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Inrush Current Measurement in the Water Pumping Station

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Abstract

Municipal water pumps use an induction motor with a Fluke 434-II power quality analyzer to measure inrush current. To pump water from the river to the reserve tank, they use two parallel 120 HP motor pumps and two parallel 180 HP motor pumps to deliver water from the reserve tank to overhead tanks distributed across the municipal areas. Four control panels equipped with soft starters supply the motors. The soft starters' purpose is to limit the motors' inrush (starting) current, thereby reducing the electrical and mechanical stresses on the motors and pumps. The supplier is commissioning the entire new system. The measurement revealed that the transformer's HT fuse tends to blow when a 180 HP motor starts, and a 120 HP motor is running. We also observed that this does not happen when a 180 HP motor runs, and a 120 HP motor starts. According to its nameplate, the transformer can supply the required current. We present the test results that demonstrate these issues.

Keywords: Fluke 434-II Power Quality Analyzer, Induction Motor, Inrush Current.

Introduction

Connecting a polyphase squirrel-cage induction motor straight to an AC supply. The motor requires a significant current draw before it can reach its operational speed (1, 2). The "inrush current" phenomenon is frequently reported to be significantly more critical than the rated current. During the start-up phase, varying degrees of transient torques are often present in addition to this enormous current. The duration of the early stage in a specific application is influenced by the inertia of the motor and load and the torque-speed characteristic of the load (3, 4). The duration of start-up transients can range from milliseconds to seconds. This varies according to several factors, including the motor's size and the load's inertia. Power loss at high current levels leads the motor to start with considerable pressure and torque changes and a quick temperature rise (5, 6). The increased initial current during the start phase can cause a drop in voltage levels in neighbouring segments of the electrical grid (7, 8). This circumstance could cause additional system components to malfunction or, in the worst-case scenario, to activate the motors safeguard systems. The user's text is already written academically and does not require further modification (9, 10). When starting up high-inertia applications like centrifuges, hammer mills, or huge fans, any methods are used to reduce the current draw. Reduced current conditions are required to ease the strain on the motor and the related mechanical system, as well as to lessen the load on the electrical system and prevent power company fines. But this decrease in beginning current also results in a comparable reduction in the motor's starting torque. For this study, beginning torque is defined as the typical torque the motor can produce to accelerate the load. Longer acceleration times and the possibility for more heating during start-up are both caused by this drop in torque. This study compares each starting method for temperature rise, acceleration time, and economic factors. In the study, Majka *et al.*, (11) stated that soft starters and variable-frequency drives (VFDs) function and considered the "conventional" starting methods. In some cases, the amplitude of inrush currents might grow by a factor of ten compared to the system's power. This assumption still holds for lighting systems, power supply units, and induction motors, among other electrical demands (12). The load's physical design affects the inrush's type and features. Using machine

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learning techniques, load transients can be used as a "fingerprint" to identify loads and load pathologies (13, 14). Due to their advantages, such as excellent reliability, durability, and economy, Sensorless induction motor (IM) drives are widely utilized in industry. The majority of these drives have been tuned to operate at zero speed. Temporary power outages frequently happen in the grid, causing the drive to trip and necessitating stopping the motor before restarting it. To get around this problem, a rotor speed calculation is required for bump-free restarting of the IM (15). Techniques like the Taylor-Fourier method can analyze inrush current measurements at a station to assess harmonic content and mitigate potential operational issues (16). A phase-controlled switch incorporates existing line impedance for realistic and accurate results and can effectively conduct inrush current measurements in a water pumping station (17).

Gobichettipalayam Water Treatment Plant

The system has 100% redundancy. Figure 1 explains the Pumping station is installed with two 500KVA transformers. The voltage rating of the Transformer is 11KV/415V, and the specifications are shown in Table 1. This water treatment plant currently has two 120HP raw water pumps. The pumps are used alternately, i.e., 12 hours/shift daily, to pump the raw water from the natural water well to the treatment plant. Then, the processed water is collected and stored in a clear water sump at a 100-meter distance through gravity. Then, any one of the 180HP pumps is used to take water from the clear water sump to 10 overhead tanks in the Municipality at 10 km distance. Previously, this station consisted of 2 × 50HP pumps, 2 × 20 HP submersible pumps, and 1 number of 30 HP submersible pumps at the raw water well. Clearwater sump is operated by 2 × 50 HP pumps (scheme 1), one 75 HP and one 100 HP pumps (scheme 2), and 2 × 75 HP pumps (scheme 3). Due to increased water demand, the scheme is now being upgraded with 120 HP and 180 HP pumps with soft starters.

Methodology

Single Line Diagram of Electrical Distribution System

Figure 2 shows that the system is supplied from alternately two 500KVA transformers, the specifications of transformer and motor are shown in Table 1 and 2. The voltage rating of the transformers is 11KV/415V. The output of the Transformer is connected to the Air Circuit Breaker (ACB) in the medium voltage panel. After the ACB, the following loads are connected in parallel

- 200KVAr capacitor banks
- 2 ×120HP motor
- 2 ×180HP motor
- 1×100HP motor
- 1x75HP motor
- 1x 50HP motor
- 3KVA Lighting loads.

Table 1: Transformer Specifications

S.No.	Make	Transformer Name Plate ID	Power Rating	PF (cosϕ)	Year of Mfg
1.	Kirloskar Electric Co. Ltd	Sl.No.ID 501 / 581	500 KVA	0.8	Sep-2012

Table 2: Motor Specifications

S.No.	Make	Motor Name Plate ID	HP	V_{nom} (V)	I_{nom}(A)	PF (cosϕ)
1	ABB	3G1J20300001843125	120	415	158	0.84
2	ABB	3G2J20410090098613	180	415	228	0.85

