

Design and Development of Autotransformer Motor Starter for Induced Draft Fan (IDF) of Batangas Sugar Central Inc.

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Abstract

Induction motors as a rotating machine draw a higher current during starting operation than under full load running conditions. With the use of reduced voltage, it limits the adverse effect of the starting current and torque that develops during across the line starting. This is in the case of Batangas Sugar Central Inc. (BSCI) where a wye – delta reduced voltage starting method was utilized in the induced draft fan (IDF) motor. Investigation of the present wye – delta starting method was done to identify the behavior of the voltage, current and torque at different stages of the operation to determine the causes of the operational problem. Performance and characteristics of the current in the present method during the switching transition were found to be defective (5 times the rated value) hence, the reason for analysis. In this study, the characteristics of the various starting method for three phases of induction motors were closely observed and comparison of the stated parameters were made in order to develop a proposed autotransformer motor starter prototype to serve as a basis of starting the IDF motor for the BSCI.

Different design requirement based on National Electrical Manufacturers Association (NEMA), Philippine Electrical Code (PEC) and National Electrical Code (NEC) were considered. The voltage, current and torque based on the motor used in the study were computed and the values obtained were compared to the measured value of the parameters using the proposed starting method in order to ensure reliability, accuracy and applicability.

The specification of the autotransformer was computed also based on the actual motor of BSCI and the corresponding values for the input parameters such as voltage, current and torque were then computed and analyzed. The results served as the basis for the BSCI in the implementation of the proposed autotransformer starting method.

The computed value of the different input parameters was supported with the measured values using the autotransformer motor starter since the values obtained were almost equal. It showed that the computed value for the starting voltage was almost the same as the actual value. The same thing was true with the computed values of current at different stages in the operation of the motor where it was concluded to be almost equivalent to the measured value using the prototype.

1. Introduction

Batangas Sugar Central Inc. (BSCI) was incorporated on April 24, 1967 with the central office in Manila and a plant operating office in Balayan, Batangas where the raw sugar plant is located. BSCI is endeavoring to continually improve its process to produce quality products, at accelerated periods at least the possible cost. To achieve that, electric motors worked together on their manufacturing process since they will serve as prime movers for other machines to operate. The operation of those motors is being monitored by personnel to ensure an effective and reliable operation of the motors that will result to the normal operation of the different machines.

Electrical department performs monitoring, check – up and maintenance of the different motors to ascertain the normal operation of the plant. During this period, the motor performance has been analyzed and the different components of the motors were inspected, cleaned, calibrated, repaired or replaced. One of the motors that the department put much emphasis is the Induced Draft Fan (IDF) motors. IDF has a very important function during start – up operation of the plant since it provides fresh air to burn the fuel in the boiler efficiently. Boiler on BSCI utilizes an IDF to pull erosive flue gases from the boiler and force them through the precipitator where fly ash and other materials are removed. IDF also draws the gases through the flue ducting and the combustion air into the furnace. This means that abnormal operation of the IDF will delay the start – up operation of the plant. Therefore, proper operation of the IDF must be maintained.

Induction motor serves as the prime movers for the IDF to operate and the operation of this motor must be properly monitored especially during starting operation. Primarily because the induction motors draw higher current during starting operation rather than in the case under full load condition. Thus, motor is subjected to its most severe service during its starting operation because of high starting current.

The electrical department of BSCI gives emphasis on the reliability and effectiveness of the operation

of the IDF motor because faults occur during starting period. The present starting method for IDF motors is becoming crucial on the safe operation of personnel and equipment as well as in the other part of the plant because during the start – up of the plant, difficulties in starting the IDF motors have been experienced. The primitive starting is jogging or jerking to acquire initial speed and an average of 6 jogging every starting operation is to be made until the motor has enough speed for running operation. This set – up of starting failed when the motor overcurrent protective device tripped during the transition period from wye - start to delta - run.

During this transition, the IDF motor experienced high inrush current of about 1145 A as compared to the normal running current which is equal to 229 A. This means that another delay will happen once the safety device tripped due to the high current during transition period. Re – starting the IDF motor also caused additional power consumption. There were also instances where main circuit breaker had been burned that caused the boiler to be inefficient in its operation. Replacement of the said breaker proved to be costly and could amount to 16,500 pesos.

The IDF motor failure during starting operation was due to the inrush current of about 5 times the full load current that caused for the overload protection to trip that result for the motor to be re – started. Re – starting the motor consumes 45 minutes to one hour stoppage since parameters such as steam pressure, frequency, voltage and current must be established to a certain value. The said failure in starting also caused for the motor to experience its severe service resulting to decrease in its life span. It is also during this phase of operation that light flickers momentarily and the most severe case could lead to the burning of the motor windings due to the high inrush current during transition period. Rewinding of the 190 KW motor of about 342,000 pesos again add up to the losses of the company. The said rewinding will always be accompanied by manpower in uninstalling and reinstalling the motor which normally lasts for about 16 hours.

