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Variable speed drive control system as a controller for a 3-phase motor using function block diagram on zelio PLC

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ABSTRACT

A 3-phase electric motor is one of the key components in industrial production processes. In industrial activities, electric motors play a significant role in the production process, as almost all machines in the industry use electric motors as their driving force. This type of motor is susceptible to overcurrent, caused either by an overload or excessive current. Common disturbances that may occur in a 3-phase electric motor include: high starting current, overcurrent, overvoltage, undervoltage, underfrequency, and short circuit undervoltage. A protection system is needed to minimize the losses caused by these disturbances, making it essential to conduct a protection system analysis to be installed on the motor. Using the Multi-Function Meter SMART 7KT as a device capable of detecting these disturbances and taking the necessary protective actions, the protection system employs a PLC (Programmable Logic Controller) and HMI (Human Machine Interface) as the interface for controlling and monitoring the protection system on the electric motor, communicated via Modbus RTU. Therefore, this protection system can safeguard the 3-phase electric motor from disturbances such as large starting current, overcurrent, undervoltage (-10% from normal voltage), overvoltage (+5% from normal voltage), and underfrequency. With this developed protection system, the risk of damage to critical or vital 3-phase electric motors can be minimized.

Keywords: Electric Motor, Multi-Function Smart 7KT, PLC, HMI.

ABSTRAK

Motor listrik 3 fasa merupakan salah satu komponen penting dalam proses produksi industri, dalam kegiatan di industri motor listrik merupakan salah satu komponen yang sangat berperan dalam proses produksi, hampir semua mesin di industri menggunakan motor listrik sebagai penggeraknya. Motor jenis ini rentan terhadap terjadinya arus lebih, baik yang disebabkan oleh beban lebih maupun arus lebih. Secara umum gangguan yang mungkin terjadi pada motor listrik 3 fasa antara lain: arus start yang besar, overcurrent, overvoltage, undervoltage, underfrekuensi, arus hubung singkat (short circuit undervoltage). Sistem proteksi ini diperlukan untuk mengurangi kerugian yang ditimbulkan akibat gangguan - gangguan tersebut, sehingga diperlukan suatu analisis sistem proteksi yang harus dipasang pada motor. Dengan menggunakan Multi Function Meter SMART 7KT digunakan sebagai perangkat yang dapat mendeteksi gangguan-gangguan tersebut dan mengambil tindakan proteksi yang diperlukan. Sistem proteksi ini menggunakan PLC (Programmable Logic Controller) dan HMI (Human Machine Interface) sebagai antarmuka untuk mengendalikan dan memonitoring sistem proteksi pada motor listrik yang dikomunikasikan melalui modbus RTU. Maka dengan adanya sistem proteksi ini dapat memproteksi motor listrik 3 fasa jika terjadi gangguan antara lain: arus start yang besar, overcurrent, undervoltage -10% dari tegangan normal, overvoltage +5% dari tegangan normal, underfrequency dan dengan adanya sistem proteksi yang dikembangkan ini, dapat mengurangi risiko kerusakan pada motor listrik 3 fasa yang penting atau vital.

Kata kunci: Motor Listrik, *Multi Function Smart 7KT,* PLC, HMI.

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1. INTRODUCTION

The growth and development of the industrial world require production process equipment and supporting devices that use electric motors[1]. In industrial activities, electric motors are one of the key components[2], especially in the production process, because almost all machines in the industry use electric motors as their driving force[3].

An electric motor is a device that converts electrical energy into mechanical energy[4]. This mechanical energy is applied in various machines used for production processes, such as lifting machines, conveyor machines, blowers, vacuum machines, and vibrators[5].

One of the most used electric motors as a driver is the 3-phase motor or 3-phase induction motor[6], because its construction is simpler and its rotation is relatively more constant with load changes compared to other types of electric motors.

This type of motor is susceptible to overcurrent[7], whether caused by overload or excessive current. Common disturbances that may occur in a 3-phase electric motor include: large starting current (overcurrent), overload, short circuit, phase imbalance (unbalance), and undervoltage[8].

This protection system is especially necessary for important or vital electric motors with large capacities, where the purchase price and repair costs in the event of damage are very expensive. Therefore, damage to the motor requires a long repair time and high costs, while the production process continues. To minimize the losses caused by these disturbances, a protection system analysis must be conducted and installed on the motor (5).