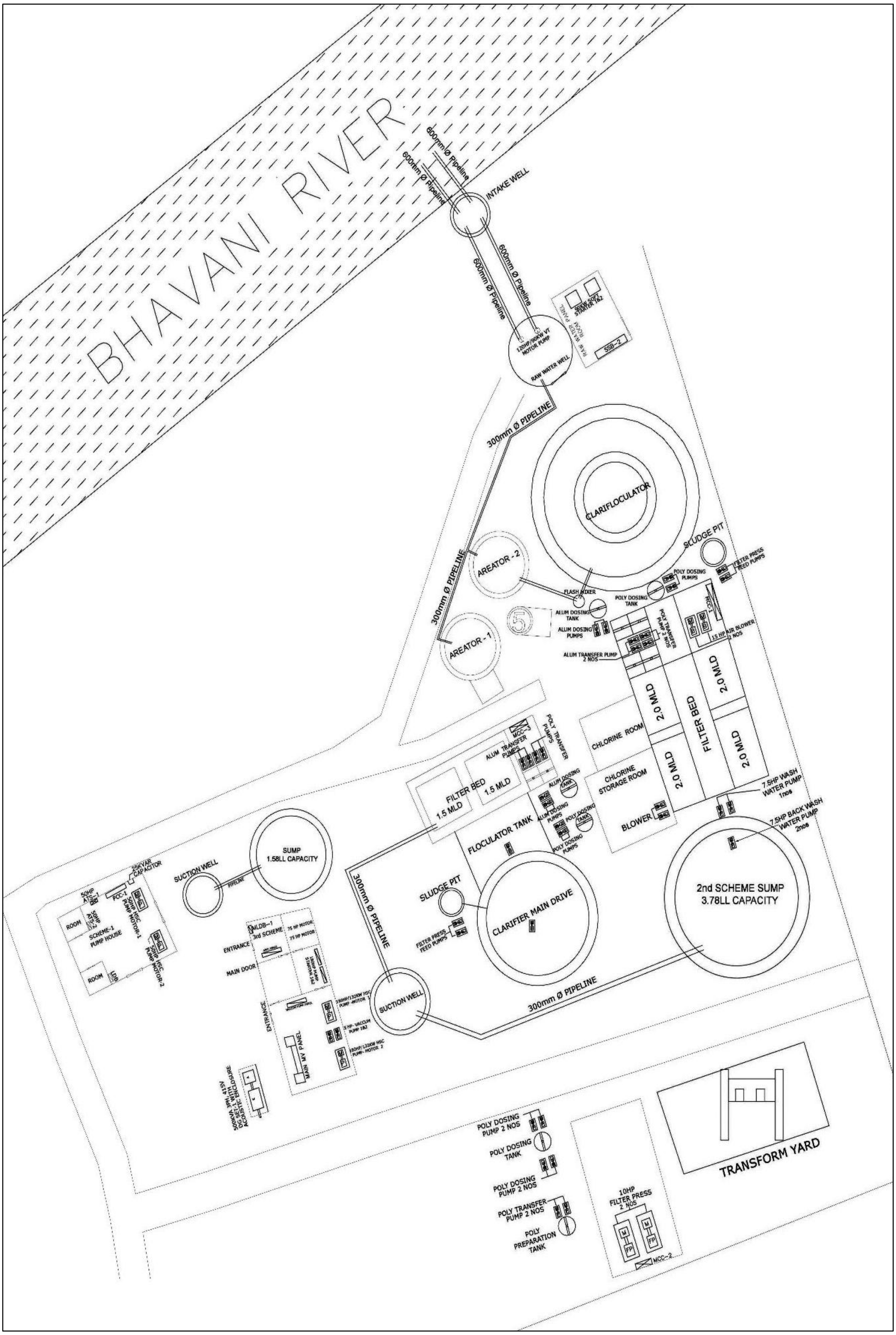

Figure 1: Gobichetipalayam Water Treatment Plant - Layout Diagram

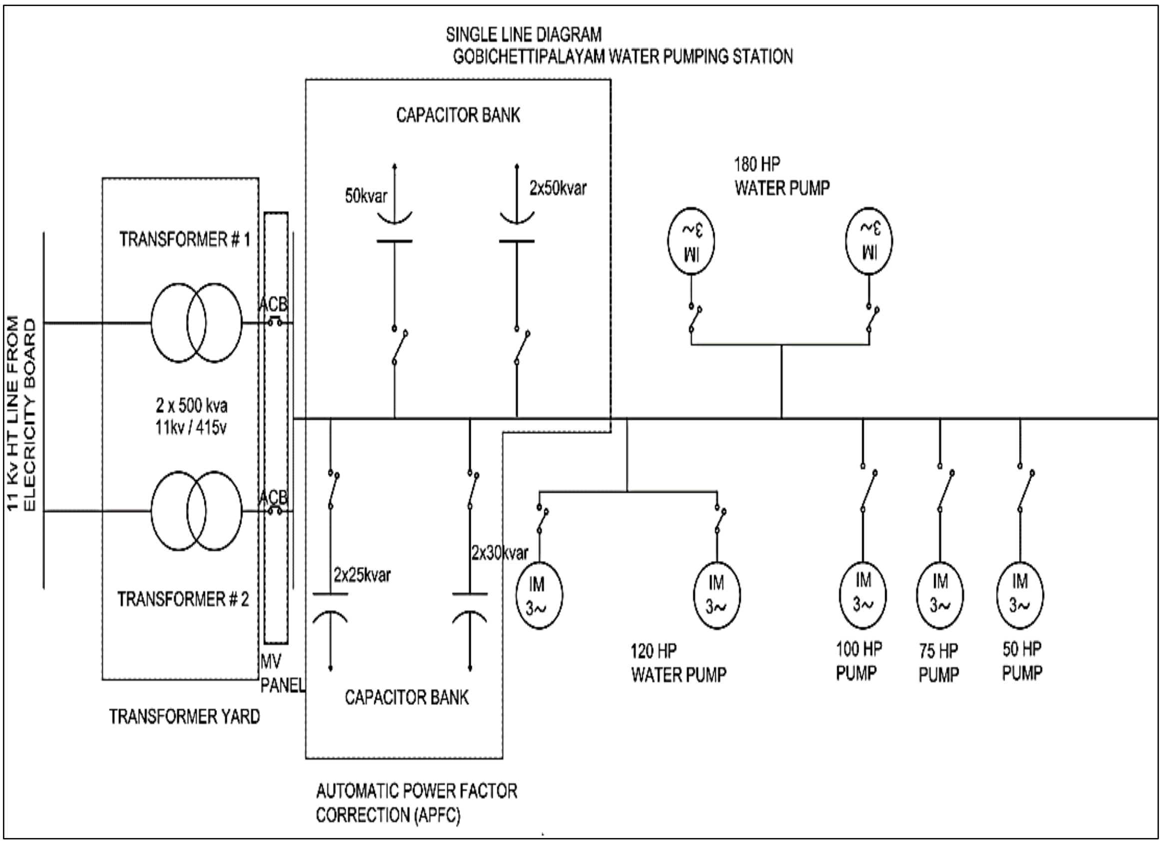

Figure 2: Single Line Diagram of Water Treatment Plant

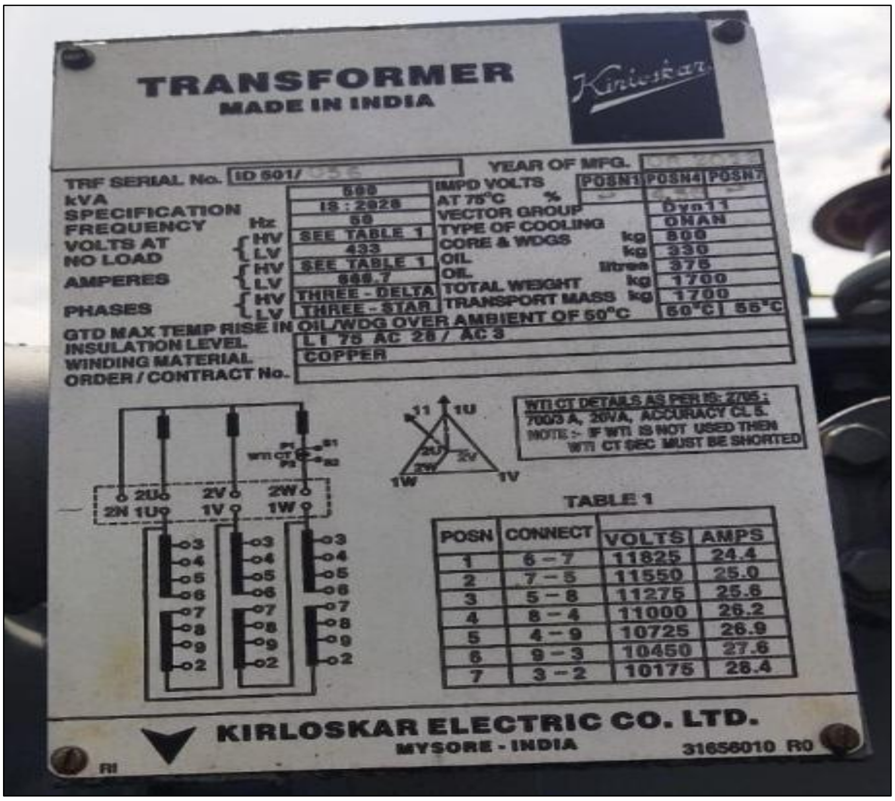

Figure 3: Name Plate Details of 500 KVA Transformer (18)