BSCI produces 4500 tons of sugar per day. One hour stoppage would mean loss of about 187 tons of sugar amounted to 346,000 pesos. The said duration of stoppage also means a loss of 5610 kgs of molasses amounted to 39,270 pesos. Therefore, one hour stoppage would result to a loss of about 385,270 pesos of the product.

The situation is alarming to the company since protection of personnel and machineries is becoming crucial. Such situations also affect the normal operation of the plant which cause losses in part of the company in terms of expected output, repair of the affected area and additional power consumption when re – starting the motor. Action to this particular problem must be dealt with immediately for its effects are not appreciable in the present and future condition of the plant. This is in this light that the design and development of a proposed autotransformer motor starter prototype for Induced Draft Fan of BSCI was conceptualized.

The study aimed to design and develop the autotransformer motor starter prototype for induced draft fan (IDF) of Batangas Sugar Central Inc.

The study focused to evaluate the existing wye – delta switching motor starter used in IDF of Batangas Sugar Central Inc. relative to design, construction, operation, and safety; to present comparative analysis of the various motor starting methods as to the starting voltage, starting current, starting torque and cost; to determine the design requirements and considerations in motor starting from the existing standards or laws such as Philippines Electrical Code (PEC), National Electrical Manufacturers Association (NEMA), National Electrical Code (NEC); to prepare the design for the autotransformer motor starter according to construction layout, circuit diagram, bill of materials and specifications; to fabricate and assemble the prototype for the proposed auto - transformer motor starter; and to perform testing and to discuss results of the developed prototype with regard to starting voltage, starting current, and starting torque.

The study is concerned mainly with designing and developing a prototype of an autotransformer motor starter for IDF of BSCI. It covers the evaluation of the existing wye - delta method of starting in terms of its design, construction, operation and safety as well as the design requirements and considerations based on PEC, NEMA and NEC. The study also describes other methods of starting for comparison purposes. It also considers the design preparations for the autotransformer motor starter. The fabrication and assembly of the proposed autotransformer starter based on the design is an important consideration of the study to test the functionality of the prototype.

The study is intended only for starting the induced draft fan motor because other types of motors need other considerations in starting. The specifications of the components and control especially the autotransformer is for the design and development of the prototype only and is not applicable to the actual set – up of the IDF motors of BSCI because of the high capacity of the actual IDF motor. However the design for higher ratings components and controls especially the auto - transformer necessary for the actual set – up of the IDF motors of BSCI was also presented for future implementation. Since the company is not ready to purchase the needed materials/equipment and components, this study is limited only to the development of the prototype and its control and protection for testing the functionality of the starting method only.

This study does not cover the analysis of fault during running operation of the IDF motor and operation of the other types of motor. The operation of the autotransformer motor starter prototype is limited only to a three phase induction motor, up to 0.75 horsepower and 220 V supply source. It is limited only to the autotransformer type of motor starting and exclude the analysis of other method of starting other than induction motor.

2. Method

To be able to come up to an appropriate design, the study made use of engineering planning and design.

Design Stage

In consideration to the design of the starting method, the researcher did a documentary analysis of the data coming from the company about the starting operation and made an interview to the personnel and staff with regards to the circumstances happened during starting operation. Doing so gave valuable information on the starting operation of the motor. To have a better understanding of the situation, inspection was conducted on the location to observe actual operation, and condition of the IDF motor where the proposed study was planned to apply.

The existing starting method for IDF motors of BSCI that uses wye – delta as the starting method was studied in terms of the different input parameters. Also, the behavior of the current in this starting method was given much emphasis and the requirements of the motors and its components during starting process were also considered. The gathered information on the existing method of starting served as the basis in the design and development of a prototype for the starting method for IDF motors of BSCI.

Other starting method such as autotransformer starting, primary resistance starter and soft starter starting were analyzed to select the most suitable starting method based on the present situation and needs of the IDF motors of BSCI. The most important factors such as the starting current and torque in selecting the method of starting for IDF motors of BSCI were also carefully analyzed. The starting current should be kept low to avoid overheating of the motor and to reduce the excessive voltage drop in the supply network. The starting torque must be about 50 percent to 100 percent more than the expected load torque to ensure that the motor run – up in a reasonable short time. After the evaluation of the existing starting method and careful analysis on the important factors in starting the motors, a design of the starting method was made.

The probable outcome of the design was primarily based on the comprehensive, wide, logical analysis and assessment of factors that affects the reliable operation during starting period. Based on the references, combined technical knowledge and experiences, the design was conceptualized.

Development Stage

After the design of the new starting method, availability of the materials based on the design was carried out. Canvassed of the materials and equipment was done in Batangas City and Cavite City and in Metro Manila. Having no readily available autotransformer to be used in the prototype, a supplier was directly contacted to fabricate the said autotransformer. While other materials/equipment such as motor, relay, contactor, circuit breaker, bulb and others were already available in the market, it also made use of some second hand materials/equipment.

The autotransformer motor starter was fabricated taking into account the behavior of the current during starting and during the switching of motor. This is to ensure that the problem encountered in the existing starting method can be eliminated.

