Design And Development Of A Sensorless Integrated Starter Generator Controller Using MOSFET-Based Shunt Regulation

Gokul R
Dept of Embedded System Technologists
Jayalakshmi Institute of Technology, Thoppur.

Abstract- *The increasing demand for improved fuel efficiency and reduced emissions has driven the development of advanced automotive electrical systems. Conventional vehicles utilize separate starter motors and alternators for engine cranking and battery charging respectively, which increases system complexity and reduces efficiency. Integrated Starter Generator (ISG) technology combines these two functions into a single electromechanical unit, thereby reducing mechanical complexity and improving energy utilization.*

This paper presents the design and implementation of a sensorless Integrated Starter Generator (ISG) controller using MOSFET-based shunt regulation. The proposed system employs a three-phase six-switch MOSFET inverter bridge that performs both motoring and charging operations. During engine startup, the inverter operates in motoring mode to drive the ISG machine and crank the engine. Once the engine starts, the ISG operates as a generator and the inverter functions as an active rectifier to convert AC power into DC for battery charging. Voltage regulation is achieved using MOSFET-based shunt control.

A sensorless control strategy based on back electromotive force (Back-EMF) estimation is implemented to eliminate the need for mechanical position sensors. This reduces system cost, improves reliability, and simplifies system integration. Experimental results demonstrate stable engine startup, efficient charging performance, and reliable sensorless operation.

Keywords: Integrated Starter Generator, Sensorless Control, MOSFET Inverter, Shunt Regulation, Automotive Power Electronics

I. INTRODUCTION

The automotive industry is undergoing rapid technological evolution due to increasing environmental concerns and the need for improved fuel efficiency. Modern vehicles incorporate numerous electronic systems such as electronic control units (ECUs), infotainment systems, advanced driver assistance systems, and safety electronics. These systems significantly increase the electrical power demand within the vehicle.

Traditional automotive electrical systems rely on two separate machines: a starter motor and an alternator. The starter motor is used to crank the engine during startup, while the alternator generates electrical energy to charge the battery and supply electrical loads during normal operation.

Although this configuration has been widely used for decades, it suffers from several disadvantages including increased system weight, mechanical complexity, and reduced energy efficiency.

Integrated Starter Generator (ISG) technology addresses these challenges by combining both starter and generator functions into a single electrical machine. The ISG system is directly coupled to the engine crankshaft and can operate as a motor during engine startup and as a generator during normal operation.

This paper presents the design and development of a sensorless ISG controller using MOSFET-based shunt regulation, enabling both motoring and charging operations using a single inverter bridge.

II. LITERATURE REVIEW

Several studies have investigated the development of Integrated Starter Generator 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 in hybrid vehicles and emphasized the role of ISG systems in energy management.

Traditional automotive charging systems employ diode bridge rectifiers and shunt regulators. Although this approach is simple, it results in energy losses due to heat dissipation.Recent research has explored the use of active rectifiers and MOSFET-based inverters to improve efficiency and enable bidirectional power flow between the battery and the motor-generator system.

However, many existing ISG systems rely on rotor position sensors such as Hall sensors or encoders. These sensors increase system cost and reduce reliability in harsh automotive environments.

The proposed system implements a sensorless control strategy using back-EMF estimation, eliminating the need for mechanical position sensors while maintaining reliable motor control.

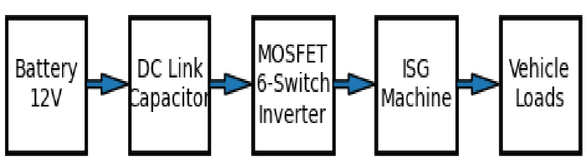
III. SYSTEM ARCHITECTURE

The proposed ISG controller integrates engine starting and battery charging functions into a single power electronics architecture.

The main components of the system include:

- Vehicle battery
- DC link capacitor
- Three-phase MOSFET inverter bridge
- Integrated starter generator machine
- Microcontroller-based control unit
- Current sensing circuit
- Voltage sensing circuit

The battery supplies DC power to the inverter during motoring mode. During charging mode, the ISG machine generates AC power which is converted to DC through the inverter operating as an active rectifier.