Figure 4: Name Plate Details of 120HP Pump (19)

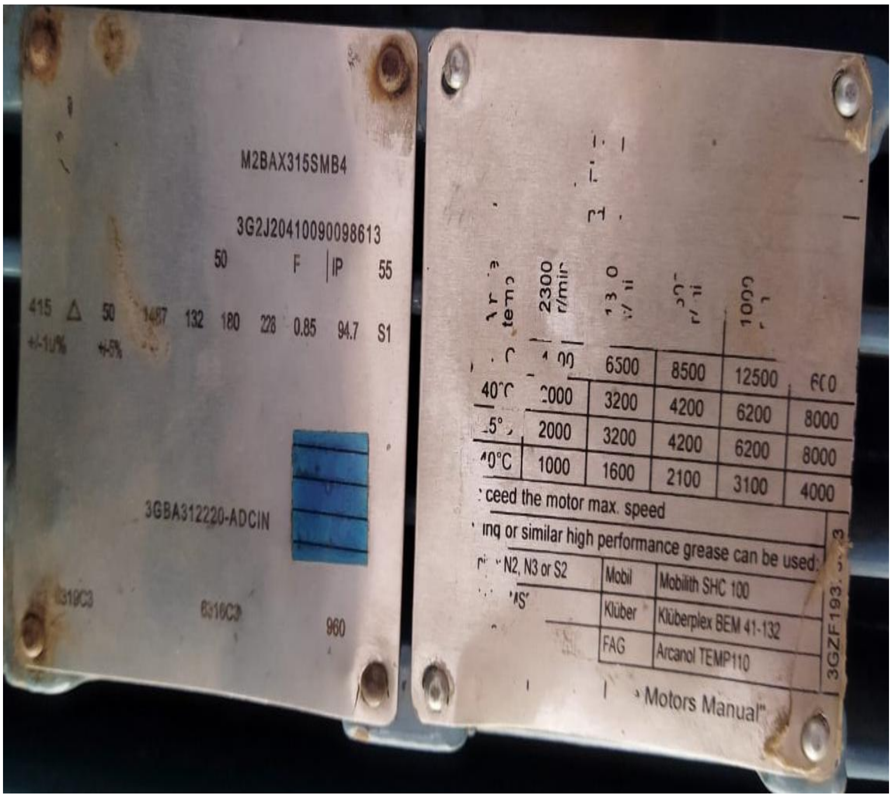

Figure 5: Name Plate Details of 180HP Pump (19)

Figure 3 shows the nameplate details of 500 kVA transformers. Figure 3 shows the nameplate details of 500 kVA transformers. The Kirloskar 3-Phase 500kVA Oil Cooled OCTC Distribution Transformer can handle 500kVA of power, works at a voltage ratio of 11kV/433kV, and cools itself with oil (18). Figure 4 shows the nameplate details of the 120 HP pump. The ABB Motor IE3 is a high-efficiency 90 kW (120 HP) induction motor designed to deliver outstanding performance and energy savings for industrial applications. With a voltage rating of 415 V and a 2 pole/3000 rpm configuration, this motor is ideal for high-speed applications that require precision and reliability (20). Figure 5 shows the nameplate details of the 180 HP pump. The Kirloskar 3-Phase 500kVA Oil Cooled OCTC Distribution Transformer can handle 500kVA of power, works at a voltage ratio of 11kV/433kV, and cools itself with oil (19).

Power Quality Analyzer Fluke 434-II

Using a phase-controlled switch makes it easier to get a good idea of the line impedance during inrush current testing in a water pumping station. This helps check the power supply's performance, set the correct fuse values, and improve power quality measurements (20). A power quality analyzer can quantify the inrush current in electrical systems or motors experiencing a sudden surge in current consumption when evaluating them. Inrush current is the peak instantaneous current that an electrical device can draw upon initial activation. Exceeding the device's nominal or operational current is feasible.

The Fluke 434-II Power Quality Analyzer evaluates power quality, trends, and energy loss in single-phase and three-phase power systems. It can measure AC/DC ranges up to 6,000 MW and executes functions such as power factor, harmonics, watts, voltages, and current. The dimensions of the Li-ion battery, LCD screen, and total size are 127 x 88 mm. Its support enables discovering, anticipating, preventing, and resolving power quality issues. The Analyzer provides a comprehensive and dependable collection of measurements for assessing the effectiveness of a power distribution network. Some give a comprehensive overview of the efficacy of power systems. Certain people are compensated for paying great attention to specific details. The Fluke 434-II Power Quality Analyzer provides an input voltage accuracy of 0.1% in compliance with IEC61000-4-30 2003 Class A requirements, as shown in Figure 6. This device also has adjustable current limitations, power log software, a larger memory capacity for data logging, mains signalling functions, and logging capabilities.

General Measurements

Voltage lines and current resistors can be evaluated for operational functionality using Scope Waveform and Scope Phasor. The arrows on the clamps identify the signal's directional orientation. A tracking system can determine the efficacy level at which an energy system is used. When you push the MONITOR button, a screen with bar graphs displaying the quality of the phase voltages appears. To visually indicate whether or not the significant factor is inside the permitted range, the color of the bar graph changes from green to red. The Fluke 434-II has seven alternative methods for setting boundaries, allowing the user to choose the best method for the situation. A significant percentage of them are accessible to forethought. The EN50160 standard defines a set of requirements. Users can access more information about each quality-related choice using the F1-F5 function keys. The numerical values of Volts, Amps, and Hertz are designated. To access this feature, press the MENU button. On a meter screen, please pick Volts, Amps, and Hertz to examine phase voltages, currents, frequencies, and crest factors. Once you have decided, press the F5-OK button. By pressing F5 and selecting the TREND option, you can see the time evolution of these numerical values. Figure 7 shows the setup version and calibration of the FLUKE 434-II Instrument used for the inrush current measurement; the serial number and calibration dates are mentioned.

Examining and Evaluating Methods

Phase voltages

Current conditions appear close to meeting the required standards. Voltage waveforms should have a sinusoidal pattern with no peaks or troughs. Using the oscilloscope's waveform, examine the waveform's shape.