Testing and Evaluation

After developing the prototype, series of testing and modification were done to test its functionality. Behavior of the different parameters such as the voltage, current and torque and the functionalities of the various components/materials were closely observed in the following testing procedures: The three - phase motor and the autotransformer starter was first connected to the 220 V source via terminal blocks located inside the starter. It was followed by switching on the main circuit breaker and the control circuit breaker in which white pilot lamp was energized indicating that the power is available in the control system. The timer was then set to delay the motor in its full load operation.

Pressing the start button placed the motor in starting operation wherein the voltage and current was monitored to ascertain that the actual values were based on the design; the orange pilot lamp was ensured to energize showing that the motor is in its starting operation. After the preset time delay, the motor was placed in its running operation in which the behavior of the voltage was observed to ensure that the motor is not disconnected to the source of voltage during the transition period. Deflection of the current was also monitored to ascertain the elimination of the inrush current which is the cause of the operational problem of the existing

wye – delta method of starting. It was also guaranteed that the run light was energized at this running operation.

It was assured that by pressing the stop and emergency stop button, the starter and the entire circuits were de – energized respectively. For safety purposes, different protective device was tested for its proper functionalities.

3. Results

The testing of the developed prototype was done at BSU – Balayan campus using three phase supply to power the motor. Repeatability test was conducted to determine the reliability and consistency of the autotransformer prototype in compared to the computed values. The following were the results of the testing and evaluation of the developed autotransformer starter prototype in terms of the characteristics of the voltage, current and torque applied to the three – phase, 220V, 0.5 HP motor:

1. Starting Voltage. Measurement of the starting voltage in the developed prototype as presented in table 1 below was found to be approximately equal to 143 V and after preset time delay the voltage shifted to 220 V supply indicating that the motor was in running condition. The said values are approximately equal to the computed values. This is also based on NEMA stating that on the 65 percent tap on autotransformer starting the voltage would reduce to 65 percent of the full voltage.

Table 1
Summary of Results for Voltage, Current and Torque of the
Autotransformer Prototype

Auto - Transformer	Voltage (V)	Current (A)	Torque (lb – ft)
At Instant of Starting	143	4.2	1.2
At Starting period	143	1.0	>1.2
Normal Running Period	220	2.1	2.88

2.Starting Current. The results of testing and evaluation in the starting currents were also summarized in table 1. The current during starting operation using the autotransformer motor starter was computed to be equal to 4.186 A at the instance of starting, 1.0 A during starting operation and 2.1 A during running condition which is nearly equal to the computed values of current in the different phases of operation

3. Starting Torque. Based on the rating of the motor used in prototype as presented in table 1, it was computed that the full load torque is equal to 2.88 lb-ft. Using the autotransformer reduced voltage starting method, starting torque of 2.88 lb-ft using the 65 percent tapping the instance of starting would reduce to 1.2 lb-ft. The said value was based on NEMA stating that the starting torque on autotransformer starting on 65 percent would reduce to 42 percent of the rated torque.

In the case of actual implementation of autotransformer starter in the IDF motor of BSCI, table 6 shows the computed values of the voltage, current and torque in different phases of operations. The starting voltage using autotransformer was computed to be equal to 299 V at 65 percent tap on the 460 V supplied line voltage.

Table 2
Summary of Evaluation for Voltage, Current and Torque of the
Autotransformer Starting in IDF motor of BSCI

Auto - Transformer	Voltage (V)	Current (A)	Torque (lb – ft)
At Instant of Starting	299	481	473
At Starting period	299	96.18	>473
Normal Running Period	460	229	1127

The values of current were computed based on the name plate ratings of the IDF motor. Using the data made by NEMA, 65 percent tap on autotransformer starting would reduce the starting current to 42 percent of the 1145 A current using full voltage starting. With that, the current at the instance of starting would be 481 A and the current at starting operation would be 96.18 A.

Using again the data made by NEMA, it was stated that the starting torque (T_s) of 65 percent tap is reduced to 42 percent of the rated torque (T_r).

$$\begin{aligned} T_r &= 5250 \times \text{HP/RPM} \\ &= 5250 \times 255/1188 \\ &= 1127 \text{ lb-ft} \end{aligned}$$

Using the computed rated torque which is equal to 1127 lb-ft, the starting torque would be reduced from 1127 lb-ft to 473 lbs-ft.

4. Discussion

This study aimed to design and develop an autotransformer motor starter prototype for induced draft fan (IDF) of Batangas Sugar Central Inc. An engineering planning and design type of study was utilized. The existing problem of the wye – delta starting method led to the conceptualization of the project study. Basically, this project study is focused on the design and development of an autotransformer starter prototype to ascertain its functionality. The proposed method of starting is designed to overcome the unsatisfactory conditions of the existing method of starting for the input parameters such as voltage, current and torque.

