Design And Development Of A Series Regulated Integrated Starter Generator (ISG) Controller With Diagnostic Features

Karthika A
Dept of Embedded System Technologists
Jayalakshmi Institute of Technology, Thoppur.

Abstract- *Modern automotive systems require efficient electrical power generation and management due to increasing electrical loads and stringent emission regulations. Conventional vehicles utilize separate starter motors and alternators for engine cranking and battery charging respectively. This configuration increases system weight, mechanical complexity, and energy losses. Integrated Starter Generator (ISG) technology has emerged as an efficient solution that combines both functions into a single electromechanical system.*

This paper presents the design and development of a Series Regulated Integrated Starter Generator Controller capable of operating in both motoring and charging modes. In motoring mode, a three-phase MOSFET inverter converts DC battery voltage into three-phase AC to drive the ISG machine and start the engine. In charging mode, the ISG machine operates as a generator and the generated AC power is rectified and regulated using three SCRs operating in series regulation mode.

A microcontroller-based control strategy is implemented to manage inverter switching, SCR firing control, and mode transition between motoring and charging. In addition, a current-based diagnostic system is implemented to detect electrical faults such as phase open faults, phase short faults, and phase-to-ground faults.The proposed ISG controller improves system efficiency, reduces mechanical complexity, and enhances system reliability. Experimental results demonstrate stable engine startup, efficient battery charging, and reliable fault detection under different operating conditions.

Keywords: Integrated Starter Generator, Automotive Power Electronics, MOSFET Inverter, SCR Series Regulation, Fault Detection

I. INTRODUCTION

The increasing demand for improved fuel efficiency and reduced emissions has led to rapid advancements in automotive powertrain technologies. Modern vehicles incorporate numerous electronic subsystems including electronic control units, infotainment systems, lighting systems, safety electronics, and driver assistance systems. These systems significantly increase the electrical power requirements of the vehicle.

Traditional automotive electrical systems rely on two independent machines: the starter motor and the alternator. The starter motor is used only during engine startup, while the alternator generates electrical energy when the engine is running. This configuration introduces additional mechanical complexity and reduces overall system efficiency.

Integrated Starter Generator (ISG) technology integrates both starter and generator functions into a single machine. The ISG system is directly connected to the engine crankshaft and can operate as a motor during engine startup and as a generator during normal operation.

ISG technology is widely used in start-stop systems and mild hybrid electric vehicles (MHEVs). The system provides several advantages including faster engine starting, improved fuel efficiency, reduced emissions, and enhanced energy management.

This paper presents the design and development of a series regulated ISG controller with integrated fault diagnostics for automotive applications.

II. LITERATURE REVIEW

Several researchers have investigated the development of ISG systems for automotive applications.

Chan (2007) presented a comprehensive overview of electric and hybrid vehicle technologies and highlighted the importance of integrated motor-generator systems in improving vehicle efficiency.

Ehsani et al. discussed the design and control of electric motor drives for hybrid vehicles and emphasized the role of ISG systems in energy management.

Various studies have explored the use of power electronic converters for ISG control. MOSFET-based inverters are commonly used in low-voltage automotive applications due to their high switching speed and low conduction losses.

Conventional alternator systems use diode bridge rectifiers combined with shunt voltage regulators. However, this approach results in energy losses because excess energy is dissipated as heat.

SCR-based series regulation offers improved efficiency by controlling the conduction interval of each phase and regulating the output voltage more effectively.

However, many existing ISG systems lack integrated fault detection mechanisms, which are essential for ensuring system reliability.

III. EXISTING SYSTEM

In conventional automotive electrical systems, the starter motor and alternator operate independently.

The starter motor is powered by the vehicle battery and draws a high current during engine startup. The alternator is mechanically driven by the engine and generates AC power which is rectified using diode bridge rectifiers.

Voltage regulation is achieved using shunt regulators that dissipate excess energy as heat.

LIMITATIONS

- High current draw during engine startup
- Low efficiency due to diode rectification losses
- Heat generation due to shunt regulation
- Increased system weight and complexity
- Lack of integrated diagnostic capability

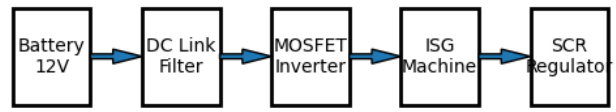
IV. PROPOSED SYSTEM

The proposed system integrates the starter motor and alternator into a single Integrated Starter Generator controlled by a microcontroller.