Figure 6: Power Quality Analyzer FLUKE 434-II (20)

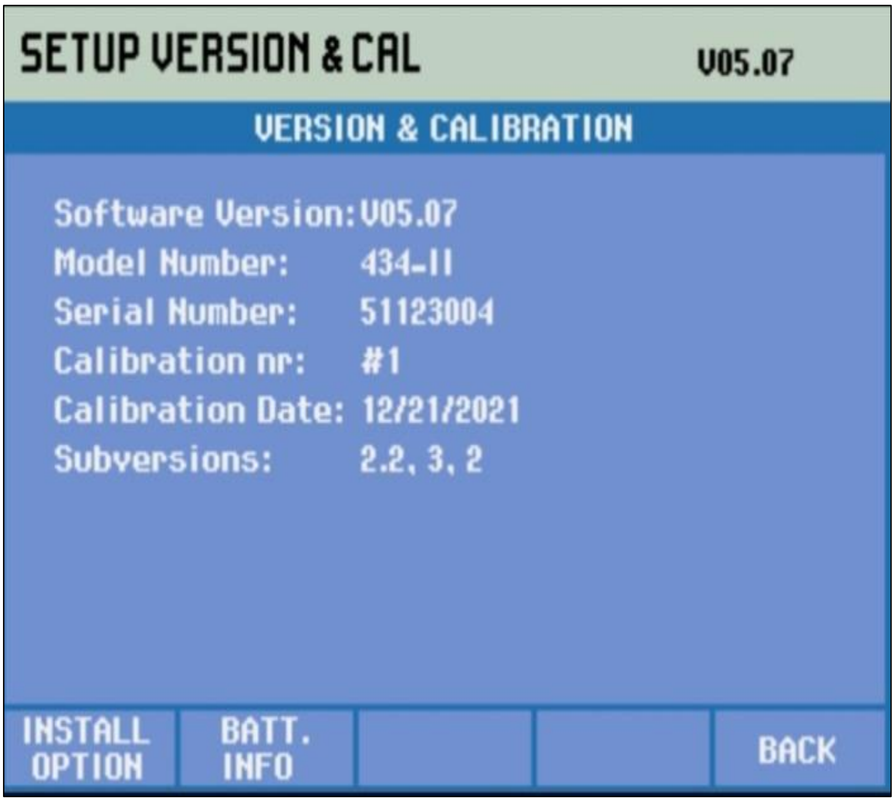

Figure 7: PQA Setup- Version and Calibration (20)

Phase Currents

The V/A/Hz notation measures current and voltage, but the Dips and Swells notation shows how these numbers interact. Inrush current happens when there is a sudden surge in electrical current, usually when a motor is turned on.

Crest Factor

When the Crest Factor exceeds 1.8, the pattern is considerably skewed. Determine departures from linearity using the waveform. These quantities are determined using Total Harmonic Distortion (THD) and harmonics mode.

Harmonics

The harmonics mode analyses voltage and current harmonics and calculates total harmonic distortion (THD) for each phase. The trend method tracks the evolution of harmonics over time.

Flicker

This method explores voltage fluctuation phenomena across short and long periods per phase. Trends enable the tracking of these empirical observations across time.

Dips and Swells

The device captures voltage changes that last approximately half a cycle.

Frequency

The given solution should strictly correspond to the specifications—the great frequency, most of the time. The frequency is displayed in volts, amperes, and hertz. The Trend panel depicts the temporal evolution of the numerical value graphically.

Unbalance

The mean values of the three phases should differ by no more than 1%. At this point, the gap must be at most 10%. This difference between the Unbalance mode and the Scope Phasor can be investigated.

Mains Signaling

The strength of the signal sent by a remote-control device, which frequently indicates the presence of a power grid, can be quantified.

Logger

This can save several measurements with high precision in a vast memory space.

Measurement of the Inrush Current of Motor

Peak currents can be detected with the Fluke 434-II. Inrush current is an electrical phenomenon that happens when a high or low-impedance load is connected, resulting in a sudden current surge. The current gradually approaches a steady state after the load reaches its normal condition. For example, the initial current required to start an induction motor may be ten times greater than the steady-state current necessary for typical operation. The "inrush" phenomenon defines the sudden voltage and current changes due to a precipitating event. An event occurs when the present wave's shape surpasses the limitations it can adjust. The image advances from the display's right edge to the top. Knowing about events that occurred before a sudden surge is feasible by utilizing a pre-triggering organization.

Inrush Trend Display Set Up in PQA - Fluke 434-II

Figures 8 and 9 show how arrow keys on a computer interface can change trigger limitations such as expected inrush time, nominal current, threshold, and hysteresis. The parameters for assessing inrush current on a power quality tester are essential for precise data collection and analysis. A power quality analyzer can observe and record inrush currents to guarantee that systems are secure and operational. This is enabled via diverse reporting options, user-friendly interfaces, and dependable measurement instruments. The maximum current determines the vertical dimensions of the display windows. The point is the minimal amount of current required to begin trend capture. On the trend display, two vertical lines denote the inrush period. The temporal interval is when the trigger event occurs, and the electrical current falls below the hysteresis threshold. The mean value of each root mean square (RMS) number measured during the initial peak is shown at the top of the screen. When you activate the Cursor, the RMS measurement data will be shown at the Cursor point.

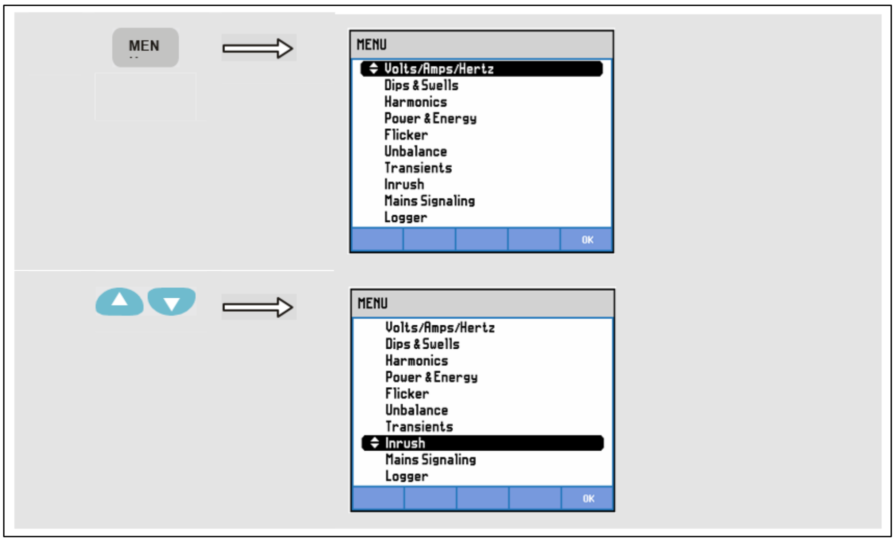

Figure 8: Inrush Current Measurement Setup Menu (20)