The project considered the assembly of the different electrical components and other materials for the construction of the control system of the autotransformer prototype. The electrical components consisted of circuit breakers, magnetic contactors, overload relay, pilot lamps, voltmeter, ammeter, relay timer, pushbuttons and terminal blocks. The other materials consisted of the panelboard, cable tray, din rail, tie wires and bolts and knots. The most important equipment in the development is the autotransformer that will use in reduction of the starting voltage.

Circuit Diagrams. Different components and materials were connected based on the circuit diagrams and found to be well functioning as it was designed. The following are the different circuit diagrams used in the development of the autotransformer motor starter prototype. Figure 1 shows power circuit diagram of the proposed autotransformer motor starter prototype in the IDF motor of BSCI.

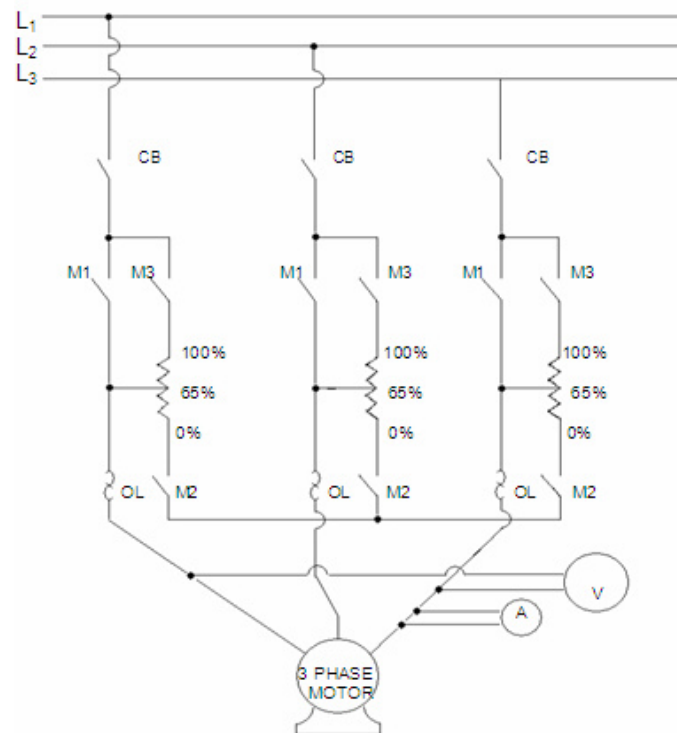


Figure 1
Power Circuit Diagram of Autotransformer Starter

The starter is designed to connect the motor windings on the 65 percent tap on the first step which reduce the starting voltage by 65 percent of the line voltage. The reduced voltage also reduced the starting current and torque by 42 percent of their starting values. After the preset time delay, part of the autotransformer is disconnected to the circuit for normal running operation.

The autotransformer power circuit diagram shown above was being controlled by the control circuit diagram shown in figure 21. The operations of this control circuit diagram were as follows: When the start button is pressed, the M1 and M2 contactor will hold its contacts which made the motor to energize and be placed in its starting operation. The M2 contactor connects the three coil ends of the autotransformer together to form the wye point to reduce the voltage at this stage of operation. The closing of contacts during starting operation is accompanied by a timer to delay the motor in its running operation. As M1 and M2 contactors started the motor, timer starts to count up to the desired settings; it is in this time that the M2 contactor open its contacts as M3 contactor hold its contact placing the motor in the full voltage operation.

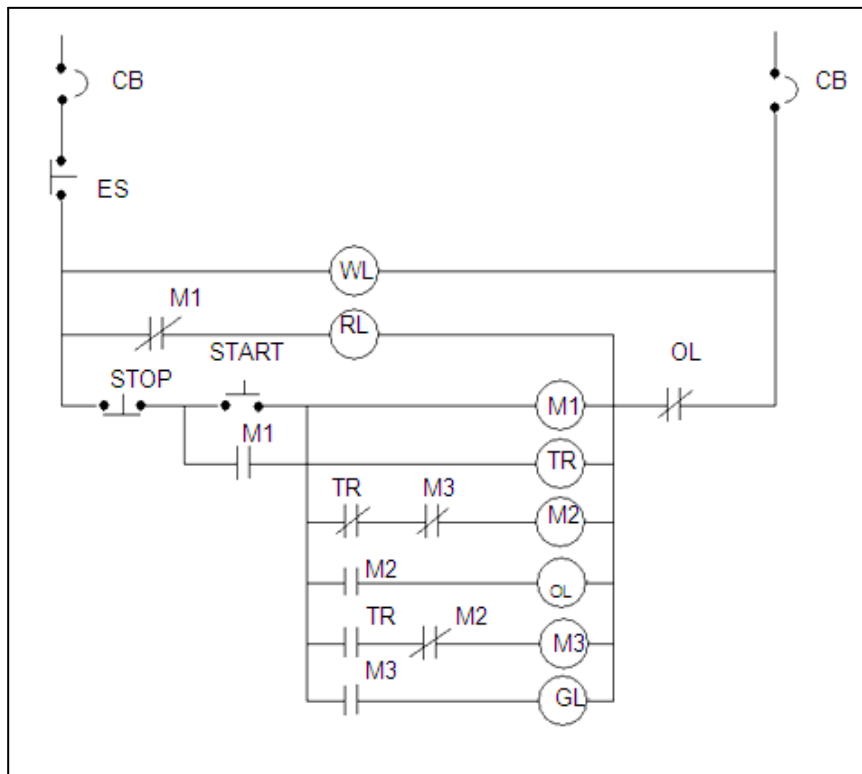


Figure 2
 Control Circuit Diagram of Autotransformer Starter

Legend:

