# Microcontroller Based Wye-Delta Starter and Protection Relay for Cage Rotor Induction Motor

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***Abstract:*** *In this study, PIC 18F4520 based wye-delta starting and protection relay was designed and manufactured with semiconductor devices for three phase cage rotor induction motors. Protection relay controls the phase absence and phase sequence before motor starting process. Designed relay system performs better than that of other electromechanical starting and protection relays, due to the decrease in the number of electromechanical components, total volume of relay, complexity of system. Furthermore, the use of microcontroller and semiconductor devices makes the new starter and protection relay design more robust and more reliable.*
***Keywords:*** *Wye-delta starting, motor protection, PIC 18F4520, cage rotor induction motor*.

## 1. Introduction

Since a large amount of energy is required to start an electric motor to overcome the inertia of whole drive system, the starting current of a cage rotor induction motor (CRIM) is increased by 2-8 times than the rated current. Starting current at direct on-line start depends on the rated power of motor and the effective rotor resistance at starting conditions [1-3]. Due to high current demand from the network, a sequence of problems such as voltage drop, high transients and, in some cases, even uncontrolled power-cut can occur during starting [1]. A torque impulse that causes considerable mechanical stress on the rotor bars and windings is also generated [3-5]. Besides, in literature and practice, there are numerous different starting methods, namely, auto-transformer start, soft-start, frequency start, rheostat start, star-delta start etc. and all mentioned methods aim to diminish these undesirable effects at start-up [1, 3].

One of the most common and economic starting methods is wye-delta starting that reduces the winding voltage by √3 times and this method is only applicable to delta connected motors. During the starting process, starting current is approximately 30 % and starting torque is approximately 25-30% of direct on line starting. Ordinarily, a wye-delta starter contains at least three contactors with mechanical and electrical interlocks, and a time limit relay which can be seen in Figure 1. 6 terminals of stator windings are connected properly by use of contactors so as to provide wye-connection and then the connection is switched to delta by another contactor while terminating neutral point at the same time. Basically, a time relay is used to adjust the duration of wye connection that effects current and torque impulse which are reduced as the motor gets closer to synchronous speed. The starting time which can also be determined practically is affected by load torque, starting torque and the inertia of drive system.

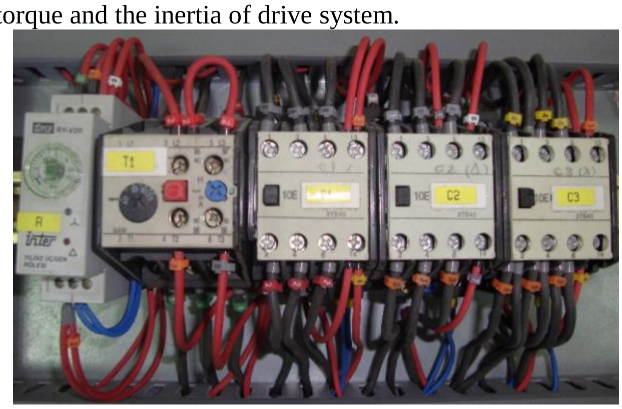


**Figure 1.** Wye-delta starter with mechanical and electrical interlocks, and a timing system.

Since electrical and mechanical interlocks of contactors abrade over time, mechanical failure, increase in maintenance cost and noise are inevitable over time. In addition, the large numbers of electromechanical components, high volume and the complexity of the relay system reduce starting performance, robustness and reliability [6, 7].

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In this study, a more reliable, robust, maintenance-free, noiseless and high-performance wye-delta starter is designed and manufactured by means of a microcontroller and semiconductor devices. Moreover, designed starter circuit also protects CRIM from phase absence and fault of phase sequence with the help of a protection relay algorithm which is embedded into the microcontroller.

## 2. Materials and Methods

Microcontroller based wye-delta starter and protection relay consists of three sub-systems which are wye-delta starter, phase protection relay for CRIM and microcontroller together with its interfaces.

### 2.1. Wye-Delta Starter for CRIM

The wye-delta starters are very common winding voltage reducing starters in industrial applications. The method aims to decrease the starting current by reducing the applied winding voltage. This also reduces the disturbances to the network. In many networks, direct on-line starting for the motors with a rated power greater than 4 kW is restricted by regulations [8]. Wye-delta starter is one of the lowest cost voltage reducing starters which is applicable only to delta connected motors in rated operation.