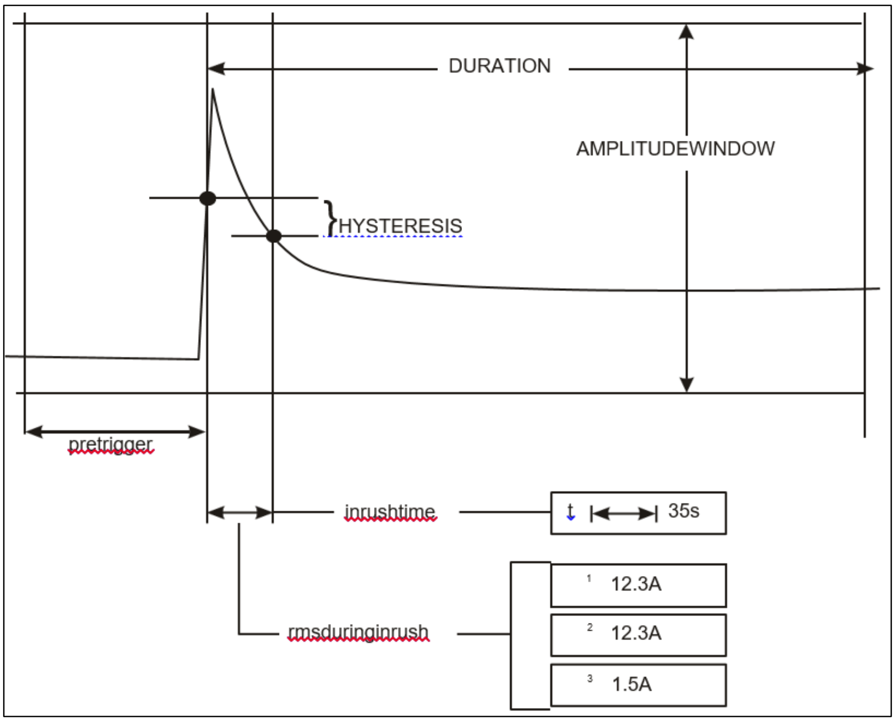

Figure 9: Inrush Characteristics and Relation with the Start Menu

Using the Cursor and Zoom buttons, you may view the granular details of the recorded Trends. Selecting television programming is possible by using the vertical arrow keys. The F1 function key can instruct the arrow keys to do the desired action. The user can change the trigger limits, which include the predicted inrush time, maximum current, nominal current, threshold, and hysteresis, as well as the offset and extent of the trend display. This is done by hitting the SETUP key and the F3 - FUNCTION PREFERENCE function key.

Initial Setup for Inrush Current Measurement in 120hp and 180hp Motors

Figure 10 shows an Initial setup for Inrush current measurement in a 120HP Motor. The Instrument was set for a nominal current of 155 Amperes with a 4 minute duration, putting a 25% threshold and 2% hysteresis. Figure 11 shows an initial setup for the current measurement of Inrush in a 180HP motor. The Instrument was set for the nominal current of 228 Amperes with 12 minutes duration and put a 50% threshold and 2% hysteresis.

Figure 10. Programming Setup for 120 HP Motors in Fluke 434-II

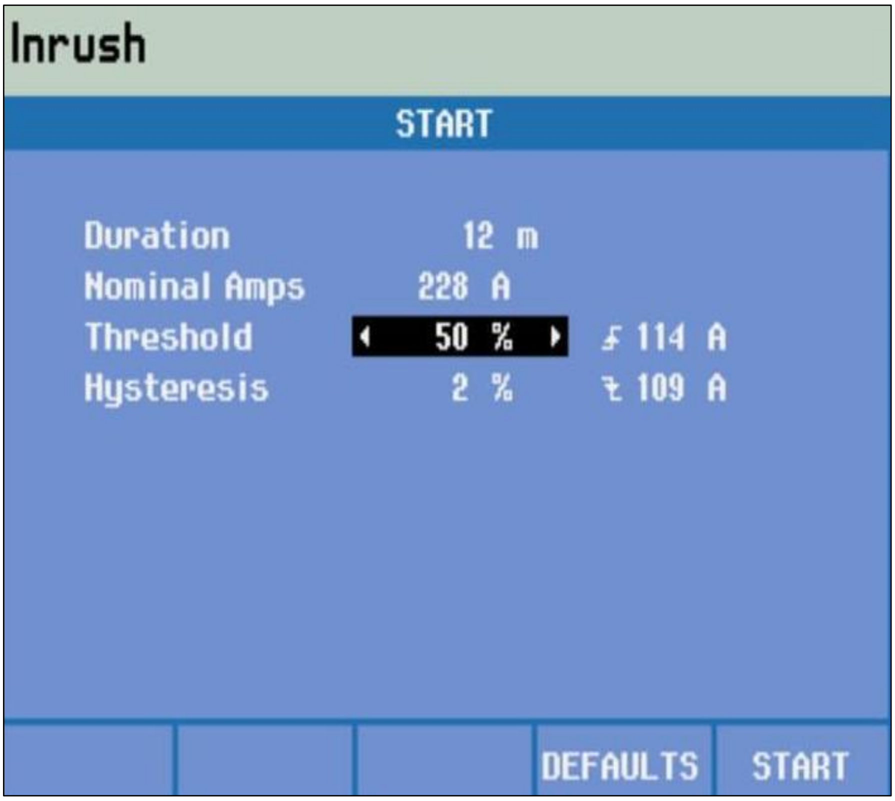

Figure 11. Programming Setup for 180HP Moto in Fluke 434-II

EN50160 Standards Limits

Figure 12 shows how the EN50160 standards specify the primary voltage characteristics at a network user's supply terminals in public low-voltage and medium-voltage electricity distribution networks under typical operating conditions. The EN50160 standard must thoroughly describe the normal operational circumstances of a public electrical system. It also specifies the limitations or parameters where voltage characteristics must remain constant. The set standard defines the energy provider's responsibilities. These include giving the client energy or electricity, ensuring an uninterrupted supply, and ensuring the network meets power quality standards. Furthermore, it limits the maximum power capacity derived from the primary power source and specifies the conditions the end user must meet. The standard also specifies the obligations of the Power User, which include both Active Power and Reactive Power. The EN50160 standard handles voltage, frequency, flicker, voltage dips, brief and lengthy interruptions, overvoltage, transient overvoltage, voltage imbalance, and harmonics, among other factors. It is critical to remember that adhering to EN50160 standards can help to mitigate specific Power Quality concerns but only partially resolve them. In contrast, an evaluation will be carried out to identify the system's level of success by assessing the electrical provider's adherence to standard compliance requirements.