CB	Circuit Breaker	RL	Red Light
ES	Emergency Stop	OL	Overload
WL	White Light	TR	Timer Relay
M1	Magnetic Contactor	YL	Yellow Light
M2		GR	Green Light
M3			

Pressing the stop button will deenergize all contactors and disconnect the motor from the line. The control circuit of the autotransformer starter has also additional contacts intended for start light, run light, stop light and for interlocking.

Autotransformer starter eliminated the open transition which caused surges and transient current which tends the contact of the magnetic contactor to deteriorate and which will cause serious damage later on that lead to breakdown of contacts. It is a closed transition in which the circuit is not interrupted during switching operation because part of the windings of the autotransformer remains in the circuit as a series reactor of the motor windings. The capacity or size of the autotransformer to be connected in the motor and in the circuit diagrams are computed as follows: For the IDF motor of BSCI, the specifications are a 190KW/255Hp, 460V, 229 A, 1188 rpm, design G. This conforms to Siskind (1982), stating that the starting current takes 5 to 7 times of the full load current, so that

$$I_{is} = 229 \text{ A} \times 5 \\ = 1145 \text{ A}$$

Using the data made by NEMA, a 65 percent tapping on autotransformer would reduce the starting current to 42 percent of the starting current using full voltage starting. Therefore,

$$I_{is} = 1145 \text{ A} \times .42 = 481 \text{ A} \\ V_s = 460 \text{ V} \times 0.65 = 299 \text{ V}$$

where I_{is} is the current at the instant of starting and V_s is the voltage during starting period. KVA rating (S) for a three phase autotransformer is equal to

$$S = 1.732 I_{ss} V_s \text{----- equation 1}$$

$$S = 1.732 \times 481 \text{ A} \times 299 \text{ V} = 249,094.508 \text{ VA} \\ = 249.0945 \text{ KVA}$$

So that, based on the computed KVA rating, a three phase 250 KVA autotransformer must be used in the IDF motor of BSCI. Since BSCI is not yet ready to purchase the autotransformer which is the major component of the starting method, another option is looked into to be able to apply the concept of the autotransformer starter in terms of prototyping. A 3phase, 0.37KW or 0.5 HP, 2.1A, 220V, 910 rpm and code letter J are the specifications for the induction motor used in the prototype.

The said specifications conform to NEMA's code letter of the motor, stating that KVA/HP for code J motor ranges from 7.1 to 7.99 KVA/HP, taking the average which is equal to 7.545 KVA/HP. Thus,

$$S = 7.545 \text{ KVA/HP}(0.5 \text{ H}) \\ = 3.7725 \text{ KVA or } 3,772.5 \text{ VA} \\ I_{is} = 3,772.5 \text{ VA} / (220 \text{ V})(1.732) = 9.9 \text{ A.}$$

Using the data made by NEMA using autotransformer starting with 65 percent voltage tapping, resulted to reduced starting current to 42 percent of the starting current which is 9.9 ampere using full voltage starting.

$$I_{is} = 9.9 \times 0.42 = 4.158 \text{ A} \\ V_s = 220 \times 0.65 = 143 \text{ V}$$

Therefore, using equation 1

$$S = (1.732)(143 \text{ V})(4.158 \text{ A}) \\ = 1.03 \text{ KVA.}$$

With that computation, a 3 phase, 1KVA, 220V autotransformer must be used in the development of the prototype.

Figure 3 below shows that with the 65 percent tapping of the autotransformer would reduce the voltage during starting period from 220V to 143 V and starting current would from 9.9 A to 4.158 A. After the preset time delay, part of the windings of the autotransformer on 65 percent tapping would be disconnected to the motor windings for full voltage operation.