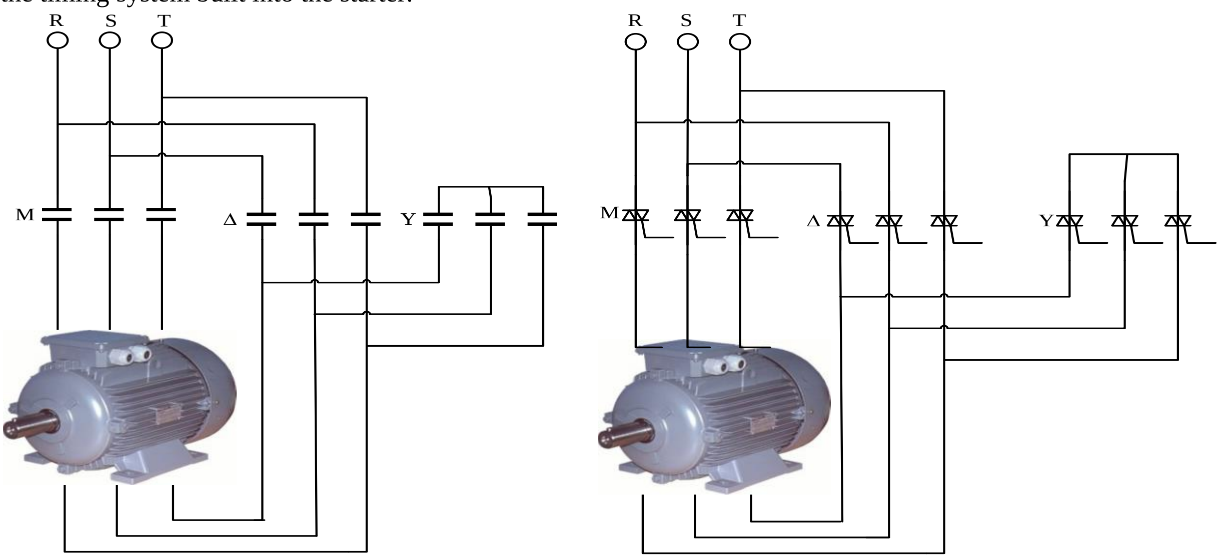
The electromechanical wye-delta starter contains at least three contactors, namely main, wye and delta contactors. The system contains also mechanical and electrical interlocks and a timing system. Figure 2a depicts a basic configuration for a wye-delta starting system with electromechanical equipment. During starting, initially, the main contactor (M) and star contactor (Y) are closed. When the motor gets close to rated speed, star contactor (Y) is opened and delta contactor (Δ) is closed. Control of contactors is provided by mechanical & electrical interlock together with the timing system built into the starter.

One of the main drawbacks of the method is current and torque impulses occurring at two different instances. First disturbance is at the very beginning of starting and the second one is at the instance of connection changing from wye to delta. First impulse happens depending on the nature of starting and second impulse is created at the time that the contacts are opened and closed. The use of electromechanical wye-delta starter creates “Open Transition” during connection change.

Since CRIM is disconnected from the line temporarily while the contacts change position, the connection is being altered from wye to delta occurs. Depending on the transition time, speed of change and the load driven by CRIM, fluctuations in motor current and torque are generated which cause unwanted mechanical and electrical facts on system. In some cases, instantaneous transient current exceeds even the locked rotor current for a short duration and this instantaneous fluctuation can be powerful enough to damage system components. In order to reduce the current and torque fluctuations, the transition time must be reduced. Since electronic switches are faster than electromechanical ones, it is possible to use semiconductor devices instead. A wye-delta starter performed with semiconductor devices such as triac is given in Figure 2b.

A triac is a solid state power switching device that allow current both directions. In other words, a triac can be triggered into conduction by both negative and positive waves and together with both negative and positive trigger pulses applied to its gate terminal. Triacs provide faster, more economical and impeccable power control than mechanical and electromagnetic switches under alternating current. Because of high commutation capability, it does not generate arc during switching operations resulting in mechanical deformations. Cooling requirements are very small due to low on-state voltage drop and dynamic resistance.

