Efficiency of a Three-Phase Low Voltage Power Supply for Electrical and Electronics Student Laboratory

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ABSTRACT

Understanding basic electrical circuit principles can be difficult for students taking up basic electrical engineering course. Enhancing learning methodologies requires experiments with adequate laboratory equipment. The lack of basic equipment required for these laboratory experiments hinder students from learning and fully comprehending their lessons. Affordable and locally designed equipment is needed as a substitute for the expensive technology that many schools in the Philippines cannot afford. This study is aimed to design, construct and test a low cost Three-Phase Low Voltage Variable Power Supply for Electrical and Electronics Laboratory with the following components: three-phase high voltage power supply of 220VAC, low voltage variable three-phase AC power supply with an output of 3V, 4.5V, 6V, 9V, 12V and DC output of ±12V, +5V, ±1.25V – ±12V. Central Philippine University College of Engineering requires laboratory subjects to facilitate and enhance learning methodologies. All output was provided with overcurrent circuit protection to protect the circuits and the components from overload and accidental short circuit. Result shows that all data have met the requirements for reliable, accurate and ready-to-use power supply equipment. The construction of the circuit was completed, thereby meeting the needs of the electronics and electrical students for a Three-Phase Low Voltage Power Supply.

Keywords: current flow, electrical circuit, low voltage variable power supply

Introduction

Experimentation in basic electrical and electronics engineering is necessary to reinforce learning among the students and to understand their lessons further. Availability of instruments and equipment related to this course is a must to address the learning needs of the students. Colleges and universities offering this course were required to have the specific equipment to facilitate and enhance learning. Colleges and universities in the Philippines specifically in the Visayas region offering electrical, electronics and allied courses could not afford to buy this expensive and imported equipment.

Central Philippine University College of Engineering requires

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laboratory subjects to facilitate and enhance learning methodologies. Engineering curriculum integrate basic electrical and electronics engineering and technology subjects. These courses require basic equipment like the low voltage Three-phase variable power supply with complete switching and protection. Most of Engineering schools and colleges have a limited number of this equipment. Classes perform laboratory experiments in large groups. Some schools have acquired this equipment abroad. Most electronic equipment requires power supply specifically DC voltages for their operation. These can be provided by batteries or by internal power supplies that convert alternating current available at the home electric outlet, into regulated DC voltages. The first element of the basic power supply circuit is transformer, which steps up or steps down the input voltage to a level suitable for the operation of the equipment.

This component is then followed by a rectifier, normally, a full-wave bridge diode converting AC voltage to pulsating DC voltage. The next stage is the capacitor filter circuit that reduces ripple voltage or harmonics from the rectified signal. To maintain the output voltage with the change in the load current and the source voltage, a regulator is then added to the output of the filtered power supply.

The modern and state-of-the-art regulated power supply is the switching type. The advantages of switching supplies are that these are smaller in size compared to linear type, low weight, low material cost, and their ability to actively regulate at no additional cost. (Maloney, 2003)

The existing equipment currently used in the Electronics and Electrical laboratories is the Lab Volt manufactured in Canada which costs a few million pesos. These are a sophisticated set of electrical and electronic equipment. It utilizes a high voltage of 220 Vac and dc. It also has complete circuit protection. Also, Hamden Company developed AC, DC Power Supply model BPS – 103A with the following features 0 – 128Vdc 6A max, 0 – 140Vac 6A max, 0 – 220 3 phase, 9A max, 220Vac 3 phase, 15A max, 0 – 150Vdc 1A max and 110V single phase 15A maximum. Lab Volt EMS 8621 power supply has 120/208, three phase 15A maximum, 0 – 120V/208V – 5A maximum, three phase 0 –120V, 8A DC. This power supply, however, does not have the electronic over current protection and variable step voltage. The Lab Volt EMMS 8621 power supply is applicable only to a very high voltage. This is not recommended for classroom use for it may compromise student's safety and cannot be used in low voltage application. The design, fabrication, and evaluation of a three – phase low voltage power supply is designed specifically for low voltage current application suitable for laboratory experiments in electrical and electronics subjects. Because of the higher cost of imported equipment, the Electrical and Electronics department could not afford to purchase the adequate number needed in the Electronics and Electrical Laboratory. As a result, experiments cannot be performed in a small group of students or individually but rather in a large group. With this scenario, it becomes difficult for an instructor to effectively demonstrate and relay information for students to better understand the subject matter.

