Reactive compensation in a three-phase distribution system

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Abstract: Reactive power drawn by loads in a distribution system is a burden resulting in increased losses and reduced transmission capability. A solution to minimize the burden on the system is to supply reactive power at the point of connection of the load. Solutions such as power factor correcting capacitors, synchronous condensers and static VAR compensators have been extensively used. This report describes a static VAR compensator comprised of a power electronic converter. The aim of this report is to describe the contents of the simulation package and instructions on how to use them.

The tutorial is divided into three parts which can be found in three separate folders and it is recommended to run the simulations in this order:

1. pqtheory: This folder contains the simulation case to understand the basic theory of VAR compensation. The simulation does not have a compensator but shows the currents that need to be supplied by the compensator.
2. Lfilter: This folder contains the simulation case where the compensator is comprised of a two level Voltage Source Converter (VSC) interfaced to the distribution system through a simple inductor (L) filter.
3. LCLfilter: This folder contains the simulation case where the compensator is interfaced to the distribution system through a inductor-capacitor-inductor (LCL) filter which offers improved filtering being a higher order filter.

Provided below is a description of the circuit files in each folder and instructions on using them.

PQ Theory Folder

	File Name	Description
1.	inputs.csv	Lists out the parameters of the simulation along with the circuit files, control files.
2.	three_ph_source.csv	Circuit schematic for the three phase source.
3.	three_ph_source_params.csv	Parameter spreadsheet for the three phase source schematic.
4.	three_ph_load.csv	Circuit schematic for the three phase R-L load.
5.	three_ph_load_params.csv	Parameter spreadsheet for the three phase load schematic.
6.	pll.py	Python control file with the phase locked loop
7.	pll_desc.csv	Parameters for the control file pll.py
8.	comp_reference.py	Python control file that generates the references for the currents to be supplied by the compensator.
9.	comp_reference_desc.csv	Parameters for the control file comp_reference.py.

The above files can be used either directly with the command line program (version 1.5.7) or with the web interface (2.0.2) in which case the simulation needs to built interactively. Check out the instructions at the end of the document to know how to use the web application.

Variables of interest:

The following are the variables that upon plotting describe the effect of the simulator.

	Variable/Meter name	Description
1.	Voltmeter_Vload1a, Voltmeter_Vload1b, Voltmeter_Vload1c	The voltages supplied to the loads. These voltages are balanced sinusoids.
2.	Ammeter_Iload1a, Ammeter_Iload1b, Ammeter_Iload1c	The currents drawn by the three phase load. These are also balanced and sinusoidal due to the linear nature of the load.
3.	Voltmeter_Vload1a, Ammeter_Iload1a	The phase a voltage at the load and the phase a current drawn by the load. Important to note here the phase angle difference between their zero crossing points. This phase angle indicates reactive power.
4.	Ammeter_Iload1a, comp_load_p_a, comp_load_q_a	This shows how the phase a load current is decomposed into two components. This decomposition is performed in the control file comp_reference.py. Notice the phase angle difference between the three currents.
5.	Voltmeter_Vload1a, comp_load_p_a, comp_load_q_a	This shows how the decomposed currents are with respect to the load voltage of phase a. One of the currents is in phase with the voltage while the other lags the voltage by 90 degrees. Therefore, one of them is the component of current that supplies active power and the other supplies reactive power.

VSI with L filter

	File Name	Description
1.	inputs.csv	Lists out the parameters of the simulation along with the circuit files, control files.
2.	three_ph_source.csv	Circuit schematic for the three phase source.
3.	three_ph_source_params.csv	Parameter spreadsheet for the three phase source schematic.
4.	three_ph_load.csv	Circuit schematic for the three phase R-L load.
5.	three_ph_load_params.csv	Parameter spreadsheet for the three phase load schematic.
6.	comp_inverter.csv	Circuit schematic for the three phase Voltage Source Converter (VSC).
7.	comp_inverter_params.csv	Parameters for comp_inverter.csv.
8.	comp_Lfilter.csv	Circuit schematic for the three phase inductor filter that interfaces the VSC with the distribution system.
9.	comp_Lfilter_params.csv	Parameters for comp_Lfilter_params.csv.

