PowerWorld Simulator Power Flow Phase Shift Groups

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Overview

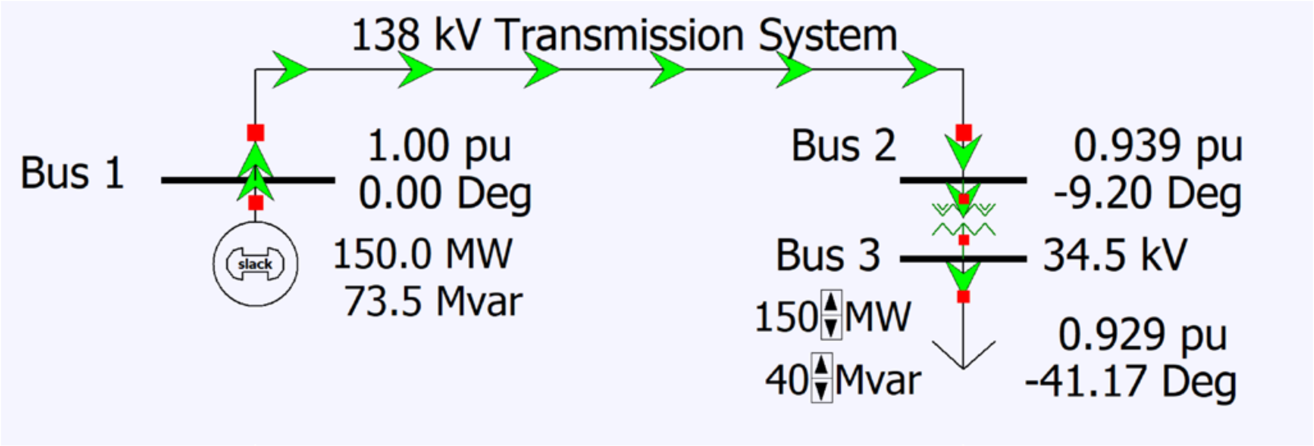
- In three-phase power systems it is very common to have two winding transformers that employ wye-connected windings on one side and delta-connected windings on the other, or to have three winding transformers with a combination of wye and delta windings
  - Such connections introduce phases shifts with multiples of 30°
- In a standard (positive sequence) power flow these phase shifts to not need to be modeled; however, increasingly they are being modeled by explicitly adding multiple of 30° phase shifts to the transformers
  - This results in corresponding phase shifts in the solution angles
- To help keep track of these phase shifts, PowerWorld has introduced a new data type known as Phase Shift Groups (PSGs)

Phase Shift Groups (PSGs)

- A PSG is defined as the set of boundary transformers that are modeled as having a specific phase shift, and the lower voltage, radial subnetwork buses affected by this phase shift
  - A simple, and quite common example, is single generator connected to the transmission system through a generator step-up transformer (GSU) that is grounded-wye on the high side, and delta on the low side
  - Another simple example is a radial load modeled with a step-down transformer
  - However, PSGs can contain larger subnetworks with many buses and several boundary transformers (e.g., a 34.5 kV network)
- A PSG can contain another PSG, having an even lower voltage
- Transformers can only be part of the boundary for a single PSG, but buses can be in multiple PSGs