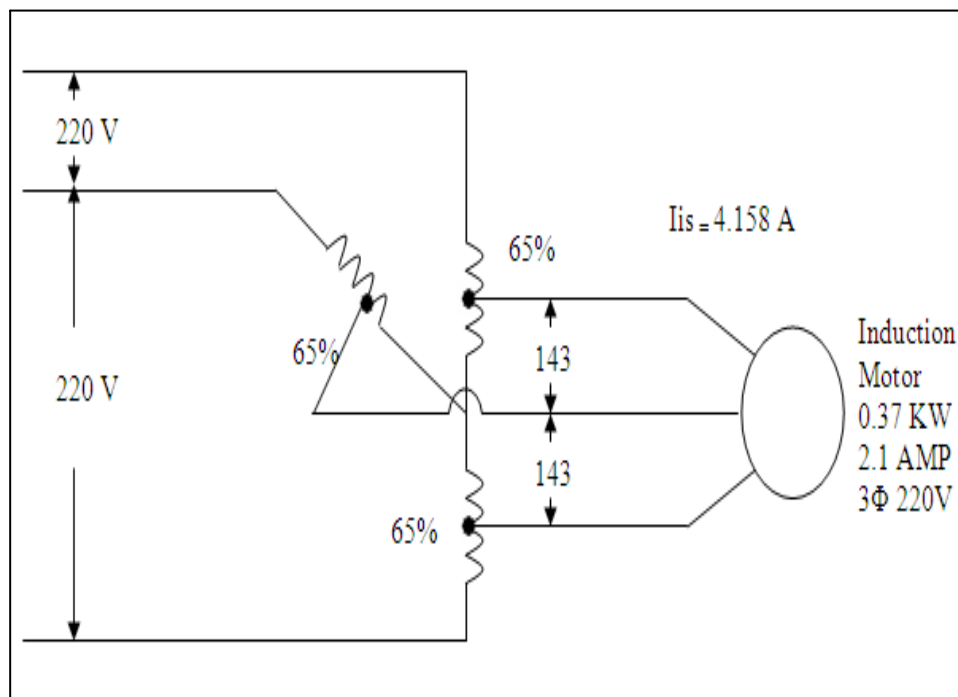


Figure 3
Autotransformer Reduced Voltage Starting

Fabrication and Assembly of the Prototype for the Autotransformer Starter. The developed prototype has four pilot lamps which show the status of operations such as the power light, start light, run light and stop light. It also has an ammeter ranges 0 -110 A which measures the current at starting and running operation of the motor and the voltmeter ranges from 0 - 300 V which measures the voltage during starting and running operation

of motor. The assembly of prototype followed the power and circuit diagrams presented.

The following are the different materials and parts of the prototype with their corresponding function: the pilot lamp which is used as an indicator for the status of the operation of the motor using the autotransformer prototype; the white lamp which indicates whether motor has a power; the red light which shows the stop status of its operation; the orange light which indicates the functioning of the motor under starting operation and the green light which indicates that the motor is functioning under the full voltage operation.

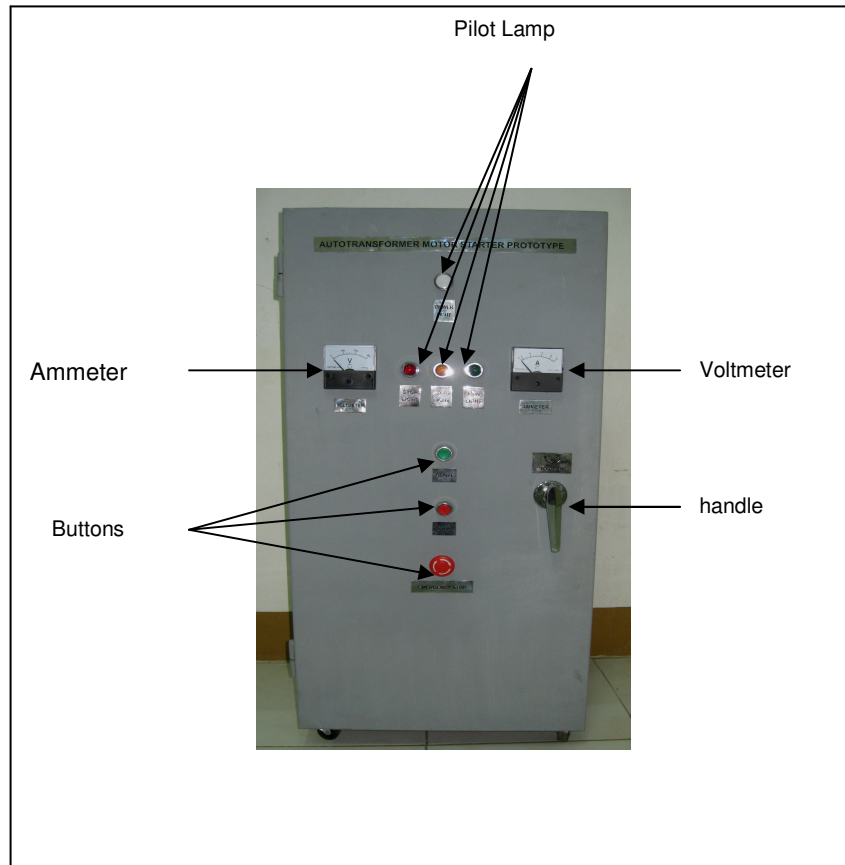


Figure 4
Front Side of the Prototype

The ammeter, on the other hand shows the actual values of motor current at the instant of starting, starting period and running period. The voltmeter shows the actual values of motor voltage during starting and running period of the motor while buttons such as start buttons energizes the components and starts the operation. The stop buttons halted the operation of the motor and the emergency stop button halted also the operation of the motor and de-activated the start push buttons. The handle used to open and close the panel board; it has also a portion in which the board can be locked for safety purposes. Timer delays the run contactor to be energized during starting period and disconnect the start contactor after the pre – set time. The circuit breaker of three poles is used as the protection that disconnect the motor from the supply source once fault occur and the two poles circuit breaker is also used as protection in the control circuit of the motor.

