Design And Construction Of Direct On Line Starter (DOL) For 3-Phase Electric Motor

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***Abstract*— In this paper, the design and construction of direct on line starter (DOL) for 3-phase electric motor is presented. Specifically, the paper presents the sizing of the key components in the power circuit of a typical direct on line (DOL) starter along with the implementation and testing of the DOL starter. Also, mathematical expressions that enable the determination of the values of key component along with the current, the voltage and the power ratings, taking into account the safety factors, component tolerance values and component efficiencies are presented. Notably, the three components are identified in the sizing computations as the Miniature Circuit Breakers (MCB), the starter contactor and the thermal overload relay. The case study DOL starter has the following input parameters values; motor power rating is 4 horse power, voltage is 415 V, power factor is 0.8., the circuit breaker sizing current safety factor is 50%, the 3phase motor efficiency is 90% and the thermal overload relay tolerance factor is 20%. Based on the current value of 7.783795 A obtained from the calculation, a 16A TP MCB and 9A market rated starter contactor are selected for the case study DOL starter. In addition, a 5.5 A to 9 A market rated thermal overload relay is selected since the calculated value current range for the thermal overload relay is 4.612619018 A to 6.918928527 A. The selected components were acquired and used to implement the DOL starter.**

Keywords*— *Direct On Line Starter, 3-Phase Electric Motor, Thermal Overload Relay, Miniature Circuit Breakers, Starter Contactor

1. INTRODUCTION

A direct on line starter, often abbreviated DOL starter is an electrical and electronic circuit composed of electro-mechanical and electronic devices which are employed to start and stop an electric motor [1,2,3]. Regardless of the motor type (AC or DC), the types of starters differ depending on the method of starting the motor [4,5,6]. A DOL starter connects the motor terminals directly to the power supply [7,8]. Hence, the motor is subjected to the full voltage of the power supply, invariably high starting current flows through the motor [7,8,9]. Apart from industrial applications, DOL starters are very useful in starting water pumps, compressors, fans and conveyor belts, among others [10,11].

Given the wide application of DOL in the power industry, it is essential that proper design of the DOL starter is carried out to suit each of the use cases. This requires accurate determination of the DOL components sizes taking into consideration the safety factors, the components efficiencies and the components tolerance values. Accordingly, in this work, the sizing of the DOL circuit components as well as implementation and testing of a DOL starter is presented. Sample case study DOL design is presented for a 4 horse power 3 phase motor.

2. METHODOLOGY

2.1 DESCRIPTION OF THE DIRECT ON LINE (DOL) STARTER CIRCUIT

The essence of this paper is to present the sizing of the key components in the power circuit of a typical direct on line starter for three phase motors and discuss the implemented DOL starter based on the design or components selection. The block diagram of DOL starter adapted from [12] is shown in Figure 1 while a more detailed schematic diagram of the DOL starter for three phase motor, as adapted from [13] is shown in Figure 2.

As shown in Figure 1 and Figure 2, a typical DOL starter has both power circuit (and the main circuit) and the control circuit [14,15]. As shown in Figure 1 and Figure 2, the three key components in the DOL power circuit are the circuit breaker, the contactor and the overload relay. The three components are identified in the sizing computations as the Miniature Circuit Breakers (MCB), the starter contactor and the thermal overload relay. Although the DOL is applicable to both single phase and three phase motors [16], however, in this work, only the three phase DOL starter is considered.

Specifically, in this work, the mathematical expressions that will enable the determination of the values of key component sizes along with the current, voltage and power ratings, taking into account the safety factors, component tolerance values and component efficiencies are presented. Sample design case study is presented and the case study DOL and motor parameter values are determined based on those mathematical expressions presented.

