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Microcontroller-Based 3-Phase Electronic Motor Starter And Protection/Control System for Motors Up To 5 Hp

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ABSTRACT
This paper presents the design of a microcontroller-based electronic starter and protection/control system for three-phase induction motors up to 5 HP. The architecture integrates two ZMPT107-1 voltage-sensing channels, an ACS758 Hall-effect current sensor, an ATmega328P controller, opto-isolated user inputs, an LCD interface and an isolated contactor-control stage. The voltage channels monitor the R and Y phases and provide sampled waveforms for voltage estimation, zero-crossing timing, frequency calculation and phase-sequence supervision. The controller implements overvoltage, undervoltage and phase-sequence protection, together with current monitoring, overcurrent supervision and a current-squared thermal protection algorithm. START, STOP and RESET commands are interfaced through PC817 optocouplers, while the MOC3041 forms part of the isolated contactor-control interface. The paper presents the hardware architecture, measurement equations and control sequence, together with calculated examples illustrating the measurement and protection principles. The proposed design provides an integrated embedded platform for monitoring and protecting small three-phase induction motors, with configurable protection parameters suited to the selected motor rating.

Keywords—Three-phase induction motor, electronic starter, ATmega328P, ACS758, ZMPT107-1, phase sequence, frequency measurement, thermal protection, opto-isolation.

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I. INTRODUCTION

Three-phase induction motors are common in industrial and utility applications because they are robust, efficient and relatively easy to maintain. Their safe operation nevertheless depends on supply conditions and loading. Undervoltage, overvoltage, abnormal frequency, incorrect phase sequence and sustained overload can result in starting difficulty, excessive heating or interruption of the driven process. Conventional motor control panels commonly combine a contactor with overload and monitoring devices. A microcontroller-based arrangement can integrate measurement, display and configurable decision logic in a compact system.

The work presented here develops an electronic starter and protection/control system for three-phase motors up to 5 HP. Its principal elements are two ZMPT107-1 voltage-sensing channels, an ACS758 current sensor and an ATmega328P controller. The R- and Y-phase signals are processed to estimate voltage, determine frequency and evaluate the phase relationship before starting. Current measurements are used for overload supervision and a current-squared thermal algorithm, providing configurable protection logic within the controller.

The paper is organised in a concise engineering format, progressing from system architecture and hardware implementation to measurement principles, protection logic, illustrative calculations and conclusions.

II. SYSTEM ARCHITECTURE

The functional block diagram in Fig. 1 shows the relationship between the three-phase supply, sensing channels, signal conditioning, controller, user inputs, display and contactor. Two ZMPT107-1 channels sense the R and Y phase voltages. The ACS758-50B senses motor current. These signals are processed by the ATmega328P, which evaluates operating conditions and controls the isolated output interface. START, STOP and RESET inputs are opto-isolated. The LCD provides local status and fault information.