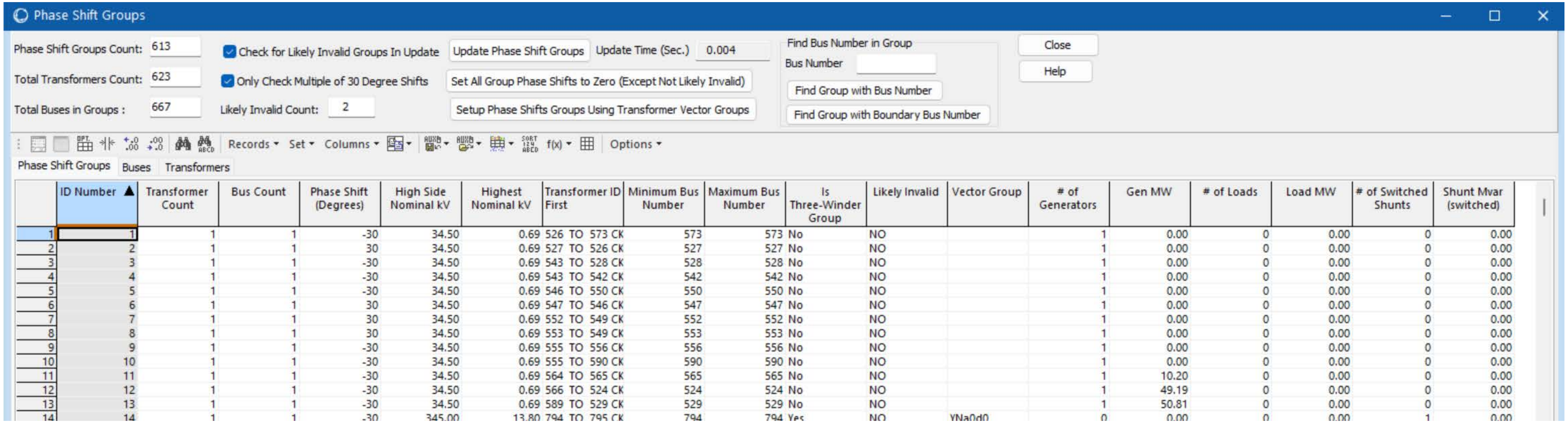
Simple PSG Example

- The below oneline shows an example in which a load is served through a 138/34.5 kV transformer (connected delta-grounded wye) in which the lower voltage lags the transmission system by 30 degrees
  - This is modeled in the power flow by having a 30 degree phase shift the Bus 2 (From) to Bus 3 (To) transformer
  - This phase shift does not need to be modeled, and has no impact on the power flow solution other than shifting the Bus 3 voltage angle; however, commonly they are modeled
- Here the PSG has a single boundary trans-former and a single bus (i.e., Bus 3)



Phase Shift Groups Dialog

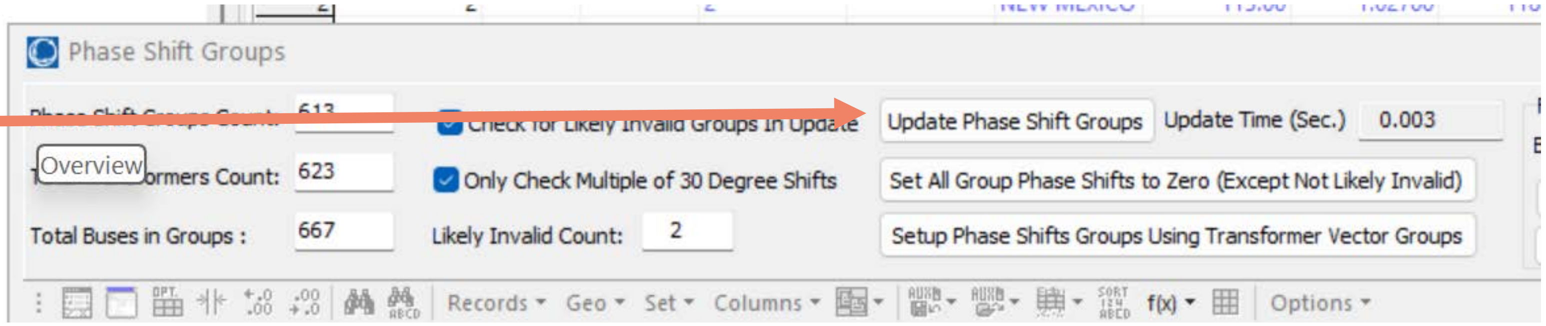
- PSGs are only calculate and shown in the **Run Mode**
- To view all the PSGs in a case select **Tools, Connections, Find Phase Shift Groups** to display the Phase Shift Groups Dialog
  - The below example is for a recent WECC case, with the bus numbers sequentially renumbered to obscure the actual system components