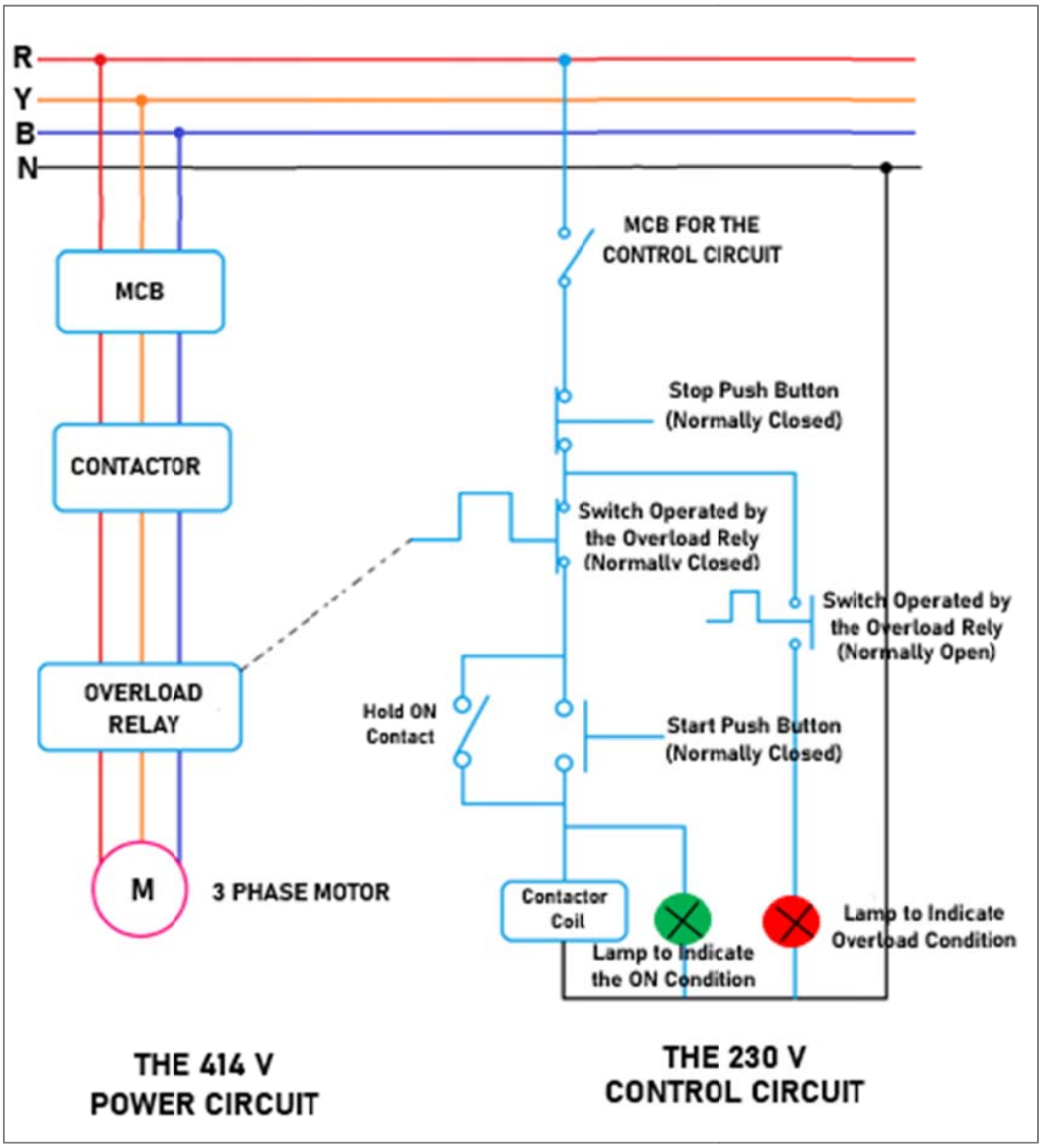

Figure 1 Block diagram of direct on line (DOL) starter

([Source: [13]])

