Modifying and Evaluating A 2HP Rotary Phase Converter for AC Machinery Laboratory Purposes

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Abstract-This paper presents a project modified to present the phase conversion technology and augments laboratory equipment in Don Honorio Ventura State University – Electrical Engineering Department. The proposed study was installed with a Phase Sequence Relay which is important to monitor the phase sequencing of the system and to ensure that phase converter is producing a three phase supply. Voltage and current were measured and recorded using scenarios on which different capacitors were used. The measured voltage unbalance output of the phase converter in this study is 1.30% which is accepted to the standards of the Philippine Distribution Code which has a standard limit of 2.5%, otherwise the three-phase supply is not consistent. This study also serves as an educational model on how three-phase load behaves in an alternative three-phase supply.

Indexed Terms- Phase Converter, Phase Sequence Relay, Three Phase, Capacitor, Voltage Unbalance

I. INTRODUCTION

In a world full of improving technology, the need for better and efficient power sources are being developed to fill in the need. Great population of devices and machines come with a great need of energy to suffice people's consumption. However, this machine comes in different types of phase connections. There are different types of phase connections, which can provide the exact supply for each specific machine like single-phase, two-phase, and poly-phase connection.

The most popular poly-phase connection that is used by grids to transfer power to substations is the three-phase connection. Three-phase system is composed of three wires which have an almost balanced current for each wire and a neutral wire that will pass the fault current on Earth. In economic aspects, three-phase system is more economical than two-phase and single-phase system since it requires less conductor materials to transfer electric power at similar voltage. Generator and motor vibrations are reduced in a three-phase system since the power transfer in to a linear balanced load is constant.

Three-phase system is commonly used as source in operating a three-phase machines and devices. In particular to this, three-phase system is advised to be used for its cheaper, affordable yet it provides a promising performance. In some places, some electric utilities do not provide three phase system connection especially on remote areas. Due to this set up, requesting for a three-phase connection to supply a three-phase powered machine would cost charges given by the utility. Upon realizing this fact, phase converters were invented to aid the need for three-phase connection. According to (PEC) Article 4.55 Rotary-Phase Converter is a device that consists of a rotary transformer and capacitor panel(s) that permits the operation of three-phase loads from a single-phase supply. The most common phase converters are single-phase to three phase converters which will allow a three phase powered machine to operate in a single-phase connection provided by the utility through the help of the phase converter.

Nowadays, phase converters play vital parts especially to a wide variety of commercial and industrial industries in rural areas which have three-phase powered motors but do not have an existing three-phase supply from the utility. Electric companies will not provide three-phase power unless requested by aspecific industry, as it costs

significantly a lot higher than single-phase connection.

Few years ago articles were made to show the cost of requesting a three phase supply from the utility. High powered electric motors invisibly operate with a three-phase electrical service which is seamlessly installed by a power company due to its higher installation cost. The rate for a three-phase electrical service is sometimes often higher than standard residential single-phase electrical service.

Even when it is not used, minimum monthly fee for three-phase service have often charged by electric utilities. Single phase service to three-phase service cost is currently at three hundred fifty to five hundred per linear foot, from the nearest existing three-phase power line in the neighborhood, which may cost much higher and often borne by the customer Anderson(2010). San Fernando Electric Light and Power Company (SFELAPCO) in the year 2002 requested to revise Section 36 of Republic Act No. 9136 and ERC Order dated on October 30, 2001 which is the power rates, with prayer for provisional authority. In lieu with this, SPELAPCO provided its rate with respect to the single-phase and three-phase account initiation charge that have a difference cost range of 80% to 85%.

Having a mind to save for the generation and installation cost, many researchers and invertors provided phase converters several decades ago. A phase converter is a machine that provides a desired phase connection by converting the elements of the electric power of the source into a specific output phase supply. Majority of phase converters are used to produce three-phase electric power from a single-phase supply, thus allowing the operation of the three-phase equipment at places that only has single-phase electrical service. Phase converters are used where three-phase service is not available from the electric company, or is cost a lot higher to install due to a remote location. Some utility will imply a higher charge for a three-phase connection due to extra equipment for transformers, metering, and extra transmission line.

Phase converters have been in used several years ago. Cotanch (1964) introduced the first phase converter in the commercial market. Beginning then, to meet the consumers need, phase converter started to improve. In a broader sense, phase converter is simply a machine that permits the conversion of an m-phase system into an n-phase system.

Different types of converter were introduced in alignment with the improving technology like Ronk and Hertz (1981) proposed a rotary-phase converter that will be supplied through a single phase source and adopted to drive a poly phase electric load. Hogan (1994) developed an “add-phase” converter that adds a phase to the already present single phase with the use of transformers.