In this study, BTA41-600B is used as switching power device which can be frequently used in static relays, heating regulation, induction motor starter, light dimmers and motor speed controllers etc.




a) b)

**Figure 2.** Wye-delta starter connection diagrams a) with electromechanical devices b) with semiconductor devices.

## 2.2. Microcontroller Based Phase Protection Relay

Microcontroller based phase protection relay provide protection against phase absence and phase sequence (or reverse sequence). Phase absence occurs when one phase or more is off which can be typically caused by a blown fuse, broken wire, loose connection or worn contact. This malfunction leads to unnecessarily high currents and the CRIM can still continue to run even after losing one phase resulting in potential motor burn-out. Reversing any two of phases or fault of phase sequence forces a CRIM to run in opposite direction. This may cause damage, accidents, injury, etc. in some practical cases.

In industrial applications, phase protection relay cannot be connected directly to CRIM. An additional contactor system with mechanical and electrical interlocks must be used. Since contactors are electromechanical devices, the life time and number of opening and closing are definite.

In this study, triacs and a microcontroller are used for phase protection making the system free from electromechanical devices. Absence and sequence (or reverse sequence) of phases connected CRIM terminals were detected by microcontroller. An LCD screen is used to visualize the situation for the user. Operational situation and error messages for the faults are printed on the LCD. Basic principle diagram of protection relay given in Figure 3.

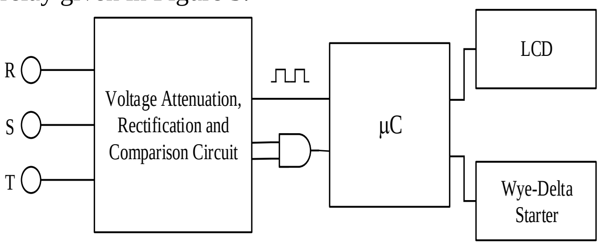



**Figure 3.** Basic principle diagram of microcontroller (µC) based protection relay.

Voltage signals sensed from three-phase terminals are converted into transformed signals via the "voltage attenuation, rectification and comparison circuit" that can be detected by the microcontroller. It can be seen in Figure 4 that each phase (R, S and T in order) has positive cycles just after the end of the positive cycle of the phase in sequence. Reversal of the phase sequence and the phase fault can be determined by this approximation.

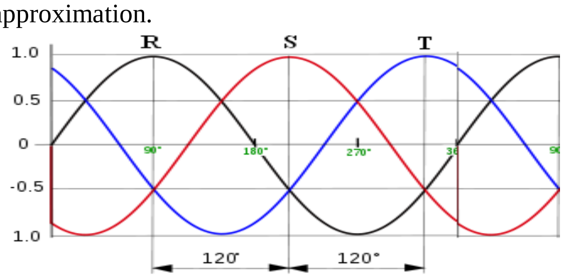



**Figure 4.** Waveform of three-phase voltages.

In order to obtain more accurate results, three open loop operated operational amplifier (OPAMP) and passive circuit elements which are illustrated in Figure 5 were used. These circuits attenuate the phase voltages and convert into square waves with 120º phase difference. In the figure given below, RE0, RE1 and RE2 are connected to E port of microcontroller to detect malfunction in phase sequence.

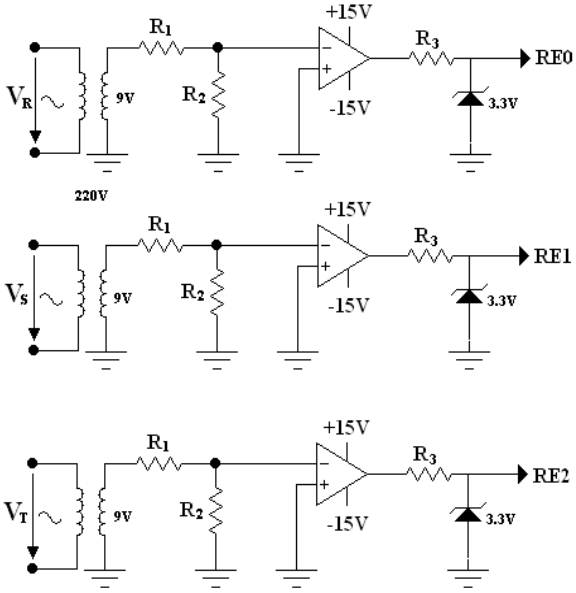



**Figure 5.** Voltage attenuation and comparison circuits performed by open-loop opamps.

In order to detect phase absence, three-phase network voltages were rectified and attenuated. Rectified and attenuated voltage signals are applied to an AND gate. If all three phases exist, the output of the AND gate will be logic 1. If there is a fault at least at one phase, the output of the gate will be logic 0. Phase absence detection circuit is given in Figure 6. In given diagram output of AND gate (RD7) is connected to microcontroller.