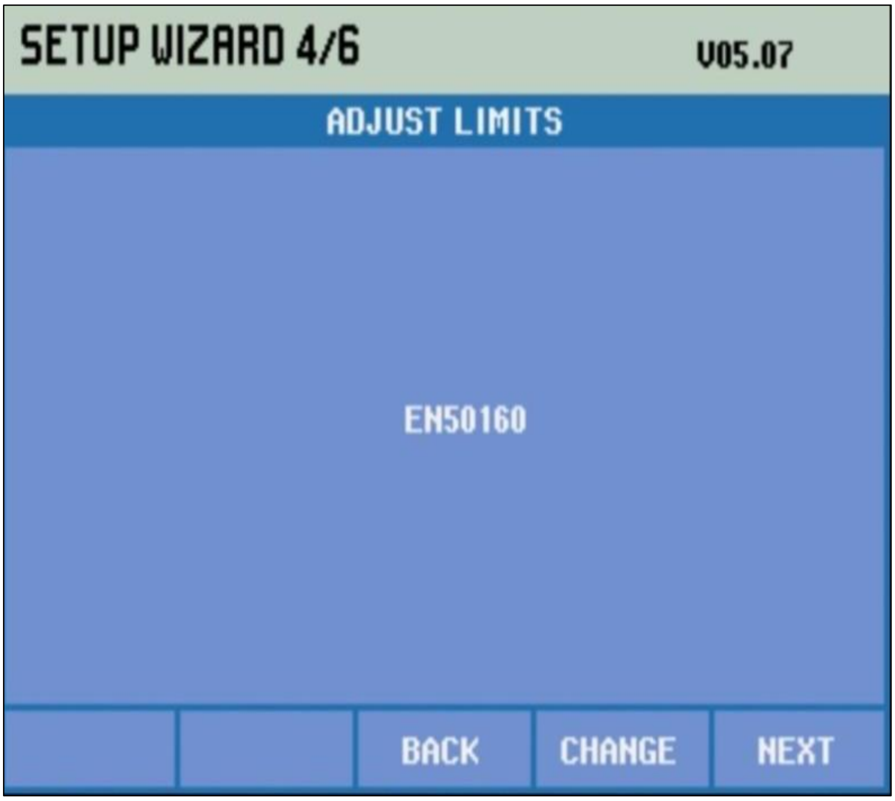

Figure 12: Standards EN50160

Low Voltage Soft Starter

The following are the excerpts from the website of Soft starter. Figure 13 illustrates the Low Voltage Flux Compensated Magnetic Amplifier (FCMA$^{plus)}$ soft starters, which are air core based series reactors, providing a complete starting solution for any motor application involving pumps, blowers, fans, or compressors. We design Customized solutions specific to each motor, analyzing motor and load torque speed curves, current speed, and moment of inertia. Soft starters are provided with a bypass device (power contactor or air circuit breaker) of customer-preferred make. When the customer requires, we offer a complete solution with a motor feeder, i.e., ACB/power contactor with MPR and metering for switching and protection purposes. All our starters are automated using a PLC with HMI, which creates reliability and helps in remote support, allowing for commissioning operations during COVID-19 times. Our soft starters' standard starting current is 3-3.5 times the full load current. Using a Dynamic Compensater, we can also reduce the starting current up to 1 1.5 times the full load current. Our LV soft starters offer our customers the best competitive value and superior value to conventional electronic soft starters.

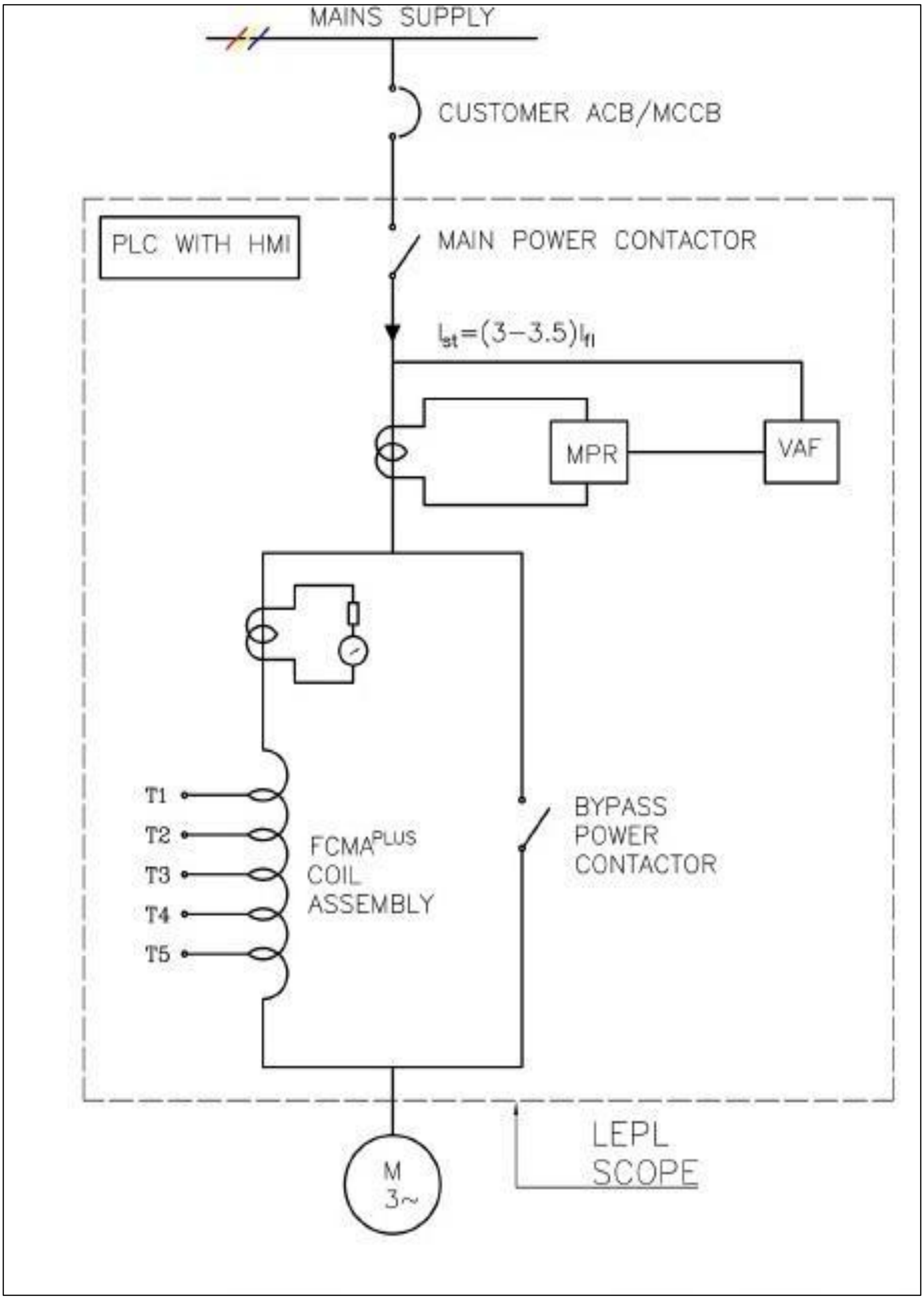

Figure 13: Soft Starter

Results and Discussion

120 HP Motor Inrush Current Measurements

Figure 14 gives voltage and current measurements of a 120HP motor. The measurements were done between 11:24 am and 11:28 am. The Instrument was set for the nominal current of 155 Amperes for 4 minutes and put a 50% threshold and 2% hysteresis.

