Belt StarterGenerator(BSG)

Software Requirements

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Table of Contents

1.Introduction

1.1 **Purpose**

In recent years, there has been a huge effort to face the challenges of the environmental impacts caused by the burning of fossil fuels. Some of the measures taken include stringent emission regulations around the world, which directly affect vehicle manufacturers by requiring them to find more environmentally friendly solutions to car designing. Some examples are turbochargers, engine downsize and cylinder deactivation to improve fuel efficiency and catalytic converters to reduce Nox emissions.

However, it is necessary to implement more drastic and effective solutions to deal with this matter. One of the most promising and relevant options are the hybrid powertrain architectures, applied in Hybrid Electric Vehicles (HEVs), which are vehicles that use internal combustion engines (ICEs) in combination with one or more electric machines (EM) connected to a battery or to an electric generator. These devices work providing propulsion to the vehicle in question, and they can act together or separately.

HEVs can be classified according to their architecture in the following categories:

- **Series HEV**: a generator is placed in series with the ICE, producing electric energy to one or more electric motors. This design does not allow direct mechanical connection between the ICE and the wheels. This model allows the ICE to be controlled independently of the power demand and close to its peak efficiency point. However, this architecture requires powerful and expensive batteries;
- **Parallel HEV**: here, both ICE and EM work independently or together to provide traction. The ICE is connected mechanically to the transmission system, while the EM is used as a support device to the engine; however, it can, in some instances, be used as the primary source of power of the vehicle. This configuration allows the ICE to operate in its most efficient stat;
- **Series-Parallel HEV**: this setup requires two electric machines: one that acts like a generator and one that acts as a motor. The second one is connected to the ICE with a planetary engine splitting device, which allows the vehicle to operate as a Series HEV or as a Parallel HEV.

Usually, parallel configurations are more widely used due to their reduced weight, size and cost. This category can be categorized according to what is called degree of hybridization, which is the ratio of power developed by an electric motor to the total power consumed by the vehicle hybridization. There are four classes:

- **Micro HEVs**: degree of hybridization is less than 5%. Here, the electric motor is used to shut down the engine when the vehicle comes to a complete stop and start it when the driver hits the pedal;

- **Mild HEVs**: in this case, the degree of hybridization can reach values up to 10% and there is a battery which also allows power assist during vehicle propulsion. Mild HEVs have increased fuel efficiency;
- **Full HEVs**: the batteries in this configuration are significantly bigger than those in the mild version. Here, the electric motor can be used as the only source of power to the vehicle;
- **Plug in HEVs**: basically possess the same configuration as a full HEV but they also have an external electric grid charging plug, bigger electrical components and a downsized engine. These vehicles can run on solely electric power for long periods of time.

The device referred to in this document as a Belt Starter Generator (BSG) is a hybridization strategy that can be classified as a PARALLEL MILD HYBRID. Therefore, it should be able to not only act as a start/stop device, but also as a torque assistance device. Furthermore, BSGs have the capacity to work the other way around charging the batteries to which it is linked.

More specifically, the purpose of this document is to present the elicitation of requirements for a Belt Start Generator applied to a hybrid system, composed of an internal Otto cycle combustion engine. The BSG is intended to assist ICE by recognizing the needs of the propulsion system, providing fuel economy, aligned to carbon emission reduction, while increasing the vehicle's torque. In an auxiliary way, the applied system for BSG additionally guarantees the recharging of embedded batteries through regenerative braking mechanism.

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Bojoi, Radu, Andrea Cavagnino, Marco Cossale, and Alberto Tenconi. "Multiphase Starter Generator for a 48-V Mini-Hybrid Powertrain: Design and Testing." IEEE Transactions on Industry Applications 52.2 (2016): 1750-758. Web.

2. Requirements

2.1 **Functional Requirements**

[TL-01] BSG CONTROL SYSTEM: the BSG (Belt Starter Generator) must operate in only one mode at a time: torque assistance, regeneration, and starter motor.

- **[FR-01] TORQUE ASSISTANCE:** In TORQUE ASSISTANCE mode, the BSG must provide torque to the vehicle, actively acting on the movement when requested through the energy stored in the batteries;

    - **[SyR-01] TORQUE REQUEST SIGNAL:**In the TORQUE ASSISTANCE mode, the BSG must be able to receive a signal indicating a TORQUE REQUEST.

    - **[SyR-02] GEAR SHIFT SIGNAL:** in the TORQUE ASSISTANCE mode, the BSG must be able to receive a signal indicating the vehicle's current gear;

    - **[SyR-03] TORQUE ASSISTANCE ENERGY SOURCE:** The TORQUE ASSISTANCE mode must function using energy from the 48V battery primarily.

    - **[SoR-01] TORQUE ASSISTANCE ACTIVATION CRITERIA:** If the BSG receives a TORQUE REQUEST signal, the system must act as a motor by providing the torque rate as defined by the input signal.