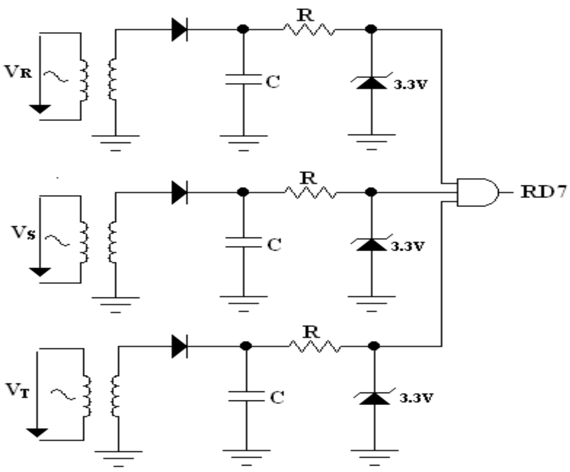



**Figure 6.** Circuit diagram of voltage attenuation and rectification.

## 2.3. Microcontroller and Its Interfaces

In this study, PIC 18F4520 microcontroller from the enhanced flash microcontroller family with 10-Bit A/D and

Nano-Watt technology is used. PIC 18F4520 has 40 MHz operating frequency, 32768 Bytes program memory, 1536 Bytes data memory, 256 Bytes EEPROM (Electrically Erasable Programmable Memory), three programmable external interrupts, four input change interrupts, five input and output units (A, B, C, D, E), four timers, one “capture / compare / PWM module and one enhanced capture / compare / PWM module”, serial communication modules, 10-bit analog digital converter module, programmable low / high voltage detection etc [9].

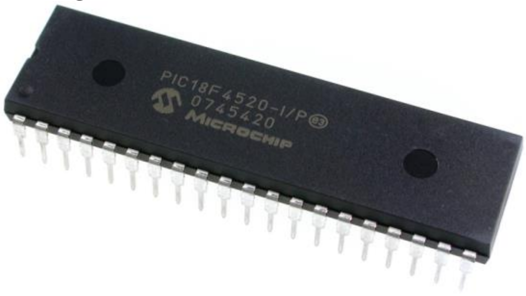



**Figure 7.** PIC 18F4520 from the enhanced flash microcontroller family with 10-Bit A/D and Nano-Watt technology [9].

Output control signals of microcontroller cannot be used directly to trigger a triac. A triac drive circuit is used both to bring the control signals to a level that can turn-on triacs and to provide an electrical isolation between the microcontroller and starter triac circuit. A simple phase drive circuit with zero voltage crossing bilateral triac driver MOC 3041 which is used in the study is given in Figure 8.

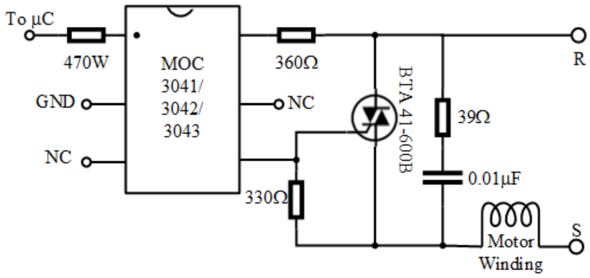



**Figure 8.** A simple phase drive circuit with zero voltage crossing bilateral triac driver [10].

Microcontroller needs a software to be prepared to process the input signals. Basic flowchart of wye-delta starter and protection relay for CRIM is depicted in Figure 9. Operational situation and faults are displayed on the LCD screen by messages prepared in Turkish.

In the prepared and embedded software, phase absence is checked initially. If there is a fault in phase(s), error message is created on LCD for the operator. Secondly, the phase absence and phase sequence are checked. If all phases exist and phase sequence is true, the CRIM is started in wye connection. The wye-delta switching time is set with a delay function in the prepared software and the time depends on the total inertia of the drive system and practical observation on speeding up. Finally, when the motor reaches around rated speed, motor windings are then connected delta by means of triacs.