Locally fabricated equipment can be utilized for experimental purposes. Developing and fabricating a three-phase low voltage power supply will provide students in Electronics and Electrical Engineering and allied courses with a low–cost power supply. This will also allow them to be able to perform hands–on experiments that can meet their level of satisfaction [9]. The power supply is simple in design and developed using locally available materials, simple circuits and components. It is very convenient and easy to use because the AC and DC supply are already in a bank and placed in the panel. All that the students have to do is plug the connectors to the value specified in the laboratory experiments.With the limited number of equipment in the electronics and electrical laboratory of the college, the design and construction of this low cost, locally made equipment was conducted to address the needs of the laboratory. This study was aimed to design, construct and test a low cost Three-Phase Low Voltage Variable Power Supply for Electrical and Electronics Laboratory.

Methodology

The block diagram of the Three – Phase Low Voltage Power Supply showed in Figure 1 is composed of eight blocks labeled with a name that corresponds to its specific functions and operation. The block diagram has eight major components: the regulated power supply both fixed and variable, the transformer bank with step down voltage from 220 VAC to a variable 3V, 4.5V, 6V, 9V, and 12VAC voltage, the overcurrent circuit protection for both AC and DC, the 220V ac output voltage directly connected to a 220VAC 3 phase line, and the low voltage DC and AC output. The regulated DC power supply design is an IC voltage regulator with variable and fixed output voltage. The output voltage is from 1.25V to 37 V with built-in over current circuit protection and for fixed IC regulator, the output voltage is being specified based on their rating and the latter has also a built overcurrent circuit protection. The AC and DC output were provided with overcurrent circuit protection. Itis carefully designed to limit the operating current to one (1) ampere and for the protection of the transformer bank and the main component specifically transistors and IC voltage regulator. Each of the circuits is provided with a fuse to further protect the circuit in case over current protection fails. The design of this power supply unit is unique compared to an existing power supply because it uses locally available materials, which are affordable and easy to use. Also, all the outputs were provided with electronically activated overcurrent circuit protections using a simple circuit design, but safe and effective.

The overcurrent circuit protection circuit board is dynamically designed and easy to use with the other power supply circuit. Lastly, this power supply is specifically designed for low voltage low power application and is safe for students to use.

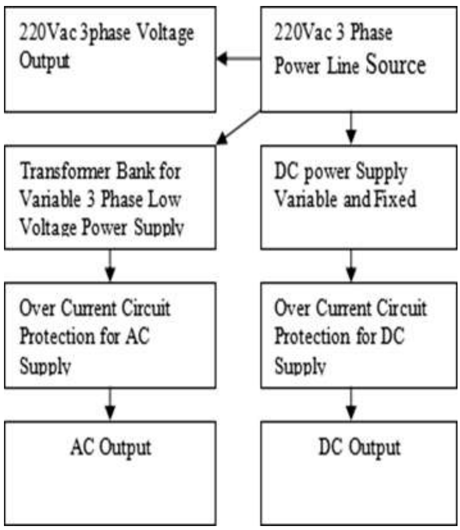

Figure 1. Block Diagram of Three – Phase Low Voltage Power Supply

Design

The design of the circuit board is split into three categories: the design of the regulated DC power supply, over current circuit protection, and the design of the three-phase transformer bank. The regulated DC power supply was used to provide the following voltages: ±12V, +5V and variable ±1.25V to 15V assuming at no load condition. The AC power supply is split into two types: the high voltage AC power supply with an output voltage of 220VAC/60Hz three phase and low voltage variable AC power supply which has five different output levels, selected by using the six position selector switch with the following output voltages: 3V, 4.5V, 6V, 9V and 12V.

Construction of the RAJ Power Supply – 3 Phase low voltage variable power supply

The construction of the three – phase low voltage power supply is done at Central Philippine University, College of Electronics Engineering Laboratory, and constructed by the designer and technician in-charge of the laboratory.

