Electricity and New Energy

Three-Phase PWM Rectifier/Inverter

Courseware Sample

86366-F0

Order no.: 86366-10
First Edition
Revision level: 12/2015

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Printed in Canada

ISBN 978-2-89640-551-0 (Printed version)
Legal Deposit – Bibliothèque et Archives nationales du Québec, 2012
Legal Deposit – Library and Archives Canada, 2012

Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
∿	Alternating current
$\overline{\sim}$	Both direct and alternating current
3∿	Three-phase alternating current
⏚	Earth (ground) terminal

Safety and Common Symbols

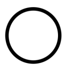
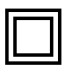
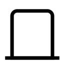
Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

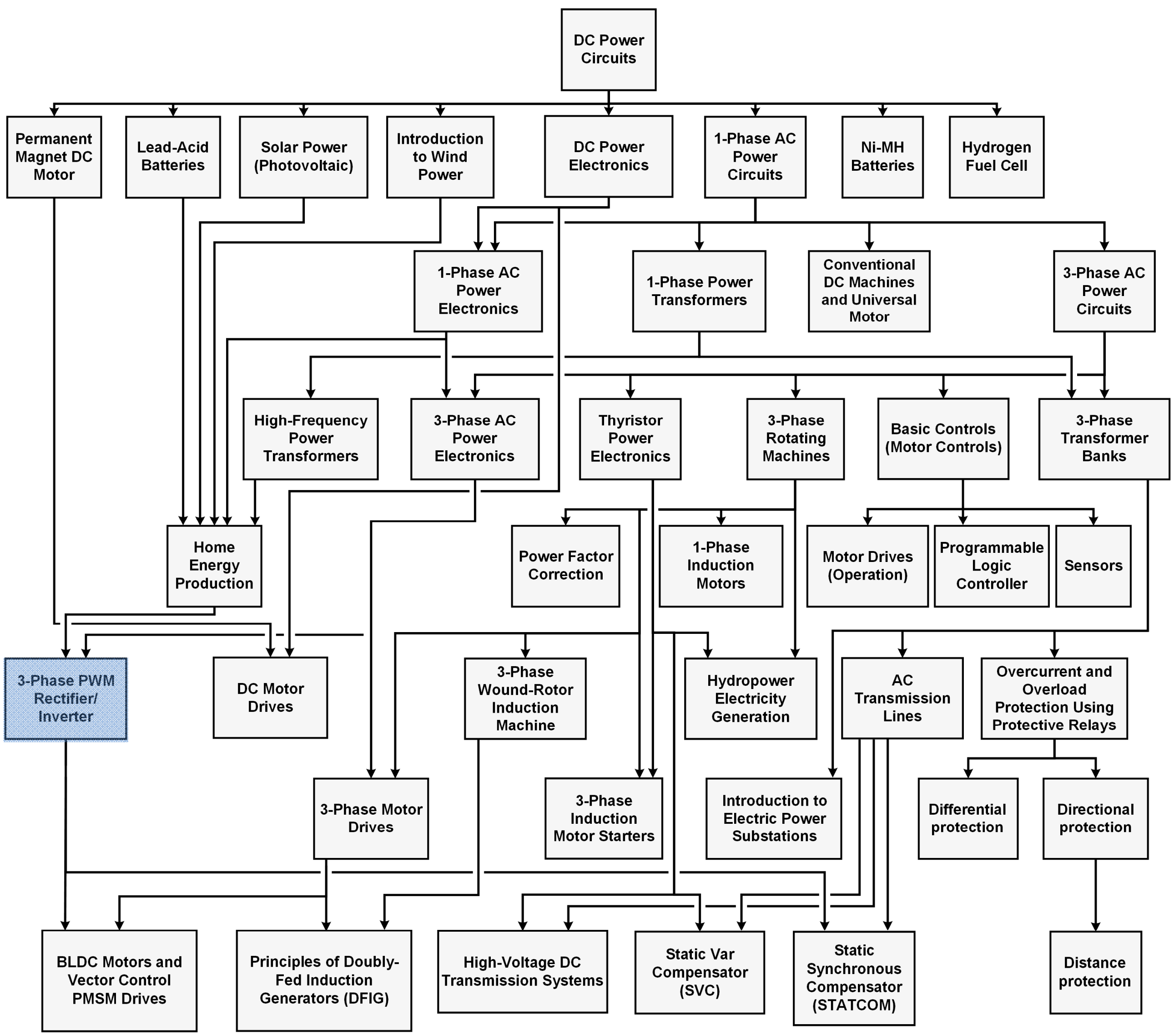
Table of Contents

Table of Contents

Preface

The production of energy using renewable natural resources such as wind, sunlight, rain, tides, geothermal heat, etc., has gained much importance in recent years as it is an effective means of reducing greenhouse gas (GHG) emissions. The need for innovative technologies to make the grid smarter has recently emerged as a major trend, as the increase in electrical power demand observed worldwide makes it harder for the actual grid in many countries to keep up with demand. Furthermore, electric vehicles (from bicycles to cars) are developed and marketed with more and more success in many countries all over the world.

To answer the increasingly diversified needs for training in the wide field of electrical energy, the Electric Power Technology Training Program was developed as a modular study program for technical institutes, colleges, and universities. The program is shown below as a flow chart, with each box in the flow chart representing a course.



The Electric Power Technology Training Program.

Preface

The program starts with a variety of courses providing in-depth coverage of basic topics related to the field of electrical energy such as ac and dc power circuits, power transformers, rotating machines, ac power transmission lines, and power electronics. The program then builds on the knowledge gained by the student through these basic courses to provide training in more advanced subjects such as home energy production from renewable resources (wind and sunlight), large-scale electricity production from hydropower, large-scale electricity production from wind power (doubly-fed induction generator [DFIG], synchronous generator, and asynchronous generator technologies), smart-grid technologies (SVC, STATCOM, HVDC transmission, etc.), storage of electrical energy in batteries, and drive systems for small electric vehicles and cars.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

A three-phase PWM rectifier/inverter consists of a three-phase bridge, a three-phase filter, line inductors, a three-phase transformer, and a current control loop. The three-phase PWM rectifier/inverter is connected to a dc power source on one side, and a three-phase ac power source on the other. By controlling the electronic switches in the three-phase bridge, it is possible to make the device act as either a rectifier (ac power-to-dc power converter) or an inverter (dc power-to-ac power converter).

A three-phase PWM rectifier/inverter enables control of the amount of active power exchanged between the dc power source and the three-phase ac power source, as well as control of the direction in which active power flows. This is achieved by varying the magnitude and phase angle of the ac current flowing in the three-phase PWM rectifier/inverter. Using the same means, a three-phase PWM rectifier/inverter also enables control of the amount of reactive power which the dc power source and the three-phase ac power source exchange. This permits using a three-phase PWM rectifier/inverter for power factor correction.

Three-phase PWM rectifiers/inverters are used in numerous applications. The most common applications include STATCOMs (for power factor correction), voltage-source converter (VSC) HVDC transmission systems (for dc power-to-ac power and ac power-to-dc power conversion), three-phase ac motor drives (for bidirectional power flow and regenerative braking), and solar panels (for dc power-to-ac power conversion).

This course teaches the basic concepts of three-phase PWM rectifiers/inverters. Students are introduced to the operation of three-phase PWM rectifiers/inverters and learn how they are represented in circuit diagrams. Students also learn the most common applications of three-phase PWM rectifiers/inverters, and are introduced to the methods used to control three-phase PWM rectifiers/inverters. Finally, the theory presented in the manual is verified by performing circuit measurements and calculations.

Figure 1. Three-phase PWM rectifiers/inverters are often used as dc-to-ac power converters in solar power farms. The above solar power farm is located in Serpa, Portugal.

About This Manual

Figure 2. Three-phase PWM rectifiers/inverters are one of the main components of VSC HVDC substations, such as the one shown in the above picture.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Prerequisite

As a prerequisite to this course, you should have read the manuals titled *DC Power Circuits*, part number 86350, *DC Power Electronics*, part number 86356, *Lead-Acid Batteries*, part number 86351, *Solar Power*, part number 86352, *Introduction to Wind Power*, part number 86353, *Single-Phase AC Power Circuits*, part number 86358, *Single-Phase AC Power Electronics*, part number 86359, *Single-Phase Power Transformers*, part number 86377, *Three-Phase AC Power Circuits*, part number 86360, *Three-Phase AC Power Electronics*, part number 86360, *High-Frequency Power Transformer*, part number 86378, and *Home Energy Production*, part number 86361.

About This Manual

Systems of units

Units are expressed using the International System of Units (SI) followed by the units expressed in the U.S. customary system of units (between parentheses).

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide

Operation of a Three-Phase PWM Rectifier/Inverter

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the block diagram of the three-phase PWM rectifier/inverter. You will identify the most common applications of the three-phase PWM rectifier/inverter and be introduced to both active power control and reactive power control using a three-phase PWM rectifier/inverter.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Block diagram of a three-phase PWM rectifier/inverter
- Applications of three-phase PWM rectifiers/inverters
  Static synchronous compensators (STATCOMs). Voltage-source converter (VSC), high-voltage direct current (HVDC) transmission systems. Three-phase induction motor drives. Solar power farms tied to a three-phase ac power network.
- Operation of the controller in a three-phase PWM rectifier/inverter

DISCUSSION

Block diagram of a three-phase PWM rectifier/inverter

Figure 8 shows the block diagram of a three-phase PWM rectifier/inverter connected to a dc power source and an ac power source. The three-phase PWM rectifier/inverter consists of a three-phase bridge (implemented using 6 high-speed electronic switches such as IGBTs), a three-phase filter, line inductors, current and voltage sensors, and a current control loop (the current control loop enables the three-phase PWM inverter to operate as a grid-tied rectifier or a grid-tied inverter). The line inductors are necessary in order to limit the rate of change of the current I_{AC} flowing through the ac side of the three-phase PWM rectifier/inverter, thus improving the stability of the current control loop. Note that three-phase filters, although not absolutely necessary to the operation of three-phase PWM rectifiers/inverters, are often added to the circuit to eliminate the distortion in the voltage waveform produced at the ac side of the three-phase PWM rectifier/inverter.