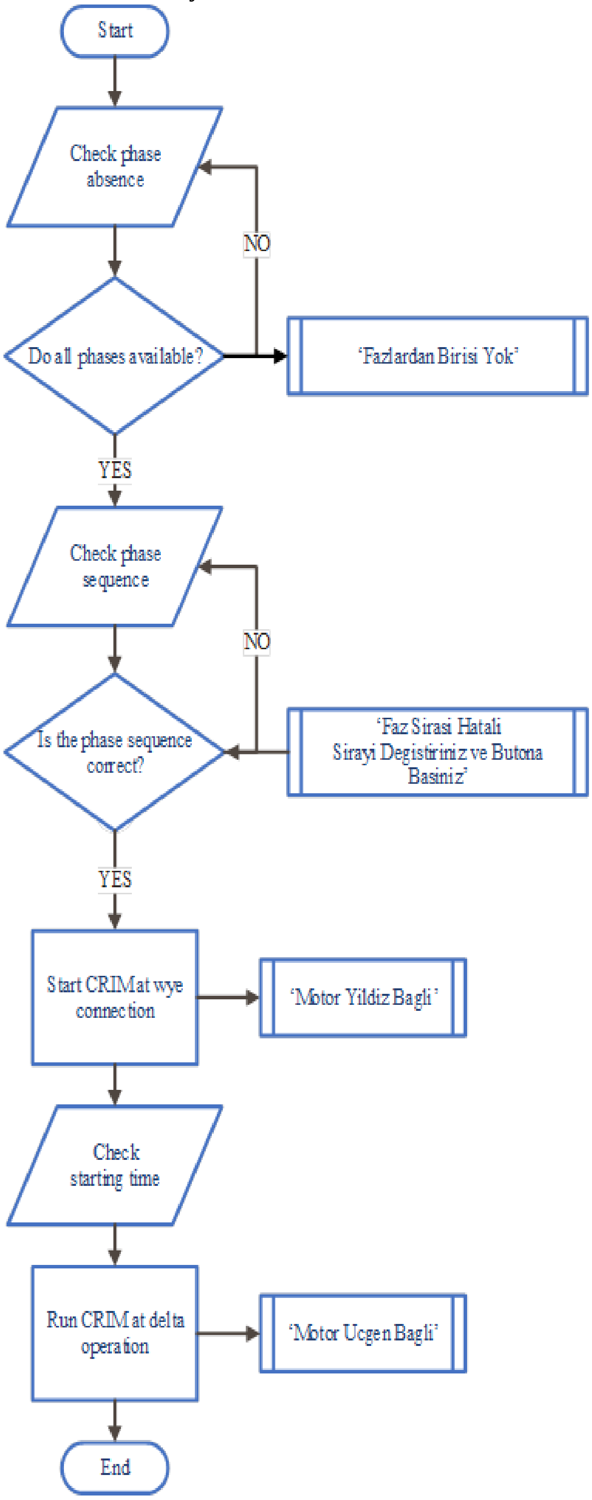



**Figure 9.** Basic flowchart of wye-delta starter and protection relay for CRIM.

## 3. Practical Implementation

All sensing and processing sub-circuits are placed on to same circuit board together with other motor protection elements and circuit breakers. All parts are installed to a box and LCD screen is mounted on the box cover. Designed and manufactured microcontroller based wye-delta starter and protection relay for CRIM Figure 10-11.

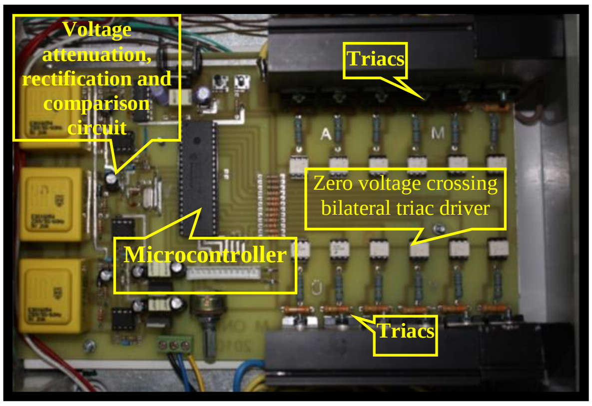



**Figure 10.** The printed circuit board of designed starter and protection relay and its layout of the elements.

**Figure 11.** The boxed designed starter and protection relay and its layout of the elements.

## 4. Test Setup and Application Studies

In order to test to microcontroller based wye-delta starter and protection relay for CRIM, the "FH2 Mk1V" test setup of "TQ Education and Training System" is used with a "FH90 induction motor kit". Motor is loaded by an "Eddy Current Brake" mounted on the bench. The test bench is a modular one that is designed for different types of low power electrical machines. Physical test setup is given in Figure 12.