The process and procedure involved in the construction of the power supply are as follows:

1. Making the layout of the power supply. This process involves arrangement of the different components of the power supply, the position of the knob, terminal post, transformer bank, switches, LED indicator, circuit boards wiring, and fuses.
2. Drilling a hole in the casing of the power supply.
3. Component assembly: putting the component into its proper places based on the component layout.
4. Wiring: making a connection between circuit components.

Testing the Circuit Design and Pre-evaluation

The testing of the design will be done at Electronics Laboratory, College of Engineering, Central Philippine University; the parameters tested are the output voltage, maximum load current.

The three source-input was tested before the testing of the circuit components, and followed by the three-phase low voltage power supply. Next are the DC output voltage and the regulated output. To make system circuit functional, the overcurrent circuit protect was inserted in each of the outputs of the power supply. It applied overcurrent to the system to test the function and operation of the circuit.

Final Evaluation and Testing

Final evaluation of the three – phase low voltage power supply was done at EN204 Electronics Laboratory tested by the personnel from the EE/ECE Department during the week of continuous operations.

The final testing and evaluation of the power supply are the same in testing the circuit design and pre-evaluation procedure.

Instrumentation

The ammeter and voltmeter are used to measure voltage and current. Additional accessories are the resistor, capacitor, inductor, and connectors used to connect each component to become a complete circuit.

During the evaluation and testing of the Three – Phase Low Voltage Power Supply Board, the following instruments were used:

DMM (Digital Multimeter).

METEX model M380 is a Digital Multimeter instrument used in measuring of Voltage, Current, and Resistance of a given circuit and component.

An oscilloscope is an instrument used to measure phase angle of a three phase output voltage.

Connectors. These accessories are used to connect one component to another to complete the circuit.

Three- Phase Power Source. These are line voltage that will provide or supply the power connected to a 220Vac line.

Data Gathered

During the performance evaluation of the three – phase low voltage power supply, the following data were gathered:

1. The phase angle of the line voltage or source and the output voltage
2. The maximum operating current.
3. The minimum and maximum output voltage of a variable regulated power supply

Parameters Analysed

The parameters of this study are the percent error of the actual measured value and the value specified by the specification sheets and the required specifications.

Result and Evaluation

The power supply shown in Figure 2 operates at 220VAC/60Hz three-phase input supply and has a three-phase variable low voltage AC output and a regulated DC output voltage with built-in over current circuit protection to protect the system from load current beyond the capacity of the power supply.

The schematic diagram of a 78XX and 79XX series IC voltage regulator shown in Figure 3 consist of the input voltage (Vi) output voltage (Vo) and the two nF capacitor. This circuit was used to regulate the fixed output voltages. The capacitor connected to the input and output terminal is used to filter out harmonics produced by the active component and the high- frequency interference. (Mehbub, 2012).

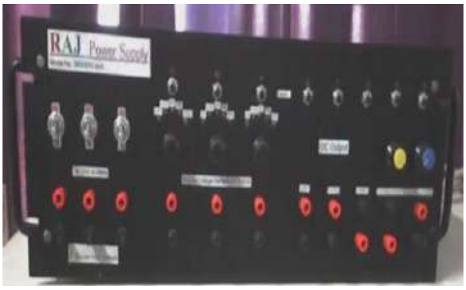

Figure 2. The Actual Three-Phase Low Voltage Power Supply

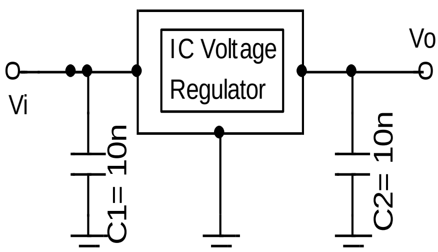

Figure 3. Fixed IC Voltage Regulator

The circuit shown in Figure 4 used LM317 and LM337 that provides a variable DC output voltage is composed of input unregulated voltage (Vi), regulated output voltage (Vo), 10 k variable resistor (P1) used to adjust an output voltage and 1 k resistor R1 used to set the operating current of the regulator.

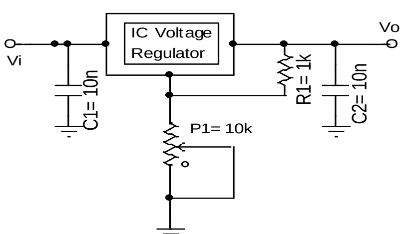

Figure 4. Variable IC Voltage Regulator

The transformer bank is used to step-down voltage from 220Vac to 3V, 4.5V, 6V, 9V, and 12V ac using the Delta – to- Wye connection.