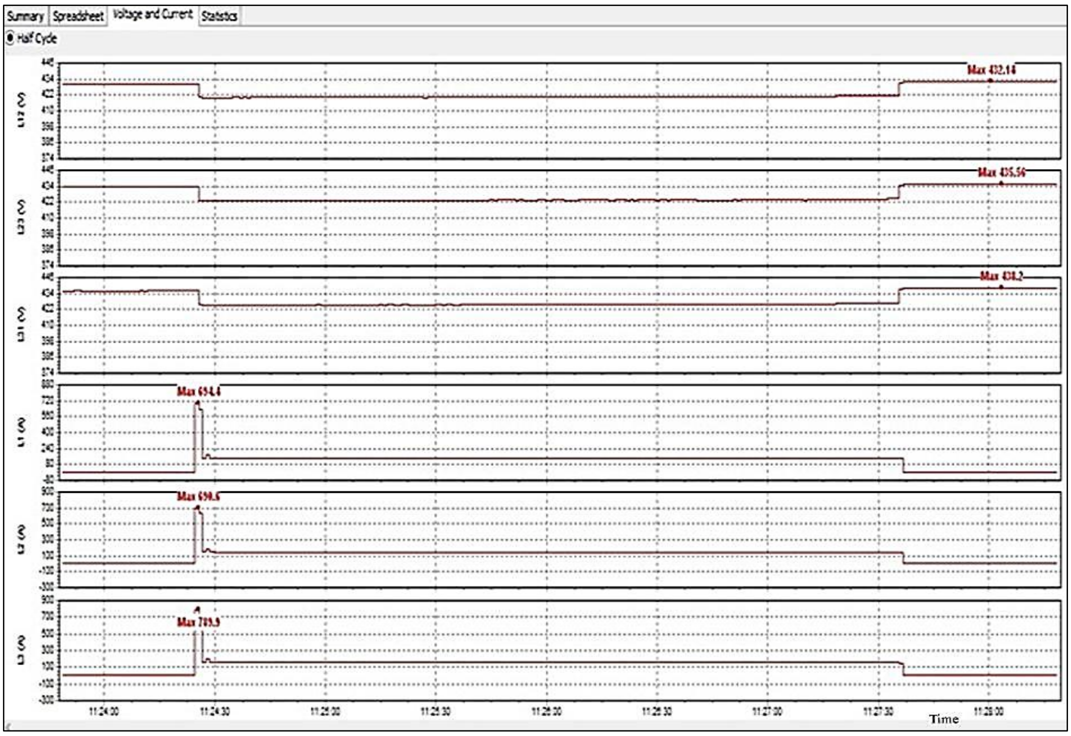

Figure 14:120 HP Motor Starting Characteristics

The above Figure 14 indicates the 3 phase voltages, namely V_{RY} (shown as L12 in the graph), V_{YB} (shown as L23 in the diagram), and V_{BR} (shown as L31in the chart). The Bottom 3 graphs in Figure 14 show 3-line currents - I_R(L1), I_Y (L2) and I_B (L3). From the chart, we observe that the inrush current in the R phase has a maximum of 694.4A for 3 seconds, the Y phase has a maximum of 690.6A for 3 seconds, and the B phase has a maximum of 789.9 A for 3 seconds. Only V_{RY} and I_R are reproduced below in Figure 15 for a clear viewing.

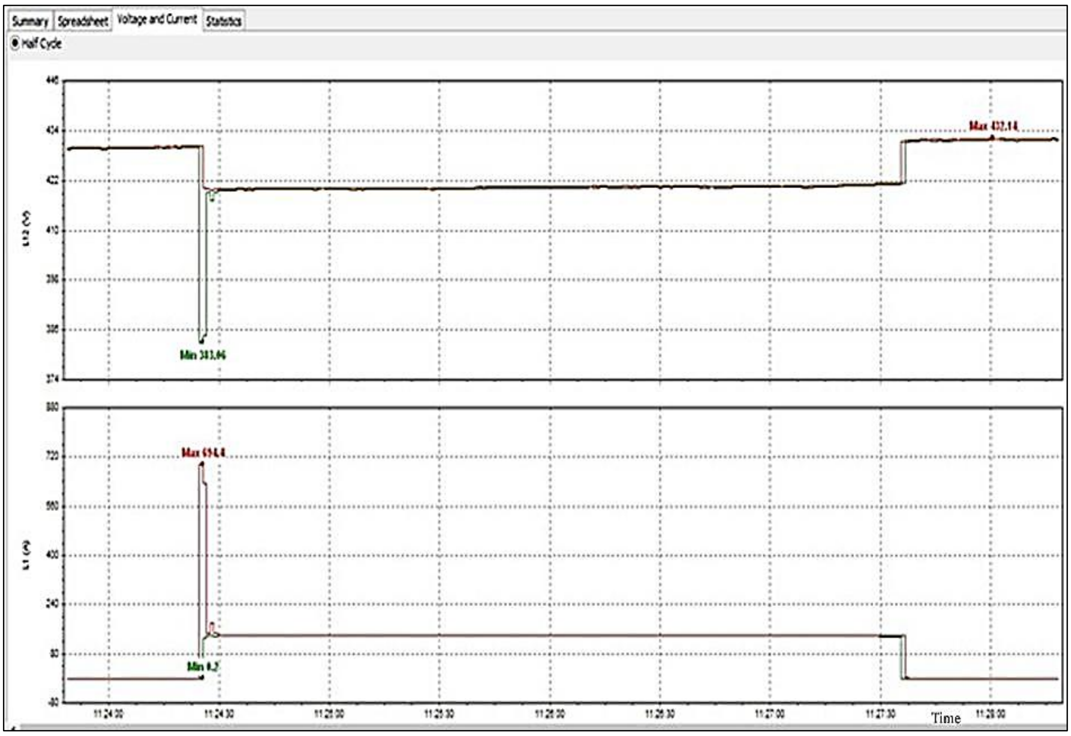

Figure 15: The Plot of V_{RY}, I_R of 120 HP Motor Starting Characteristics

From the nameplate of the 120HP motor, it is found that the nominal current of $I_n$is is 155 Amperes. During measurement using a Power Quality Analyser, it is observed that the inrush current in I_R = 4.48%, I_Y = 4.45%, and I_B = 5.09%. This appears to be higher than the published data of 3.5 times. The supply voltages are V_{RY}=432.14V, V_{YB}=435.6V, V_{BR}=438.2V.

180 Hp Motor Inrush Current Measurements

Figure 16 gives voltage and current measurements of the 180HP motor. The measurement was carried out between 2:12 p.m. and 2:24 p.m. The Instrument was set for a nominal current of 228 Amperes with a duration of 12 minutes and put a 50% threshold and 2% hysteresis. Figure 16 indicates the 3 phase voltages, namely V_{RY} (shown as L12 in the graph), V_{YB} (shown as L23 in the diagram), and V_{BR} (shown as L31in the chart). The Bottom 3 graphs in Figure 16 show the 3-line currents - I_R (L1), I_Y (L2), and I_B (L3). From the chart, we observe that the inrush current in the R phase has a maximum of 819.8 A for 3 seconds, the Y phase has a maximum of 859 A for 3 seconds, and the B phase has a maximum of 941.1 A for 3 seconds.

From the nameplate of the 180HP motor, it is found that the nominal current of I_n is 228 Amperes. During measurement using a Power Quality Analyser, it is observed that the inrush current in I_R = 3.59%, I_Y = 3.76%, and I_B = 4.12%. This appears to be higher than the published data. The supply voltages are V_{RY} = 396.48V, V_{YB} = 397.78V, V_{BR} = 399.36V. The results show that the proposed soft starters, which initiate motors at pump stations to mitigate the impact of inrush currents, can enhance the pump station system efficiency.