	ID Number	Transformer Count	Bus Count	Phase Shift (Degrees)	High Side Nominal kV	Highest Nominal kV	Transformer ID First	Minimum Bus Number	Maximum Bus Number	Is Three-Winder Group	Likely Invalid	Vector Group	# of Generators	Gen MW	# of Loads	Load MW	# of Switched Shunts	Shunt Mvar (switched)
1	1	1	1	-30	34.50	0.69	526 TO 573 CK	573	573	No	NO		1	0.00	0	0.00	0	0.00
2	2	1	1	30	34.50	0.69	527 TO 526 CK	527	527	No	NO		1	0.00	0	0.00	0	0.00
3	3	1	1	-30	34.50	0.69	543 TO 528 CK	528	528	No	NO		1	0.00	0	0.00	0	0.00
4	4	1	1	-30	34.50	0.69	543 TO 542 CK	542	542	No	NO		1	0.00	0	0.00	0	0.00
5	5	1	1	-30	34.50	0.69	546 TO 550 CK	550	550	No	NO		1	0.00	0	0.00	0	0.00
6	6	1	1	30	34.50	0.69	547 TO 546 CK	547	547	No	NO		1	0.00	0	0.00	0	0.00
7	7	1	1	30	34.50	0.69	552 TO 549 CK	552	552	No	NO		1	0.00	0	0.00	0	0.00
8	8	1	1	30	34.50	0.69	553 TO 549 CK	553	553	No	NO		1	0.00	0	0.00	0	0.00
9	9	1	1	-30	34.50	0.69	555 TO 556 CK	556	556	No	NO		1	0.00	0	0.00	0	0.00
10	10	1	1	-30	34.50	0.69	555 TO 590 CK	590	590	No	NO		1	0.00	0	0.00	0	0.00
11	11	1	1	-30	34.50	0.69	564 TO 565 CK	565	565	No	NO		1	10.20	0	0.00	0	0.00
12	12	1	1	-30	34.50	0.69	566 TO 524 CK	524	524	No	NO		1	49.19	0	0.00	0	0.00
13	13	1	1	-30	34.50	0.69	589 TO 529 CK	529	529	No	NO		1	50.81	0	0.00	0	0.00
14	14	1	1	-30	345.00	13.80	794 TO 795 CK	794	794	Yes	NO	YNa0d0	0	0.00	0	0.00	1	0.00

Calculating the Phase Shift Groups

- PSGs are determined by the transformer phase shifts, and hence they are calculated, as opposed to being directly defined
- The number of PSGs in a case can change depending on the topology
- By default, currently the PSGs are not automatically calculated, but they are automatically calculated anytime the Phase Shift Group Dialog is first displayed
  - This calculation is usually quite fast. For example, for the 27,000 bus WECC case the calculation took about 4 ms.
- A button is provided on the PSGs Dialog to update the groups