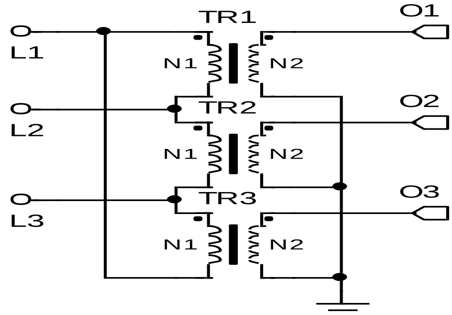

Figure 5. Three Phase Transformer Bank

The rotary switch is used to select the variable ac supply output to 3V, 4.5V, 6V, 9V, and 12V ac from the three phase wye connected transformer bank.

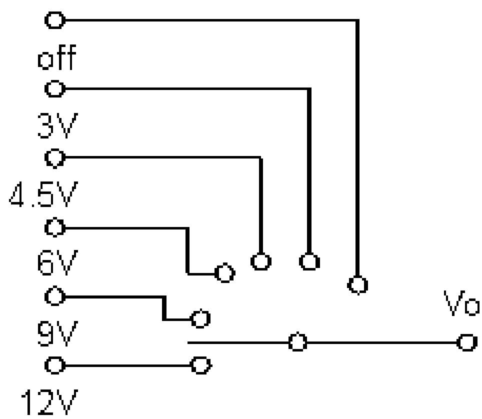

Figure 6.Six Position Selector Rotary Switch

Protection Circuit

The circuit shown in Figure 7 is the overcurrent protection circuit; relay (RL1) is used to automatically switch on and off the output terminal automatically. T2 is the PNP transistor used to senses the error voltage and triggered the relay on by triggering the gate terminal of SCR1. The 2 ohm resistor R1 controls the maximum operating current. When the voltage across R1 equal or higher than 2V the transistor T2 will turn on, thereby triggering the SCR1 to turn the relay on, and the PB1 is the push button used to reset the supply whenever there is an overload in the power supply.

The output of each power supply protects the system from overload, when the current is more than the power supply rating or the line is being short-circuited. The circuit will automatically shut off and the LED indicator will light indicating that the circuit is overloaded and the system needs to be reset.

The reset button is provided in each line using the normal ON push-button. Pressing this momentarily resets the system back to its normal operation.

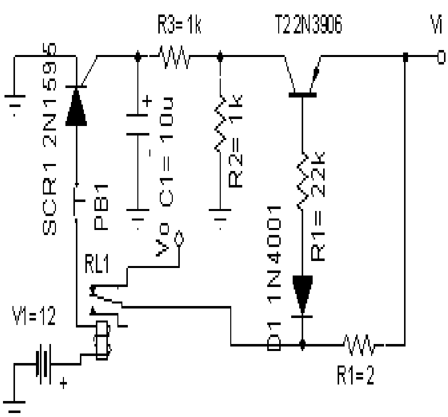

Figure 7. Over-Current Protection Circuit

Result of Voltage Measurement

Data in Table 1 shows that the expected source voltage on the calculated value was 220VAC/60Hz, whereas the actual supply uses to test the instrument were 210.8VAC/60Hz, 211.5VAC/60Hz and 211.3VAC/60Hz on Phase 1, Phase 2 and Phase 3, respectively. These voltages were not constant because voltage depends on the line source voltage. The 220VAC/60Hz was the typical line voltage source and the standard value voltage being used. These voltages were checked before the testing of the secondary output voltage of the connected transformer.

Table 1
Source Voltage Reading

Expected Value per Phase	Measured Value		
	Phase 1	Phase 2	Phase 3
220VAC/60Hz	210.8V	211.5V	211.3V

The expected values per phase reading were 3V, 4.5V, 6V, 9V, and 12V. During the testing, the actual measured values per phase were shown in Table 2 where: for Phase 1, 3.09V, 4.56V, 6.06V, 8.97V, and 11.88V; for Phase 2, 3.07V, 4.58V, 6.08V, 9.01V and 11.95V; and for Phase 3, 3.07V, 4.57V, 6.07V, 8.99V, and 11.92V.