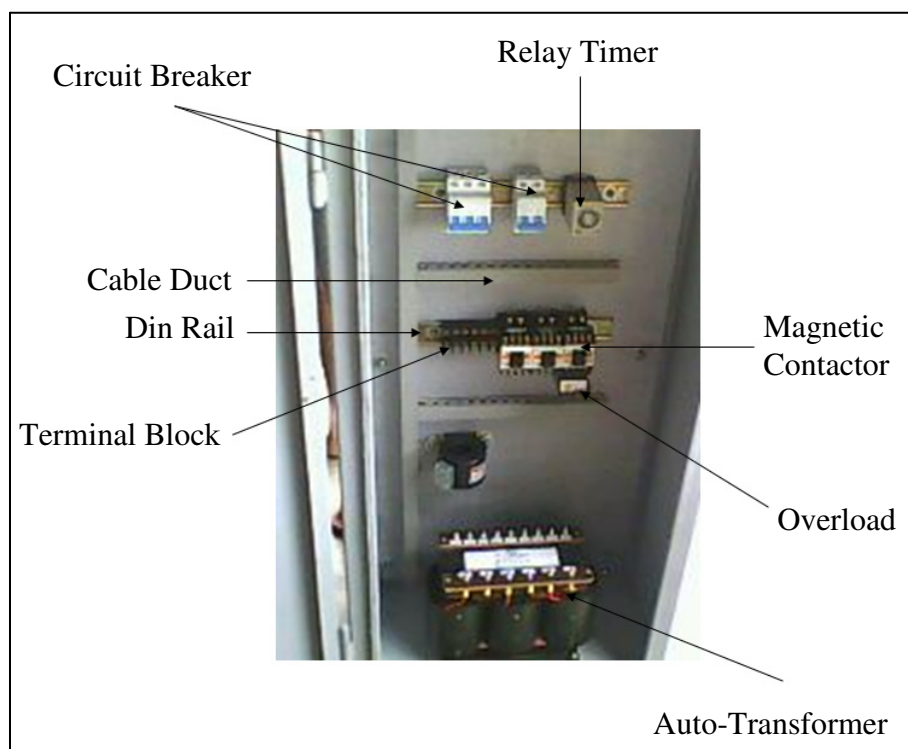


Figure 5
Inside Part of the Prototype

With regards to the cable duct, it is used to carry the wires in the control circuit while the din rail is used to hold the different components such as the timer relay, circuit breakers, terminal blocks and the magnetic contactor in the control circuit. The magnetic contactors are used to connect and disconnect a certain branch of the circuit based on the design process of the control, while a terminal block is used as a connector for the supply source and the motor as the load. The overload relay protects the operation by disconnecting the motor to the circuit the moment it detects the overloading while the autotransformer is used to reduce the voltage during starting operation of the motor. The developed prototype was tested and evaluated for the verification of its functionality. This was done through series of testing in terms of actual measurement of voltage, current. The torque is evaluated in terms of the measured parameters. The value of the voltage, current and torque for the actual set – up of the motor of BSCI were also evaluated and found to have a better characteristics as compared to the existing wye- delta starting method.

5. Findings

The existing wye – delta method of starting for IDF motors of BSCI was evaluated in terms of starting voltage, current and torque. Transition of the motor from starting to running operation was also given an emphasis. The said parameters were also evaluated using the developed autotransformer motor starter prototype. After the development of the prototype, the following findings are drawn:

1. Evaluation of the existing starting method of IDF motors of BSCI.

1.1. Design. The design of present starting method for IDF motors of BSCI was the wye-start, delta-run connection. The starting method is designed to reduce the starting voltage by 58 percent during starting method and reconnect to delta connection to apply the 100 percent supplied voltage to the motor. The said method of starting was also designed to reduce the starting current and torque by 33 percent with respect to their rated values.

1.2. Construction. The starting method was constructed based on the presented power circuit diagrams for wye-delta starting method. The different materials and components were connected based on the control circuit diagrams. The construction follows the standards and requirements of the existing laws.

1.3. Operation. During the operation of the existing method, it is found out that the starting voltage is

reduced by 58 percent with respect to the line voltage. In the case of IDF motors of BSCI, the voltage is reduced from 460 V to 267 V. The current at the instance of starting was 378 A while the current during starting operation was reduced to approximately equal to 76 A which is 33 percent of the current during normal operation. The torque reduced to 33 percent with respect to the rated torque.

1.4. Safety. The high inrush current which was approximately 5 times the rated current is unsafe for the motor. It is also unsafe for the other components because it may result to the malfunctioning of the devices.