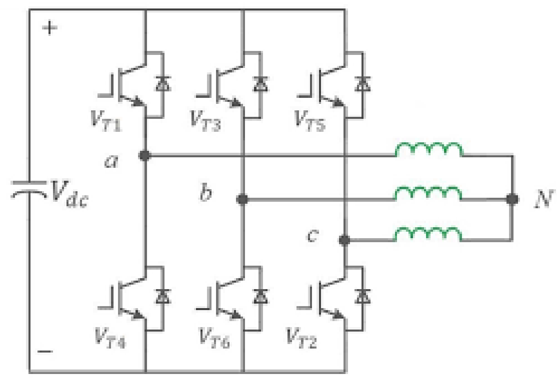
IV. MOSFET INVERTER BRIDGE

The power conversion stage consists of six MOSFET switches arranged in a three-phase bridge configuration. Each motor phase consists of one high-side MOSFET and one low-side MOSFET.

This configuration enables bidirectional power flow between the battery and the ISG machine.

The MOSFET inverter performs the following functions:

- DC-to-AC conversion during motoring mode
- AC-to-DC conversion during charging mode
- Voltage regulation through shunt control



V. MOTORING MODE OPERATION

During engine startup, the ISG machine operates as a motor. The battery supplies DC power to the inverter which generates three-phase AC voltage using Pulse Width Modulation (PWM).

The inverter switching sequence produces rotating magnetic fields in the stator windings, generating torque that rotates the engine crankshaft.

The motoring process can be summarized as follows:

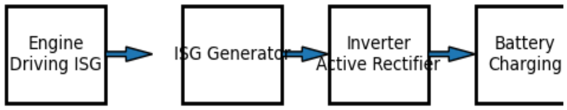
1. Engine start command is received from the vehicle control unit.
2. The inverter generates three-phase AC voltage.
3. The ISG machine produces electromagnetic torque.
4. The engine crankshaft begins to rotate.
5. Once combustion begins, the engine operates independently.

VI. CHARGING MODE OPERATION

After the engine starts, the ISG machine switches to generator mode. Mechanical energy from the engine is converted into electrical energy.

The generated three-phase AC voltage is applied to the inverter bridge, which now operates as an active rectifier.

The rectified DC voltage is used to charge the battery and supply electrical loads within the vehicle.



VII. SHUNT VOLTAGE REGULATION

Battery voltage regulation is achieved using MOSFET-based shunt control. When the battery voltage exceeds the desired charging level, the controller modulates the inverter switching pattern to dissipate excess energy within the machine windings.

This method allows voltage regulation without additional external regulators.

Advantages of MOSFET-based shunt regulation include:

- Reduced hardware complexity
- Fast response time
- Integration with inverter control
- Reduced component count

VIII. SENSORLESS CONTROL STRATEGY

Conventional motor drive systems use position sensors such as Hall sensors or encoders to determine rotor position. However, these sensors increase cost and reduce reliability.

To overcome these limitations, a sensorless control strategy based on back-EMF estimation is implemented.

The back EMF of the motor phase is given by

$E=Ke\omega$

where

E = back EMF voltage
Ke = back EMF constant
ω = rotor angular speed

The controller estimates rotor position by detecting the zero crossing of back EMF signals.

IX. MATHEMATICAL MODELING

The electrical behavior of the ISG machine can be described by the phase voltage equation

$$V = Ri + L\frac{di}{dt} + e$$

where

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

The electromagnetic torque generated by the motor is given by

$T=KtI$

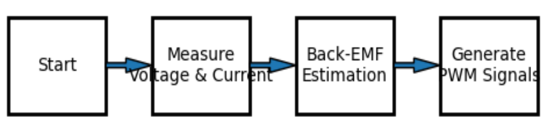
where

Kt = torque constant
I = current

X. CONTROL ALGORITHM

The microcontroller executes a real-time control algorithm responsible for

- PWM generation for inverter switching
- Mode switching between motoring and charging
- Battery voltage monitoring
- Current monitoring
- Fault detection
- Sensorless rotor position estimation

