Instructor's Manual
to accompany

INDUSTRIAL ELECTRONICS

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Industrial Electronics by James A. Rehg and Glenn J. Sartori

Instructor's Guide

Introduction

Thank you for adopting our text for your course, if you have any questions about the presentation of the material, please contact us by email. The instructor's guide includes a section on teaching information and the answers to end-of-chapter questions and problems. The teaching information includes: chapter comparisons with other industrial electronics textbooks, suggestions on how to use the text in different curriculum configurations, some suggestions for chapter use, and suggested laboratory experiments from industrial electronics laboratory manuals.

Teaching Information – Chapter Cross Reference

The following table provides a cross reference between the chapters in our text and the chapters of four other texts on the market. You will notice that the chapters in out text follow a bottom-up content development that starts with the building block components, such as switches and solid state devices, and concludes with systems used in manufacturing and control machines that are an integration of these components. While our chapters can be used in any sequence in a course, we made every effort to match chapter content with the instructional sequence of a traditional course. If you are currently using another industrial electronics text, the cross reference will show how our textbook can be easily adapted to the content of your current course outline. The notes that follow the cross reference table identify differences in topic content for our text compared to the other four IE texts.

Comparison of Chapters in Rehg/Sartori with Other Industrial Electronic Text

***Rehg/Sartori* Chapter**		***Maloney* Chapter Number**	***Kissell* Chapter Number**	***Maas* Chapter Number**	***Bartelt* Chapter Number**
Number	**Title**				
1	Introduction to Industrial Electronics	None Note 1	None Note 1	None Note 1	None Note 1, 22
2	Discrete Control, Input and Output Devices	None	11 & 15	None	16 Note 21, 22
3	Solid State Devices in Industrial Electronics	1 and 2 Note 4	1, 2 & 7	1 & 9 Note 4	2 Note 4

4	Operational Amplifiers and Linear ICs	8 Note 5	8 Note 5	2 Note 5	2 Note 5
5	SCRs, Triacs and Other Thyristors	4, 5 & 6	4 and 5	7 & 8	2 Note 17
6	Discrete Automation Sensors and Devices	None	6 Note 12	5 Note 12	16 Note 24
7	Analog Process Control Devices and Sensors	10 & 11 Note 6	10 & 11	3 & 4 Note 16	9, 10, 11, 12, & 13 Note 23
8	Safety	20 Note 7	6, 15, Appendix A Note 19	None	None
9	DC Motors and Control Circuits	12 & 16 Note 8	12 Note 18	10 Note 8	4 & 7 Note 18
10	AC Motors and Variable Speed Drives	11, 14 & 16 Note 9	11 and 12	9 & 10 Note 9	5 & 8 Note 9
11	Special Purpose Motors and Control Devices	11 & 13	11 Note 11	10 Note 15	6 Note 15
12	Programmable Logic Controllers	3 Note 2	3 Note 2	13 Note 2	17, 18, & 19 Note 2
13	Embedded Microcontrollers	None	None	12 Note 14	None
14	Open and Closed Loop Process Control	15 & 18 Note 10	9 Note 13	13 Note 10	1, 3, 15, 20, 22, 23, & 24
15	Industrial Robots - Operation and Programming	19 Note 3	14 Note 20	14 Note 3	None
16	Data Communication Between Intelligent Machines	None	16	None	None

Notes:
1. Troubleshooting is covered in most chapters but a comprehensive troubleshooting approach is not provided.
2. No coverage of the new PLC languages and the PLC standard IEC 61131.
3. No coverage of robot programming or the types of path control used in robot programming.
4. Only transistors as switches are covered. No coverage of transistor amplifiers, inverters and converters, JFETs, CMOS, and solid-state relays.
5. No coverage of active filters such as low and high pass, band pass and band elimination filters, Norton amplifiers, and linear ICs.
6. No coverage of flow, level, viscosity and density sensors.
7. No coverage on presence sensing devices, interlocks, safety strategies and safety design.
8. No coverage of magnetic theory and DC traction motor.
9. No coverage on motor data plates.