Phase converters are also constructed and designed through the use of induction motors like Wales (1994) introduced a rotary-phase converter consisting of a rotating unit and a bank of oil-filled capacitor. The rotating unit will act as a generator, and with the aid of the capacitors it produces a third phase in the third lead. The three-phase converter leads can be then connected by a three-phase motor through a motor starter. Arno (1996) proposed a three-phase induction motor as a phase converter, once an induction motor is started across a single phase line and allowed to run idle, it can serve as a source of three-phase power for additional three phase motors. Smith (1996) introduced the use of three-phase induction motor where in two motor windings are connected into a single-phase supply.

Studies are also made to improve the system of the phase converter. Valdez, Santos, Salangsang, and Quito (2015) developed and provided a phase converter which has a Phase Monitoring Relay so that the evaluation of the phase converter will be more significant through several parameters. Newman Jr.(2009) improved the system of a phase converter by reducing the noise in the motor. A converter than can automatically control the three-phase load and it can also automatically shut down the system upon reaching the required power of the load. Yoshiya Ohnumaand Jun-ichi Itoh (2012) provided a new circuit configuration and a control method for a single-phase to three phase power converter with power decoupling function. This charge circuit leads to obtain an input and output voltages transfer ratio of 0.707. Absorbing power

ripple in converter with frequency that is twice that of the power supply frequently requires large smoothing capacitors. Indirect matrix proposed topology with an active buffer was built for decoupling of power ripple and the buffering energy is being provided by the voltage variation of the capacitor rather than its capacitance.

Studies are made with respect to the output waveform of the phase converter. Cruise, Landy, and McColluch (1999) studied the effect of the harmonic content of the voltage waveform of the reduced topology phase converter on the starting and run up torque of the three phase induction motor with particular reference. And for a few years, Chen, Divan, and Novotny (1992) studied the topology for driving a three-phase motor load from single-phase supply and concluded under steady state condition, a converter with one extra capacitor and balanced voltage output supply can nearly retain its full starting torque during motor starting.

Several studies are also made to reduce the power loss of the phase conversion system. Dabu, Mallari, Olalia, and Tolentino (2018) developed a capacitor bank to reduce the power consumed by a 3/4Hp motor connected into a 1Hp single-phase to three-phase converter. The study showed that by connecting a capacitor in each terminal line before the load will decrease the power consumed by the system. Rotary Phase Converters can be used efficiently with the help of a proper capacitor bank. Dias, Santos, Jacobina, and Da Silva (2009) studied about supplying a three phase motor from single-phase grid using the application of a universal filter configuration. The motor in this study is being supplied with the same frequency from the grid. Initial hypothesis is tested that through the variation of motor phase voltage and through appropriate transformer selection the conversion losses is possible to minimize.

Through the years, idler motors are developed to support the phase converter. Phase converters can be produced using any method cited on the previous pages. However, cost, efficiency, and the power it supplies vary on how the system is designed. The difference of this study to an existing phase converter is that some components have been removed like the forward reverse motor control circuit to make the system simple and to equalize the cost of production even this study tends to increase the maximum load capacity of the system.

According to Valdez, Santos, Salangsang, and Quito (2015) the technology of AC Machinery plays an important role in the field of Electrical Engineering (EE). AC Machinery enhances the knowledge of EE students about the importance of motors in the industry of Electrical Engineering. However, EE students and professors, who tend to use three-phase powered motors for their AC Machinery Laboratory are being held back due to the absence of three-phase supply and to the charges enforced by the utility on changing the supply from a single-phase to three-phase connection. Also, AC Machinery Laboratory students and professors on areas where only 1Hp Rotary Phase

Converter exists are being held back to use a motor that will exceed the maximum load capacity of the phase converter.

This study aims to modify an existing study about rotary single-phase to three-phase converter and evaluate the system in relation to its voltage and current. This rotary phase converter can aid the needs for three-phase power connection of EE students and professors to power a three-phase motor on their AC Machinery Laboratory Exercises and will maximize the power output of a regular household outlet to increase the maximum load capacity it can attain.

Null Hypothesis (H_o)
Thereis nosignificant differencebetween the performance of the load on a single-phaseto three-phase converter supply and three-phase supply.

Thereis no significantcorrelationdifference between the voltage on a single-phase to threephase converter with and without capacitor intervention.

