6 Pulse Back to Back Converter VTB Model

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Brief Description of Model

This model is intended to be used for demonstration purposes, in a standalone fashion. It is not intended to be connected to other model components, but rather to produce graphical results for analysis by itself.

The parameters setting screen shows a diagram of the 6-Pulse Back to Back system, made up of modules, consisting of two sides, each with its three-phase 2-level Voltage Sourced Converter (VSC) converter modules with YY transformer and ac filters, module of a three-phase system (or machine). The two sides are connected Back-to-Back, with a capacitor module on the dc side. Lower dc bus and the ac system neutrals are grounded, but with the machine neutral is grounded through a resistor.

When in operation, any one side acts as a rectifier sending power from ac to dc side and the other side acts as an inverter receiving power from dc to ac side. The resistor in parallel with the filter has a large value, so that it does not affect the system, but it does enhance the numerical stability.

PWM operation of the converters is based on comparison of a triangular wave with the control sine wave.

The data input shown in this document is based on 1 volt, 1 amp, and 1ohm nominal values. Externally these parameters can be scaled to any real system. For example, externally 1 volt can be assumed to be 1kV, 1 ampere as 500 A, in which case 1ohm would equal 1000 V/500 A = 2 ohms. This means all the simulation voltages should be multiplied by 1000, all current by 500 and all impedances by 2 to relate to that real system.

The Back to Back system has been assigned a positive polarity on the dc side and any excursion in the negative dc voltage side is clamped to zero. Power reversal occurs through current reversal.

Operation of this PC version of the Back to Back system is not locked to real time and the code runs as fast as the PC processor will serially solve the simulation math and plot the selected waveforms on the screen. On a typical PC, the simulation math of this system

actually runs much faster than the real time, and most of the total time taken is for serially plotting of the waveforms.

Arrows for the current flows in the diagram are designated as the positive direction. The parameters are also identified on the diagram.

To select the variables you wish to plot, right click on a converter block on the diagram and select "Add/Remove Scope" to bring up the list of variables. All the variable parameters are available for plotting and any variable can be added to or removed from the selected list for plotting by double clicking on the variables. It is suggested that he following be selected to give a good set for observing system and converter operation:

i5a_L, i5a_R, Vg1_L, Id_L, Id_R, Vd

Naturally with 6 graphs for plot, the Program will run very slow, but you will see the important waveforms.

Parameters

Parameters	Definition of set parameters	DefaultValues
Vd	Initial DC Voltage	1.0 Volts
C	DC Capacitor	200m Farads
CfL	AC Filter Capacitor (Left side)	1.0m Farads
CfR	AC Filter Capacitor (Right side)	1.0m Farads
RLControl	1 means left side has Vd control and right side has Id or ac power control, 0 means left side has Id or ac power control and right side has Vd control	1
Vdset	Control set value of Vd	1.1 Volts
Id_power_set	Control set value of Id, or 3 phase ac power p or P	1 Amp/watt
gen_ampli_L	Peak ac voltage of left system (generator/motor)	0.5 Volts
gen_ampli_R	Peak ac voltage of right system (generator/motor)	0.5 Volts
freqL	Frequency of left system	60 Hz
freqR	Frequency of right system	60 Hz
PhiL	Initial phase angle of ac voltage left system	0 degrees
PhiR	Initial phase angle of ac voltage right system	0 degrees
tri_ampliL	Value of triangular control signal as pu of control sine wave(left side)	1.2 PU
tri_ampliR	Value of triangular control signal as pu of control sine wave(right side)	1.2 PU
r3L	Transformer primary resistance (valve side) (left side)	5m ohms
r3R	Transformer primary resistance (valve side) (right side)	5m ohms
r4L	Transformer secondary resistance (system side) (left side)	5m ohms
r4R	Transformer secondary resistance (system side) (right side)	5m ohms