10.	pll.py	Python control file with the phase locked loop
11.	pll_desc.csv	Parameters for the control file pll.py
12.	comp_reference.py	Python control file that generates the references for the currents to be supplied by the compensator.
13.	comp_reference_desc.csv	Parameters for the control file comp_reference.py.
14.	currcon_inverter.py	Python control file with PI controller implemented in the synchronous dq reference frame.
15.	currcon_inverter_desc.csv	Parameters for the control file currcon_inverter.py.
16.	modulator.py	Python control file with sine triangle pulse width modulation to generate the firing signals for the switches of the VSC.
17.	modulator_desc.csv	Parameters for the control file modulator.py

Variables of interest:

This simulation is an extension of the previous one so therefore the previous variables can also be plotted.

	Variable/Meter name	Description
1.	comp_curr_d, currcon_curr_d	These two variables plotted in the same graph show the tracking performance of the VSC with the current controller in rotating d axis. Note that the compensator is turned on at 0.1s to allow the PLL to lock onto the system frequency.
2.	comp_curr_q, currcon_curr_q	These two variables plotted in the same graph show the tracking performance of the VSC with the current controller in rotating q axis.
3.	Voltmeter_Vload1a, Ammeter_Icompa, comp_load_q_a	This shows with respect to phase a of the distribution system how the compensator supplies the reactive power component of the current that lags the load voltage by 90 degrees.
4.	Voltmeter_Vload1a, Ammeter_Isource1a, comp_load_p_a	This shows again with respect to phase a how due to the compensator action, the source will need to supply only the active component of the current which is in phase with the load voltage. Also notice the decrease in magnitude of the source current.
5.	Ammeter_Icompa, Ammeter_Icompb, Ammeter_Icompc	This shows the three phase compensator currents. Though they have a sinusoidal template they still have significant switching frequency harmonics that the L filter was not able to attenuate. This is why an LCL filter is preferred as compared to an L filter.

VSI with LCL filter

	File Name	Description
1.	inputs.csv	Lists out the parameters of the simulation along with the circuit files, control files.
2.	three_ph_source.csv	Circuit schematic for the three phase source.
3.	three_ph_source_params.csv	Parameter spreadsheet for the three phase source schematic.
4.	three_ph_load.csv	Circuit schematic for the three phase R-L load.
5.	three_ph_load_params.csv	Parameter spreadsheet for the three phase load schematic.
6.	comp_inverter.csv	Circuit schematic for the three phase Voltage Source Converter (VSC).
7.	comp_inverter_params.csv	Parameters for comp_inverter.csv.
8.	comp_LCLfilter.csv	Circuit schematic for the three phase inductor-capacitor-inductor (LCL) filter that interfaces the VSC with the distribution system.
9.	comp_LCLfilter_params.csv	Parameters for comp_LCLfilter_params.csv.
10.	pll.py	Python control file with the phase locked loop
11.	pll_desc.csv	Parameters for the control file pll.py
12.	comp_reference.py	Python control file that generates the references for the currents to be supplied by the compensator.
13.	comp_reference_desc.csv	Parameters for the control file comp_reference.py.
14.	currcon_inverter.py	Python control file with PI controller implemented in the synchronous dq reference frame.
15.	currcon_inverter_desc.csv	Parameters for the control file currcon_inverter.py.
16.	modulator.py	Python control file with sine triangle pulse width modulation to generate the firing signals for the switches of the VSC.
17.	modulator_desc.csv	Parameters for the control file modulator.py

Variables of interest:

This simulation is an extension of the previous cases so therefore those variables can also be plotted.

	Variable/Meter name	Description
5.	Ammeter_Icompa, Ammeter_Icompb, Ammeter_Icompc	This shows the three phase compensator currents. It can be noticed how much smoother these are as compared to the previous L filter case. This is due to the advanced filter provided by the LCL filter.

About Python Power Electronics

Python Power Electronics is a free and open source circuit simulator that can be found on the website:
http://www.pythonpowerelectronics.com/

All the latest updates in the project are added to the Updates page:
http://www.pythonpowerelectronics.com/contents/updates.html

The latest version of the software can be found on the link:
http://pythonpowerelectronics.com/contents/softwaredownloads.html

In order to install the software, read the document INSTALL.pdf:
http://pythonpowerelectronics.com/contents/papers/INSTALL.pdf

To use the software, check out the user manual:
http://pythonpowerelectronics.com/contents/papers/django_user_manual.zip

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