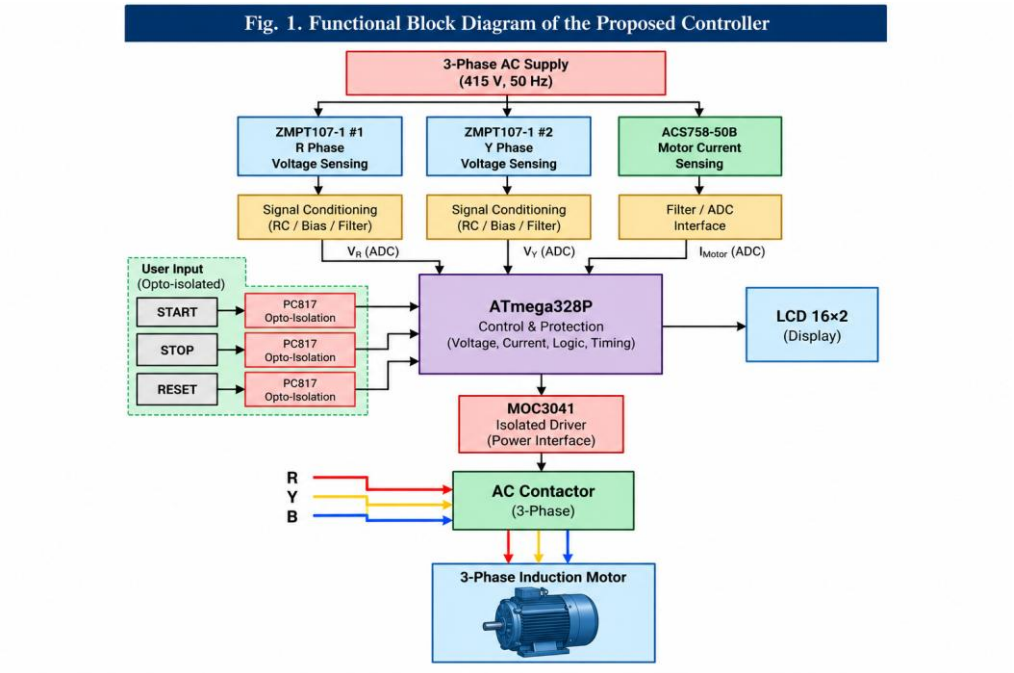


Fig. 1. Functional block diagram of the proposed controller.

The diagram represents the intended functional signal flow. In the implemented circuit, the contactor remains the power-switching device; the microcontroller and opto-isolated driver do not directly carry the motor's three-phase load current.

III. CIRCUIT SCHEMATIC AND HARDWARE

Figure 2 is the supplied component-level schematic for the proposed controller. It contains the LCD 16×2 interface, ATmega328P microcontroller unit, ACS758 current-sensor circuit, opto-isolated external inputs, MOC3041 contactor-control interface, voltage and phase-sequence monitoring circuits, and power/control supply section. The schematic is reproduced as supplied; its component values and net labels should be checked against the final PCB and firmware revision before fabrication.

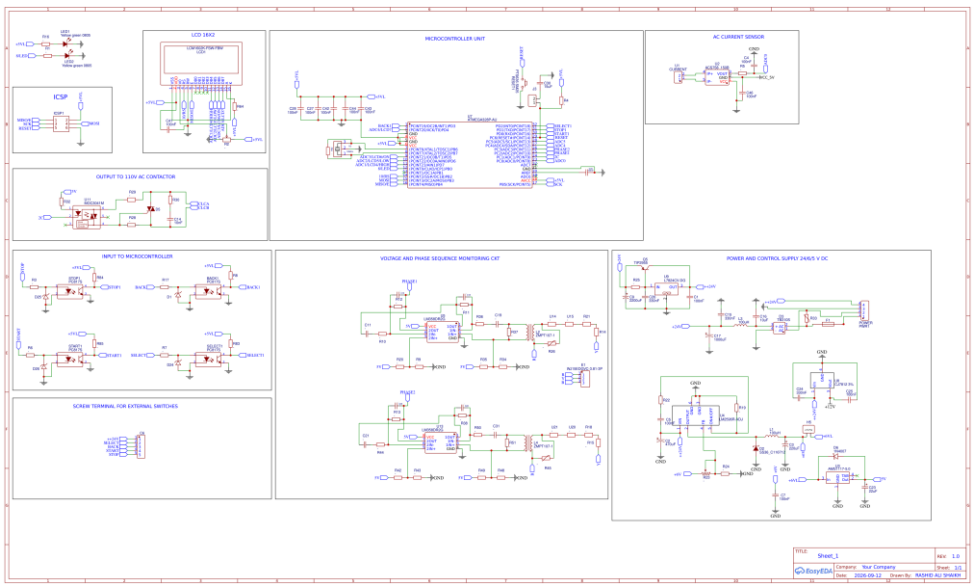


Fig. 2. Component-level schematic supplied for the 3-phase electronic motor starter.

A. ATmega328P controller

The ATmega328P is the central processing unit. It reads conditioned analog inputs, calculates voltage and current values, estimates supply frequency from zero-crossing timing, evaluates the monitored phase relationship, scans user inputs, updates the LCD and controls the isolated contactor interface. The actual firmware pin mapping must follow the net labels and pin assignments in the supplied schematic.

B. Voltage and phase-sequence monitoring

The schematic includes two voltage-monitoring channels identified as PHASE1 and PHASE2. Each channel includes a ZMPT107-1 transformer and an LM358-based conditioning stage, with associated resistors and capacitors. The conditioned signals provide the basis for analog voltage estimation and timing-related functions. The available schematic supports a two-channel R/Y monitoring description; it does not support a claim that all three phase voltages are independently measured.

C. ACS758 current sensor

The ACS758-50B is a Hall-effect current sensor. Its output is centered around approximately half the supply voltage at zero current for a bidirectional variant, with the actual offset and sensitivity dependent on the specific device and operating conditions. The controller converts the analog output to current using a calibrated zero-current offset and sensitivity. The sensitivity value used in example firmware must be verified on the actual sensor module and board.