10. No coverage of open and closed loop theory, fuzzy controllers and standard tuning processes for closed loop control systems.
11. No coverage of permanent magnetic motors, brushless motors, optical encoders and resolvers.
12. Only photoelectronic devices. No coverage of proximity sensors, automation sensors and vision systems.
13. Limited coverage of closed loop theory and no coverage of fuzzy controllers.
14. No coverage of product data sheets and development systems.
15. No coverage of coreless motors.
16. No coverage of viscosity, density and humidity sensors.
17. No coverage of programmable unijunction transistors and controlled thyristor switches.
18. No coverage of the DC traction motor.
19. Only coverage of light curtains and no coverage on presence sensing devices, interlocks, safety strategies and safety design.
20. No coverage of robot programming and programming techniques.
21. Only switch covered is the limit switch.
22. Few numerical end-of-chapter numerical problems.
23. No coverage of viscosity and density sensors.
24. Vision systems not covered.

Teaching Information – Curriculum Fit

This text was designed for the traditional industrial electronics course in the two- and four-year engineering technology curriculums. However, it would also be an excellent text for the Mechatronics (mechanical-electronics) course used in mechanical engineering and mechanical engineering technology curriculums to expose those students to electro-mechanical concepts. The text is comprehensive so select the chapters and chapter sections that are useful to the program based on the other courses taken by your students. The following general guidelines may prove useful for content selection.

If the curriculum has:

No course on rotating machinery *Then*: include Chapters 9, 10, and 11.

A 3 credit rotating machinery course *Then*: use the text for both the motors class and the industrial electronics class.

A 5 credit rotating machinery course *Then*: use just the sections in

		Chapter 11 not covered in the earlier course.
No course in robotics	*Then*:	include Chapter 15
A course in robotics	*Then*:	cover Sections 15-7 to 15-10 if robot programming was not covered in the robot course.
No course in PLCs	*Then*:	include Chapter 12
One or two courses in PLCs	*Then*:	cover Sections 12-7 to 12-9 on the new IEC 61131 new programming languages since they are not often included in a traditional PLC course.
Courses in semiconductors and amplifiers	*Then*:	skip Chapter 3 or just use it for a quick review of semiconductor theory. A review of op amps may be especially useful since they are used often in many chapters of this text.

Teaching Information – Chapter Overview

The following suggestions are offered for each of chapters:

Chapter 1 – The four important topics in the chapter are: an overview of manufacturing systems used in industry, development of a general process for troubleshooting large electro-mechanical systems, the learning pyramid, and the technology tree. The problems at the end of the chapter are a good review of DC and AC circuit theory problems

Chapter 2 – The chapter thoroughly covers switches and actuators, devices often overlooked in curriculum courses, which are important building blocks for all machines and systems. The process systems example introduced here using process parameter switches and discrete control is expanded in later chapters using more complex control systems. A robot control problem is introduced here using relay ladder logic, and in Chapter 12 the same problem will be solved using PLCs.

Chapter 3 – The chapter attempts to answer the question, "What are the minimum competencies in solid state analog devices and circuits necessary to know if you are going to work in automation control or on electronics found in industry." If students have previous courses in solid-state devices and amplifier theory, this chapter may serve as an assigned reading chapter but without class lecture. Another option would be to use one class to hit the high spots for a general review of the topic.

Chapter 4 – The topics in this chapter are often not well understood by students even after the completion of an operational amplifier class. Review of the entire chapter, coverage of the more frequently used configurations, or coverage of the configurations not covered in previous courses are all options for this chapter in the course. In any case, operational amplifiers are used so often on industrial electronic systems that some degree of coverage of this chapter is important in an IE course.

Chapter 5 – Thyristors are used in most industrial electronic circuits and systems, so a thorough understanding of their operation and the common circuits that use them is critical. Complete coverage of this chapter is important for work in the IE area.

Chapter 6 – Automation sensors are also used on every machine and system in industry; therefore, they are another important topic area that should be covered in detail.

Chapter 7 – This chapter combined with Chapter 14 makes an excellent introduction for a full controls class or provide a good understanding of process controls when no additional control work is planned.

Chapter 8 – This chapter can be covered completely for a good overview of personal safety practices and the design of safety systems for machine safety. If a shorter version is desired cover only the first four sections.

Chapter 9 and 10 – Complete coverage of DC and AC motors plus control circuits and electronic drives.

Chapter 11 – This chapter includes a number of special purpose motors that may need to be covered if the motors course does not address the operation special purpose motors.