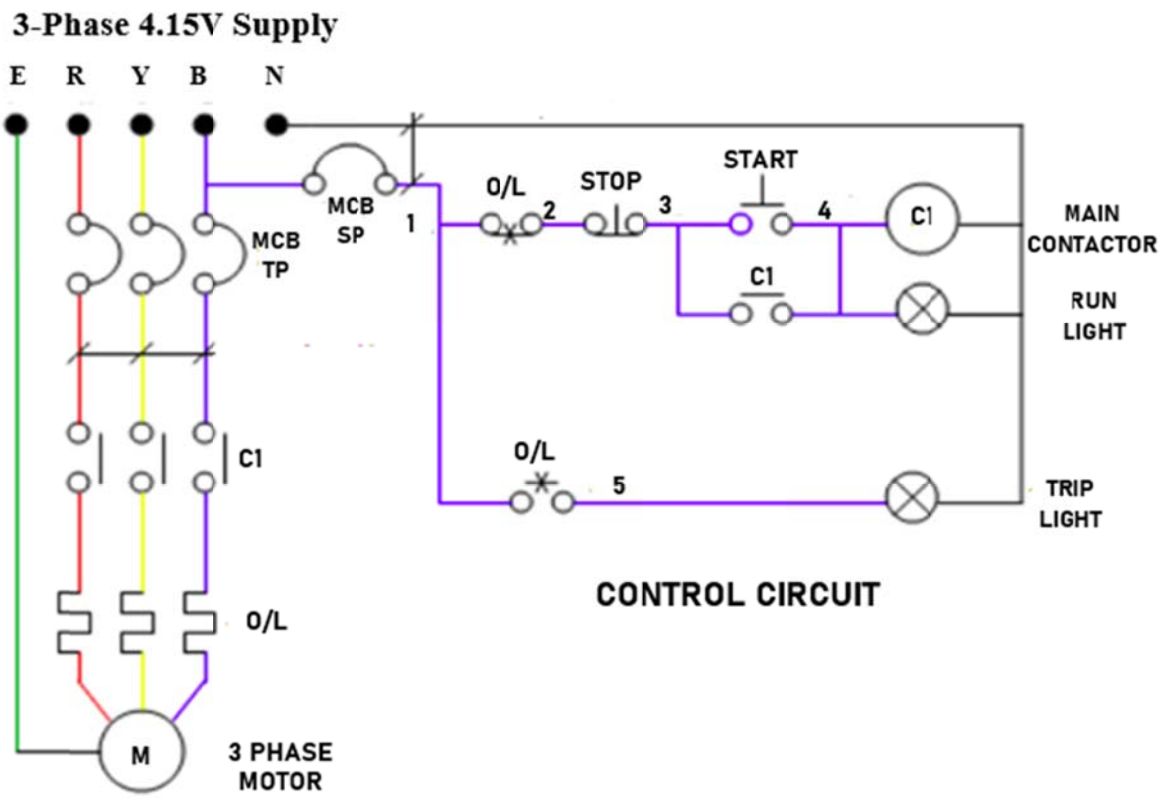

Figure 2 The schematic diagram of direct on line (DOL) starter for three phase motor

(source: [12])

2.2 SIZING OF THE DIRECT ON LINE (DOL) STARTER COMPONENTS

The sizing of the three major components of the DOL starter power circuit is presented in two stages, each of which has an algorithm that specifies the sequence of steps and calculations that are required to obtain the estimates of the components sizes which will help in the selection of the closest component size available in the market which can be selected in respect of the computed component values. The two stages required in the DOL starter power circuit components sizing procedure are;

i. Sizing of the DOL starter circuit breaker and starter contactor
ii. Sizing of the DOL starter thermal overload relay

2.2.1 SIZING OF THE DOL STARTER CIRCUIT BREAKER AND STARTER CONTACTOR

In the DOL starter power circuit, the circuit breaker connects the main supply and the magnetic contactors. On the other hand, the contactor for the DOL is connected between the DOL circuit breaker and the DOL thermal overload protection relay. The steps used for sizing of the DOL circuit breakers and starter contactor are as follows [17]:

Step 1: Read in the 3-phase electric motor size (that is the motor power rating), which may be expressed in horsepower (HP). Express the power rated power in watts.