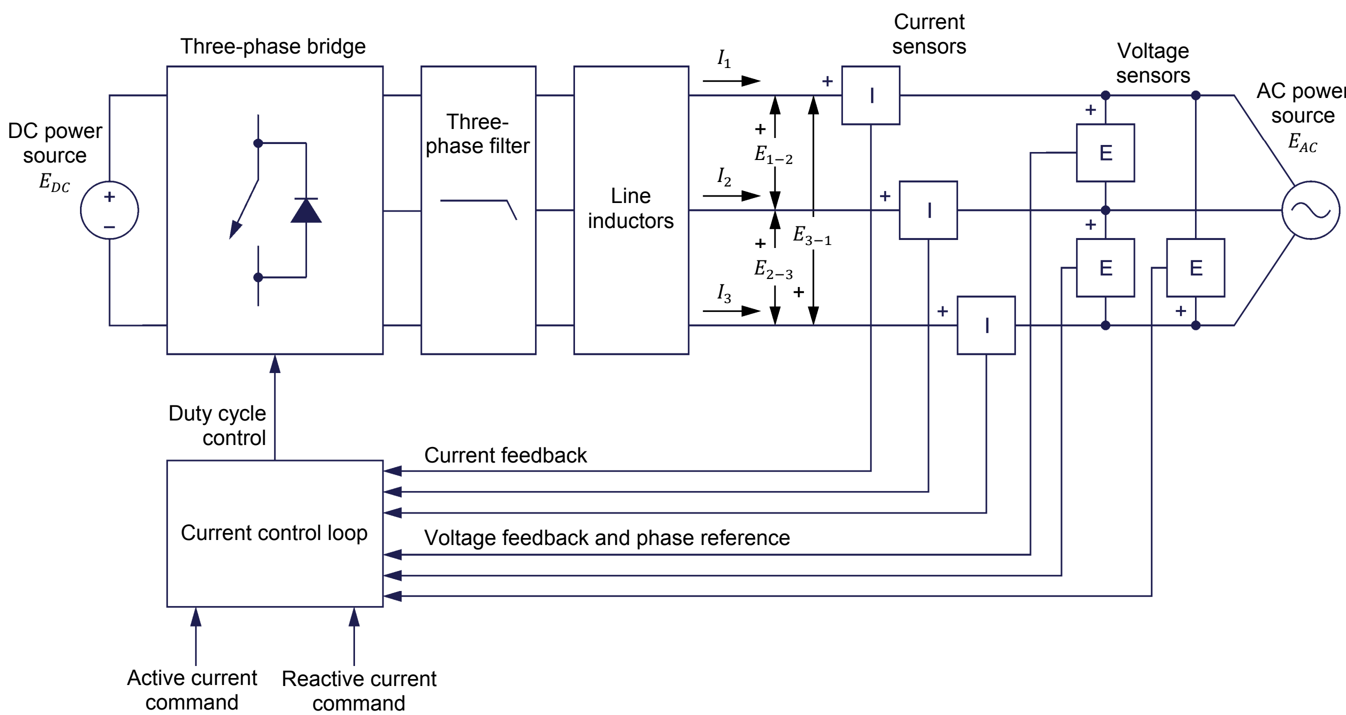


Figure 8. Block diagram of a three-phase PWM rectifier/inverter connected to a dc power source and an ac power source.

Just as for single-phase grid-tied inverters, it is necessary for the dc power source to produce a dc voltage E_{DC} high enough to allow the three-phase PWM rectifier/inverter to impose a certain three-phase ac current I_{AC}. The higher the value of the three-phase ac voltage E_{AC} across the ac side of the three-phase PWM rectifier/inverter, the higher the voltage E_{DC} that the dc power source must produce. The same means used to eliminate or reduce this limitation in single-phase grid-tied inverters are used in three-phase PWM rectifiers/inverters (e.g., connecting batteries in series to increase the dc power source voltage, adding a three-phase step-down transformer to decrease the voltage at the ac side of the rectifier/inverter).

Applications of three-phase PWM rectifiers/inverters

Nowadays, three-phase PWM rectifiers/inverters are used in a multitude of applications. Some of the most common applications include:

– Static synchronous compensators (**STATCOMs**)

– Voltage-source converter (**VSC**), high-voltage direct current (**HVDC**) transmission systems

– Three-phase motor drives

– Solar power farms tied to a three-phase ac power network

The following subsections describe each of these applications in more detail.

Static synchronous compensators (STATCOMs)

Static synchronous compensators (STATCOMs) serve the same basic purpose as **synchronous condensers** and static var compensators (**SVCs**), i.e., to supply a fast-reacting, precise, and variable amount of reactive power to the system to which they are connected. Because of this, STATCOMs are often used for dynamic voltage compensation of ac transmission lines, as well as dynamic power factor correction (i.e., dynamic reactive power compensation) in industrial applications operating with large random peaks of reactive power demand.

STATCOMs usually consist of several converter valve units (such a converter valve unit is shown in Figure 9) interconnected to form the three-phase bridge required to implement a three-phase PWM rectifier/inverter. Each of these converter valve units consists of a stack of transistors or thyristors. The three-phase PWM rectifier/inverter in a STATCOM is used to convert dc power from the dc power source into reactive power exchanged with the ac power system connected to the STATCOM. By adjusting the reactive current command of the three-phase PWM rectifier/inverter, it is possible to vary the amount of reactive power that the STATCOM exchanges with the ac power system. The use of a three-phase PWM rectifier/inverter in a STATCOM allows rapid and precise control of the amount of reactive power exchanged with the ac power system and, consequently, dynamic compensation of the voltage or dynamic power factor correction.

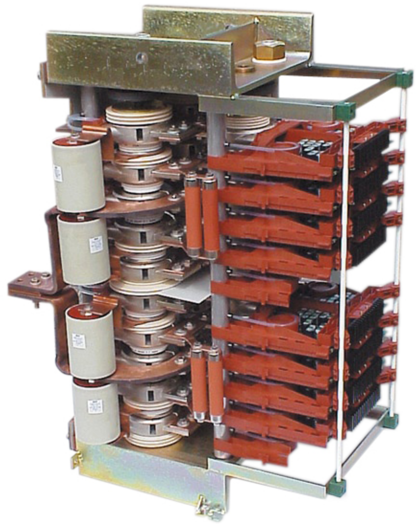


Figure 9. A STATCOM converter valve unit consists of a stack of transistors or thyristors. The above converter valve unit is made of a stack of integrated gate-commuted thyristors or IGCTs (photo courtesy of ABB).

Figure 10. STATCOM substation in Turkey (© Copyright 2012 Guc Kalitesi).

Voltage-source converter (VSC), high-voltage direct current (HVDC) transmission systems

High-voltage direct current (HVDC) transmission systems are a type of electrical transmission system that uses dc current instead of ac current. HVDC transmission systems are often used for long-distance and underwater transmission of electrical power, where the use of direct current presents advantages over alternating current. HVDC transmission systems also allow electrical power transmission between unsynchronized power networks or power networks operating at different frequencies, and can increase the stability of a power network by preventing the propagation of cascading power failure.

Figure 11. VSC HVDC converter valves in an offshore wind farm power generating station north of Germany (photo courtesy of ABB).

Three-phase PWM rectifiers/inverters are commonly used in voltage-source converter (VSC) HVDC substations to convert three-phase ac power into dc power, and vice-versa. VSC HVDC substations, as opposed to current-source converter (CSC) HVDC substations, are used for comparatively lower power applications.

Figure 12. 350 kV VSC HVDC substation linking the ac power network of northeastern Namibia to that of central Namibia. This substation also helps in stabilizing both networks (photo courtesy of ABB).

Three-phase induction motor drives

Three-phase induction motors are often used in the industry because of their low cost, high durability, and low maintenance requirements. However, the rotation speed of a three-phase induction motor mainly depends on the frequency of the ac power source to which it is connected. This means the rotation speed is quasi-fixed when the motor is powered directly by the ac power network, and it is often convenient to add a three-phase motor drive to the induction motor in order to be able to vary its speed.

Three-phase PWM inverters are often used in three-phase induction motor drives to produce three-phase, variable-frequency voltage. Since the frequency of the three-phase voltage produced by the three-phase PWM inverter can be adjusted as needed and the rotation speed of an induction motor is proportional to its operating frequency, the rotation speed of the induction motor can be varied by adjusting the frequency of the three-phase PWM inverter.

In standard three-phase induction motor drives, a power-diode rectifier is used to supply the required dc power to the three-phase PWM inverter, as shown in Figure 13. Since power flow in a power-diode rectifier is unidirectional, regenerative braking (the process of returning the energy accumulated during motor braking to the ac power source) is impossible. When the energy accumulated during motor braking is returned to the dc bus through the three-phase PWM inverter, it is dissipated in a dump resistor before reaching the power-diode rectifier.

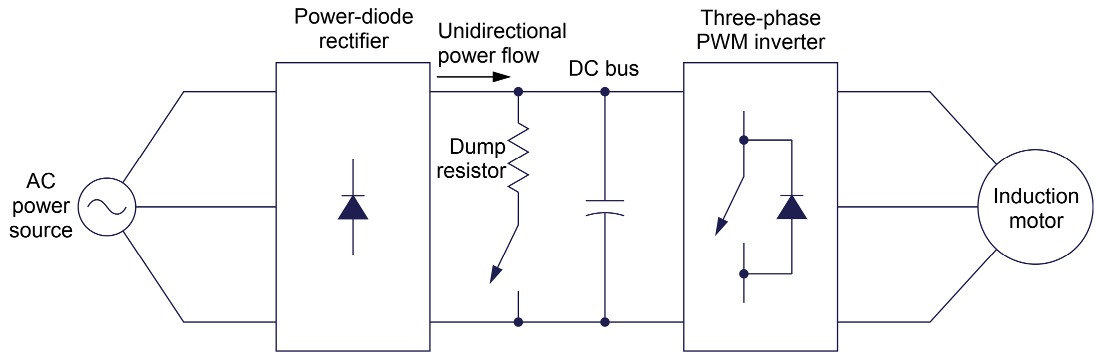


Figure 13. Three-phase induction motor drive using a power-diode three-phase rectifier for ac-to-dc power conversion.

Instead of the power-diode rectifier used in standard three-phase induction motor drives, it is possible to use a three-phase PWM rectifier/inverter to supply the dc power required by the three-phase PWM inverter, as shown in Figure 14. Power flow is possible in both directions in such an induction motor drive, therefore energy accumulated during motor braking can be returned to the three-phase ac power source. Because of this, three-phase PWM rectifiers/inverters are often used in high-power induction motor drives and in applications where the energy accumulated from regenerative braking is significant.