D. User input isolation

The schematic shows START, STOP, BACK and SELECT inputs connected through PC817 optocouplers. The user-input section therefore includes four isolated command signals. The paper's protection/control description should distinguish the operator commands from the automatic protective trip logic.

E. Contactor interface

The output stage uses a MOC3041 opto-triac driver and associated discrete components as shown in the supplied schematic. The block diagram identifies the downstream device as an AC contactor. The contactor coil voltage and interface ratings must match the actual hardware; the schematic title references a 110 V AC contactor interface. The MOC3041 is not itself a motor power contactor and must only be used within its datasheet ratings and the intended driver topology.

F. Power and control supply

The schematic contains a multi-rail power and control supply section with 24 V, 6 V and 5 V rails identified. The exact rail loading, thermal dissipation, isolation boundary and regulation margins should be checked against the component datasheets and final PCB layout. A circuit diagram alone does not establish compliance with mains safety requirements.

IV. MEASUREMENT PRINCIPLES

A. RMS voltage calculation

For N sampled values x_n of the conditioned waveform, the AC component can be estimated after removing the sample mean:

$V_sensor,RMS = \sqrt{[(1/N)\ \Sigma\ (x_n - \bar{x})^2]}$

The corresponding mains RMS voltage is obtained by applying a calibration factor determined from comparison with a reference instrument. This calibration must account for the transformer, burden/conditioning network, ADC reference and sampling range.

B. Zero-crossing and frequency

A zero-crossing detector provides a timing event associated with a voltage waveform crossing its reference level. For a 50 Hz sinusoidal supply, the full-cycle period is 20 ms and adjacent half-cycle crossings are nominally 10 ms apart. If Δt is a measured half-cycle interval, frequency can be estimated as $f = 1/(2\Delta t)$. The firmware must reject missing or implausible timing intervals and should use a suitably conditioned digital edge rather than a noisy analog threshold.

C. Phase-sequence supervision

Phase-sequence supervision is based on the relative timing of the two monitored voltage channels. Correct operation requires a defined relationship between the analog conditioning polarity, zero-crossing edge and expected R/Y phase displacement. The criterion must be verified with both phase orders during commissioning. Because only two phase channels are shown, the function should be described as monitored-phase relationship/sequence supervision, not comprehensive three-phase phase-loss protection.

D. Current measurement

The instantaneous current estimate is:

$i_n = (V_OUT,_n - V_OFFSET)/S$

where V_OFFSET is the measured zero-current output and S is the calibrated sensor sensitivity in volts per ampere. The RMS estimate is $I_RMS = \sqrt{[(1/N)\ \Sigma\ i_n^2]}$. Calibration should be performed at multiple known current points and under the same wiring and ADC conditions used in service.

V. PROTECTION AND CONTROL LOGIC

A. Start permissives

On a START command, the controller should verify that measured voltage values, frequency and monitored phase relationship are within their configured acceptance windows. The contactor command is issued only if the permissives are satisfied and no latched fault is present. The STOP input should de-energize the contactor interface regardless of the operating state.

B. Overcurrent supervision

A current threshold can be defined relative to the motor's nameplate full-load current, I_R. To avoid trips from short transient peaks, the threshold may be required to persist for a specified time. The threshold and delay must be selected from the motor's starting current, load characteristics and manufacturer guidance. They must not be treated as universal settings for all motors up to 5 HP.

C. Overvoltage, undervoltage and phase-sequence protection

The controller evaluates the RMS voltage estimates from the R- and Y-phase sensing channels against configured upper and lower limits. If either monitored voltage exceeds the overvoltage threshold or falls below the undervoltage threshold, the control logic blocks a new start or de-energizes the contactor during operation. The phase-sequence function compares the relative timing of the conditioned phase signals and permits operation only when the detected relationship matches the sequence established during commissioning. These functions provide automatic supervision of abnormal monitored supply conditions. The numerical thresholds should be selected according to the motor rating, supply specification and commissioning measurements.

D. Current-based thermal model

A simple normalized heating accumulator uses the approximate I^2 relationship:

$$\Theta(t) = \int (I(t)/I_R)^2 \, dt$$

For a constant current, the accumulation rate is proportional to $(I/I_R)^2$. Thus, 1.25 times rated current gives a relative rate of 1.5625 and 1.5 times rated current gives 2.25. A practical model also needs a cooling term and a validated trip threshold. These parameters should be derived from motor thermal data or tests; illustrative values alone do not establish a safe overload characteristic.