Step 2: Calculate the 3-phase electric motor full load current (FLC)

Step 3: Account for the safety factor in the FLC obtained in step 2.

Step 4: Select the most suitable circuit breaker based on the available market ratings and the value of the 3 phase motor current obtained in Step 3.

Step 5: Select the most suitable starter contactor based on the available market ratings and the value of the 3 phase motor current obtained in Step 3.

The circuit breaker sizing computation is based on the three phase motor current which is obtained from the equation for the three phase motor power (P_m) expressed in terms of the voltage (V_m), the current (I_m) and the power factor pf as follows [17]:

$$P_m = (\sqrt[2]{3})(V_m)(I_m)(pf) \quad (1)$$

When the motor power is expressed in horse power, (which is denoted as P_{mHP}), it can be converted to power in watt as follows;

$$P_m = (764)(P_{mHP}) \quad (2)$$

The circuit breaker sizing current is determined as follows [17]:

$$I_m = \frac{P_m}{(\sqrt[2]{3})(V_m)(pf)} \quad (3)$$

The circuit breaker sizing current with safety factor, denoted as I_{mCbSf} is given as;

$$I_{\mathrm{mCbSf}} = \left(1 + \frac{SF_{\mathrm{CbCsf}}}{100}\right)(I_{\mathrm{m}}) \quad (4)$$

Where SF_{CbCsf} is the circuit breaker sizing current safety factor expressed in percentage. The case study numerical calculations are performed for the sizing of the DOL starter circuit breaker with the following parameters;

i. The 3 phase motor rating is 4 horse power,
ii. The voltage is 415 V
iii. The power factor is 0.8.
iv. The circuit breaker sizing current safety factor is 50%

Step 1: Given that the 3 phase motor rating is 4 horse power, then, P_{mHP} = 4 HP.

Hence, the motor power in watts is given from Equation 2 as;

$$P_{\mathrm{m}} = (764)(4) = 2984 \text{ W}$$

Step 2: The full load current (FLC), I_{m} is given as;

$$I_{\mathrm{m}} = \frac{2984}{(\sqrt[2]{3})(415)(0.8)} = 5.189196 \text{ A}$$

Step 3: The circuit breaker sizing current with safety factor is given from Equation 4 as;

$$I_{\mathrm{mCbSf}} = \left(1 + \frac{50}{100}\right)(5.189196) = 7.783795 \text{ A}$$

Step 4: Select the most circuit breaker

The closest available circuit breaker rating in the market is the 16 A Miniature Circuit Breakers (MCB) which is designed to carry 3 phase motors with current rating between 6 and 63 A. Thus, the 16 A TP MCB is selected for the case study DOL starter. It is a three phase MCB that trips when the current exceeds 16 A.

Figure 2 The image of the selected 16 A TP MCB

Accessed at https://proteusswitchgear.com/

Step 5: Select the most suitable starter contactor

The two closest available starter contactor rating in the market are 9 A and 12 A. Hence, the 9 A market rated starter contactor is selected since the calculated value is 7.783795 A.

2.2.2 Sizing of the DOL starter thermal overload relay

The thermal overload relay connects the starter contactor and the 3 phase motor. The major function of the thermal overload relay is to protect the 3 phase motor against overvoltage.

The steps used for sizing of the DOL thermal overload relay are as follows [17]:

Step 1: Read in the 3-phase electric motor size, which may be expressed in horsepower (HP). Express the power in watts.

Step 2: Calculate the 3-phase electric motor full load current (FLC) tacking the motor efficiency into consideration.

Step 3: Determine the thermal overload relay current tolerance factor based on the FLC value obtained in step 2.

Step 4: Determine the thermal overload relay current lower limit

Step 5: Determine the thermal overload relay current upper limit

Step 6: Select the most suitable thermal overload relay based on the available market ratings and the value of the current obtained in Step 4 and Step 5.