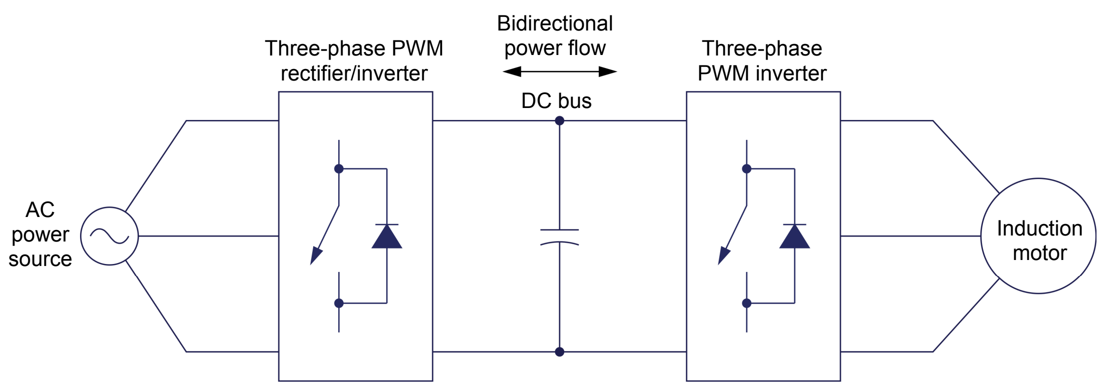


Figure 14. Three-phase induction motor drive using a three-phase PWM rectifier/inverter for ac-to-dc power conversion.

Solar power farms tied to a three-phase ac power network

The power produced by the solar panels in a solar power farm is dc power. It is necessary to convert this dc power to three-phase ac power before it can be supplied to the electrical power transmission system due to most electrical power transmission systems being designed to carry three-phase ac power.

Three-phase PWM rectifiers/inverters are often used to convert dc power produced by the solar panels in a solar power farm into three-phase ac power. When used for such applications, three-phase PWM rectifiers/inverters are generally referred to as three-phase grid-tied inverters. This is due to the amplitude, frequency, and phase angle of the voltage at the ac side of the PWM rectifier/inverter being imposed by the local ac power network and the three-phase PWM rectifier/inverter always operating as an inverter.

Figure 15. Three-phase PWM rectifier/inverter used for dc-to-ac power conversion in a solar power plant.

Operation of the controller in a three-phase PWM rectifier/inverter

The block diagram of a three-phase PWM rectifier/inverter is illustrated in Figure 16. The amplitude and phase angle of the currents flowing through the ac side of a three-phase PWM rectifier/inverter are regulated using a current control loop implemented in the three-phase PWM rectifier/inverter controller. This controller monitors the currents flowing through the ac side of the three-phase PWM rectifier/inverter (I_A, I_B, and I_C), the line voltages across the ac side of the PWM rectifier/inverter (E_{A-B}, E_{B-C}, and E_{C-A}), and the voltage across the dc side of the PWM rectifier/inverter (E_{DC}). Using the measured values of these parameters, the controller determines the switching signals to be applied to the three-phase bridge so the line voltages at the ac side result in ac currents whose amplitude and phase angle correspond to the desired values (i.e., the amplitude and phase angle values of the ac currents defined by the active current command and reactive current command of the PWM rectifier/inverter). The operation of a three-phase PWM rectifier/inverter controller is covered in more detail in Appendix E.

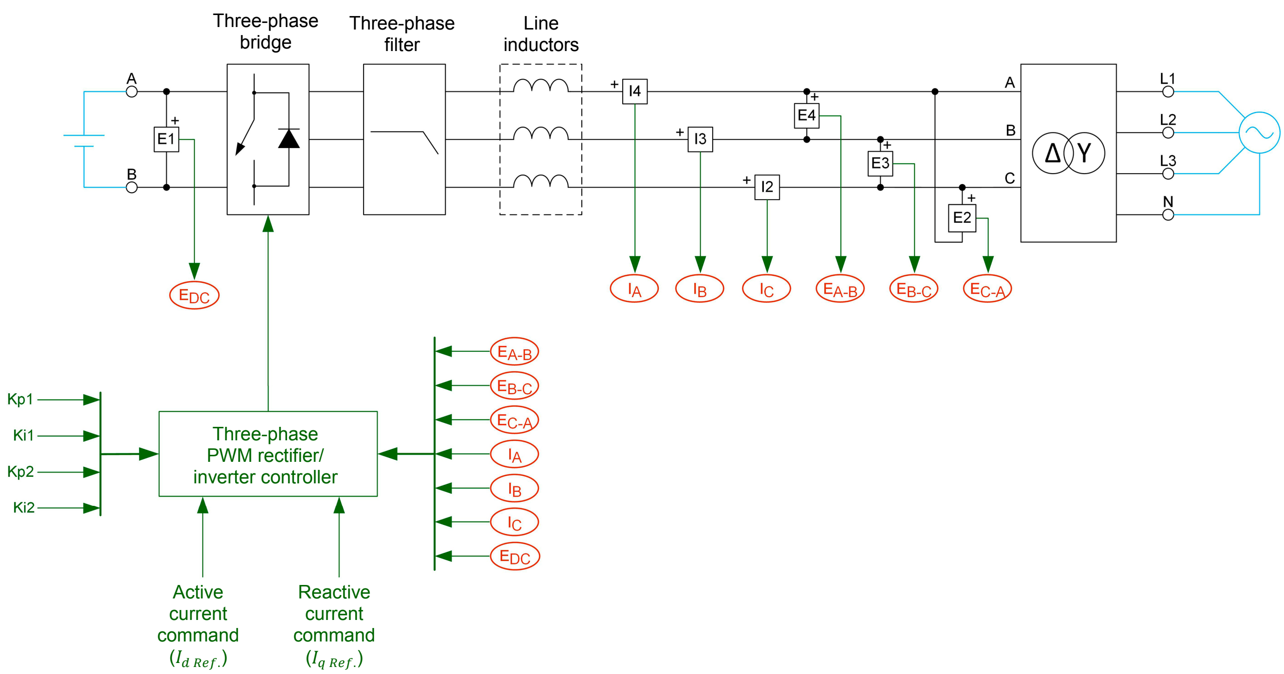


Figure 16. Block diagram of a three-phase PWM rectifier/inverter.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up and connections
- Active current command of a three-phase PWM rectifier/inverter
- Reactive current command of a three-phase PWM rectifier/inverter
- Active current command and reactive current command of a three-phase PWM rectifier/inverter

PROCEDURE

WARNING

High voltages are present in this laboratory exercise. Do not make or modify any banana jack connections with the power on unless otherwise specified.

Set up and connections

In this section, you will set up a three-phase PWM rectifier/inverter connected to a dc power source and a three-phase ac power source. You will then set up the measuring equipment required to study the operation of the three-phase PWM rectifier/inverter.

1. Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required to perform this exercise.

   Install the required equipment in the Workstation.

2. On the Power Supply, make sure that the ac and dc power switches are set to the *O* (off) position, then connect the Power Supply to a three-phase ac power outlet.

3. On the Four-Quadrant Dynamometer/ Power Supply, make sure that the main power switch is set to the *O* (off) position, then connect its *Power Input* to an ac power outlet.

4. Connect the *Power Input* of a Data Acquisition and Control Interface to the 24 V ac power supply.

   Connect the *Power Input*s of both Data Acquisition and Control Interface modules together.

   Connect the *Low Power Input* of the IGBT Chopper/Inverter to the *Power Input* of one of the Data Acquisition and Control Interface modules.

   Turn the 24 V ac power supply on.

5. Connect the USB port of each Data Acquisition and Control Interface to a USB port of the host computer.

6. Turn the Four-Quadrant Dynamometer/Power Supply on, then set the *Operating Mode* switch to *Power Supply*.

7. Turn the host computer on, then start the LVDAC-EMS software.

In the LVDAC-EMS Start-Up window, make sure that both Data Acquisition and Control Interface modules are detected. Make sure that the *Three-Phase PWM Rectifier/Inverter Control* and *Computer-Based Instrumentation* functions are available for either or both Data Acquisition and Control Interface modules. Select the network voltage and frequency that correspond to the voltage and frequency of your local ac power network, then click the *OK* button to close the LVDAC-EMS Start-Up window.

8. Before you begin connecting the equipment, record in the space below the serial number of the Data Acquisition and Control Interface (DACI) you will use to control the three-phase PWM rectifier/inverter, and the serial number of the DACI you will use for data acquisition.

Serial number of the DACI controlling the three-phase PWM rectifier/inverter: __________

Serial number of the DACI used for data acquisition: __________

9. Connect the equipment as shown in Figure 17 and Figure 18. Use the Four-Quadrant Dynamometer/Power Supply to implement the dc power source. Use the Power Supply to implement the three-phase ac power source. Note that points A1, A2, A3, and A4 in Figure 17 are to be connected to the corresponding points in Figure 18.

Note that the three-phase resistive load (resistors R_1, R_2, and R_3) is added to the circuit to provide a neutral point for connection of the voltage inputs used for data acquisition. This enables measurement of the phase voltages and allows observation of the waveforms and phasors of the voltage and current related to each of the three phases. Because of the high resistance of the three-phase resistive load (and, consequently, of the low current flowing in it), the amount of active power dissipated in this load has virtually no effect on the amount of active power P transferred by the three-phase PWM rectifier/inverter.