E. Fault latching and reset

When a configured protection condition is detected, the controller removes the contactor command and records a fault state. A reset command should clear the latch only after the fault has been removed and safe restart conditions have been restored. The final firmware should debounce user inputs and define whether automatic restart is prohibited after a trip.

VI. ILLUSTRATIVE CALCULATIONS

The following calculated examples illustrate the voltage/current measurement calculations and normalized thermal response used to explain the proposed protection logic. They provide numerical examples for understanding the algorithms and their design implications.

Quantity	Reference value	Illustrative value	Relative deviation
R-phase voltage	415 V	414.2 V	−0.19%
Y-phase voltage	415 V	416.1 V	+0.27%
Frequency	50.00 Hz	49.92 Hz	−0.16%
Current example	6.80 A	6.87 A	+1.03%

Table 1. Illustrative calculated values; not measured test data.

I/I_R	Relative I^2 heating rate	Interpretation
1.00	1.00	Reference rate
1.10	1.21	21% higher than reference
1.25	1.5625	56.25% higher than reference
1.50	2.25	2.25 times reference rate
2.00	4.00	4 times reference rate

Table 2. Normalized current-squared relationship.

The calculations demonstrate why sustained overload current can increase heating more rapidly than current itself. They also provide a basis for selecting initial monitoring ranges and planning calibration and performance evaluation of the completed prototype.

VII. PROTECTION RESPONSE

Table 3 summarizes the intended control response for the principal monitored conditions.

Monitored condition	Controller response	Contactor action
Voltage within configured limits	Start permissive available	May energize on START
Undervoltage	Voltage fault	Blocked / de-energized
Overvoltage	Voltage fault	Blocked / de-energized
Incorrect phase sequence	Phase-sequence fault	Blocked / de-energized
Sustained overcurrent	Overcurrent fault	De-energized after configured delay
Thermal threshold reached	Thermal fault	De-energized
STOP command	Stop command	De-energized

VII. DISCUSSION

The principal contribution of the proposed arrangement is the integration of voltage sensing, supply-condition supervision, current monitoring, digital processing, operator interface and contactor command in one embedded controller. The protection logic includes undervoltage, overvoltage and phase-sequence supervision alongside overcurrent and current-based thermal functions. This integrated approach provides a compact platform for displaying electrical parameters and responding to configured abnormal supply or load conditions.

System performance depends on sensor calibration, waveform conditioning, ADC sampling, noise immunity, firmware timing, contactor-coil compatibility and appropriate thermal-model settings. The schematic and firmware should therefore be verified as one integrated design, with protection parameters matched to the motor rating and operating characteristics.

VIII. ADVANTAGES AND APPLICATIONS

The design provides integrated voltage/current monitoring, frequency estimation, monitored-phase sequence supervision, LCD status display and configurable firmware-based protection. Potential applications include small pump and fan drives, workshop equipment and utility motors within the intended rating. Actual application suitability depends on the motor nameplate, supply system, installation category and validated protection settings.

IX. LIMITATIONS AND FUTURE WORK

Further development can expand the voltage-sensing architecture to three channels for full three-phase voltage supervision. Additional evaluation can include calibrated voltage/current measurements, phase-order tests, missing-signal detection, overload time-current characterization, contactor endurance assessment, fault logging and comparison with reference instruments and motor thermal data.

X. CONCLUSION

A microcontroller-based three-phase electronic motor starter and protection/control architecture for motors up to 5 HP has been described. The design combines two ZMPT107-1 voltage-sensing channels, an ACS758 current sensor, an ATmega328P controller, opto-isolated operator inputs, an LCD and a MOC3041-based contactor interface. The integrated control strategy includes RMS voltage estimation, undervoltage and overvoltage protection, zero-crossing-based frequency calculation, phase-sequence supervision, current monitoring, overcurrent protection and a current-squared thermal model. These functions provide a unified approach to monitoring supply conditions and protecting small three-phase induction motors through the contactor-control path.

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APPENDIX A — ARDUINO FIRMWARE STATUS

The Arduino firmware should be finalized against the signal labels and pin assignments in the supplied schematic. The final sketch should map the LCD, START, STOP, BACK, SELECT, voltage-sensing and current-sensing signals to the corresponding ATmega328P pins, and implement zero-crossing timing consistent with the actual conditioning circuit. Phase-sequence logic should be commissioned by testing both phase orders and confirming the expected timing relationship.

For safe commissioning, retain an independent correctly rated motor overload device, isolate all mains circuitry during programming, and verify the contactor interface and supply isolation against the final PCB and component datasheets.