These value voltages were based on the measured source voltage as shown in Table 1. The values of these voltages were not regulated because when the source voltage

changes, the output voltage will also change.
The percent differences are not constant because the values depend on the line source voltage regulation.

The purpose of these measurements is to ensure that all three transformers provide acceptable output voltages.

Table 2
AC Output Voltage Reading

Expected	Measured Value (V)			% Difference		
	Ø1	Ø2	Ø3	Ø 1	Ø2	Ø3
3	3.09	3.07	3.07	-3	-2.33	-2.33
4.5	4.56	4.58	4.57	-1.33	-1.77	-1.55
6	6.06	6.08	6.07	-1	-1.33	-1.16
9	8.97	9.01	8.99	0.33	-0.11	0.11
12	11.88	11.95	11.92	1	0.42	0.66

As shown in Table 3, the expected values for each output voltage were based on the type of IC regulator used in the circuit. The measured value obtained in +5V regulator was 5.04V with a percent difference of –0.8%. For +12V and –12Vthese were 12.03V and –11.87V with a percent difference of –0.25% and 1.08%, respectively.

The results were based on the NO LOAD condition. This value was determined to ensure that the voltage regulator provides an accurate output voltage and to ensure its functionality.

Table 3
DC Output Voltage Reading

Expected Value	Measure Value (V)	% Difference
+5	5.04	–0.8
+12	12.03	–0.25
–12	–11.87	1.08
+1.25→15	+1.25→ 15	–0.24 → 0
–1.25→-15	-1.27→-15.98	-1.44→ 6.53

The expected maximum load current was 1A for both AC and DC as shown in Table 4. But the measured value obtained from this test was approximately 0.6A for AC and 0.7A for DC. The difference of value will not significantly affect the consistency of the power supply. It only shows that the power supply will handle only that amount of the maximum load current. The maximum condition is not determined because it will cause permanent damage to the active component as well as the circuit and system itself. However, the maximum load current can be further achieved by adjusting the value of sensing resistor R1 using the precision resistor.

This substantial percent difference of 40 % and 30% respectively was due to the tolerance of the resistor and during the implementation approximate value of resistor was used rather than the actual calculated value because of its availability in the local supplier. The value of a current of 0.6 A and 0.7A is enough to demonstrate the experiments in the basic electrical and electronics subjects. The experiments will be designed not to exceed this operating current.

Table 4
Current Reading

Maximum Load Current	Expected	Measured	% difference
AC	1A	0.6A	40%
DC	1A	0.7A	30%

Data in Table 5 shows that the expected phase angle per phase is 120^{0}. On the other hand, angle per phase is 116.47^{0}, 121.76^{0}, 116.47^{0} for phase 1, phase 2, and phase 3, respectively. This only shows that the system voltages were balanced and the power supply not contributing changes in the power factor of the supply voltage. The wave form shown in Figure 8, 9 and 10 show that the voltage per phase is approximately balanced.

Table 5
Phase Angle Measurements

Expected Value/Ø	Measured Value		
	Ø1	Ø2	Ø3
120 degrees/Ø	116.47^{0}	121.76^{0}	116.47^{0}