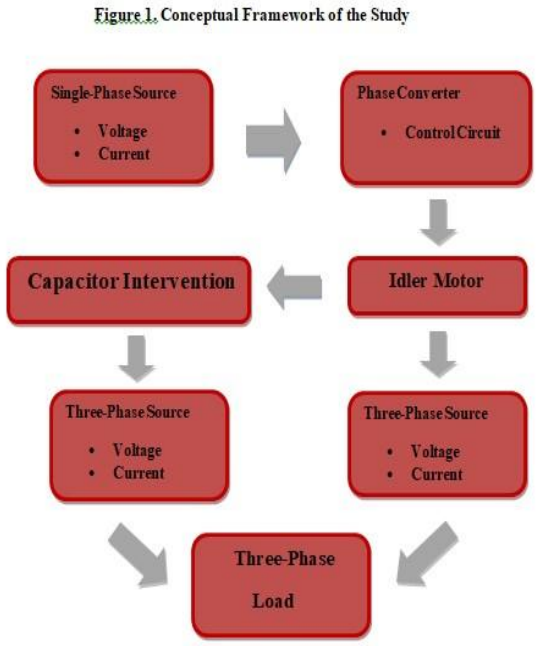
Alternative Hypothesis (H_a)
There is a significant difference between the performance of the load on a single-phase to three-phase converter supply and three-phase supply.

There is a significant correlation difference between the voltage on a single-phase to three phase converter with and without capacitor intervention.

This study will focus on modifying and evaluating a rotary phase converter and produce a maximum of 2Hp three phase supply out of a single-phase supply given by the regular household outlet. This study also tends to enforce specific capacitors on the system that will aid the phase converter on mobilizing a three phase powered load.

Requestingfor athree-phase connection from the utility tends to give the AC Machinery Laboratory students and professors specific charges from the utility. This study will produce a phase converter forthe AC Machinery Laboratory Exercises of the Electrical Engineering Department. This phase converter will save EE students and professors from the charges that may arise on requesting a three-phase connection from the utility.

Figure 1. Conceptual Framework of the Study

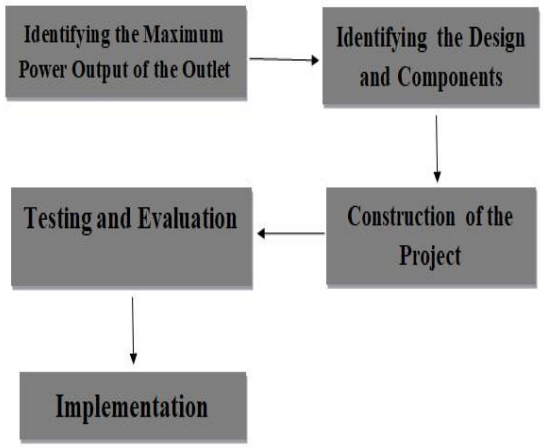


As shown on Figure 1, to produce a three phase-supply from a single-phase supply, a rotary type phase converter with an idler motor and control circuit is needed. Idler motor is an induction motor used to produce a third phase in the third winding that came from a single-phase supply. Phase converter control circuit function is for controlling the operation of the system. The control circuit of the converter was built with the combination of magnetic contactor, overload relay, push buttons, indicator lamps, and phase monitoring relay. Capacitor bank consisting of different rating of capacitors will be added onto the system and can be used efficiently on reducing the phase difference between voltage and current.

II. METHODOLOGY

Referring to Figure 2, single-phase electric power is used to produce three phase electric power locally to run three phase loads. The maximum output of a household convenience outlet will serve as guide in constructing phase converter. A 2Hp idler motor was considered that will serve as the third line of the three-phase supply. Wires, capacitors, and circuit protection ratings were considered to produce a better system. In the construction, wiring diagrams served as guide in proper designing of the project. For testing, phase converter was evaluated with certain cases like no-load and on-load condition, and also voltage and current were checked. Implementation of the project was done after all the testing.

Figure 2. Methodology



I. Identifying the Maximum Power Output of the Outlet

As shown on the Appendix D, the maximum current rating of the outlet is 16A. The system will use a

standard single-phase voltage output of 230V. The proponets obtained that the maximum power is about 3680 watts.

II. Identifying the Design and Components

A. Selection of Idler motor

The study tends to maximize the output power of the single-phase outlet. However, the study will consider some interventions that may occur in producing a rotary phase converter. The maximum output power of the outlet is 3680 watts with a current rating of 16A. The study will use a Single Phase Idler Motor which will not exceed the maximum power rating of the outlet.