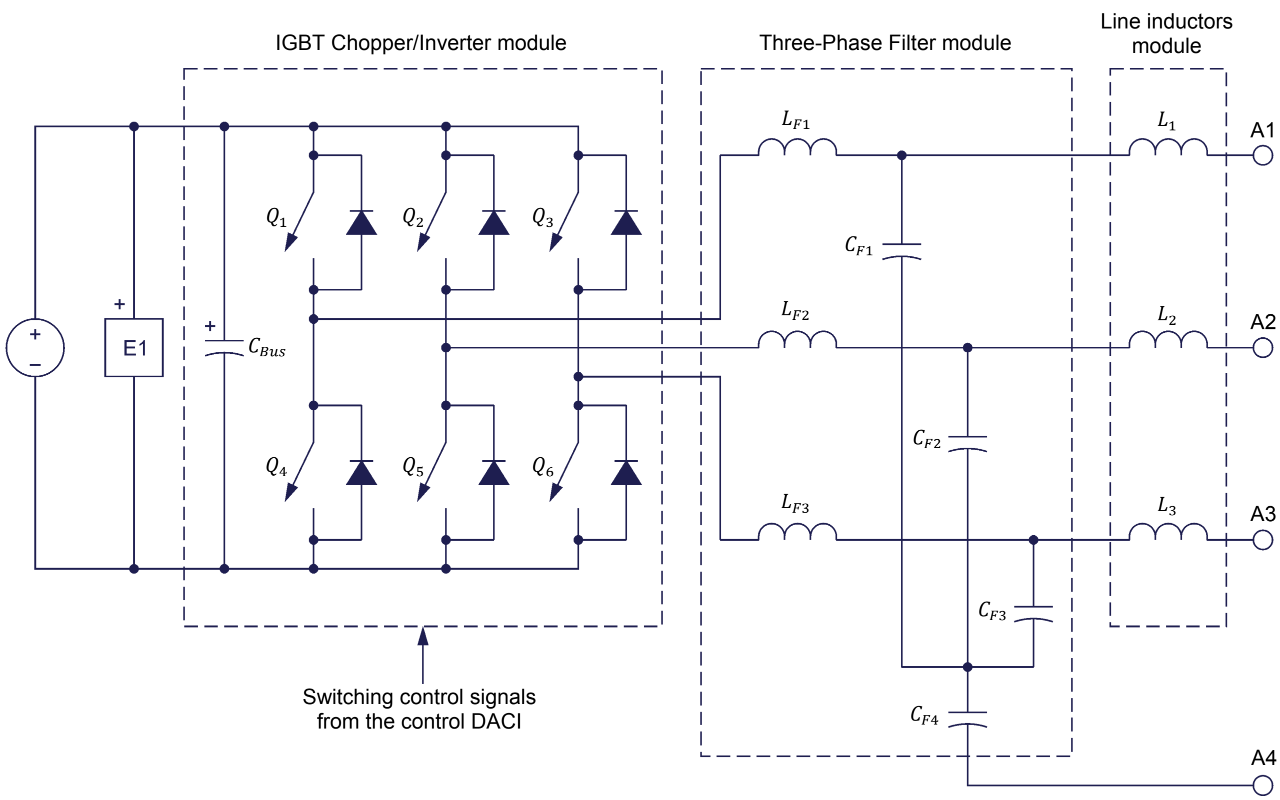
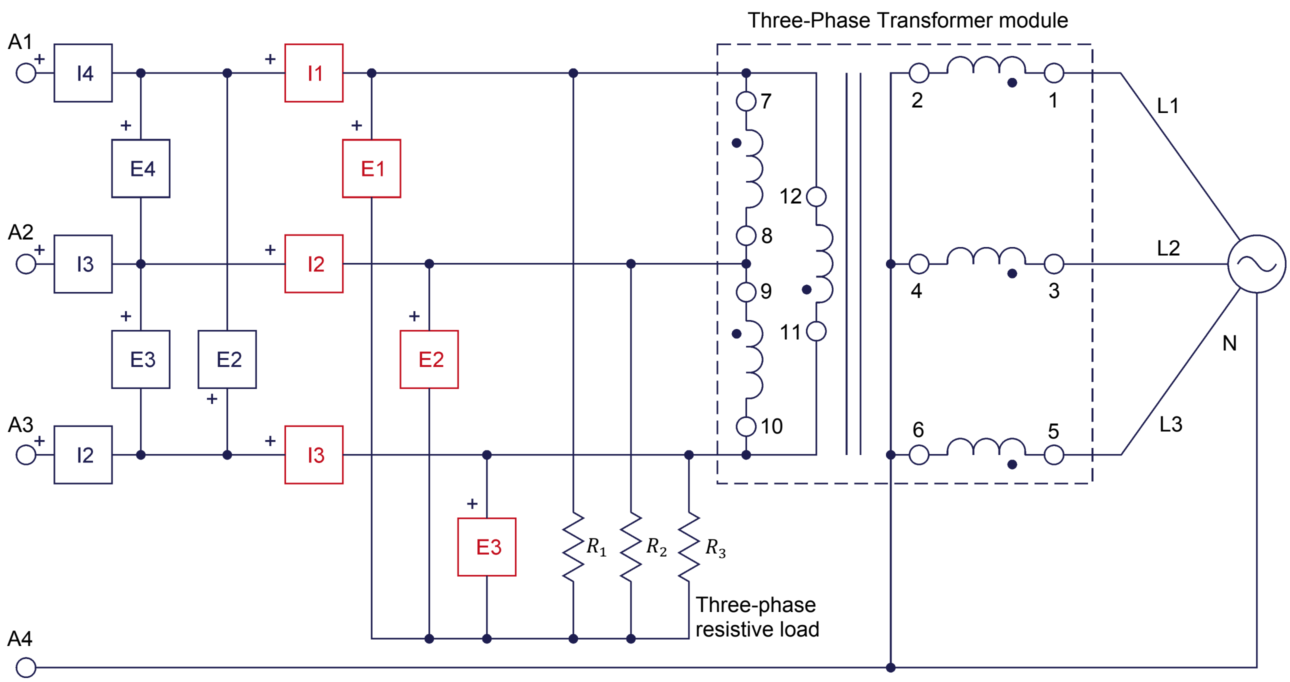


Figure 17. Three-phase PWM rectifier/inverter connected to a dc power source and a three-phase ac power source.

Appendix D shows in more detail the equipment and connections that are required for each circuit diagram symbol used in this manual.

*In Figure 17 and Figure 18, **blue inputs** represent voltage and current inputs from the Data Acquisition and Control Interface used to **control the three-phase PWM rectifier/inverter**. **Red inputs** represent voltage and current inputs from the Data Acquisition and Control Interface used for **data acquisition**. Note that the inputs used for control cannot be used for data acquisition, and vice-versa.*



Local ac power network		R_1, R_2, R_3 (Ω)
Voltage (V)	Frequency (Hz)	
120	60	1200
220	50	4400
240	50	4800
220	60	4400

Figure 18. Three-phase PWM rectifier/inverter connected to a dc power source and a three-phase ac power source.

10. Connect the *Digital Outputs* of the Data Acquisition and Control Interface used for controlling the three-phase PWM rectifier/inverter to the *Switching Control Inputs* of the IGBT Chopper/Inverter using a DB9 connector cable.

Make sure that the *Dumping* switch on the IGBT Chopper/Inverter is set to the O position. This allows power from the three-phase ac power source to be supplied to the dc power source instead of being dissipated in a dump resistor inside the IGBT Chopper/Inverter.

11. Make the necessary switch settings on the Resistive Load to obtain the resistance value indicated in the table of Figure 18 for your local ac power network voltage and frequency.

Appendix C lists the switch settings required on the Resistive Load, the Inductive Load, and the Capacitive Load in order to obtain various resistance (or reactance) values.

The value of the resistive loads used in the circuits of this manual depend on your local ac power network voltage and frequency. Whenever necessary, a table below the circuit diagram indicates the value of each component for ac power network voltages of 120 V, 220 V, and 240 V, and for ac power network frequencies of 50 Hz and 60 Hz. Make sure to use the component values corresponding to your local ac power network voltage and frequency.

12. In LVDAC-EMS, open the Three-Phase PWM Rectifier/Inverter Control window. A dialog box appears. Select the serial number of the Data Acquisition and Control Interface used to control the three-phase PWM rectifier/inverter (recorded in step 8), then click the *OK* button to close the dialog box and open the Three-Phase PWM Rectifier/Inverter Control window.

In the Three-Phase PWM Rectifier/Inverter Control window, make the following settings:

– Make sure that the *Function* parameter is set to *Three-Phase PWM Rectifier/Inverter*. This function allows manual control of the active current command and reactive current command of the three-phase PWM rectifier/inverter.

– Make sure that the *Active Current Command* parameter is set to 0 A. This sets the active current component of the three-phase current flowing through the ac side of the three-phase PWM rectifier/inverter to 0 A.

– Make sure that the *Reactive Current Command* parameter is set to 0 A. This sets the reactive current component of the three-phase current flowing through the ac side of the three-phase PWM rectifier/inverter to 0 A.

– Make sure that the *Phase Adjustment* parameter is set to 0°. This parameter can be used to adjust the phase shift between the ac voltage and current waveforms produced by the three-phase PWM rectifier/inverter.

- Make sure that the *Active Current Controller Prop. Gain (Kp1)* parameter is set to 0.3.
- Make sure that the *Active Current Controller Int. Gain (Ki1)* parameter is set to 4.
- Make sure that the *Reactive Current Controller Prop. Gain (Kp2)* parameter is set to 0.3.
- Make sure that the *Reactive Current Controller Int. Gain (Ki2)* parameter is set to 4.
- Make sure that the *Status* parameter of the *Three-Phase PWM Rectifier/Inverter* is set to *Stopped*.

13. On the Four-Quadrant Dynamometer/Power Supply, select the *200 V DC Bus* function using the *Function* push-button on the front panel of this module. This enables the Four-Quadrant Dynamometer/Power Supply to operate as a 200 V dc power source that can either supply or absorb power.

14. In LVDAC-EMS, open the Metering window. A dialog box appears. Select the serial number of the Data Acquisition and Control Interface used for data acquisition (recorded in step 8), then click the *OK* button to close the dialog box and open the Metering window.

In the *Option* menu of the Metering window, select *Acquisition Settings* to open the corresponding dialog box. Set the *Sampling Window* to 8 cycles, then click *OK* to close the dialog box. This enables better accuracy when measuring the different parameters of the three-phase PWM rectifier/inverter (e.g., the three-phase reactive power).

In the Metering window, set the meters as indicated below:

- Set one meter to measure the three-phase active power P (metering function *PQS1 + PQS2 + PQS3*) that the three-phase PWM rectifier/inverter transfers between the dc power source and the three-phase ac power source.
- Set another meter to measure the three-phase reactive power Q (metering function *PQS1 + PQS2 + PQS3*) that the three-phase PWM rectifier/inverter exchanges with the ac power source.
- Finally, set a meter to measure the power factor PF of the three-phase PWM rectifier/inverter [*PF (EI1, EI2, EI3)*].

Active current command of a three-phase PWM rectifier/inverter

In this section, you will vary the active current command of the three-phase PWM rectifier/inverter (while the reactive current command is set to zero), and observe the phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter. For each value of the active current command, you will observe the total harmonic distortion in the currents flowing through the ac side of the three-phase PWM rectifier/inverter. You will also observe the waveforms of the phase voltages and currents at the ac side of the three-phase PWM rectifier/inverter, measure the power factor of the three-phase PWM rectifier/inverter, and analyze the results. Finally, you will record the active power and reactive power transferred via the three-phase PWM rectifier/inverter for each active current command value.

15. On the Four-Quadrant Dynamometer/Power Supply, start the 200 V dc power source by pressing the *Start/Stop* push-button on the front panel of this module.

Turn the three-phase ac power source in the Power Supply on.

In the Three-Phase PWM Rectifier/Inverter Control window, start the three-phase PWM rectifier/inverter by clicking the *Start/Stop* button or by setting the *Status* parameter to *Started*.

16. In the Metering window, measure the three-phase active power P and reactive power Q transferred via the three-phase PWM rectifier/inverter. Record these values in the row of Table 1 corresponding to the present combination of active current command and reactive current command values.

Table 1. Three-phase active power P and reactive power Q transferred via the three-phase PWM rectifier/inverter for different combinations of active current command and reactive current command values.