Necessary connections between CRIM and designed starter were established. The created scenario is to start the motor in wye connection, to run the motor 5 secs and to switch to delta connection by microcontroller based wye-delta starter. When everything is permissible "phase sequence is ok", "motor is wye connected" and "motor is delta connected" (all in Turkish) is written on LCD screen respectively, as seen in Figure 13-14.

During tests, one of the phases was deactivated on purpose, and the starter immediately interrupted CRIM while "one of the phases is missing" (in Turkish) is displayed. (Figure 15) After the phase fault was cleared, the phase sequence is changed for test. "Phase sequence is incorrect, change order and press button" (in Turkish) message is displayed and the motor is not allowed to start. (Figure 16)

CRIM can only be allowed to start in wye connection after clearing all faults.

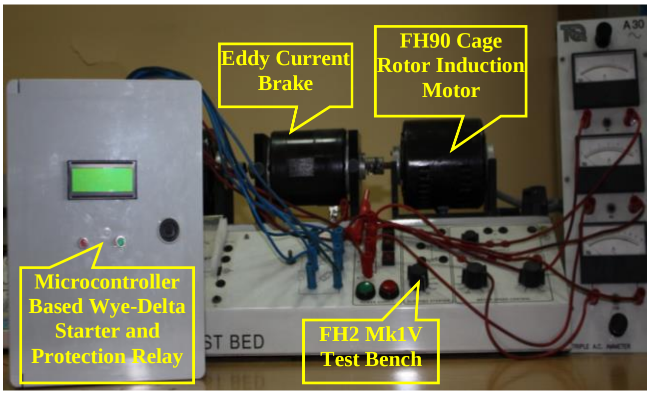



**Figure 12.** Test setup for designed starter and protection relay.


**Figure 13.** The state that the phase sequence is confirmed by the microcontroller and CRIM windings are wye connected.


**Figure 14.** The state that the phase sequence is confirmed by the microcontroller and CRIM windings are delta connected.


**Figure 15.** The state that the one of the phases is in fault.


**Figure 16.** The state that the one of the phases is in fault.

## 5. Conclusion

In this study, microcontroller based wye-delta starter and protection relay for cage rotor induction motors is designed, manufactured and physically tested. The starter and the relay are separated into three main sub-systems and all sub-systems were designed individually and the system is integrated. The sub-systems are “electronic wye-delta starter consisting of triacs”, “microcontroller based phase protection relay” and “microcontroller and its interfaces”.

Nine triacs were used to connect the stator windings of a CRIM instead of three three-phase contactors. Triacs were driven by a phase drive circuit with zero voltage crossing bilateral triac driver.

Sensor circuits for phase sequence and phase absence detection are designed. Phase voltages are attenuated and compared with reference voltage to adapt the converted signals to microcontroller inputs. For evaluating phase absence, measured phase voltages are rectified and applied to an AND gate. All obtained signals are processed by a routine in the microcontroller for detection and visualization. Fault and operational messages are displayed on LCD screen in Turkish.

Practical electronic relay and starter was produced and laboratory tests were performed. Regular start-up procedure without faults was put into practice and expected messages were seen on screen while the motor started according to the prepared scenario. Missing phase and incorrect phase sequences were created and it was seen that the motor was protected by the electronic relay and all expected error messages were seen on screen. It was tested that motor was allowed to start after all faults were cleared.

A low-volume, noise-free, robust, reliable, long-life electronic starter and a protection relay was produced. All disadvantages of mechanical and electromechanical starters and relays were overcome. A faster system response was provided by replacing electromechanical switches and a faster transition interval is provided, since mainly mechanical time-constant is highly greater than electrical one. Acoustic noise was eliminated by using semi-conductor switches. A maintenance-free and a robust starter was provided by removing mechanical contacts. Also the life of the starter was extended by implementing soft-switches. Total volume of the starter was reduced. Overall, system reliability was increased.

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