Again, the case study DOL starter has the following parameters;

i. The 3 phase motor rating is 4 horse power

ii. The voltage is 415 V
iii. The power factor is 0.8.
iv. The circuit breaker sizing current safety factor is 50%
v. The 3phase motor efficiency is 90%
vi. The thermal overload relay tolerance factor is 20%

Step 1: Given that the 3 phase motor rating is 2 horse power, then, P_{mHP} = 4 HP.

Hence, the motor power in watts is given from Equation 2 as;

$$P_{\mathrm{m}} = (764)(4) = 2984 \text{ W}$$

Step 2: The full load current (FLC) considering the motor efficiency, $\eta_{m\%}$ (expressed in percentage) is denoted as I_{meff} and it is given as;

$$I_{\mathrm{meff}} = \frac{I_{\mathrm{m}}}{\left(\frac{\eta_{m\%}}{100}\right)} = \frac{P_{\mathrm{m}}}{\left(\sqrt[2]{3}\right)(V_{\mathrm{m}})(pf)\left(\frac{\eta_{m\%}}{100}\right)} \quad (5)$$

$$I_{\mathrm{meff}} = \frac{2984}{\left(\sqrt[2]{3}\right)(415)(0.8)\left(\frac{\eta_{m\%}}{100}\right)} = 5.765774 \text{ A}$$

Step 3: Determine the thermal overload relay current tolerance factor based on the FLC obtained in step 2.

The thermal overload relay current tolerance factor is denoted as I_{mTorTf} and it is given as;

$$I_{\mathrm{mTorTf}} = \left(\frac{Tf_{\mathrm{Tor}}}{100}\right)(I_{\mathrm{meff}}) \quad (6)$$

Where Tf_{Tor} is the thermal overload relay tolerance factor expressed in percentage.

$$I_{\mathrm{mTorTf}} = \left(\frac{20}{100}\right)(5.765774) = 1.153155 \text{ A}$$

Step 4: Determine the thermal overload relay current lower limit denoted as I_{mTorLW} where

$$I_{\mathrm{mTorLW}} = I_{\mathrm{meff}} - I_{\mathrm{mTorTf}} = I_{\mathrm{meff}} - \left(\frac{Tf_{\mathrm{Tor}}}{100}\right)(I_{\mathrm{meff}}) \quad (7)$$

$$I_{\mathrm{mTorLW}} = 5.765774 - 1.153155 = 4.612619018 \text{ A}$$

Step 5: Determine the thermal overload relay current upper limit denoted as I_{mTorUP}

$$I_{\mathrm{mTorUP}} = 5.765774 + 1.153155 = 6.918928527 \text{ A} \quad (8)$$

Step 6: Select the most suitable thermal overload relay based on the available market ratings and the value of the current obtained in Step 4 and Step 5.

The two closest available thermal overload relay rating in the market are the 4 A to 6 A rating and the 5.5 A to 9 A rating. Hence, the 5.5 A to 9 A market rated thermal overload relay is selected since the calculated value is 4.612619018 A to 6.918928527 A.

3. ASSEMBLING AND TESTING OF THE DOL STARTER

The assembling of the components and materials include the fixing of the cable trunk on the tray with bolt and nuts as well as fixing of the components such as MCCB, MCB, Electromagnetic contactor and set of connectors on the cable rail. This was done properly and tested before wiring to ensure the step-by-step construction of the starter.

Mounting of the components and wiring includes fixing of the emergency switch, selector switch, start and stop push button switch, indicator lights were properly arranged on the top cover of the panel. This consists of the control circuit while the main circuit components were mounted on the inside of the panel as the wiring was connected to both the main circuit and the control circuit down to the supply for testing.