Based on the Philippine Electrical Code (PEC) Table section 4.30.14.2 shown in Appendix E, the study identified a maximum of 2Hp single-phase motor rating with a full-load current of 12A which allows a 4A allowance with respect to the maximum current rating of the outlet.

The study will use a different three-phase powered motor(s) which is lower than the rated power of the the phase converter to avoid system failure. Considering that induction motors do have higher starting current than its rated current. Due to the data gathered previously, the study will provide a Rotary Phase Converter using a 2Hp idler motor.

B.Wire Sizing

Wires must be properly sized according to the idler motors full load current.

For power circuit, two sets of wires must be sized in a single motor phase converter installation:

1. The single-phase wires to the supply.
2. The three-phase wires to the motor.

According to Philippine Electrical Code (PEC) Table section 4.30.14.2 and Table section 4.30.14.4 a 2Hp, 230 volts, full-load currents in single-phase alternating-current motor and three-phase alternating-current motor have a full-load current of 12A and 6.8A respectively. Using the formula for the safety factor of motors: minimum ampere rating of phase converter input wires = 1.25 x motor full load current (single-phase motor) for the single-phase wires from the supply to the motor, and minimum ampere rating of motor circuit wire = 1.25 x motor full load current (three-phase motor) for the threephase wires to the motor. The proponents have determined the values of currents, the single-phase wires to the supply and the three-phase wires to the motor have a current of 15A and 8.5A respectively. Therefore; size of wires was 3.5 mm^2

C. Circuit Breaker

Circuit breaker were sized according to maximum ampere rating of phase converter input wires and maximum ampere rating of motor circuit wire.

D. Relays

The study used three types of relays, power relays (magnetic contactor), thermal overload relay, and phase sequence relay. According to National Electrical Manufacturers Association (NEMA) standard contactor for 2Hp motor, proponents used a NEMA 1 magnetic contactor because the maximum capacity horsepower of the said component is 7.5Hp. Its auxiliary contacts will serve as switching tool for the indicator lamp and it will homogenize or balance out changes in electrical frequency which comes from a power supply as well as to act as a safeguard. The thermal overload relay will switch off the system if the motor draws too much current for an extended period of time. The phase sequence relay will protect the loads from improper phase sequence.

E. Capacitors

In this study, running capacitor and starting capacitor ratingarebased according to some trials made by the proponents, based on how balanced the three-phase voltage of the phase converter.

III. CONSTRUCTION OF THE PROJECT

In developing the project, the materials were carefully chosen in the construction of the phase converter. The materials are connected based on the diagrams which show safety devices are placed to ensure the safety of the whole system to malfunction.

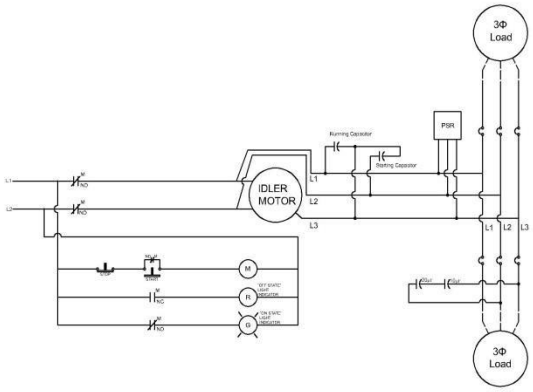


Figure 3. Phase Converter Diagram

IV. TESTING AND EVALUATION

Different parameters where in the phase converter undergoes conditions in which the project was tested include the phase converter at no-load condition and the phase converter with different loads condition including the capacitors to be used and effect of the intervening capacitors. Voltage, current, power, and speed were measured at No-Load Condition. 400uF rated capacitor as a starting capacitor connected to L_2-L_3 and 15uF rated initially running capacitor connected to L_1-L_3

Running capacitors are also evaluated and determined the necessary rating.

Scenario 1: 15uF and 20uF rated at 440V connected to L_1-L_3 and L_2-L_3 (L_{13}& L_{23}) Scenario 2: 15uFand 13.3uF rated at 440V connected to L_1-L_3 and L_2-L_3 (L_{13}& L_{23}) Scenario 3: 15uF and 10uF rated at 440V connected to L_1-L_3 and L_2-L_3 (L_{13}& L_{23}) Scenario 4: 15uF and 8uF rated at 440V connected to L_1-L_3 and L_2-L_3 (L_{13}& L_{23}) Scenario 5: 15uF and 6.67uF rated at 440V connected to L_1-L_3 and L_2-L_3 (L_{13}& L_{23}) Scenario 6: 15uF and 5.7uF rated at 440V connected to L_1-L_3 and L_2-L_3 (L_{13}& L_{23}) Materials that were used in this experiment were:

- Tachometer
- Clamp Meter/Voltmeter and Ammeter
- Multitester
- Wattmeter
- Three-Phase Induction Motor Load (1Hp and 3/4Hp three-phase motor)

Voltage, current, speed, and power were evaluated and compared with other cases and the phase converter performance was evaluated through comparing on the usual three-phase supply. Capacitors were also evaluated to determine the effect of the capacitor in the system.