2. RESEARCH METHOD

In industrial automation, many types of protocols are known for communication between controllers, actuators, and field sensors. One of these protocols is Modbus. Modbus RTU is a compact variant of Modbus used in serial communication. The RTU format is equipped with a cyclic redundancy check (CRC) mechanism to ensure data reliability. Modbus RTU is the most used implementation of the Modbus protocol. Each data frame is separated by an idle period (silent).

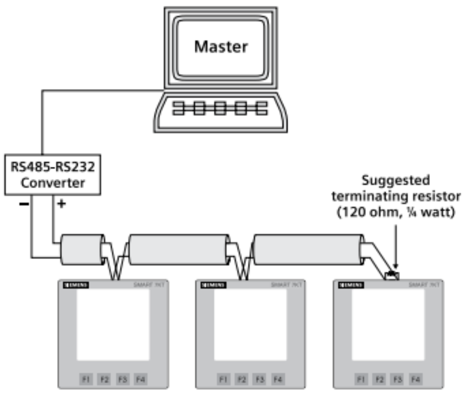

Figure 1. Modbus RTU

The diagram shows a two-wire RS-485 daisy-chain network linking a single Master (PC/PLC) to three HMI/SMART panels. The master's RS-232 port is converted to RS-485 using an RS232↔RS485 converter, after which the differential lines A/+ and B/− are routed serially from device 1 → device 2 → device 3. A 120-Ω, ¼-W terminating resistor is placed at the end of the bus to absorb reflections and preserve signal integrity (in longer/fast links, termination is typically used at both ends). Proper wiring requires consistent A/B polarity and unique device addresses (e.g., for Modbus RTU), short stubs, and a shielded twisted pair with a good reference/ground. The topology is a bus—not a star—and communication is usually half-duplex with the master polling the nodes. This arrangement provides a simple, robust, and scalable way to connect multiple HMIs to one controller.

Figure 2. 3-Phase Induction Motor

The 3-phase motor protection system here uses the Multi-Function Meter SMART 7KT as a sensor. In this motor protection system, the multifunction meter is used to measure, monitor, and control parameters such as measuring voltage on phase and phase-to-phase, measuring current, measuring active, reactive, and apparent power, measuring power factor, and frequency. This can be seen in Figure 3.

Figure 3. Multi-function Smart 7KT ESP32 Module

PLC is a digital control system designed for industrial use with memory programming[9]. The PLC works by analyzing input signals and then adjusting the output according to the user's needs. The Mitsubishi FX3U PLC can be seen in Figure 4.

Figure 4. PLC Mitsubishi FX3U

The RS-485 expansion functions as a connector between the RS-485BD socket and the PLC. By using this extension, the PLC can communicate using RS-485 with a maximum total distance of 50 meters. The RS-485 ADP expansion can be seen in Figure 5.

Figure 5. RS-485 expansion

The HMI functions to display data, making it easier to control and monitor a system. This device operates online and in real-time by reading data sent through the I/O ports used by its controller system. The Mitsubishi GS2107 HMI can be seen in Figure 6.

Figure 6. HMI Mitsubishi GS2107

RS-485 is a serial data communication technique developed in 1983, which allows data communication over a relatively long distance of up to 1.2 km using AWG-24 twisted pair cables. It features automatic flow control of RS485 signals and automatic switching of transmission and reception directions. Using this module is as simple as operating a serial port. In this system, RS485 is used as a link between the PLC and the Inverter or VSD Frenic Multi. The RS-485 to USB converter can be seen in Figure 7.

Figure 7. *RS-485 to USB*

A magnetic contactor functions to connect or disconnect the electrical flow from the power source to other electrical equipment. Inside the magnetic contactor, there are 2 switch poles: NO (Normally Open) and NC (Normally Closed). This can be seen in Figure 8

Figure 8. *Magnetic Contactor*

A Current Transformer (CT) is an electrical device that transforms current, changing the current magnitude from large to small and vice versa, according to needs. The Current Transformer (CT) functions to reduce the current magnitude in the system so that it can be read by the Metering panel or connected measuring devices. This can be seen in Figure 9.

Figure 9. *Current Transformer (CT)*

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A relay is a switch operated electrically and is an electromechanical component consisting of two main parts: an electromagnet (coil) and a mechanical part (a set of switch contacts).

Figure 10. *Relay*

3. RESULTS AND DISCUSSION

This chapter will explain the working diagram, flowchart, trainer design, and wiring diagram of the 3-Phase Motor Protection System using the Multi-Function Meter SMART 7KT based on PLC and HMI via MODBUS RTU Communication.