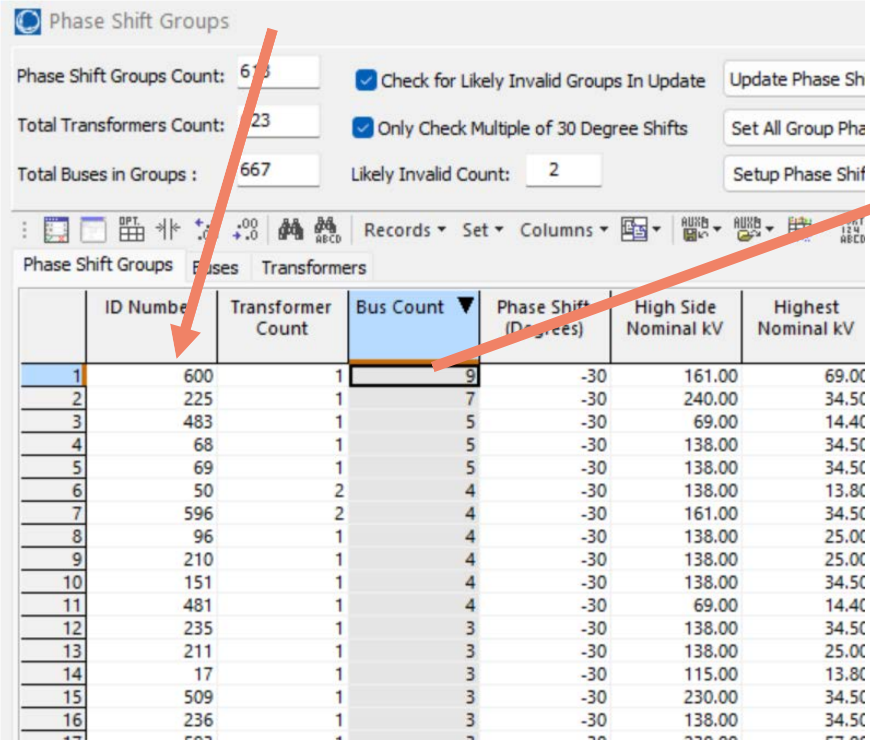


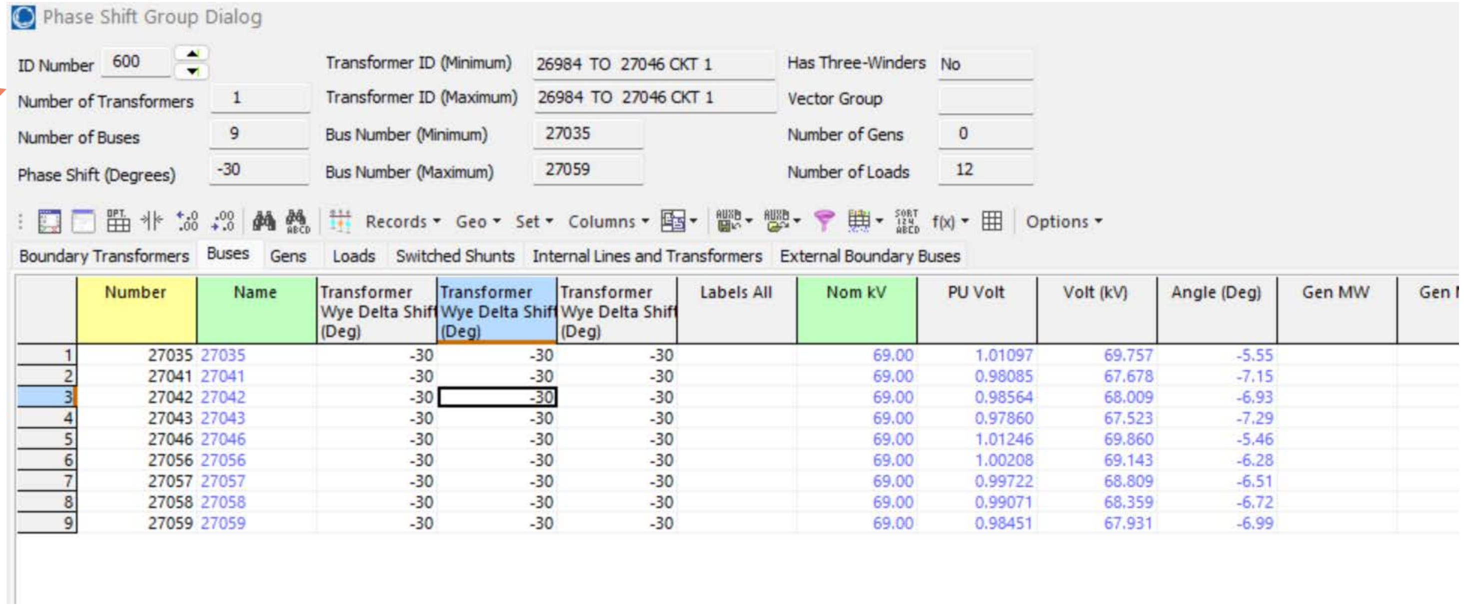
Viewing the Dialog for Individual PSGs

- The PSGs Dialog is a regular Case Info display in which the dialog for any PSG can be shown by right-clicking and selecting **Show Dialog**

