		Aktiv effekt	na	-1 / -0,1	na	0,95 / 1 / 1,05
3		Aktiv effekt	na	1 / 0,1	na	0,95 / 1 / 1,05
4		Aktiv effekt	Spänning @ X kV	-1 / -0,1	0 / 0,33 * Pmomentan / -0,33 * Pmomentan	Justeras manuellt
5		Aktiv effekt	Q @ X kV	-1 / -0,1	0 / 0,33 * Pmomentan / -0,33 * Pmomentan	0,95 / 1 / 1,05
6		Aktiv effekt	Spänning @ X kV	1 / 0,1	0 / 0,33 * Pmomentan / -0,33 * Pmomentan	Justeras manuellt
7		Aktiv effekt	Q @ X kV	1 / 0,1	0 / 0,33 * Pmomentan / -0,33 * Pmomentan	0,95 / 1 / 1,05
8		na	Spänning @ X kV	na	1 / 0 / -1	Justeras manuellt
9		na	Q @ X kV	na	1 / 0 / -1	0,95 / 1 / 1,05

Figure 21: Specification of various operating conditions that may be relevant to the studied plant.

In the next sheet, Ex_Vindpark, an example is provided illustrating how to define and select relevant simulation scenarios for specifically a wind power plant with the capability to control active power as well as voltage or reactive power at 33 kV. This gave a total of 24 operating points to consider.

Under the tab Simulerade_fall, the simulation cases required by the grid code and performed by the connecting party are listed. The required information includes:

ID:
Each case is assigned a number to identify it, starting from 1 and increasing thereafter.

Active control mode:
Describes the applied control mode of active dynamics, for example active power.

Reactive control mode:
Describes the applied control mode of reactive dynamics, for example reactive power or voltage. The voltage level at which reactive control is applied should also be specified, as it may be defined at either the plant output terminals or the grid connection point.

Power rating (MVA):
The power rating of the plant to be connected in MVA.

Active power (pu):
Active power flow of the studied plant, where positive values indicate flow towards the plant (consumption) and negative values indicate flow out from the plant (production).

Reactive power (pu):
Reactive power flow of the studied plant, using the same sign convention as for active power.

Timestep simulation (µs):
Applied time step during simulation, typically in the range between 1 and 50 µs.

Base voltage at perturbation (kV):
Base voltage as specified in the ZY-Toolbox in kV.

Desired voltage magnitude (pu):
Desired voltage magnitude at the connection point as specified in the ZY-Toolbox. This parameter may need to be found by trial and error as detailed in Section 7 Parameter settings for the wind park example. More generally, when operating in voltage control mode to achieve a specified reactive power exchange, the voltage setpoint must be adjusted accordingly to obtain the desired power flow.

Snapshot time (s):
Time at which data recording is initiated, as specified in the ZY-Toolbox.

Magnitude of perturbations (%):
Size of injected perturbations in relation to the base voltage as specified in the ZY-Toolbox.

Starting frequency (Hz):
Starting frequency of the admittance scan as specified in the ZY-Toolbox.

Ending frequency (Hz):
Ending frequency of the admittance scan as specified in the ZY-Toolbox.

Frequency step (Hz):
Frequency step of the admittance scan as specified in the ZY-Toolbox.

Steady state time (s):
Should be long enough to allow the studied plant to reach a stable operating point after applied perturbation as specified in the ZY-toolbox.

Comments:
Any comments providing further information on the simulated case.

Note: If the simulation is performed over a broad frequency span, it may be a good idea to divide the range into smaller intervals. At higher frequency, larger frequency steps may be acceptable. This can be an effective way to decrease simulation time when lower frequency resolution is applicable. An example of how to report this properly is given in the sheet Ex_Vindpark, row 8-10 and in Figure 22.

L	M	N
Startfrekvens (Hz)	**Slutfrekvens (Hz)**	**Frekvenssteg (Hz)**
1 / 250 / 1000	250 / 1000 / 2500	1 / 5 / 25
1 / 250 / 1000	250 / 1000 / 2500	1 / 5 / 25
1 / 250 / 1000	250 / 1000 / 2500	1 / 5 / 25

Figure 22: Reporting of frequency information when varying frequency intervals have been applied.

In the following sheets, the simulation data obtained for each considered case is reported. The sheets are named according to the ID number of the corresponding case. If any of the prepared sheets are not used, remove them from the template by right-clicking and selecting “Delete”.

Note: In sheets 1 and 2, example data is provided that should be replaced with the connectee’s own admittance data. These example data are intended for demonstration purposes only and should not be interpreted as actual data. Note also that the studied frequency range should follow the project-specific requirements, typically 1–2500 Hz.

For each case, the following parameters are to be reported for both positive and negative sequence in the appropriate columns, as shown in Figure 23:

- Perturbation frequency f_p
- Positive sequence self-admittance Y_p and phase angle $ph(Y_p)$
- Positive sequence coupled admittance Y_{cp} and phase angle $ph(Y_{cp})$
- Negative sequence self-admittance Y_n and phase angle $ph(Y_n)$
- Negative sequence coupled admittance Y_{cn} and phase angle $ph(Y_{cn})$

The case simulations must thus be performed for both positive and negative sequence voltage perturbations. The results provided by the ZY-Toolbox in the form of .csv files can be directly copied into the Excel template without further post-processing.

fp	Yp	ph(Yp)	Ycp	ph(Ycp)	Yn	ph(Yn)	Ycn	ph(Ycn)
1	0,000131	-90,7037	8,85E-05	84,8892	0,000137	89,14144	8,89E-05	-85,3653

Figure 23: Columns in the Excel-template where results are to be reported. The subscript p denotes positive sequence, and the subscript n denotes negative sequence.