Chapter 12 – This chapter on PLCs can be used a variety of ways. If a previous PLC course is taken that includes Allen Bradley PLCs, then Section 12-6 can be eliminated. If the first course used a generic approach, then you may want to include this section so students would know how to program in the RS Logix 500 language. In either case, the balance of the chapter is important because it introduces the IEC 61131 standard for programming of PLCs. In addition to coverage of four of the five (the fifth language is not supported and used in the US) programming languages, the chapter covers tag (variable) based PLC programming. Few PLC courses cover the new languages, that is why it is included here.

Chapter 13 – An overview of embedded controllers is presented.

Chapter 14 – This is a comprehensive chapter on process control. When this chapter is grouped with Chapters 2, 6, 7 and 12 you have good instrumentation and controls coverage. This chapter explains the theory behind analog and digital process control and the development of a good control strategy.

Chapter 15 – Robotics includes two fundamental elements: hardware and software. Often courses address the hardware component but skip the programming element for servo and non-servo robots. This chapter on robots addresses both so if a previous robot course does not have a programming component, then Sections 15-7 through 5-10 would add that necessary competency.

Chapter 16 – The final chapter provides an overview of network theory and coverage of the networks found in manufacturing settings.

Laboratories for Industrial Electronics

If the IE course has a laboratory associated with it, then the following table provides some suggested laboratories exercises from two laboratory manuals. Note that neither manual has experiments that fit some chapters perfectly, while some chapters have numerous experiments that can be used. When a no exercise is listed you may be able to have additional exercises used from an earlier chapter to get better hands-on experience for that material.

Suggested Laboratory Exercises for Rehg/Sartori

***Rehg/Sartori* Chapter**		***Devenport* Experiments for Industrial Electronics 4th ed**	***Davis* Modern Industrial Electronics 4th ed**
Number	**Title**	**Exercise Number**	**Exercise Number**
1	Introduction to Industrial Electronics		
2	Discrete Control, Input and Output Devices		1
3	Solid State Devices in Industrial Electronics	22	2 to 10, 34, 35
4	Operational Amplifiers and Linear ICs	1 to 14	16 to 18
5	SCRs, Triacs and Other Thyristors	23 to 29	19 to 25
6	Discrete Automation Sensors and Devices	34, 35	37
7	Analog Process Control Devices and Sensors	30 to 33, 36 to 38	26 to 29
8	Safety		
9	DC Motors and Control Circuits	15, 16, 39 to 41	38
10	AC Motors and Variable Speed Drives	20, 21	40
11	Special Purpose Motors and Control Devices	17, 18, 19	39
12	Programmable Logic Controllers	49	36

13	Embedded Microcontrollers		
14	Open and Closed Loop Process Control	42 to 45	17
15	Industrial Robots - Operation and Programming		
16	Data Communication Between Intelligent Machines		

The solution to end-of-chapter questions and problems follows. We welcome any comments you may have on ways to improve the text or for additions you would like to see added. Please email either Jim Rehg (james@rehg.org) or Glenn Sartori (rg492@sbcglobal.net) with any comments or questions.

Chapter 1 - Questions

1. The switch from water power to steam power caused the industrial revolution.
2. Changes in manufacturing are driven primary by a need for increased productivity.
3. At the start of the 20th century the electrification of manufacturing and the invention of the electric motor moved manufacturing to the next level.
4. The process of a machine measuring the product output and automatically correcting for improper operation is call feedback control.
5. Project : Many complex parts are used to build a one-of-a-kind product. - Job shop: - Non-complex products with few parts and small production volume. – Repetitive: 110 percent repeat business, multi-year contracts, high but variable production quantities. – Line: (1) the delivery time required by the customer is often shorter than the total time it takes to build the product, (2) the product has many options or models, and (3) an inventory of subassemblies is normally present.
6. Repetitive, Line, and Continuous.
7. Robots can be reprogrammed and retooled to a wide variety of automation tasks.
8. FMS are made up of a number of linked FMCs.
9. Fixed automation machines are designed for a small number of products and FMCs are designed to be flexible and produce a variety of products.
10. Project
11. The tree indicates the technologies that you must know and pyramid shows the sequence of to learn about the products.
12. *Troubleshooter*—A skilled person employed to locate trouble or make repairs on machinery or technical equipment.