The PSG ID Number is an arbitrary positive value

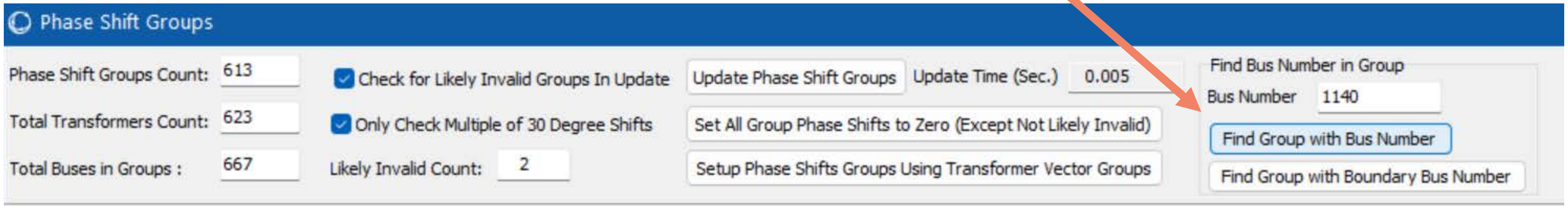
The dialog shows details on the objects in the PSG; this example has nine buses, connected to the transmission grid through a single boundary transformer



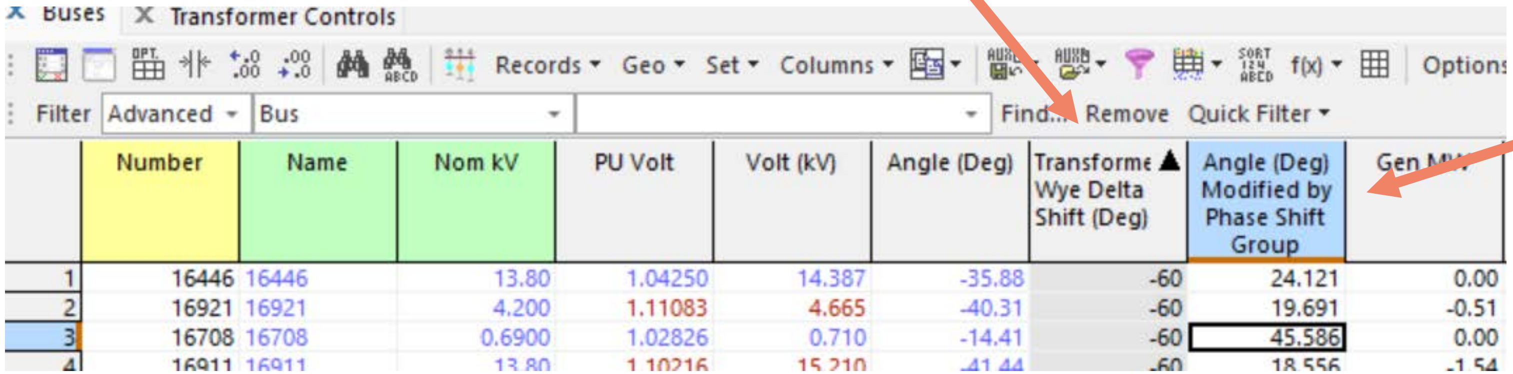


Finding PSGs for Specific Buses

- Whether a bus is in a PSG (or multiple ones) is determined either by using the **Find Bus Number in Group** option on the PSGs Dialog