2. Comparative analysis of the various starting method.

2.1. Starting Voltage. The autotransformer starting method on 65 percent tap would reduced the voltage by 65 percent of line voltage, the wye-delta method of starting would reduced the voltage by 58 percent of the line voltage, primary resistance and part winding would reduced the starting voltage by 70 percent and 65 percent respectively with respect to the line voltage.

2.2. Starting Current. On 65 percent tap, the autotransformer would reduced the starting current by 42 percent of the current using full voltage starting, 33 percent for wye-delta, 70 percent for primary resistance and 65 percent on part winding starting method all with respect to the full voltage starting.

2.3. Starting Torque. The torque was reduced to 42 percent on autotransformer, 33 percent on wye-delta, 49 percent in primary resistor and 48 percent on part winding starting method with respect to the rated torque.

2.4. Cost. Wye-delta starting method has the least cost while autotransformer has the highest cost of implementation.

3. Design requirements and considerations of motor starting based on existing standards and laws.

3.1. Philippine Electrical Code (PEC). Based on this code, each controller shall be capable of starting, stopping and interrupting the locked – rotor current of the motor. In an autotransformer starter, it shall provide off position, a running position and at least one starting position. It shall be provided by overcurrent protective device located within the motor control center of ampere rating not less than twice the full load current of the motor.

3.2. National Electrical Manufacturers Association (NEMA). According to this association, the use of integer sized contactor, one overload relay per phase and source of external control power is necessary in the operation of the motor and the controller. Starter shall also provide for field installation of up to 3 normally open and 4 normally close interlock in addition to hold in interlock. The stop/start functions shall be controlled automatically with the use of additional relay.

3.3. National Electrical Code (NEC). As stated on this code, the need for circuit protection through the use of fuses or circuit breakers are necessary in the operation to protect the motor and the starter from excessive heat. The protection shall be sized according to the rated carrying capacity of the conductor and of the motor. The ampere rating or setting of the overcurrent protective device shall not exceed to the rating of the common power bus.

4. Design of the Autotransformer Motor Starter Prototype

4.1. Construction. The sized of panel board used in the autotransformer starter was 19.5 x 11.5 x 39.5 inches. The autotransformer also used 3 x 3 inches voltmeter and ammeter for monitoring purposes of voltage and current. Standard size of pilot lamps and push buttons were also used in the prototype.

4.2. Circuit Diagrams. Different components and materials were connected based on the circuit diagrams and found to be well functioning as it was designed.

4.3. Bill of Materials and Specifications. The total amount allotted in the development of the autotransformer motor starter prototype was 17,513.75 pesos.

5. Fabrication and Assembly of the Prototype for the Proposed Autotransformer Starter.

The developed prototype has four pilot lamps which show the status of operations such as the power light, start light, run light and stop light. It also has an ammeter ranges 0 -110 A which measures the current at starting and running operation of the motor and the voltmeter ranges from 0 - 300 V which measures the voltage during starting and running operation of motor. The assembly of prototype followed the power and circuit diagrams presented.

6. Performed Testing on the Prototype Developments

6.1. Starting Voltage. The measured value of starting voltage is approximately equal to the computed

value which is 143 V.

6.2. Starting Current. The measured value of starting current at the instant of starting is approximately equal to computed value which is 4.2 A and measured value at starting period is approximately equal to the computed value which is 1.0 A. The switch transition from starting to running condition is in closed transition that eliminates the occurrence of inrush current of about 9.9 A.

6.3. Starting Torque. The computed values for torque during starting to running operation of the motor was found to be equal to 1.2 lb-ft and 2.88 lb-ft respectively.

Conclusions

Based on the foregoing results, the following conclusions were drawn:

1. The design of the existing method of starting produced the least value of the starting current that result to unreasonable drop of the torque.
2. Autotransformer method of starting provides the highest torque per ampere of the line current as compared to the other method of starting while wye – delta has the least cost in the implementation of the starting method.
3. The design requirements and considerations were based on NEMA, PEC and NEC standards which include ratings of the components, condition and safety of the motor during starting method.
4. The autotransformer motor starter design is based on the circuit plans and layouts. The panel board used is also based on the layout of the different components and materials. The autotransformer starter eliminated the open transition problem encountered in the wye – delta method of starting.
5. The autotransformer motor starter prototype is fabricated and assembled according to good engineering practices.
6. The developed autotransformer motor starter prototype is accurate and reliable. The computed values for the input parameters such as the starting voltage, current and torque are almost equal to the measured values during actual testing of the prototype.

Recommendations

Based on the findings and conclusions of the project study the following recommendations are offered:

1. Application of the method of starting to the actual set – up of the IDF motors of BSCI is recommended to validate the results obtained in the computation and evaluation.
2. It is recommended to use the properly insulated panelboard for safety purposes.
3. On the actual set –up, the use of branded components on the control system is also recommended.
4. Enough space in each component in the panel board is advisable for ease of the wiring and maintenance.
5. Further study in the enhancement of this study is recommended.

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