Active current command (A)	Reactive current command (A)	Three-phase active power P (W)	Three-phase reactive power Q (var)
0.0	0.0		
+1.5	0.0		
-1.5	0.0		
0.0	+1.5		
0.0	-1.5		
1.0	-1.0		
1.0	1.0		
-1.0	1.0		
-1.0	-1.0		

The results are presented in the following table.

Three-phase active power P and reactive power Q transferred via the three-phase PWM rectifier/inverter for different combinations of active current command and reactive current command values.

Active current command (A)	Reactive current command (A)	Three-phase active power P (W)	Three-phase reactive power Q (var)
0.0	0.0	-0.03	-0.83
+1.5	0.0	222	-1.51
-1.5	0.0	-207	-2.00
0.0	+1.5	1.51	-217
0.0	-1.5	-2.33	218
1.0	-1.0	148	147
1.0	1.0	146	-146
-1.0	1.0	-141	-143
-1.0	-1.0	-143	140

17. In LVDAC-EMS, open the Phasor Analyzer, then make the required settings in order to observe the phasors of line currents I_1, I_2, and I_3 flowing through the ac side of the three-phase PWM rectifier/inverter. Also, make the required settings in order to observe the phasors of phase voltages E_{1-N}, E_{2-N}, and E_{3-N} across the ac side of the three-phase PWM rectifier/inverter. Select the phasor of phase voltage E_{1-N} as the reference phasor.

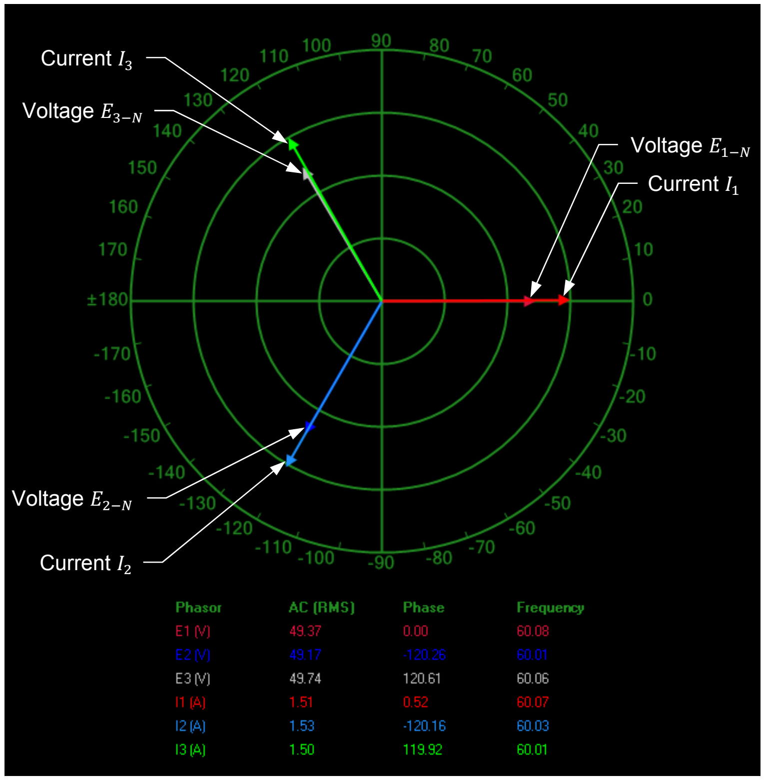
18. In the Three-Phase PWM Rectifier/Inverter Control window, set the *Active Current Command* parameter to 0.5 A.

Check that the phasors of line currents I_1, I_2, and I_3 in the Phasor Analyzer are virtually in phase with the phasors of phase voltages E_{1-N}, E_{2-N}, and E_{3-N}, respectively. If necessary, modify the *Phase Adjustment* parameter so that they are in phase.

19. In the Three-Phase PWM Rectifier/Inverter Control window, slowly increase the *Active Current Command* parameter to 1.5 A. While doing so, observe in the Phasor Analyzer what happens to the phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter. Repeat step 16.

The resulting phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter are shown below.

Phasor Analyzer Settings
Current Scale........................0.5 A/div
Reference Phasor.......................... E1
Voltage Scale.........................20 V/div



Phasors of the phase voltages E_{1-N}, E_{2-N}, and E_{3-N} and line currents I_1, I_2, and I_3 at the ac side of the three-phase PWM rectifier/inverter when the active current command is equal to 1.5 A and the reactive current command is set to zero.

What is the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter when the active current command of the three-phase PWM rectifier/inverter is positive and the reactive current command is set to zero? Explain briefly.

When the active current command of the three-phase PWM rectifier/inverter is positive and the reactive current command is set to zero, the phase voltages and corresponding line currents at the ac side of the three-phase PWM rectifier/inverter are in phase. This is because the present values of the active and reactive current commands (1.5 A and 0.0 A, respectively) set the phase angle of the line currents at the ac side of the three-phase PWM rectifier/inverter to 0° (i.e., the line currents are in phase with the corresponding phase voltages).

What is the direction of active power flow? Explain briefly.

Active power flows from the dc power source to the three-phase ac power source since the line currents are in phase with the corresponding phase voltages at the ac side of the three-phase PWM rectifier/inverter. This is confirmed by the positive polarity of the active power, which indicates that the three-phase PWM rectifier/inverter operates as an inverter.

20. In LVDAC-EMS, open the Harmonic Analyzer. Make sure that the fundamental frequency is set to the frequency of your local ac power network, then set the number of harmonics displayed to 15. Display the harmonic content of the line current I_1 (input *I1*) flowing through the ac side of the three-phase PWM rectifier/inverter. Record the value of the total harmonic distortion (THD) in line current I_1.

THD in line current I_1 = _______%

THD in line current $I_1 \cong 4\%$

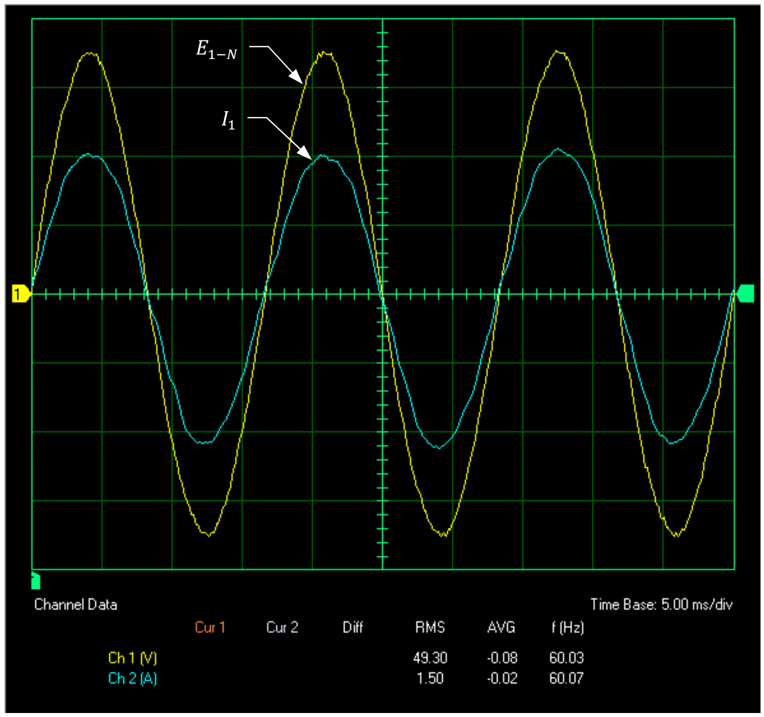
Considering the value of the THD in line current I_1 you just recorded, what can you conclude about the amount of harmonics produced by the three-phase PWM rectifier/inverter when it acts as an inverter?

The THD value in line current I_1 is relatively low, i.e., it is less than 10%, indicating that the three-phase PWM rectifier/inverter produces few harmonics when it acts as an inverter.

21. In LVDAC-EMS, open the Oscilloscope, then display the waveform of phase voltage E_{1-N} and that of line current I_1 at the ac side of the three-phase PWM rectifier/inverter.

The resulting waveforms of phase voltage E_{1-N} and line current I_1 at the ac side of the three-phase PWM rectifier/inverter are shown below.

Oscilloscope Settings
Channel-1 Input E1
Channel-1 Scale ....20 V/div
Channel-1 Coupling .... DC
Channel-2 Input I1
Channel-2 Scale ....1 A/div
Channel-2 Coupling .... DC
Time Base .... 5 ms/div



Waveforms of phase voltage E_{1-N} and line current I_1 at the ac side of the three-phase PWM rectifier/inverter when the active current command is equal to 1.5 A and the reactive current command is set to zero.

When the three-phase PWM rectifier/inverter acts as an inverter, what can you conclude about the appearance of the waveform of phase voltage E_{1-N}, the appearance of the waveform of line current I_1, and the phase shift between both waveforms?

Both the waveform of phase voltage E_{1-N} and that of line current I_1 at the ac side of the three-phase PWM rectifier/inverter are virtually sinusoidal when the three-phase PWM rectifier/inverter acts as an inverter. The two waveforms are also perfectly in phase.

22. In the Metering window, measure the power factor PF of the three-phase PWM rectifier/inverter. Record the value below.

Power factor $PF =$ _______

Power factor $PF = 1.00$

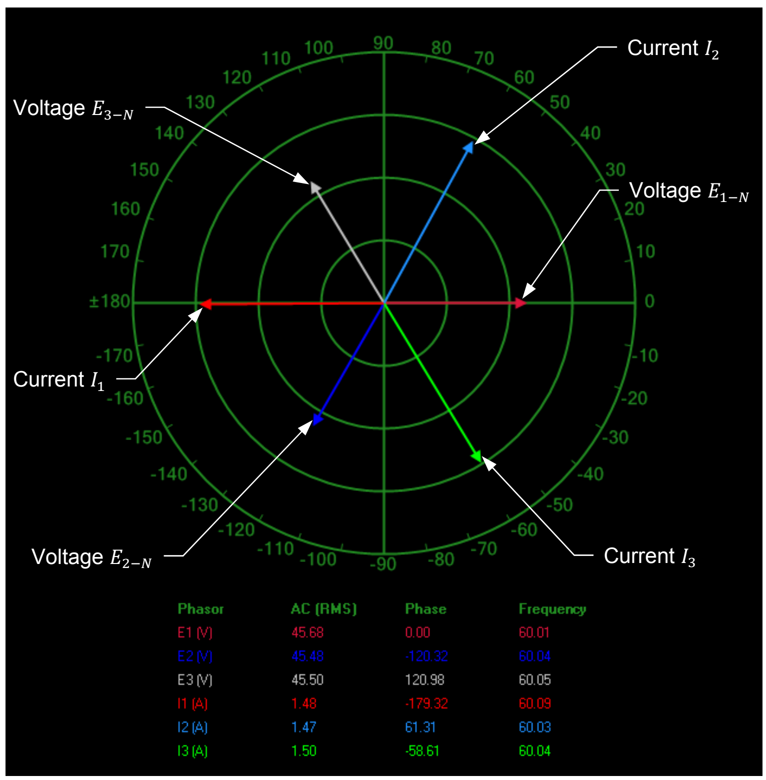
What can you conclude about the power factor PF of the three-phase PWM rectifier/inverter when it acts as an inverter?