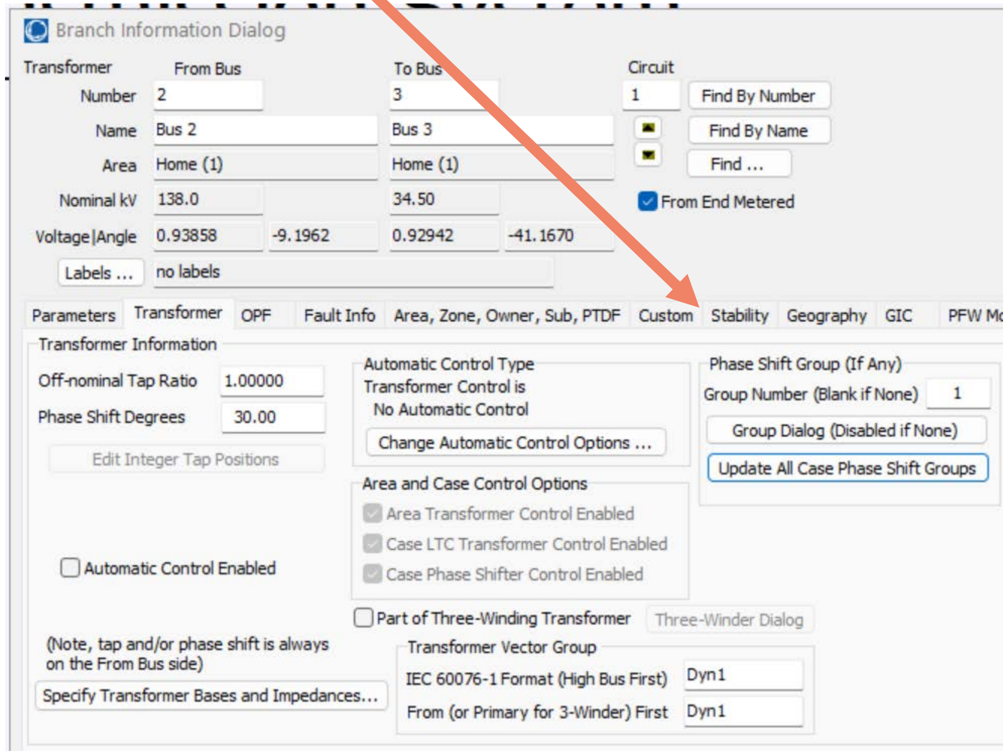
- Or on the Buses Case Info display showing the **Voltage\Phase Shift in Degrees Due to Wye Delta Shifts**



Shows the bus angle with the shifts due to the PSGs removed, useful for comparing phase angles across the case

PSG Dialog Viewed From Transformer Info Dialog

- The PSG dialog can also be shown from the Transformer page of the Branch Information Dialog
  - If the PSGs have not been calculated, use the **Update All Case Phase Shift Groups** button to calculate (or update) them
- This dialog also shows the transformer's vector group, if any
- The next few slides briefly cover vector groups
- The PSGs at defined by the modeled phase shifts not the vector groups, but as noted later, the phase shifts can be set from the vector groups



Transformer Vector Groups

- Transformer vector groups are used to fully specify the connections between the windings on a three or two winding transformer
- Vector groups are not needed for power flow, but they are needed if the power flow is used to initialization fault analysis or harmonics, and are a needed input for geomagnetic disturbance (GMD) analysis
- A vector group consists of symbols in capital letters telling the connection type for the high-voltage winding (Y,D, or Z for zigzag) and small letters for the intermediate and low-voltage winding
  - If a neutral point is brought out an N or n is used; for auto transformers the lower voltage symbol is replaced by an "a"
  - Phase displacement is given by clock numbers (0 to 11) indicating 30 degree intervals of lag from the high voltage winding

Transformer Vector Groups, Example

- The table gives examples of vector groups used in a 10,000 bus industry power flow model
  - Note the table contains a mixture of vector groups for three winding and two winding transformers
  - Such metrics are easy to obtain from data on any PowerWorld Case Info display by right-clicking on the field and selecting **Set/Toggle/Columns, Get Column Metrics**, to display the Grid Metrics, and then selecting the **Histograms and Groupings** page