r5L	AC system resistance (left side)	15m	ohms
r5R	AC system resistance (right side)	15m	ohms
L3L	Transformer magnetizing inductance (left side)	1	henry
L3R	Transformer magnetizing inductance (right side)	1	henry
l3L	Transformer primary inductance (valve side) (left side)	0.1m	henry
l3R	Transformer primary inductance (valve side) (right side)	0.1m	henry
l4L	Transformer secondary inductance (system side) (left side)	0.1m	henry
l4R	Transformer secondary inductance (system side) (right side)	0.1m	henry
l5L	AC system inductance (left side)	0.2m	henry
l5R	AC system inductance (right side)	0.2m	henry
NL	Secondary/primary Transformer ratio (left side)	1.1	
NR	Secondary/primary Transformer ratio (right side)	1.2	
fdbkcountL	Number of steps for control feedback sampling (left side)	1	
fdbkcountR	Number of steps for control feedback sampling (right side)	1	
alpha_VdL	Control transfer function multiplier for Vd control (left side)	-1	
alpha_VdR	Control transfer function multiplier for Vd control (right side)	-1	
kp_VdL	Proportional function of Vd control (left side)	100	
kp_VdR	Proportional function of Vd control (right side)	100	
ki_VdL	Integral function of Vd control (left side)	1000	
ki_VdR	Integral function of Vd control (right side)	1000	
alpha_idL	Control transfer function multiplier for Id control (left side)	1	
alpha_idR	Control transfer function multiplier for Id control (right side)	1	
kpL	Proportional function of Id or ac power control (left side)	0	
kpR	Proportional function of Id or ac power control (right side)	0	
kiL	Integral function of Id or ac power control (left side)	250	
kiR	Integral function of Id or ac power control (right side)	250	
Interval	Integration time step = Time step set under "Simulation Parameters" menu divided by this Interval number	1	
XPWM_L	PWM frequency as a multiplier of the main frequency (left side)	33	
XPWM_R	PWM frequency as a multiplier of the main frequency (left side)	33	
Id(0), power(1), Power_p(2)	0 means Id control, 1 means p control and 2 means P control (P and p are explained later)	1	
Rf_L	Resistor in series with filter capacitor Cf (left side)	0.1	ohms
Rf_R	Resistor in series with filter capacitor Cf (right side)	0.1	ohms
Rp_L	Resistor in parallel with the filter (left side)	40	ohms
Rp_R	Resistor in parallel with the filter (Right side)	40	ohms
Rn_L	Resistor in the generator neutral (left side)	1	ohms
Rn_R	Resistor in the generator neutral (right side)	1	ohms
In the Schematic Editor screen, under "RC Solver", select "Simulation Properties" and set the following:			
Time Step	This set time is actually the plot time step. The actual integration time step= This Time Step divided by the Interval number	3.333 microseconds	
Sim. Stop Time	The simulation run will stop at the end of this time	100 sec	

Close this screen with OK. Then under "RC Solver" on the menu bar, select Simulation Parameters. Select time step as 3 microseconds and the Simulation Stop Time as 100 seconds. Click save on the menu bar to save these values. Close this box by clicking OK.

<u>Comment on Parameters</u>
Double click on a converter box to see the parameter box for explanations below.
The initial Vd may be set to 0 or any value. Since all initial currents are 0, it is desirable to set the initial Vd reasonably close to the control set Vd for a successful start up dynamics. In the default case, initial Vd is given a value of 1.0V and control set Vd of 1.1V. The set Vd should always be positive.

Direction of power flow is determined by the sign of the "Set Id or power"; + means power will flow from left to right and - means from right to left.

The value of the dc capacitors C needs to be large enough to support the dc voltage with high level of harmonics in the dc current. In the default case C is set at 0.2 Farads.

In this simulation, a simple capacitor Cf is used to filter ac harmonics. The higher the PWM frequency, lower is the required value of Cf. For a PWM frequency XPWM of 33x60 = 1980 Hz chosen for both sides, a value of 1.0 m Farads is chosen. Depending on the value of Cf and the system inductance, a harmonic current may get amplified in the current flowing into the system. To avoid this a small resistance Rf is inserted in series with Cf. For the default case, this value is 0.1 ohms. It also reduces the initial transient current through the filter capacitors when starting the simulation.