13. Problem solving is solving a problem never seen before, but exercises are solution you know for previously solved problems.
14. When changes are made to the data used by the program and in very large programs that do not have a specific set of events occur until much after the software was installed.
15. a. List all of the system components that would be replaced in the advent of a failure. b. Arrange the list of system components with inputs at the top, outputs at the bottom, and the remaining items in the order that signal or information flows through them. c. Put all of the block diagram components into rectangles and apply signal flow techniques to link the rectangles in the diagram.
16. a. Record and study all system symptoms. b. Locate points on the system block diagram where abnormal operation is occurring. Place a right bracket ( ]) after each abnormal block. c. Move to the left along the signal flow path from each bad bracket until normal operation is observed. Place a left bracket ([ ) to the right of the block where a normal output was detected.
17. Power flow indicates power distribution and signal flow shows how information, signals, and data move from block to block.
18. The linear signal path is a series connection of blocks, a divergent signal path is present when a single block feeds two or more blocks, a convergent signal path is present when signals from two or more blocks feed into a single block, a feedback signal flow is created when part of the output signal is diverted back to the input of the system and added to the input signal, Switched signal flow paths include linear, divergent, or convergent paths, with switches present to change the flow of the signal.
19. Start the troubleshooting measurements half way between the input and the

output on a signal path.

20. When brackets enclose system blocks with a divergent path, the stage before the divergence is fault-free if any of the divergent paths are normal. In convergence, if all convergent inputs are necessary for a good output then a good output means that all inputs are correct, but if that is not the case then each convergent input must be checked except the one producing the good output.
21. If the change of a switch position causes the output fault to disappear then the problem is in the path that the switch was in before switching. If that is not the case, then the problem is down stream of the switch.
22. The concept of using more general checks as the brackets are widely separated and letting the test become more specific as the brackets move closer together.
23. Those are the easiest test to make and cost less in time and effort.
24. If the front panel controls are not set properly then all others tests are not valid. Also those are the easiest test to make and cost less in time and effort.
25. They are an accurate record of what the problems is and what has been done to identify the cause of it.
26. If you don't understand how the system operates in detail it is impossible to troubleshoot faults.
27. If a fault was detected then it is equally important to determine why the system failed so that type of failure could be prevented in the future.
28. If the symptoms are related then troubleshoot them as they were one type of problem. If they are unrelated, then troubleshoot each one as thought it were a single problem.
29. A failure is either a totally random event (a component failing) or a human driven

event (a fork lift hitting a cable). In either case it would be statistically unusual for two of these to occur at the same time that were totally unrelated.

Chapter 1 - Troubleshooting Problems

1a. Left bracket on input side of power amplifier and right bracket on output side of speaker #1

1b. Left bracket on input side of microphone #1 and right bracket on output side of mixer.

1c. Left bracket on output side of power amplifier and right bracket on output side of speaker #2.

2. It is unlikely that both speakers would fail simultaneously so if a single failure is involved then the bracket could move to the output of the power amplifier.
3. We don't know if both microphones are good since one could be bad and volume controls on the mixer could be set low for the other one. If the volume controls were set to a nominal position before the microphone test then the single failure assumption could be applied and the bracket moved.
4. The left bracket would move to the input of the power amplifier instead of the movement of the right indicated in the solution.
5. If the switch to the CD did not cause an output then the problem is in the power amplifier since both speakers cannot be bad (single failure assumption). The left bracket is placed on the input side of the power amplifier and the right is placed on the output side in Figure 1-5. The next test is made at the output of the summing amplifier. If the test indicates that the unit is good then the left bracket moves to the output of that unit. If the test is bad then the right bracket moves to output of that unit. The fault is found by

continuing this process until one unit has brackets on the input and output.

Chapter 1 - Prerequisite Circuit Problems

1. Resistor color code.

Color code	R,Y,O	Br,W,Bl, G	O,V,Gn, S	Gn,Gr,R	V,Y,Bl,G	Bu,R,Bl, G	W, Y,O
ohms	24000	1900000 0	3700000	5800	74	62	94000
kilo –ohms	24k	19000k	3700k	5.8k	0.074k	0.062k	94k
meg - ohms	0.024M	19M	3.7M	0.0058M	0.000074 M	0.000062 M	0.094M
Tolerance range	28000 19200	19.95M 18.05M	4.07M 3.33M	6960 4640	77.7 70.3	65.1 58.9	112.8k 75.2k

2. Calculate the missing two values in each column.

Resistance	15 k	200	7500	0.4 M	120	0.5 u	30 k
Voltage	30 v	50 mv	600 v	141.4 v	12 v	500 uv	1732 v
Current	2mA	250 ua	0.08 a	0.35 ma	100 ma	1000 a	57.7 ma
Power	60 mw	12.5 w	48 w	50 mw	1.2 w	0.5 w	0.1 kw