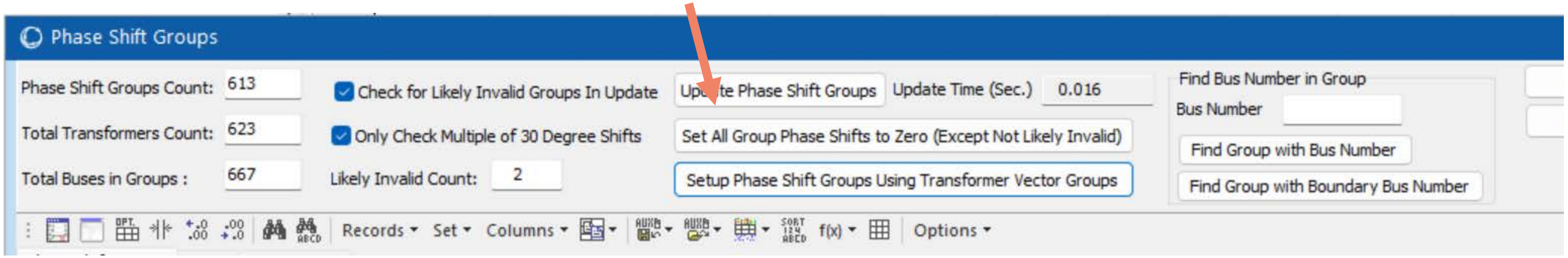
	Text Value	Percent	Count	Cumulative Count	Cumulative Percent
1	YNyn0	36.622	683	683	36.622
2	YNd1	25.094	468	1151	61.716
3	YNa0d1	16.783	313	1464	78.499
4	YNa0	11.260	210	1674	89.759
5	Dyn1	3.753	70	1744	93.512
6	YN0d1d1	1.609	30	1774	95.121
7	Dd0	1.072	20	1794	96.193
8	YN0yn0yn0	0.590	11	1805	96.783
9	YN0yn0d1	0.536	10	1815	97.319
10	D0d2	0.483	9	1824	97.802
11	YNd11	0.429	8	1832	98.231
12	YNa	0.214	4	1836	98.445
13	Dy1	0.214	4	1840	98.660
14	D1y0y0	0.214	4	1844	98.874
15	YNd5	0.214	4	1848	99.088
16	Yyn0	0.161	3	1851	99.249
17	D1yn0yn0	0.161	3	1854	99.410
18	Yy0	0.107	2	1856	99.517
19	YNynd1	0.107	2	1858	99.625
20	Ynyn	0.107	2	1860	99.732
21	YNd5d5	0.107	2	1862	99.839
22	Dyn	0.054	1	1863	99.893
23	Yd1	0.054	1	1864	99.946
24	Dyn11	0.054	1	1865	100.000

Transformer Vector Groups, Standards

- The complete format for the vector groups is given in either IEEE Std C57.12.70-2020 or IEC 60076-1
  - Both of these standards require that the first field in the vector group is the high voltage winding, followed by the medium voltage winding, and then the lowest voltage winding (for a three winder)
  - The standards also specify that the high-voltage winding has a phase displacement of 0 (12 o'clock position)
- Other software packages use a slightly different format in which the symbols are organized base on the From/To bus values, and the first phase displacement does not need to be zero
- Simulator supports both formats including for input and output

Modifying the Phase Shift Groups

- There are currently two options for modifying the transformer phase shifts that define the PSGs
  - Neither option changes the power flow solution
  - **Set All Group Phase Shifts to Zero** changes the Phase Shift field to zero for all the transformers defining PSGs
  - **Set Phase Shift Groups Using Transformer Vector Groups** sets the transformer phase shifts based on their vector groups; this command does not modify existing phase shifts, so if this is desired first select the **Set All Group Phase Shifts to Zero** command



Likely Invalid Phase Shift Groups

- In calculating the PSGs it is possible that the transformers have unbalanced phase shifts, such as two transformers feeding a radial distribution network with only one having a 30 degree shift
- These groups are flagged as “Likely Invalid”, and might require model changes
- Testing on the North American grids indicates these situations are quite rare, with only two flagged as “Likely Invalid” out of 4400 PSGs

PSG Applications

- Since these phase shifts do not affect the power flow solution, PSGs will likely initially be use for informational purposes
  - Identifying the lower voltage radial subnetworks
- As transformer vector groups become more common, their phase shifts can now be easily added (or removed) from a case
- PSGs can help when comparing bus phase angles across a network
- PSGs are needed when the power flow is used for initializing harmonic analysis (e.g., with the new GICHarm functionality)
- PSGs can also help with flat start solutions since the initial bus angles can be uniformly adjusted to account for these phase shifts`