Under the last tab Plottar, Bode plots of the self- and coupled admittances are generated. An example of a Bode-plot for positive sequence admittance is illustrated in Figure 24. The purpose of this is to easily identify signs of unwanted converter behavior.

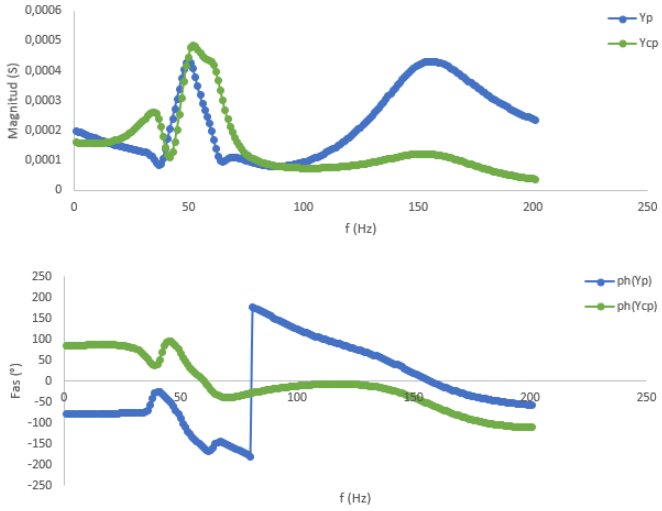


Figure 24: Bode-plot of positive sequence admittance generated by the template.

11.1 Excel file format

It is important that the contents of the Excel-template follow a strict and consistent structure, as the data will later be used for automated analysis and further studies. Deviations from the requirements below may lead to errors during import or incorrect results. The requirements below specifically apply to the sheets where the connectee reports their admittance data.

Structure:
Data should begin from row 3, while rows 1-2 contain headers. Columns A-I must be filled in according to the specified headers. The column order must not be changed, and no additional columns are to be added. Each sheet should only contain data from one specific simulation case.

Data content:
The following requirements apply to the data:

- All values must be numeric
- No text values are allowed, such as ”N/A”, ”-” or similar
- No empty cells should be present within the data range
- Units must not be changed: frequency in Hz, admittance in S, and angle in degrees
- Frequency values must be sorted in ascending order

Each row should represent a complete data point, meaning that all columns must contain values. After exporting from the .csv file, no manual

modifications of the data values should be made, except for changing the decimal separator if required by local Excel settings.

Number format and compatibility:
Excel uses different decimal separators depending on language settings (e.g., comma in Swedish Excel, dot in English Excel). To ensure that plots and further analyses function correctly, local settings must be followed.

Data must always be interpreted as numeric. Therefore, ensure that values are imported or pasted as numbers, not text, so that all calculations and figures are handled correctly.

Sheet Naming:
Sheet names must follow a consistent and unique naming convention using sequential ID numbers, as previously described. The names are used in plot references and further analysis, and therefore must be exact. Pay particular attention to avoid extra spaces or unintended characters.

11.2 Managing large data sets and additional simulation cases

If the simulation data inserted into the Excel sheet contains more than 5000 rows the limits of the graphs need to be extended to include these data points. Right click the plot of interest, choose “Mark data” and then “Edit” the data-series interval required, see Figure 25.

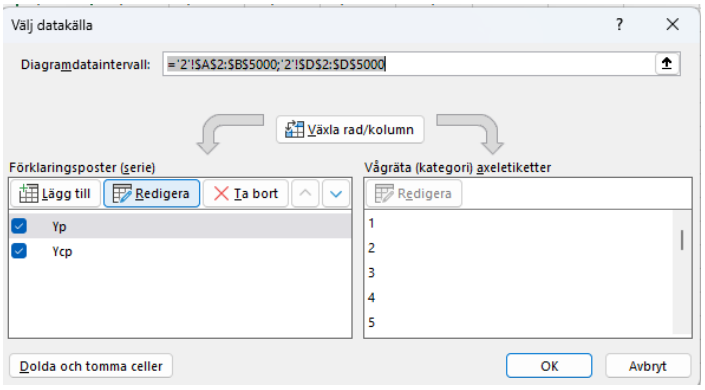


Figure 25: Selection of correct diagram interval to be included in the graph.

If more than eight simulation cases are performed, additional tabs for data reporting must be added. First, fill in the details of each additional case in the Simulerade_fall sheet. Then, copy one of the existing data tabs by right-clicking it, select “Move or copy…”, tick the box to create a copy, and rename the tab to the appropriate case ID, continuing the numbering sequentially. Finally, fill the tab’s columns with the corresponding admittance data.

Under the Plottar tab, a new set of plots must be added. First, copy the contents of column P and paste them two columns to the right, keeping the source column width. This will generate a total of four new plots for each additional simulation case. Next, for each plot, right-click and select “Mark Data”, followed by “Edit” for each series. For each series (two per plot), update the reference to point to the correct Excel tab corresponding to the case. The row and column references do not need to be changed, as they are identical across all tabs. For example, in Figure 25, if adding a case with ID 9, the sheet reference ‘2’! in the diagram data interval should be changed to ‘9’!.