The control used in this simulation is quite basic. The control pulses for each side are derived, by comparing a control sawtooth wave of X times its main frequency, with the three-phase main-frequency control sine waves. The control sine wave is maintained as 1 pu, while the amplitude of triangular wave is set in the user as tri_ampli. This is set as 1.2 pu in the default case.

Each converter has two feedback PI controllers, one for dc voltage control and the other for dc current or power control. In the BTB system, one of the converters is assigned to control the dc voltage Vd, and the other converter assigned to control the dc current Id or dc power p (sum of instantaneous power v x i) or dc power P (rms sum of positive and negative sequence power. When "RLControl" is set to 1 (as in the default case), the left side converter (rectifier) is assigned dc voltage control and its dc current/power control is disabled, and the right converter (inverter) is assigned to dc current Id or power p or P control and its dc voltage control is disabled. Opposite is the case when "RLControl" is set to 0. The control feedback loop is closed by controlling the phase angle of the control sine waves, which in turn, changes the phase angles of the ac voltages generated by the Converters.

The simulated Back to Back system does not have an outer loop system control, such as a control, which will automatically reduce the set current or power of the inverter control if

the dc voltage is inadequate to maintain the set current. The system is therefore liable to collapse, if the set parameters are outside the steady state stability**.**

Y/Y transformer voltage ratios are defined by individual ratios N. These are set at 1.1 and 1.2 for the left and right side respectively, in the default case.

The two ac systems are represented by balanced three-phase sine-wave generator voltages in series with balanced R-L impedances. In the default case, both sides are set at 0.5V, although each side may have different values. Each side may have a different frequency, however both are given 60Hz frequency for the default case.

Also the inverter side ac system can represent an R-L load, by setting its generator voltage to a very low value, such as 0.01V and increasing the value of series r5 and l5 to represent a load.

For good harmonic performance and to avoid dc component in the ac voltages, the values of XPWM should be odd numbers and multiple of 3., i.e., 3, 9, 15, 21, 27, ----. The two sides may have different values, however in the default case both have the same value of 33, which means that both have PWM frequency of 60 X 33 = 1980 Hz.

Output Variables

While this model is intended to be used as a standalone analysis tool, there are two signal connections to the model that can be connected to other VTB components, that show the total power consumed by the left and right side generators, respectively.

The table below lists the variables available for graphical analysis:

Variable Name	Description	Units
i3a_L	Line current, phase A, left side, converter side Y-Y transformer	Amps
i3a_R	Line current, phase A, right side, converter side Y-Y transformer	Amps
i3b_L	Line current, phase B, left side, converter side Y-Y transformer	Amps
i3b_R	Line current, phase B, right side, converter side Y-Y transformer	Amps
i3c_L	Line current, phase C, left side, converter side Y-Y transformer	Amps
i3c_R	Line current, phase C, right side, converter side Y-Y transformer	Amps
i4a_L	Line current, phase A, left side, motor/generator side Y-Y transformer	Amps
i4a_R	Line current, phase A, right side, motor/generator side Y-Y transformer	Amps
i4b_L	Line current, phase B, left side, motor/generator side Y-Y transformer	Amps
i4b_R	Line current, phase B, right side, motor/generator side Y-Y transformer	Amps
i4c_L	Line current, phase C, left side, motor/generator side Y-Y transformer	Amps
i4c_R	Line current, phase C, right side, motor/generator side Y-Y transformer	Amps
i5a_L	Motor/generator line current, phase A, left side	Amps
i5a_R	Motor/generator line current, phase A, right side	Amps
i5b_L	Motor/generator line current, phase B, left side	Amps