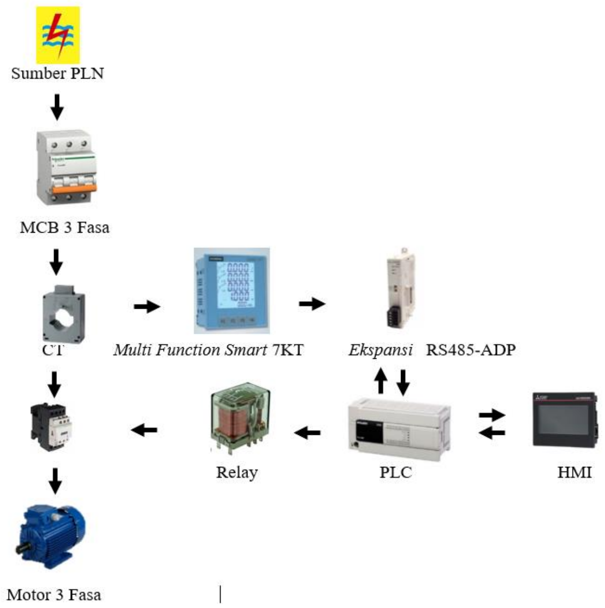

Figure 11. *Block Diagram*

The explanation of the working diagram of the above device is as follows:

1. PLN 220 Volt is used as the control circuit power source, and the 3-Phase MCB is used as protection for the power circuit and the 3-phase induction motor.
2. CT (Current Transformer) is used to measure the current entering the circuit.
3. Multi-function Meter Smart 7KT is used for monitoring, which will later be transferred to the PLC.
4. PLC is used to execute the data collected by the Multi-function Smart 7KT for control or operation of the Multi-function Smart 7KT.
5. RS48-ADP expansion is used as a connector between the PLC and the Multi-function Smart 7KT.
6. Magnetic Contactor is used as an automatic switch that works like a regular switch, connecting or disconnecting the electric current. When the copper coil is supplied with alternating current, the switch inside will connect or change its condition automatically.
7. Relay is used to activate the contactor.
8. HMI is used to display the monitoring results from the Multi-function Smart 7KT and input set points to be entered into the PLC.
9. 3-Phase Induction Motor is the target to be protected.

3.1. Ladder Diagram PLC

The creation of the ladder diagram for the PLC[10] is done using the GX-Programmer software. The inputs and outputs used in the ladder diagram will serve as reference addresses for the creation of the HMI and wiring diagram. Below is the ladder diagram from the design created using the CX-Programmer software.

The ladder diagram in Figure 12 is designed using the GX-Programmer software. The first row contains two Modbus protocol commands. The second row's cycle for uploading/downloading data is used to provide a time cycle for processing data that will be transferred in the special relay function M8012. The third row features the ADPRW function for sending and receiving data, with the frequency setpoint value desired using code H0. The fourth row is for the setpoint program. The fifth row is for protection. The sixth row is for controlling and resetting when a motor trip occurs. The last row functions to turn on the indicator light on the HMI screen.

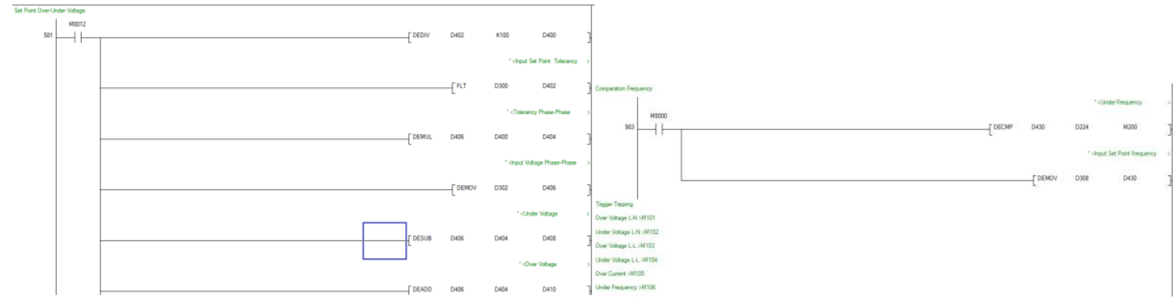

Figure 12. *Ladder Diagram PLC*

3.2. Desain HMI

This design is used for system display on the HMI screen. The process involved in creating the HMI design with the Mitsubishi FX3U type uses a programming application called GT Designer Mitsubishi.