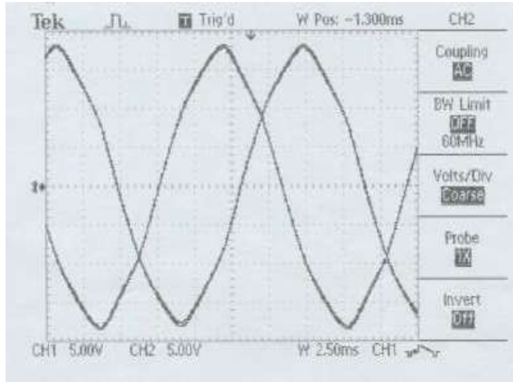

Figure 8. Voltage Waveform of Ø1

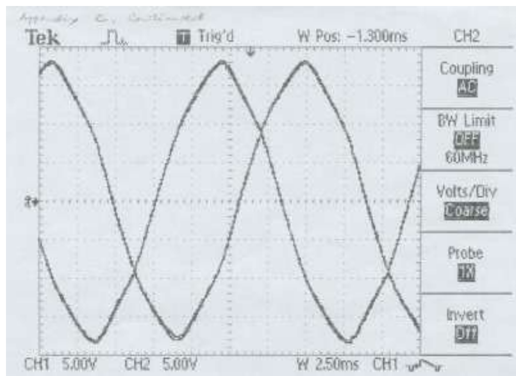

Figure 9. Voltage Waveform of Ø2

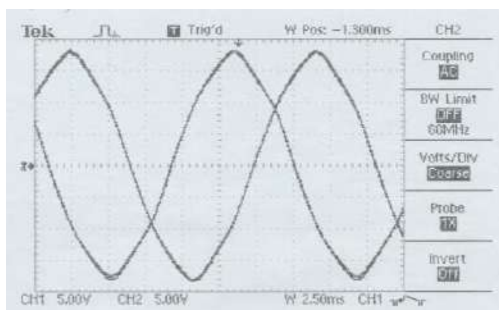

Figure 10. Voltage Waveform of Ø3

Based on the results of the testing and evaluation of the system, the power supply provides acceptable results. The individual circuit component provide an accurate result with an acceptable percent error and also gives reliable response to the varying load current specifically the overcurrent circuit protections.

The circuit was successfully designed and developed using the locally available materials. It is simple and very useful. The power supply can now be mass produced to address the needs of the school, colleges, and universities.

Summary

This study aimed to design, construct, and test the three-phase low voltage variable power supply for Electronics and Electrical Laboratory. Furthermore, the study designs and develops a system basic circuit board, integrating each discrete component, calculate the component values and determine the circuit and active component parameters, test and evaluate the designed circuit, construct the circuit board, and do the final testing and evaluation of the constructed circuit board and the entire system.

The block diagram of the system is composed of eight blocks: the regulated power supply both fixed and variable, the transformer bank with step down voltage from 220 VAC to a variable 3V, 4.5V, 6V, 9V, and 12VAC voltage, the over current circuit protection for both AC and DC, the 220V ac 220VAC 3 phase line, and the low voltage DC and AC output.

The regulated DC power supply design is an IC voltage regulator with variable and fixed output voltage. The output voltage is from 1.25V to 37 V with built-in over current circuit protection, and for fixed IC regulator, the output voltage is being specified based on their rating and the latter has also a built over current circuit protection.

Based on the drawn diagram, the Three-Phase Low Voltage Variable Power Supply was constructed and pre-evaluated at the Electrical and Electronics Laboratory College of Engineering Central Philippine University.

The parameters tested were the phase angle (for AC output voltage only), the AC and DC output voltages, and the maximum load current also, for both DC and AC output. Final testing was done for a week at the Electronics Laboratoryby the students. The power supply functions normally and is reliable by protecting overcurrent and short circuit, therefore being safe for educational use because it utilizes a low voltage with complete overcurrent protections.

The regulated DC power supply has no problem with the variation of the line voltage, because the output is regulated, capable of maintaining the output voltage within a tolerable limit even if the source voltage varies. The load current of 0.6A for AC and 0.7A for DC is more than enough for the required laboratory experiments, because the laboratory experiments were designed for low current (normally from 10mA – 100mA load current). The resulting phases are approximately 120 degrees for each phase, which only shows that the lines are balanced when the power supply was tested.

Conclusion

The design, construction, and evaluation of a three–phase low voltage power supply for the Electronics and Electrical Engineering Laboratory was successfully done using locally available materials, simple circuit design and minimal number of components, therefore making the system more affordable. The integration and the test evaluation of each component was successful with precise results. The construction of the circuit was completed and the final testing and evaluation was also successful, providing accurate results for measurements. The system was also evaluated to use the best circuit option for this design. Furthermore, this power supply meets the needs of the Electronics and Electrical students.

Recommendation

Based on the results of test, it is recommended that the current capability of the power supply be increased. The 2 ohms resistor five Watt connected to the overcurrent protection circuit) will be changed to less than 2 ohms and the transformer bank will be changed to 2 A rating. The load current capability of the power supply normally depends on the rating of the transformer used for AC voltage output and for DC output voltage. The addition of series pass transistor and also the transformer rating must be higher depending on the maximum load current.

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