V. IMPLEMENTATION

This project was implemented for the AC Machinery Laboratory purposes of the Electrical Engineering Department to demonstrate phase conversion in AC Machinery and others, concerning to polyphase connection.

VI. RESULT AND DISCUSSION

Table 1. Condition of Phase Converter Using Different Ratings of Running Capacitors at No-Load Condition

	Supply Voltage	Voltage			Input Current	Current			Speed RPM
		L_1L_2	L_2L_3	L_1L_3		L1	L2	L3	
Scenario 1	235	237	235	258	1.3	1.2	0.6	1	3647
Scenario 2	235	233	234	243	1.0	1	0.8	1.3	3648
Scenario 3	234	236	237	241	0.9	0.9	1	1.4	3648
Scenario 4	234	235	236	240	1.0	0.8	1	1.3	3649
Scenario 5	235	227	228	232	1.1	0.6	0.6	0.7	3647
Scenario 6	234	232	243	230	1.2	1.2	1.1	0.5	3648

Line to line voltages and line currents were measured using a clamp meter with respect to the single-phase supply voltages and input current as shown on Table 1. The capacitor value used during each case provided different effects with respect to the output line voltages and line current of the phase converter. During each case, the idler motor presented a little variation to its speed.

Table 2. Voltage Unbalance on the Phase Converter in each Scenario.

	Voltage			Unbalanced Voltage (%)
	$L_1 L_2$	$L_2 L_3$	$L_1 L_3$	
Scenario 1	237	235	258	6.04%
Scenario 2	233	234	243	2.70%
Scenario 3	236	237	241	1.30%
Scenario 4	235	236	240	1.30%
Scenario 5	227	228	232	1.30%
Scenario 6	232	243	230	3.40%

Table 2 was used to identify what type of capacitor will be used, wherein the voltage unbalance was determined in each scenario. As shown in the accumulated results from Table 2, case 3 to case 5 showed 1.30% voltages unbalance which is accepted in compliance with Philippine Distribution Code's recommendation of 2.5% voltage unbalance. However, case 5 showed the best result with respect to the output line current of the phase converter as shown on Table 1. (Refer to Appendix R for computation).

Table 3. Load Parameters Operating with Phase Converter.

Load	Rating	Voltage(V)			Current (A)			Speed (RPM)
		L_{12}	L_{23}	L_{31}	L_1	L_2	L_3	
Induction Motor	3/4 HP	230	221	224	1.7	1.9	1.8	1798
Induction Motor	1 HP	231	226	220	1.7	1.7	1.8	3596
Induction Motor	1 and 3/4 HP	223	228	232	3.7	3.8	3.7	3600/1799

Table 4. Load Parameters Operating without Phase Converter

Load	Rating	Voltage(V)			Current (A)			Speed (RPM)
		L_{12}	L_{23}	L_{31}	L_1	L_2	L_3	
Induction Motor	3/4 HP	231	231	232	1.7	1.7	1.5	1795
Induction Motor	1 HP	234	233	235	1.5	1.6	1.5	3592
Induction Motor	1 and 3/4 HP	232	234	233	3.3	3.4	3.3	3592/1801

Based on the result shown in Table 3 and Table 4, the voltage, current, and speed can be compared. The line to line voltages produced by the phase converter are somehow unbalanced while the existing three-phase supply line to line voltages are almost balanced.

CONCLUSION

From the data and results acquired in this study, there are several conclusions worth stating. First, the line to line voltages produced by the phase converter are somehow unbalanced while the existing three-phase supply line to line voltages are almost balanced. Second, the capacitor intervention has a great effect on balancing the line to line voltages. Third, the performance of the induction motor when it comes to speed, when it is connected to a three-phase supply and to a phase converter, was almost the same. Lastly, phase converter can be a substitute due to the absence of a three-phase supply in the system.

RECOMMENDATION

Tuning capacitors are very crucial in terms of voltage balancing. However, developing a variable tuning capacitor is recommended for developing this study. It is also recommended for future researchers to study the effect of using a synchronous motor in phase conversion. Further studies dealing with phase converters and their intervention to its power and energy consumption are also recommended.

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