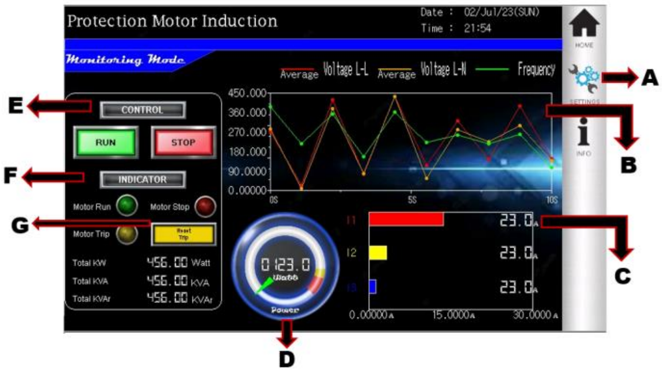

Figure 13. *Design Monitoring*

Description:

A: Set Point Setting
B: Monitoring Graph
C: Displaying Current R, S, T
D: Displaying Active Power on the Motor
E: Motor Control
F: Motor Indicator
G: Reset Motor Trip

The creation of the first display design on the HMI[11] consists of a monitoring graph display and is also used to display the electric motor control, allowing for turning it on and resetting it when a motor trip occurs. This display is also used to monitor power, voltage, current, and frequency.

Figure 14. *Input Set Point*

Additionally, the dashboard includes export options, specifically for Excel and PDF formats, located just below the relay controls. These options facilitate data recording and reporting, allowing the admin to save the monitored data for analysis or documentation purposes. The combination of real-time data monitoring and export capabilities makes this dashboard practical for managing electrical systems in industrial or residential settings.

The selection of display parameters and control logic prioritizes safety, reliability, and operator usability. Phase voltages, current, frequency, power, and power factors are shown as primary indicators of motor health and load efficiency, while a trend graph reveals transients or drift that static numbers can miss. Set points (e.g., under/over-voltage and overcurrent limits) are placed near live values with standard color cues (green/yellow/red) to reduce interpretation errors, and Excel/PDF export supports reporting and audits. The control logic applies Start/Stop with permissive, protection for common faults (under/over-voltage, overcurrent, phase loss), latched trips requiring manual reset, hysteresis/debounce to prevent hunting, Auto/Manual modes for operations and maintenance, soft-start/ramp to limit inrush, and a communication-loss failsafe. Together, these choices ensure the motor runs only under safe conditions, prevent uncontrolled restarts, extend equipment life, and speed fault diagnosis.

3.3. Device Testing

Device testing is the process of testing conducted to ensure that the tool or device functions according to the specified requirements and intended purpose. This process involves operating the device under certain conditions to evaluate its performance, identify potential issues, and ensure that the device is safe, effective, and efficient for use in its application.

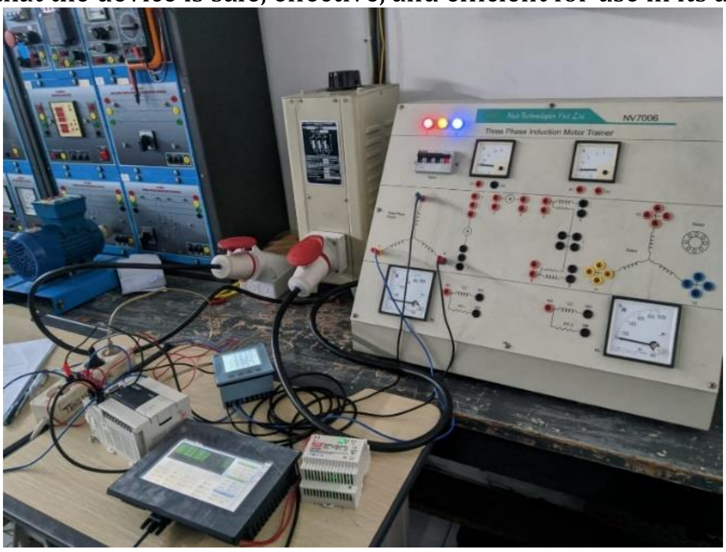

Figure 15. *Testing Undervoltage, Overvoltage, Frequency*

Figure 16. *Testing Overcurrent*, *Frequency*

Tabel 3.1. Result Data

No.	Testing	Set Point	Measurement Result	Description	Action
1.	*Overvoltage* (L – L)	399 V	413 V	Protected	Motor Trip Indicator On
2.	*Undervoltage* (L – L)	361 V	331 V	Protected	Motor Trip Indicator On
3.	*Overvoltage* (L – N)	230 V	241 V	Protected	Motor Trip Indicator On
4.	*Undervoltage* (L – N)	208 V	189 V	Protected	Motor Trip Indicator On
5.	*Overcurrent*	1 A	1.5 A	Protected	Motor Trip Indicator On
6.	*Frequency*	50 Hz	49 Hz	Protected	Motor Trip Indicator On
7.	Arus *Start*	2 A	2.7 A	Protected	Motor Trip Indicator On