The power factor PF of the three-phase PWM rectifier/inverter is equal to unity when it acts as an inverter.

23. In the Three-Phase PWM Rectifier/Inverter Control window, set the *Active Current Command* parameter to 0 A. Then, slowly decrease the *Active Current Command* parameter to -1.5 A. While doing so, observe in the Phasor Analyzer what happens to the phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter. Repeat step 16.

The resulting phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter are shown below.

Phasor Analyzer Settings
Current Scale .... 0.5 A/div
Reference Phasor E1
Voltage Scale .... 20 V/div



Phasors of the phase voltages E_{1-N}, E_{2-N}, and E_{3-N} and line currents I_1, I_2, and I_3 at the ac side of the three-phase PWM rectifier/inverter when the active current command is equal to -1.5 A and the reactive current command is set to zero.

What is the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter when the active current command of the three-phase PWM rectifier/inverter is negative and the reactive current command is set to zero? Explain briefly.

When the active current command of the three-phase PWM rectifier/inverter is negative and the reactive current command is set to zero, the line currents are phase shifted by 180° with respect to the corresponding phase voltages at the ac side of the three-phase PWM rectifier/inverter. This is because the present values of the active and reactive current commands (-1.5 A and 0.0 A, respectively) set the phase angle of the line currents at the ac side of the three-phase PWM rectifier/inverter to 180° (i.e., the line currents are phase shifted by 180° with respect to the corresponding phase voltages).

What is the direction of active power flow? Explain briefly.

Active power flows from the three-phase ac power source to the dc power source since the line currents are phase shifted by 180° with respect to the corresponding phase voltages at the ac side of the three-phase PWM rectifier/inverter. This is confirmed by the negative polarity of the active power, which indicates that the three-phase PWM rectifier/inverter operates as a rectifier.

24. In the Harmonic Analyzer, record the value of the total harmonic distortion (THD) in line current I_1 flowing through the ac side of the three-phase PWM rectifier/inverter.

THD in line current I_1 = _______%

THD in line current $I_1 \cong 4\%$

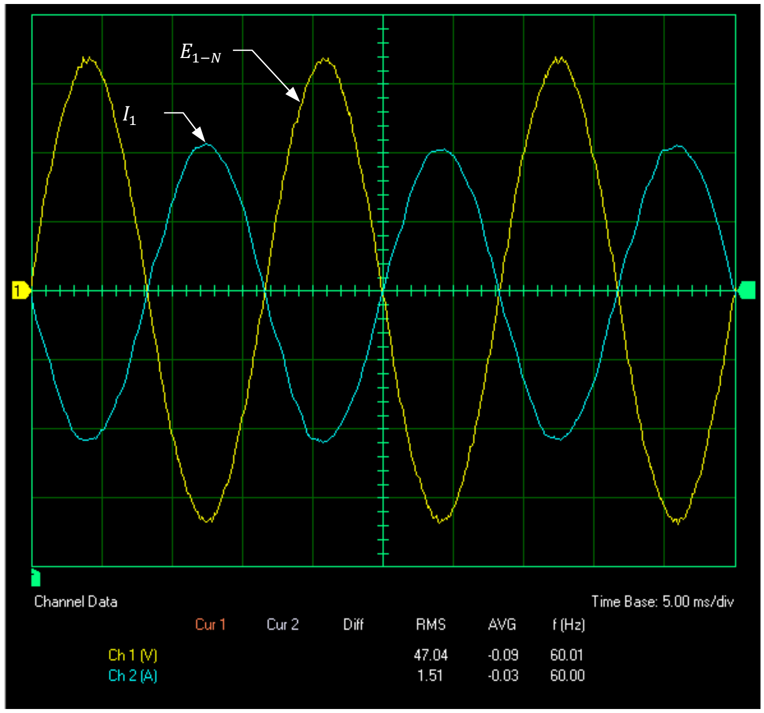
Considering the value of the THD in line current I_1 you just recorded, what can you conclude about the amount of harmonics produced by the three-phase PWM rectifier/inverter when it acts as a rectifier?

The THD value in line current I_1 is relatively low, i.e., it is about 5%, indicating that the three-phase PWM rectifier/inverter produces few harmonics when acting as a rectifier.

25. On the Oscilloscope, observe the waveform of phase voltage E_{1-N} and that of line current I_1 at the ac side of the three-phase PWM rectifier/inverter.

The resulting waveforms of phase voltage E_{1-N} and line current I_1 at the ac side of the three-phase PWM rectifier/inverter are shown below.

Oscilloscope Settings
Channel-1 Input E1
Channel-1 Scale .... 20 V/div
Channel-1 Coupling .... DC
Channel-2 Input I1
Channel-2 Scale ....1 A/div
Channel-2 Coupling .... DC
Time Base .... 5 ms/div



Waveforms of phase voltage E_{1-N} and line current I_1 at the ac side of the three-phase PWM rectifier/inverter when the active current command is equal to -1.5 A and the reactive current command is set to zero.

When the three-phase PWM rectifier/inverter acts as a rectifier, what can you conclude about the appearance of the waveform of phase voltage E_{1-N}, the appearance of the waveform of line current I_1, and the phase shift between both waveforms?

Both the waveform of phase voltage E_{1-N} and that of line current I_1 at the ac side of the three-phase PWM rectifier/inverter are virtually sinusoidal when the three-phase PWM rectifier/inverter acts as a rectifier. The two waveforms are also phase shifted 180° one from the other.

26. In the Metering window, measure the power factor PF of the three-phase PWM rectifier/inverter. Record the value below.

Power factor $PF =$ _______

Power factor $PF = 1.00$

What can you conclude about the power factor PF of the three-phase PWM rectifier/inverter when it acts as a rectifier?

The power factor PF of the three-phase PWM rectifier/inverter when acting as a rectifier is equal to unity.

27. From the observations made in this part of the exercise, can you conclude that the amount of active power transferred and the direction of active power flow in a three-phase PWM rectifier/inverter can be controlled using the active current command? Explain briefly.

Yes, the amount of active power transferred and the direction of active power flow in a three-phase PWM rectifier/inverter can be controlled by varying the value and polarity of the active current command, respectively. The higher the value of the active current command, the higher the amount of active power transferred via the three-phase PWM rectifier/inverter. Furthermore, when the active current command of the three-phase PWM rectifier/inverter is of positive polarity, active power is transferred from the dc power source to the three-phase ac power source. Conversely, when the active current command of the three-phase PWM rectifier/inverter is of negative polarity, active power is transferred from the three-phase ac power source to the dc power source.

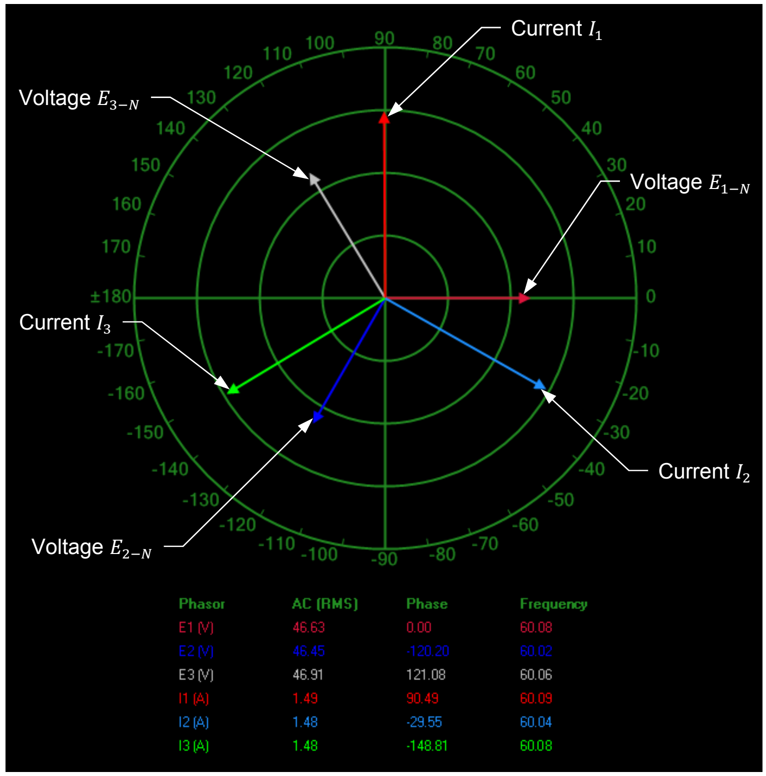
Reactive current command of a three-phase PWM rectifier/inverter

In this section, you will set the active current command back to 0 A. You will vary the reactive current command of the three-phase PWM rectifier/inverter (while the active current command is set to zero), observe the phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter, and analyze the results. Finally, you will record the active power and reactive power transferred via the three-phase PWM rectifier/inverter for each reactive current command value.

28. In the Three-Phase PWM Rectifier/Inverter Control window, set the *Active Current Command* parameter to 0 A. Then, slowly increase the *Reactive Current Command* parameter to 1.5 A. While doing so, observe in the Phasor Analyzer what happens to the phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter. Repeat step 16.

The resulting phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter are shown below.

Phasor Analyzer Settings
Current Scale .... 0.5 A/div
Reference Phasor E1
Voltage Scale .... 20 V/div



Phasor	AC (RMS)	Phase	Frequency
E1 (V)	46.63	0.00	60.08
E2 (V)	46.45	-120.20	60.02
E3 (V)	46.91	121.08	60.06
I1 (A)	1.49	90.49	60.09
I2 (A)	1.48	-29.55	60.04
I3 (A)	1.48	-148.81	60.08

Phasors of the phase voltages E_{1-N}, E_{2-N}, and E_{3-N} and line currents I_1, I_2, and I_3 at the ac side of the three-phase PWM rectifier/inverter when the reactive current command is equal to 1.5 A and the active current command is set to zero.

What is the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter when the reactive current command of the three-phase PWM rectifier/inverter is positive and the active current command is set to zero? Explain briefly.

When the reactive current command of the three-phase PWM rectifier/inverter is positive and the active current command is set to zero, the line currents lead the corresponding phase voltages at the ac side of the three-phase PWM rectifier/inverter by 90°. This is because the present values of the active and reactive current commands (0.0 A and 1.5 A, respectively) set the phase angle of the line currents at the ac side of the three-phase PWM rectifier/inverter to 90° (i.e., cause the line currents to lead the corresponding phase voltages by 90°).