i5b_R	Motor/generator line current, phase B, right side	Amps
i5c_L	Motor/generator line current, phase C, left side	Amps
i5c_R	Motor/generator line current, phase C, right side	Amps
V3a_L	Line to ground voltage, phase A, left side, converter side Y-Y transformer	Volts
V3a_R	Line to ground voltage, phase A, right side, converter side Y-Y transformer	Volts
V3b_L	Line to ground voltage, phase B, left side, converter side Y-Y transformer	Volts
V3b_R	Line to ground voltage, phase B, right side, converter side Y-Y transformer	Volts
V3c_L	Line to ground voltage, phase C, left side, converter side Y-Y transformer	Volts
V3c_R	Line to ground voltage, phase C, right side, converter side Y-Y transformer	Volts
Vfa_L	Filter capacitor voltage, phase A, left side	Volts
Vfa_R	Filter capacitor voltage, phase A, right side	Volts
Vfb_L	Filter capacitor voltage, phase B, left side	Volts
Vfb_R	Filter capacitor voltage, phase B, right side	Volts
Vfc_L	Filter capacitor voltage, phase C, left side	Volts
Vfc_R	Filter capacitor voltage, phase C, right side	Volts
Vg1_L	Motor/generator internal voltage, phase A, left side	Volts
Vg1_R	Motor/generator voltage, phase A, right side	Volts
Vg2_L	Motor/generator voltage, phase B, left side	Volts
Vg2_R	Motor/generator voltage, phase B, right side	Volts
Vg3_L	Motor/generator voltage, phase C, left side	Volts
Vg3_R	Motor/generator voltage, phase C, right side	Volts
v5a_L	Motor/generator terminal to ground voltage, phase A, left side	Volts
v5a_R	Motor/generator to ground voltage, phase A, right side	Volts
v5b_L	Motor/generator to ground voltage, phase B, left side	Volts
v5b_R	Motor/generator to ground voltage, phase B, right side	Volts
v5c_L	Motor/generator to ground voltage, phase C, left side	Volts
v5c_R	Motor/generator to ground voltage, phase C, right side	Volts
Id_L	DC current, left side	
v1n_L	Transformer neutral to ground voltage, left side	Volts
v1n_R	Transformer neutral to ground voltage, right side	Volts
power_qL	Reactive power, left side	Watts
power_qR	Reactive power, right side	Watts
power_L	sum of positive and negative sequence power Left side	Watts
power_R	sum of positive and negative sequence power Right side	Watts
power_pL	sum of instantaneous power v x I Left side	Watts
power_pR	sum of instantaneous power v x I Right side	Watts
Vd	DC voltage	Volts

Example of Model Use

After the parameters are set, click OK on the Parameter Values screen. Then on the "VTB Schematic Editor" screen, click on the start arrow button on the upper right and side. This should bring up the VXE screen with individual waveforms. There are many ways to examine the waveforms, one way is suggested as follows:

Double click on the screen and a composite of all waveforms will appear. Then temporarily stop the run with button next to the start button. With the right click bring up a menu and click a button labeled "Same Range", and all the waveforms show up on the same Y scale with X scale showing the simulation time. With the right click again remove "Always show legend" under "overlays" to remove the legends from the screen, which are blocking part of the waveforms. Note that, because the simulation starts with zero initial values of currents, the simulation takes a few tens of cycles to reach steady state. The envelope of the waveforms should indicate when steady state has arrived. To move ahead faster, hold down the right button for a few seconds and let go and the VXE will dump the stored data; do this as often as you wish. Expand the end or any part by holding down the left button and envelope the end part, to see these waveforms in greater detail. After some running time, you may want to pause, with a click on the pause button, to further examine the waveforms. Left click on any waveform will highlight that waveform and show its label just above the waveforms when the cursor is brought near the top of the waveforms.

As the simulation progresses beyond about 2 seconds, the time line begins to dominate the Y scale. Highlight it with a click on it, and then press "delete", to get rid of it. Similarly any other waveform can be deleted.

Numerical values can be read by holding down Alt and Ctrl keys and click on the left mouse button.

VXE has many additional features for viewing waveforms and collecting data files etc.

All numerical dynamic simulations have numerical instability and inaccuracy. For the Default case good accuracy is obtained with step size of 3.333 microsecs. or less. You can check that by running cases with different step sizes and examining the waveforms. Numerical instability of the default case occurs at well over 200 µs