It can be observed in the test with a measured voltage of 413 Volts for the line voltage and 241 Volts for the phase voltage using an autotransformer to create troubleshooting. The overvoltage program can protect the 3-phase induction motor from damage, The test with a measured voltage of 331 Volts for the line voltage and 189 Volts for the phase voltage, using an autotransformer to create troubleshooting shows that the undervoltage program can protect the 3-phase induction motor from damage.

The tests verified that all protection functions operated correctly—each scenario (OV/UV L–L and L–N, overcurrent, under-frequency, and inrush) triggered the *Protected* status and trip indicator. However, several set points are too close to nominal values and risk nuisance trips: OV L–L at 399 V tripped at 413 V and OV L–N at 230 V tripped at 241 V. Adopting ±10% limits is recommended (≈440/360 V for L–L and ≈253/207 V for L–N). The under-frequency trip at 49 Hz (−2%) should include a short delay. The overcurrent set point of 1 A is below the measured nominal current of 1.5 A; a threshold of 1.2–1.3×In with time delay is advised. The inrush limit of 2 A should be increased (or mitigated via a soft starter/VFD) given the measured 2.7 A starting current, balancing safety with operational reliability.

For a 1.5 Hp motor, when the test was conducted, the measured starting current was 2.7 Amperes using a set point of 2 Amperes. The program was able to protect the motor by limiting the starting current if it exceeds the set point for a duration of 0.5 seconds and for a 1.5 Hp motor, when the test was conducted, the measured nominal current was 1.5 Amperes using a set point of 1 Ampere. The program was able to protect against overcurrent when the current exceeded the set point of 1 Ampere, allowing the PLC to trigger the breaker to trip. The under-frequency test was conducted using a set point value of 50Hz. If the measured frequency is lower than 50Hz, the program will activate the protection for the electric motor by turning it off.

4. CONCLUSION

The design of the protection system for current, voltage, and frequency on a 3-phase electric motor was successfully implemented using the Multi-Function Meter Smart 7KT based on PLC and HMI through Modbus RTU communication. Testing was conducted using a 3-phase electric motor with set point values of 1 A for current, 399 V for voltage, and 50 Hz for frequency. During testing, when the measured current exceeded 1 A, overcurrent occurred; if the voltage was +5% above the normal voltage, overvoltage occurred; and if the frequency was less than 50 Hz, underfrequency occurred. Therefore, if the set point values exceed or fall below the specified limits, the motor will trip or shut down. The protection system for current, voltage, and frequency on the 3-phase motor was successfully designed using the Multi-Function Meter Smart 7KT to detect disturbances and take the necessary protective actions, which are then transferred to the PLC. The PLC serves as the control system, and the HMI is used to monitor the protection system on the electric motor, communicated via Modbus RTU.

In practice, implementing PLC–HMI–based current, voltage, and frequency protection with a Modbus RTU meter delivers immediate industrial benefits: enhanced safety and asset life by preventing overcurrent, phase loss, and voltage/frequency deviations; reduced downtime and maintenance costs through fast fault isolation and clear trip diagnostics on the HMI; improved energy efficiency as operators can monitor power/power factor and tune set points using real data; easier audit compliance via exportable logs and trends; and scalable, interoperable integration for additional motors/feeders. For further development, calibrate set points to standards and nameplate data (e.g., ±10% voltage limits, inverse-time overcurrent, short delays for frequency) and add hysteresis to avoid nuisance trips; expand diagnostics to include phase unbalance/sequence, locked-rotor detection, thermal modeling, and THD alarms; integrate soft starters/VFDs to limit inrush and coordinate trips; strengthen data security and role-based access with time-stamped event logging; connect to a historian/SCADA or cloud dashboards for analytics and predictive maintenance; improve alarm management per ISA-18.2 and conduct HMI usability testing; and verify robustness with EMC/environmental tests, fail-safe behavior on communication loss, and, where required, functional-safety assessment.

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