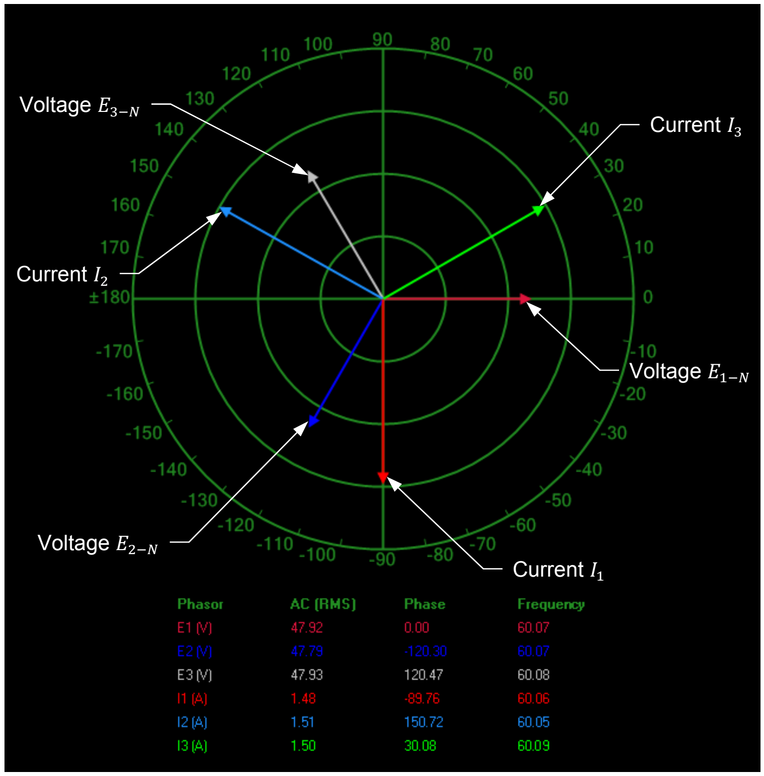
What is the direction of reactive power flow? Explain briefly.

Reactive power flows from the three-phase ac power source to the dc power source since the line currents lead the corresponding phase voltages by 90°. This is confirmed by the negative polarity of the reactive power. In other words, the ac power source acts as a capacitor and supplies reactive power to the dc power source via the three-phase PWM rectifier/inverter.

29. In the Three-Phase PWM Rectifier/Inverter Control window, set the *Reactive Current Command* parameter to 0 A. Then, slowly decrease the *Reactive Current Command* parameter to -1.5 A. While doing so, observe in the Phasor Analyzer what happens to the phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter. Repeat step 16.

The resulting phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter are shown below.

Phasor Analyzer Settings
Current Scale........................0.5 A/div
Reference Phasor.......................... E1
Voltage Scale..........................20 V/div



Phasors of the phase voltages E_{1-N}, E_{2-N}, and E_{3-N} and line currents I_1, I_2, and I_3 at the ac side of the three-phase PWM rectifier/inverter when the reactive current command is equal to -1.5 A and the active current command is set to zero.

What is the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter when the reactive current command of the three-phase PWM rectifier/inverter is negative and the active current command is set to zero? Explain briefly.

When the reactive current command of the three-phase PWM rectifier/inverter is negative and the active current command is set to zero, the line currents lag behind the corresponding phase voltages at the ac side of the three-phase PWM rectifier/inverter by 90°. This is due to the fact that the present values of the active and reactive current commands (0.0 A and -1.5 A, respectively) set the phase angle of the line currents at the ac side of the three-phase PWM rectifier/inverter to -90° (i.e., cause the line currents to lag behind the corresponding phase voltages by 90°).

What is the direction of reactive power flow? Explain briefly.

Reactive power flows from the dc power source to the three-phase ac power source because the line currents lag behind the corresponding phase voltages by 90°. In other words, the ac power source acts as an inductor and absorbs reactive power from the dc power source via the three-phase PWM rectifier/inverter.

30. From the observations made in this part of the exercise, can you conclude that the amount of reactive power transferred and the direction of reactive power flow in a three-phase PWM rectifier/inverter can be controlled using the reactive current command? Explain briefly.

Yes, the amount of reactive power transferred and the direction of reactive power flow in a three-phase PWM rectifier/inverter can be controlled by varying the value and polarity of the reactive current command, respectively. The higher the value of the reactive current command, the higher the amount of reactive power transferred via the three-phase PWM rectifier/inverter. Furthermore, when the reactive current command of the three-phase PWM rectifier/inverter is of positive polarity, reactive power is transferred from the three-phase ac power source to the dc power source. Conversely, when the reactive current command of the three-phase PWM rectifier/inverter is of negative polarity, reactive power is transferred from the dc power source to the three-phase ac power source.

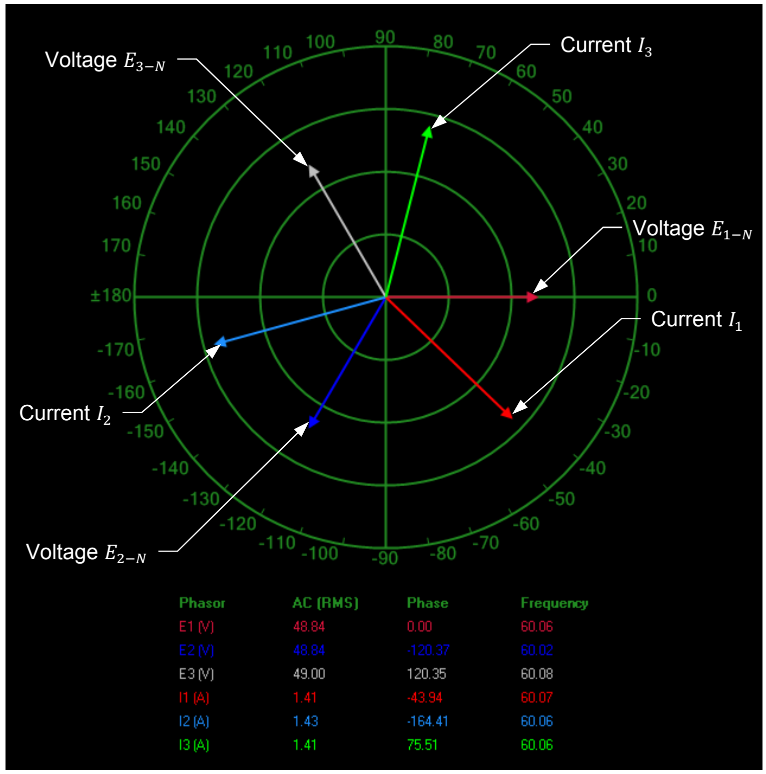
Active current command and reactive current command of a three-phase PWM rectifier/inverter

In this section, you will vary both the active current command and reactive current command, and observe the phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter. You will confirm that the phase shift measured between the phasors of the phase voltages and line currents for various combinations of active current command and reactive current command are as expected. You will also record the active power and reactive power transferred via the three-phase PWM rectifier/inverter for each combination of active current command and reactive current command. Finally, you will analyze the active power and reactive power values you measured in this exercise.

31. In the Three-Phase PWM Rectifier/Inverter Control window, set the *Active Current Command* and *Reactive Current Command* parameters to 1.0 A and -1.0 A, respectively. Repeat step 16. Observe in the Phasor Analyzer the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter.

The resulting phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter are shown below.

Phasor Analyzer Settings
Current Scale .... 0.5 A/div
Reference Phasor E1
Voltage Scale .... 20 V/div



Phasors of the phase voltages E_{1-N}, E_{2-N}, and E_{3-N} and line currents I_1, I_2, and I_3 at the ac side of the three-phase PWM rectifier/inverter when the active current command is equal to 1.0 A and the reactive current command is equal to -1.0 A.

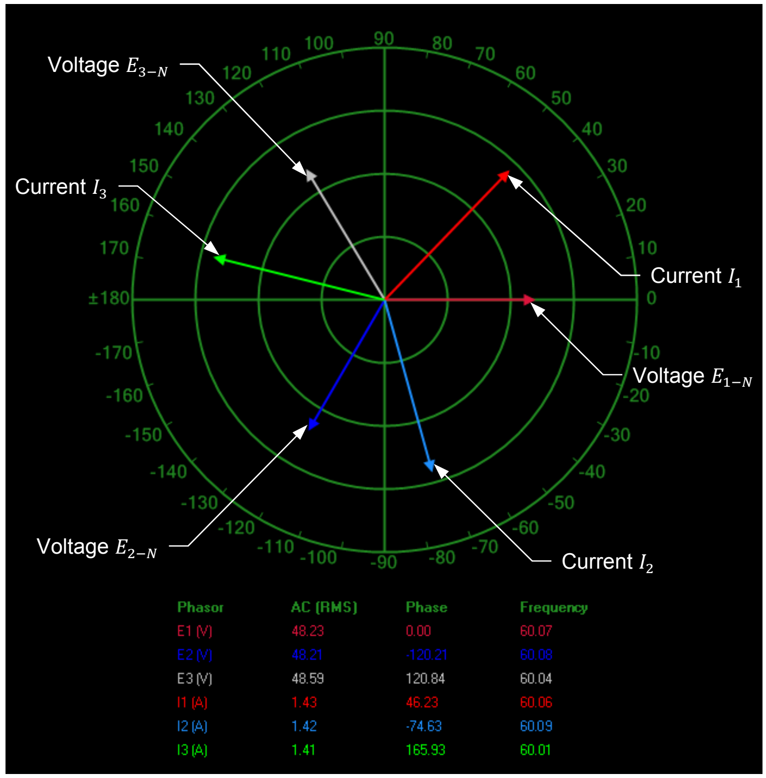
Is the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter as expected? Explain briefly.

Yes, since the present values of the active and reactive current commands (1.0 A and -1.0 A, respectively) set the phase angle of the line currents at the ac side of the three-phase PWM rectifier/inverter to -45° (i.e., cause the line currents to lag behind the corresponding phase voltages by 45°).

32. In the Three-Phase PWM Rectifier/Inverter Control window, set the *Reactive Current Command* parameter to 1.0 A. Repeat step 16. Observe in the Phasor Analyzer the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter.

The resulting phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter are shown below.

Phasor Analyzer Settings
Current Scale ....0.5 A/div
Reference Phasor E1
Voltage Scale..........................20 V/div



Phasors of the phase voltages E_{1-N}, E_{2-N}, and E_{3-N} and line currents I_1, I_2, and I_3 at the ac side of the three-phase PWM rectifier/inverter when the active current command and the reactive current command are both equal to 1.0 A.