The picture of the components and materials mounted on the panel tray is shown in Figure 3. The picture of the DOL starter after the completion of the wiring of the main circuit and the control circuit is shown in Figure 4. Again, the Picture of the DOL starter showing the various push buttons and indicator lights after the completion of the wiring of the main circuit and the control circuit is shown in Figure 5.

At the final completion of all the stages of construction, the testing of the starter was carried out by connecting the three phase 415 V power supply with neutral for the single phase was connected to the panel. The earth was also connected to the ground of the motor. Finally, the three phase supply was connected through the thermal overload relay three lines to the motor and the motor starts by pressing the start push button switch to energies the main contactor that passes the supply to the electric motor.

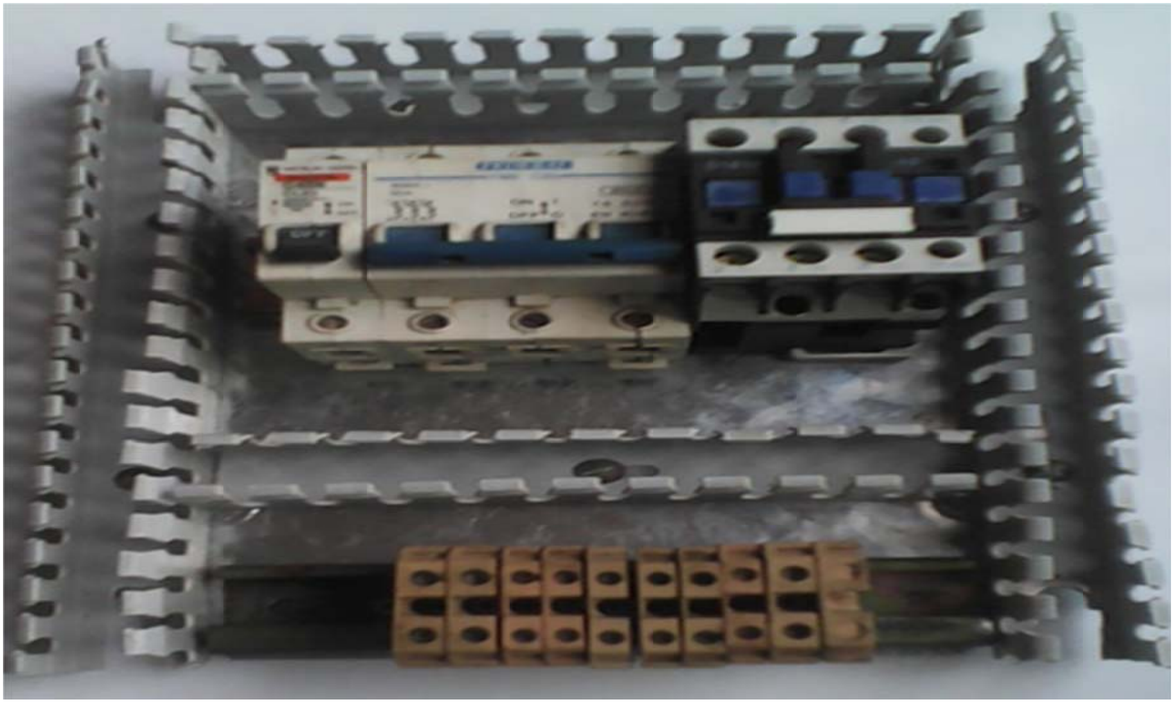

Figure 3 Picture of the components and materials mounted on the panel tray

Figure 4 Picture of the DOL starter after the completion of the wiring of the main circuit and the control circuit.

Figure 5 Picture of the DOL starter showing the various push buttons and indictor lights after the completion of the wiring of the main circuit and the control circuit.

4. CONCLUSION

The sizing of the key components of direct online starter for three phase motor is presented. The study focused on the components of the power circuit of the DOL starter and presented the mathematical equations for calculating the parameter values for those components. The calculated values were used in the selection of available components in the markets. After the design calculations and procurement of the best suits available complements for the DOL starter design, the components were assembled and tested to validate the prototype design.

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