3. Calculate the capacitive reactance. Express the answer in kilo-ohms.

Capacitance Frequency	0.01 uf	0.001 f	0.005 uf	15 uf	10 pf
400 hertz	39.788k	397.886	79.577k	0.026k	39788.6

		k			k
2000 rad/s	50k	0.0005k	100k	0.0333 k	50000k

4. Calculate the inductive reactance. Express the answer in kilo-ohms.

Inductance / Frequency	10 mh	0.5 h	500 uh
400 hertz	0.0251 3k	1.2566 k	0.00125 6k
2000 rad/s	0.02k	1k	0.001k

Insert Figure 1-11 here

5. Figures 1-11a and b

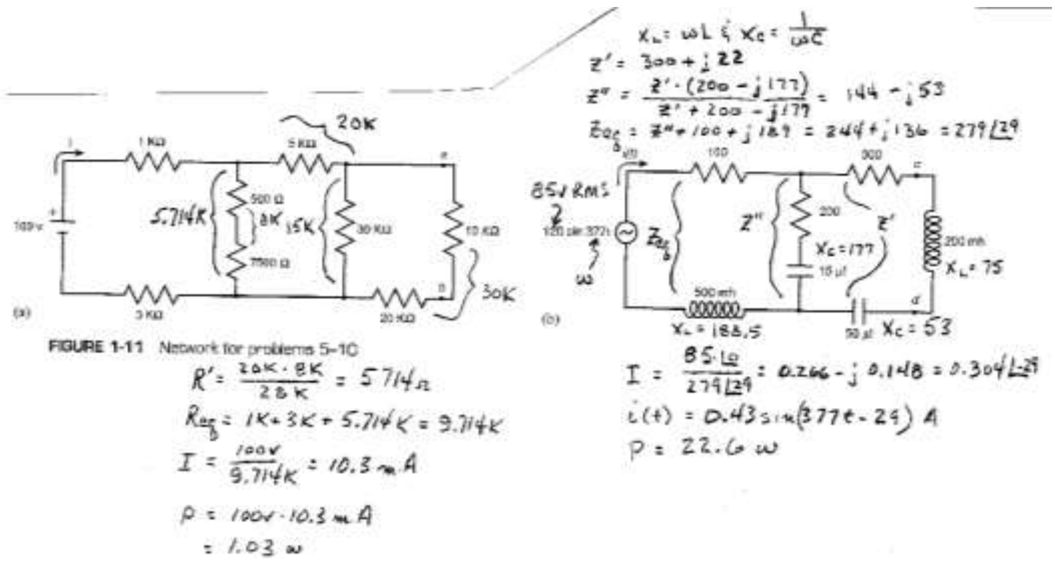


FIGURE 1-11 Network for problems 5–10

6. Calculate the current flowing from terminal a to b in Figure 1-11a
7. Calculate the current flowing from terminal c to d in Figure 1-11b.

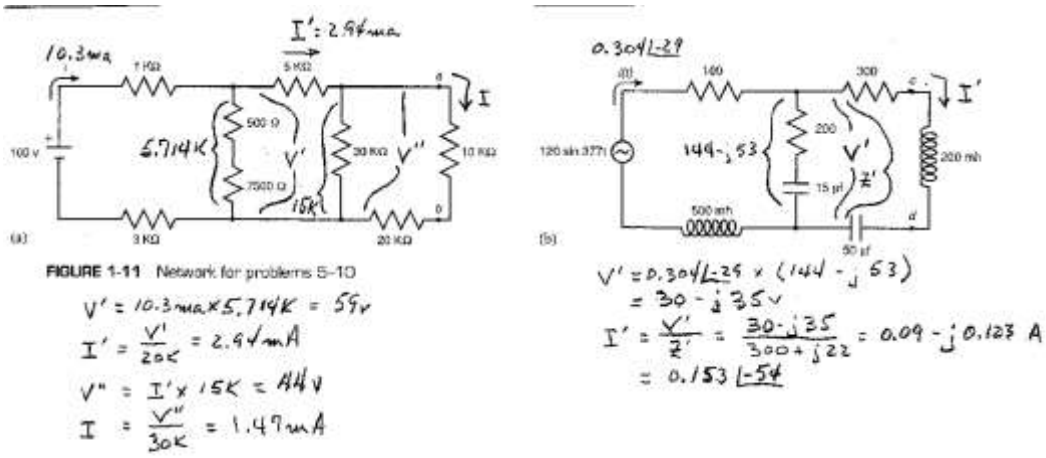
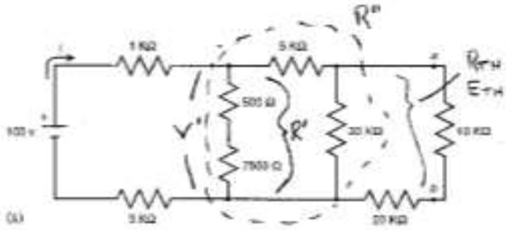