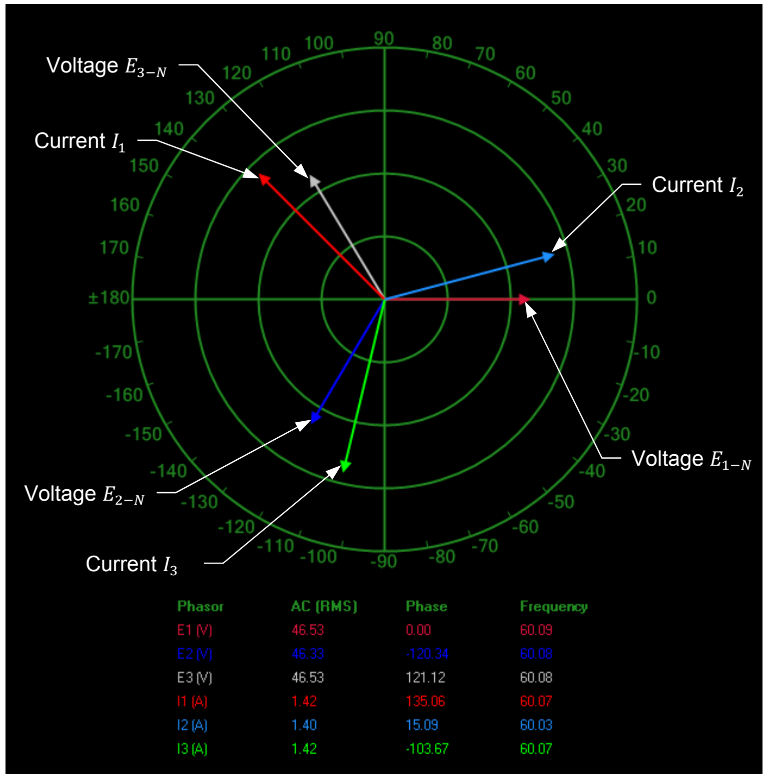
Is the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter as expected? Explain briefly.

Yes, since the present value of both the active and reactive current commands (1.0 A) sets the phase angle of the line currents at the ac side of the three-phase PWM rectifier/inverter to 45° (i.e., causes the line currents to lead the corresponding phase voltages by 45°).

33. In the Three-Phase PWM Rectifier/Inverter Control window, set the *Active Current Command* parameter to -1.0 A. Repeat step 16. Observe in the Phasor Analyzer the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter.

The resulting phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter are shown below.

Phasor Analyzer Settings
Current Scale .... 0.5 A/div
Reference Phasor E1
Voltage Scale .... 20 V/div



Phasors of the phase voltages E_{1-N}, E_{2-N}, and E_{3-N} and line currents I_1, I_2, and I_3 at the ac side of the three-phase PWM rectifier/inverter when the active current command is equal to -1.0 A and the reactive current command is equal to 1.0 A.

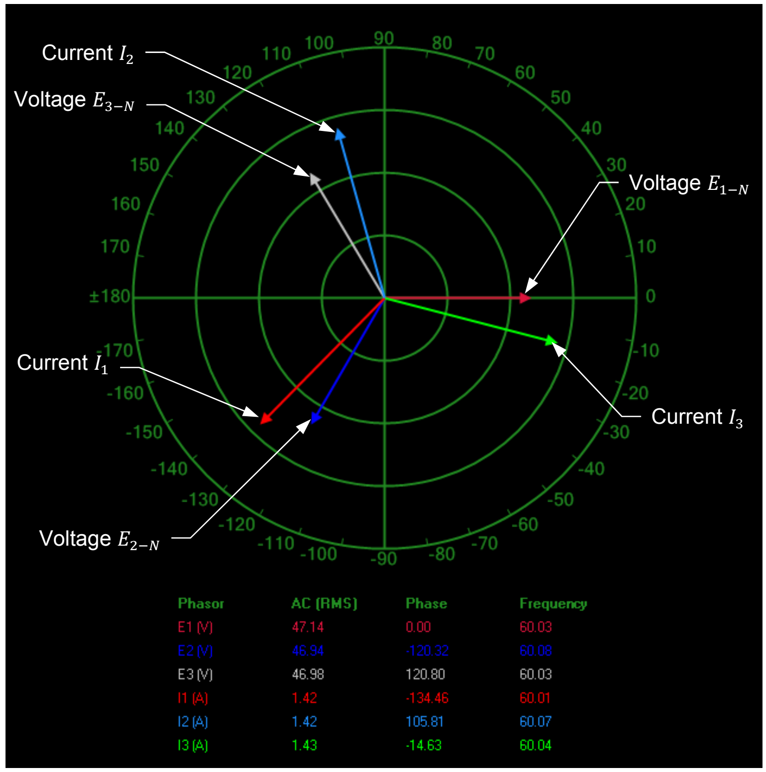
Is the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter as expected? Explain briefly.

Yes, since the present values of the active and reactive current commands (-1.0 A and 1.0 A, respectively) set the phase angle of the line currents at the ac side of the three-phase PWM rectifier/inverter to 135° (i.e., cause the line currents to lead the corresponding phase voltages by 135°).

34. In the Three-Phase PWM Rectifier/Inverter Control window, set the *Reactive Current Command* parameter to -1.0 A. Repeat step 16. Observe in the Phasor Analyzer the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter.

The resulting phasors of the phase voltages and line currents at the ac side of the three-phase PWM rectifier/inverter are shown below.

Phasor Analyzer Settings
Current Scale......................... 0.5 A/div
Reference Phasor E1
Voltage Scale .... 20 V/div



Phasors of the phase voltages E_{1-N}, E_{2-N}, and E_{3-N} and line currents I_1, I_2, and I_3 at the ac side of the three-phase PWM rectifier/inverter when the active current command and the reactive current command are both equal to -1.0 A.

Is the phase shift between the phase voltages and the corresponding line currents at the ac side of the three-phase PWM rectifier/inverter as expected? Explain briefly.

Yes, since the present value of both the active and reactive current commands (-1.0 A) sets the phase angle of the line currents at the ac side of the three-phase PWM rectifier/inverter to -135° (i.e., causes the line currents to lag behind the corresponding phase voltages by 135°).

35. On the Four-Quadrant Dynamometer/Power Supply, stop the 200 V dc power source by pressing the *Start/Stop* push-button.

Turn the three-phase ac power source in the Power Supply off.

In the Three-Phase PWM Rectifier/Inverter Control window, stop the three-phase PWM rectifier/inverter by clicking the *Start/Stop* button or by setting the *Status* parameter to *Stopped*.

36. Considering the results you recorded in Table 1, can a three-phase PWM rectifier/inverter be used to transfer any combination of active power and reactive power between the ac power source and the dc power source? Explain briefly.

Yes, the three-phase PWM rectifier/inverter can either supply or absorb reactive power while supplying active power to the three-phase ac power source (i.e., while operating as an inverter). Also, the three-phase PWM rectifier/inverter can either supply or absorb reactive power while receiving active power from the three-phase ac power source (i.e., while operating as a rectifier).

37. Considering the results you recorded in Table 1, can you conclude that a three-phase PWM rectifier/inverter can be used for dynamic voltage compensation as well as for dynamic power factor correction? Explain briefly.

Yes, because the three-phase PWM rectifier/inverter can either supply reactive power to the three-phase ac power source or absorb reactive power from the three-phase ac power source. The exact amount and direction of flow of the reactive power transferred being determined by the magnitude and polarity of the reactive current command.

38. Close LVDAC-EMS, then turn off all the equipment. Disconnect all leads and return them to their storage location.

Conclusion

In this exercise, you familiarized yourself with the block diagram of a three-phase PWM rectifier/inverter. You learned what the most common applications of three-phase PWM rectifiers/inverters are and were introduced to active power and reactive power control using a three-phase PWM rectifier/inverter.

Review Questions

1. How is it possible to vary the amount and direction of flow of the active power which a three-phase PWM rectifier/inverter transfers between a dc power source and a three-phase ac power source? Explain briefly.

   The amount and direction of flow of the active power which a three-phase PWM rectifier/inverter transfers between a dc power source and a three-phase ac power source can be varied by adjusting the active current command of the three-phase PWM rectifier/inverter. When the active current command is positive, the dc power source supplies active power to the three-phase ac power source via the three-phase PWM rectifier/inverter. On the other hand, when the active current command is negative, the three-phase ac power source supplies active power P to the dc power source via the three-phase PWM rectifier/inverter. The higher the magnitude of the active current command, the higher the amount of active power transferred.

2. How is it possible to vary the amount and direction of flow of the reactive power that a three-phase PWM rectifier/inverter exchanges with a three-phase ac power source? Explain briefly.

   The amount and direction of flow of the reactive power that a three-phase PWM rectifier/inverter exchanges with a three-phase ac power source can be varied by adjusting the reactive current command of the three-phase PWM rectifier/inverter. When the reactive current command is negative, the three-phase PWM rectifier/inverter supplies reactive power to the three-phase ac power source (i.e., the ac power source acts as an inductor). On the other hand, when the reactive current command is positive, the three-phase PWM rectifier/inverter absorbs reactive power Q from the three-phase ac power source (i.e., the ac power source acts as a capacitor). The higher the magnitude of the reactive current command, the higher the amount of reactive power exchanged.

3. Is it possible for a three-phase PWM rectifier/inverter to act either as a rectifier or an inverter (i.e., to transfer active power) while at the same time being used for power factor correction (i.e., to exchange reactive power). Explain briefly.

   Yes, it is possible for a three-phase PWM rectifier/inverter to act either as a rectifier or an inverter (i.e., to transfer active power) while simultaneously being used for power factor correction (i.e., to exchange reactive power). This can be achieved independently by adjusting both the active current command and the reactive current command so that the amounts of active power and reactive power transferred via the three-phase PWM rectifier/inverter are equal to the desired values.

4. Name three of the most common applications of three-phase PWM rectifiers/inverters.

   The four common applications of three-phase PWM rectifiers/inverters mentioned in this manual are listed below. Other applications are possible.

   – Static synchronous compensators (STATCOMs)

   – Voltage-source converter (VSC), high-voltage direct current (HVDC) transmission systems

   – Three-phase motor drives

   – Solar power farms tied to a three-phase ac power network

5. Explain how a three-phase PWM rectifier/inverter can be used for dynamic power factor correction.

A three-phase PWM rectifier/inverter can be used for dynamic power factor correction by adjusting the amount of reactive power being exchanged with the system to which it is connected. This adjustment must result in the amount of reactive power which the system exchanges with the ac power network being as close as possible to zero, thereby ensuring the power factor of the system remains as close as possible to unity.

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