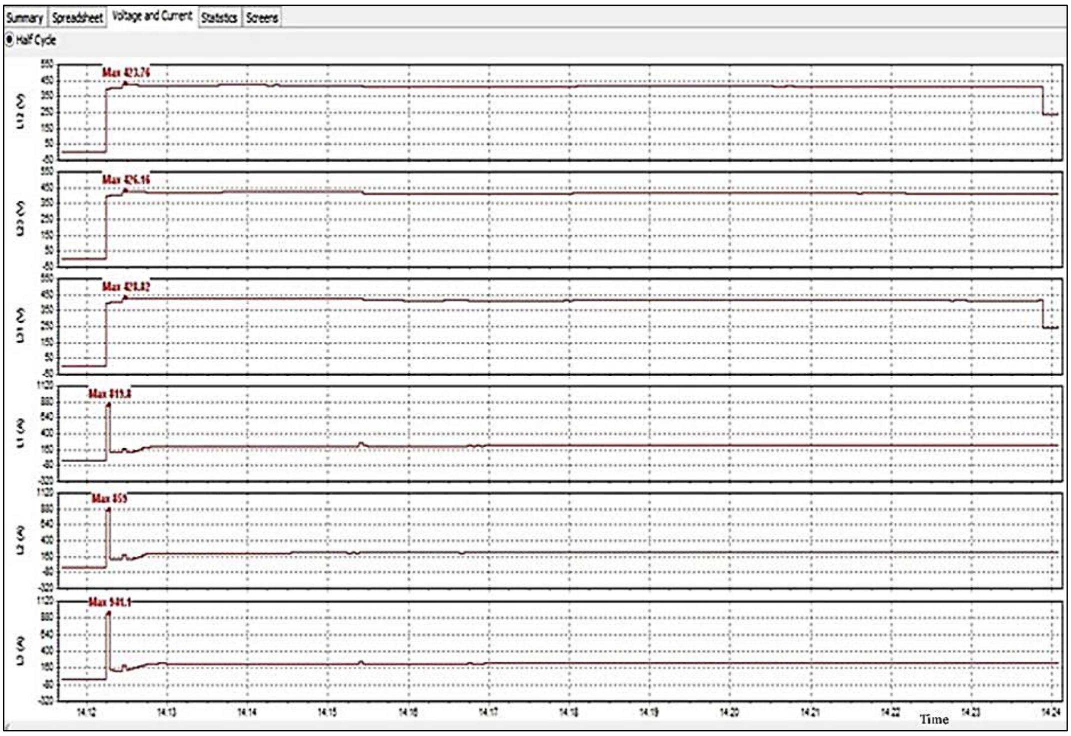

Figure 16:180 HP Motor Starting Characteristics

Only V_{RY} and I_R are reproduced below in Figure 17 for a clear viewing. Figure 18 illustrates the phasor unbalance of point of common coupling (PCC). It emphasizes the phase angle relationship between voltage and current during measurement.

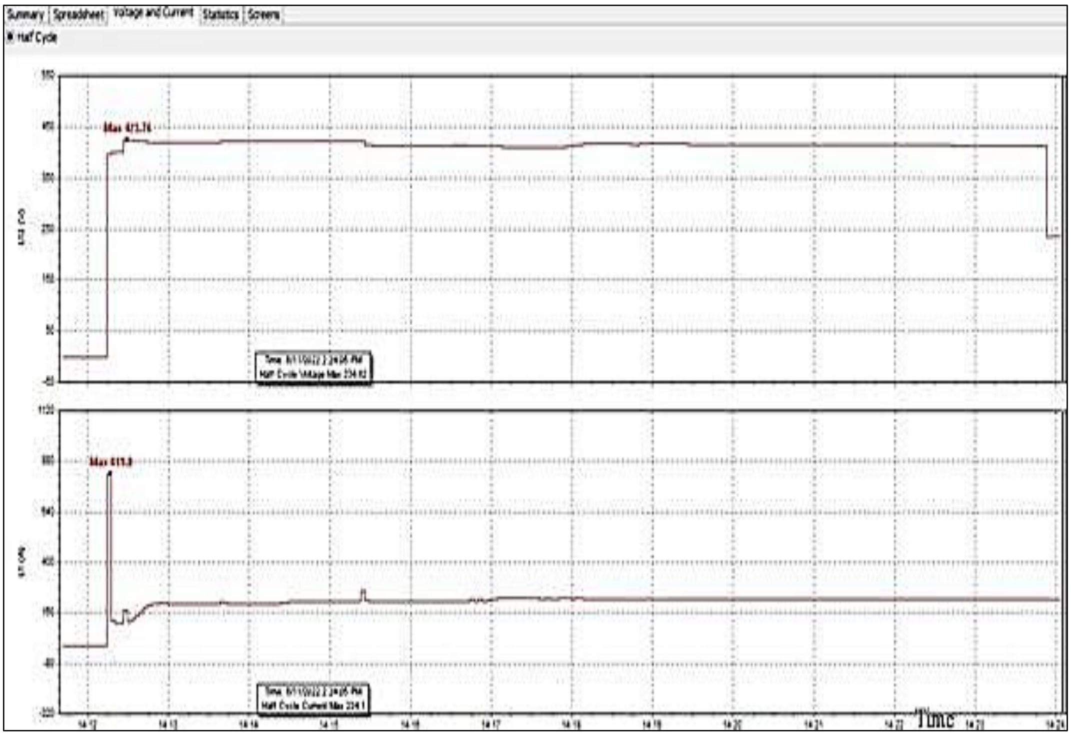

Figure 17: Plot of V_{RY}, I_R of 180 HP Motor Starting Characteristics

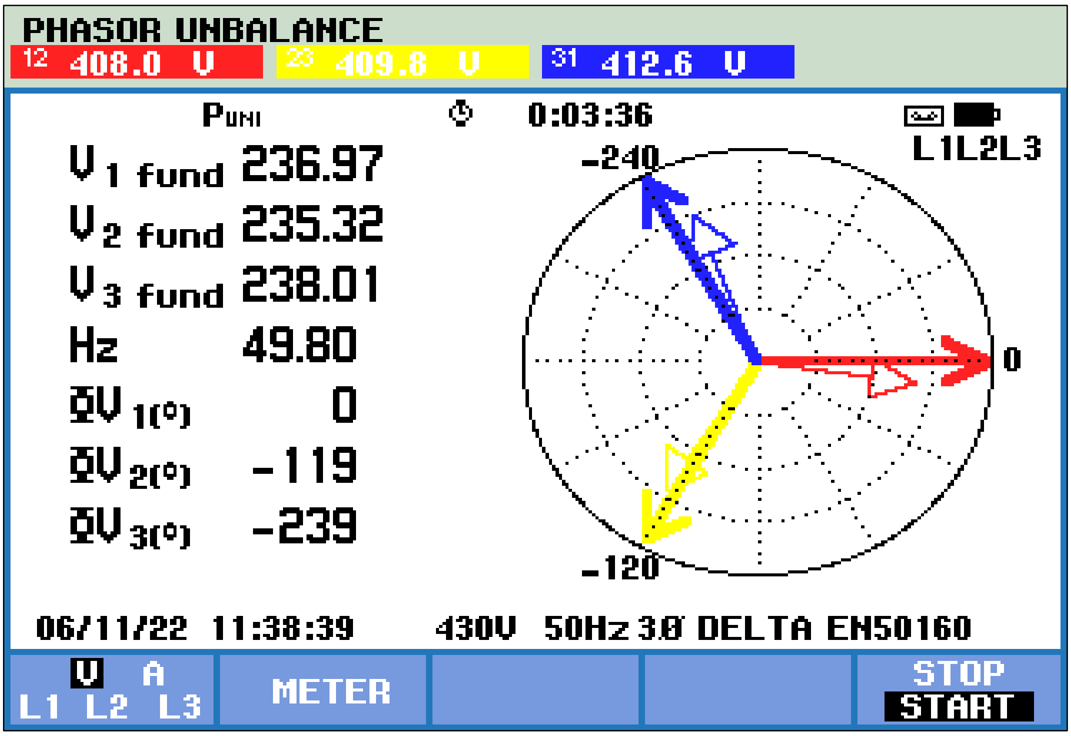

Figure 18: 180 HP Motor Phasor Unbalance

Conclusion

The empirical data and experimental studies show that the size of the Inrush Current during the early phase of operation surpasses the value provided in the soft starter's technical specifications. This means the 120-HP motor draws 153 amps of current when it starts. When the 180-horsepower motor is turned on, both the start-up and operational currents surpass the capacity of the Transformer. The occurrence of a flare frequently prevents the event of undesired circumstances. Before delving into the causes of blown fuses, it is essential to address the issue of excessive inrush current, which remains despite the motor's gradual start-up.

Abbreviations

VFDs: Variable-Frequency Drives
ACB: Air Circuit Breaker

Acknowledgement

Nil.

Author Contributions

All authors have equally contributed.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Approval

Not applicable.

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