FIGURE 1-11 Network for problems 5–10

8. Calculate the voltage across the 10k ohm resistor from the Thevenin equivalent.
9. Calculate the voltage across the 200 mh inductor from the Thevenin equivalent.

$$V_{200mh} = \frac{42\angle 21 \times (0+j75)}{(0+j75)+(263+j133)} = 2.8+j9 = 9.4\angle 73$$



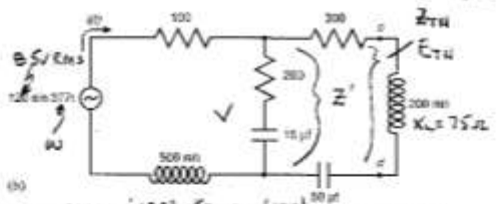


FIGURE 1-11 Network for problems 5-10

$$R' = \frac{4K \times 8K}{12K} = 2.7K$$

$$R_{TH} = \frac{(2.7K+5K)\times 30K}{(2.7K+5K)+30K} + 20K = 26K$$

$$R'' = \frac{35K \times 8K}{43K} = 6.5K$$

$$E_{TH} = \frac{100V \times 6.5K}{1K+3K+6.5K} = 62V$$

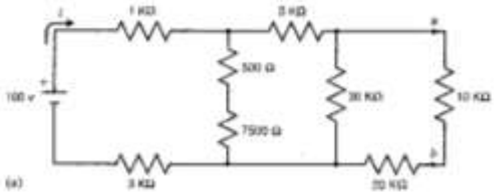
$$V_{10K} = \frac{62V \times 10K}{10K + 26K} = 17.2\ V$$

$$Z' = \frac{(100+j189)\times(200-j177)}{(100+j189)+(200-j177)} = -37+j186 = 190\angle 101$$

$$Z_{TH} = Z' + (300-j53) = 263+j133 = 295\angle 27$$

$$E_{TH} = \frac{85\angle 0 \times Z'}{Z'+(100+j159)} = 40+j15 = 42\angle 21$$

10. Convert the Thevenin voltage source in Problems 8 and 9 to the equivalent Norton current sources.



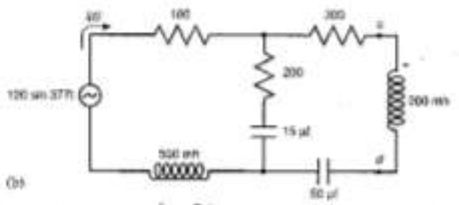


FIGURE 1-11 Network for problems 5-10

$$I_N = \frac{E_{TH}}{R_{TH}} = \frac{62}{26K} = 2.38\ mA$$

$$R_N = R_{TH} = 26K$$

$$I_{10K} = \frac{I_N \cdot R_N}{R_N + 10K} = 1.72\ mA$$

$$I_N = \frac{42\angle 21}{295\angle 27} = 0.142 - j0.14 = 0.14\angle -6$$

$$Z_N = Z_{TH} = 295\angle 27$$

$$I_{200mh} = \frac{0.14\angle -6 \times 295\angle 27}{295\angle 27 + (0+j75)} = 0.125\angle -17$$

11. Use Kirchhoff's voltage and current laws and Ohm's law to find the following values for the circuit.

$I_1 = \frac{54.5V}{10\Omega} = 5.45A$

$I_2 = I_1 - 1.3A = 4.15A$

loop 1 $-65V - 150V + V_R + 83V = 0$

$V_R = 132V$

loop 2 $+100V - 54.5V - 83V - 132V - 27.5 - 81.75 + V = 0$

$V = 278.75V$

$R = \frac{132V}{4.15A} = 31.8\Omega$