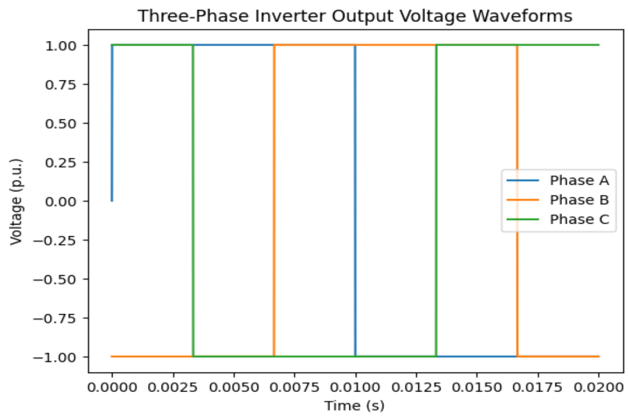


XI. EXPERIMENTAL RESULTS

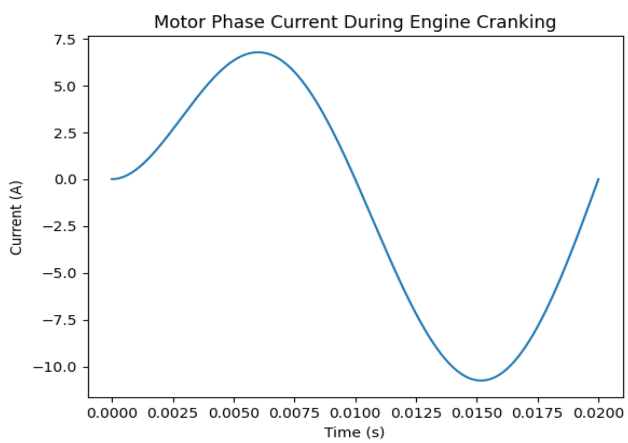
The proposed ISG controller was tested under various operating conditions.During motoring mode, the inverter generated balanced three-phase voltages and successfully started the engine.

During charging mode, the system maintained stable battery voltage.

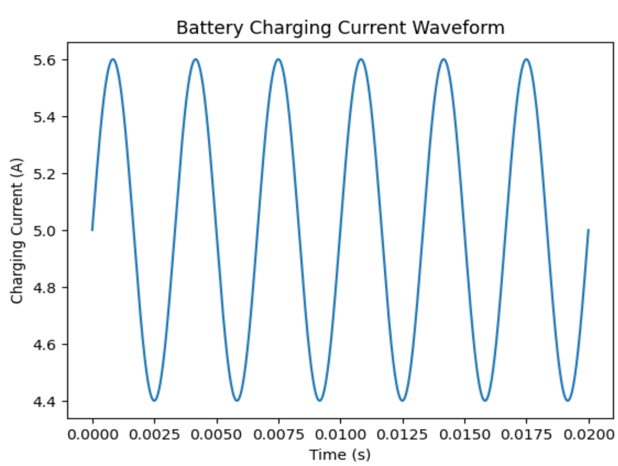
1.Three-Phase Inverter Output Voltage



2. Motor Phase Current During Engine Cranking



3.BATTERY CHARGING CURRENT



XII. DISCUSSION

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

- Reduced component count
- Improved system integration
- Bidirectional power flow capability
- Elimination of mechanical position sensors
- Simplified hardware design

However, shunt regulation introduces some energy losses compared to series regulation.

XIII. CONCLUSION

A sensorless Integrated Starter Generator controller using MOSFET-based shunt regulation has been designed and implemented. The system successfully performs both engine cranking and battery charging using a single inverter bridge.

The elimination of mechanical position sensors improves system reliability and reduces cost. The proposed architecture provides a compact and efficient solution for modern automotive electrical systems.

XIV. FUTURE SCOPE

Future work may include

- Field Oriented Control (FOC) implementation
- Integration with 48-V mild hybrid systems
- CAN communication with vehicle ECU
- Regenerative braking capability

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