The system consists of the following major components:

- Vehicle battery
- DC link capacitor
- MOSFET inverter
- ISG machine
- SCR series regulator
- Microcontroller control unit
- Current sensing circuit

SYSTEM BLOCK DIAGRAM



The battery supplies DC power to the inverter during motoring mode. The inverter drives the ISG machine to start the engine. During charging mode, the ISG machine generates AC power which is rectified and regulated by SCR devices.

V. MATHEMATICAL MODELING

The ISG machine can be modeled using the standard three-phase synchronous machine equations.

The phase voltage equation is given by

$$V = Ri + L(di/dt) + e$$

where

V = phase voltage
R = phase resistance
L = phase inductance
i = phase current
e = back EMF

The electromagnetic torque of the machine is given by

$$T = k\Phi I$$

where

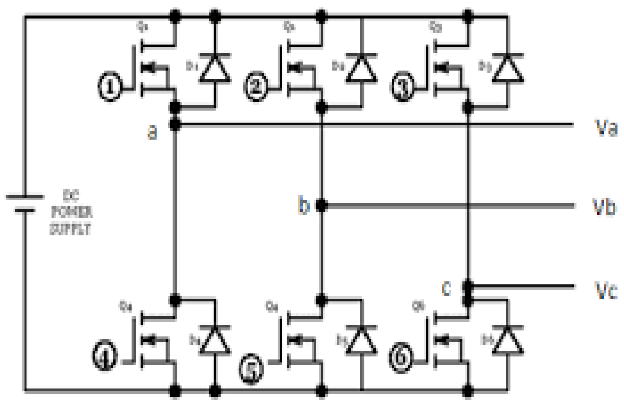
Φ = magnetic flux
I = current
k = machine constant

These equations are used to analyze the motoring and generating behavior of the ISG machine.

VI. MOTORING MODE OPERATION

During engine startup, the ISG machine operates as a motor.The inverter converts DC battery voltage into three-phase AC voltage. PWM control is used to regulate the switching of MOSFET devices.

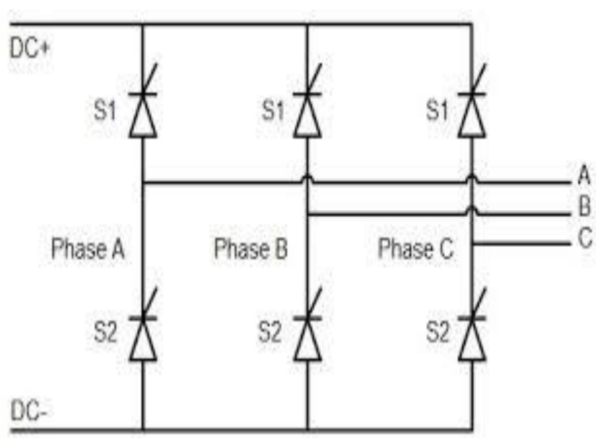
INVERTER DIAGRAM



VII. CHARGING MODE OPERATION

After the engine starts, the ISG machine switches to generator mode.The generated three-phase AC voltage is rectified using SCR devices.

SCR REGULATOR



The output voltage is controlled by adjusting the SCR firing angle.

VIII. CONTROL STRATEGY

The microcontroller performs the following functions:

- PWM generation for inverter control
- SCR firing pulse generation
- Mode switching between motoring and charging
- Fault detection

The control algorithm ensures smooth transition between operating modes.

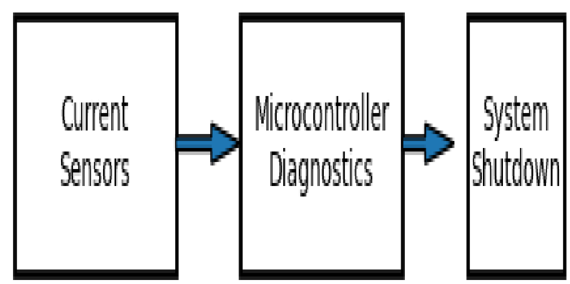
IX. DIAGNOSTIC SYSTEM

The diagnostic system continuously monitors phase currents using current sensors.

FAULT TYPES

- Phase open fault
- Phase short fault
- Phase-to-ground fault

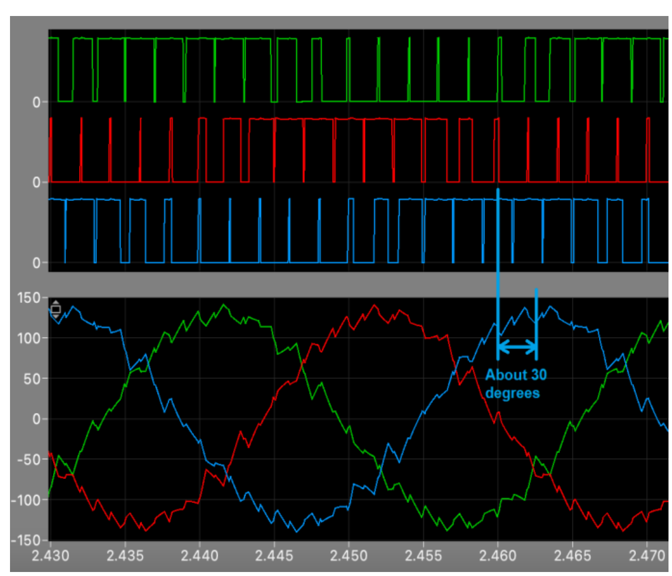
Diagnostic Architecture



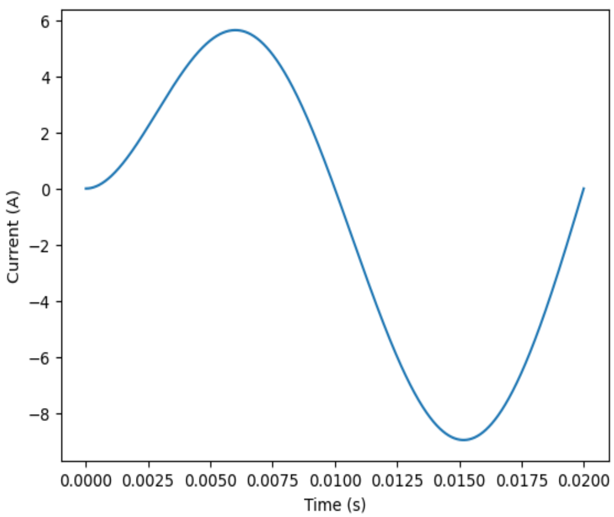
X. EXPERIMENTAL RESULTS

The proposed ISG controller was tested under various operating conditions.

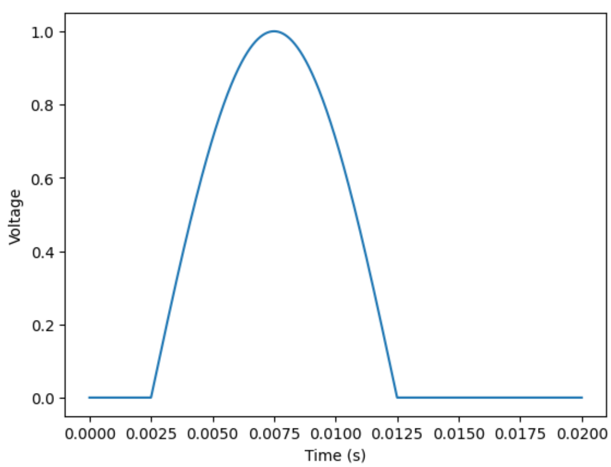
Inverter Voltage Waveform



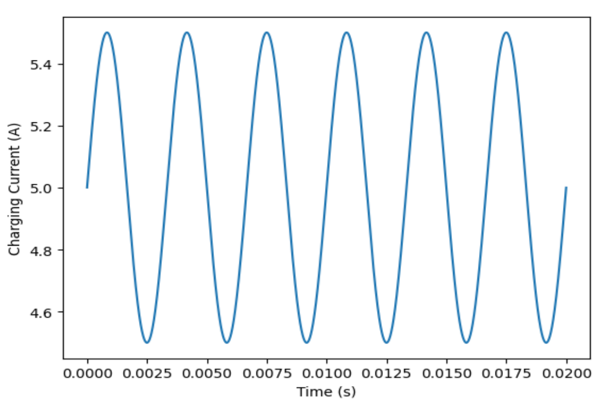
MOTOR CURRENT DURING STARTUP



SCR RECTIFIER OUTPUT



BATTERY CHARGING CURRENT



The results demonstrate stable system operation and efficient charging.

XI. DISCUSSION

The proposed system provides several advantages compared to conventional automotive electrical systems.

The MOSFET inverter provides efficient motor drive capability, while the SCR regulator improves charging efficiency.

The integrated diagnostic system ensures reliable operation and protects the system from electrical faults.

XII. CONCLUSION

A series regulated integrated starter generator controller with diagnostic features has been designed and implemented. The system successfully performs both motoring and charging operations while ensuring system protection through fault detection mechanisms.

XIII. FUTURE SCOPE

Future work may include:

- Integration with 48-V mild hybrid systems
- Regenerative braking capability
- CAN communication interface
- AI-based predictive diagnostics

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