    - **[SoR-02] TORQUE ASSISTANCE AFTER SOFT START:** After the application of the START/STOP function, the TORQUE ASSISTANCE mode must be activated in order to move the vehicle from a stationary position;

    - **[SoR-03] TORQUE DURING GEAR SHIFT:** when the gear shift signal indicates the value 0, the BSG must comprehend this as a gear shift, and therefore must function in the TORQUE ASSISTANCE mode in order to increase efficiency during the process of gear shift;

- **[FR-02] RECHARGE MODE**: In the RECHARGE mode, the BSG must use the ALTERNATOR FUNCTION or the REGENERATIVE BRAKING FUNCTION to recharge both the 48V and 12V main batteries of the vehicle:

- **[FR-03] ALTERNATOR FUNCTION:** While in RECHARGE MODE and while the engine is working and BSG is not functioning in one of the specified modes, the system must work providing charge to the batteries through the belt;

- **[FR-04] REGENERATIVE BRAKING FUNCTION**: When the vehicle is moving and the brake pedal is activated, the BSG must work in RECHARGE MODE through regenerative braking.

    - **[SyR-04] BRAKE ACTIVATION SIGNAL:** In the REGENERATIVE BRAKING mode, the BSG must be able to receive a signal indicating the activation of the brake pedal for adjustment.

    - **[SyR-05] VEHICLE SPEED SIGNAL:** In the REGENERATIVE BRAKING mode, the BSG must be able to receive a signal indicating the vehicle's speed.

    - **[SoR-04] REGENERATIVE BRAKING ACTIVATION CRITERIA:** If BSG receives a signal indicating that the braking system was activated and another that indicates that the car is moving, the BSG must actuate in REGENERATIVE BRAKING mode;

- **[FR-05] STARTER MOTOR MODE:** In the STARTER MOTOR mode, the BSG must, upon request, start the vehicle's engine or provide a soft start**:**

    - **[SyR-06] ENGINE START SIGNAL:** In the STARTER MOTOR mode, the BSG must be able to receive a signal indicating that the driver turns on the engine.

    - **[SyR-07] ENGINE SOFT START SIGNAL:** In the STARTER MOTOR mode, the BSG must be able to receive a signal indicating that the engine should be activated, coming from the START/STOP system;

    - **[SyR-08] STARTER MOTOR ENERGY SOURCE:** The STARTER MOTOR mode must function using energy from the 48V battery primarily;

    - **[SoR-05] ENGINE START CRITERIA:** If the BSG receives the signal specified in SyR-05, it must function in STARTER MOTOR MODE assisting the engine in its start;

    - **[SoR-06] ENGINE SOFT START CRITERIA:** If the BSG receives the signal specified in SyR-06, it must function in STARTER MOTOR MODE assisting the engine in its soft start;

Parallel to the control of the electric machine, supervisory processes must take place, ensuring that all functions and systems integrated with the BSG operate harmoniously.

- **[FR-06] BATTERY MONITORING:** The BSG must monitor and control the charge level of both batteries, preventing either of them from discharging excessively;

    - **[SyR-09] 12V BATTERY CHARGE SIGNAL:** The BSG must be able to receive a signal indicating the current charge of the 12V battery;

    - **[SyR-10] 48V BATTERY CHARGE SIGNAL:** The BSG must be able to receive a signal indicating the current charge of the 48V battery.

    - **[SyR-11] 12V BATTERY CHARGING CURRENT SIGNAL:** The BSG must be able to receive a signal indicating the current charging current provided by the 12V battery;

    - **[SyR-12] 48V BATTERY CHARGING CURRENT SIGNAL:** The BSG must be able to receive a signal indicating the current charging current provided by the 48V battery;

    - **[SoR-07] CHARGING PRIORITY:** If both batteries have the same charge, priority should be given to charging the main 12V battery of the car.

    - **[SoR-08] TORQUE ASSISTANCE 48V LIMITATION:** If the 48V battery's charge is below a reference value, the TORQUE ASSISTANCE mode must not operate;

    - **[SoR-09] 12V BATTERY USE LIMITATION:** If the 12V battery's charge is below a reference value,it should not be used to provide energy to any of the BSGs functions;

    - **[SoR-10] STARTER MOTOR USE OF 12V BATTERY:** If the 48V battery is unable to provide energy for the execution of the STARTER MOTOR mode, the 12V battery must supply the necessary energy for the required actions, given its charge is within the referenced value specified.

    - **[SoR-11] STARTER MOTOR CRITICAL SCENARIO:** If the 48V battery's charge is below a reference value, the STARTER MOTOR may still operate if necessary;

    - **[SyR-13] 12V BATTERY VOLTAGE SIGNAL:** The system must be able to receive a signal indicating the 12V battery voltage

    - **[SyR-14] 48V BATTERY VOLTAGE SIGNAL:** The system must be able to receive a signal indicating the 48V battery voltage;

    - **[SoR-12] BATTERIES UNCOUPLING:** If both batteries are fully charged, they must be uncoupled from the system in order to preserve their lifespan;

    - **[SoR-13] BATTERIES CHARGE WARING:** The system must provide a warning on the drivers panel that informs that both batteries have low charge and this can compromise engine start;

- **[FR-07] SAFETY SWITCH:** the BSG must be able to be shut down in case there are abnormalities in the system that prevent the mechanism to work safely;

    - **[SyR-15] SAFETY SIGNAL:** The BSG must be able to receive a signal indicating failures in the system;

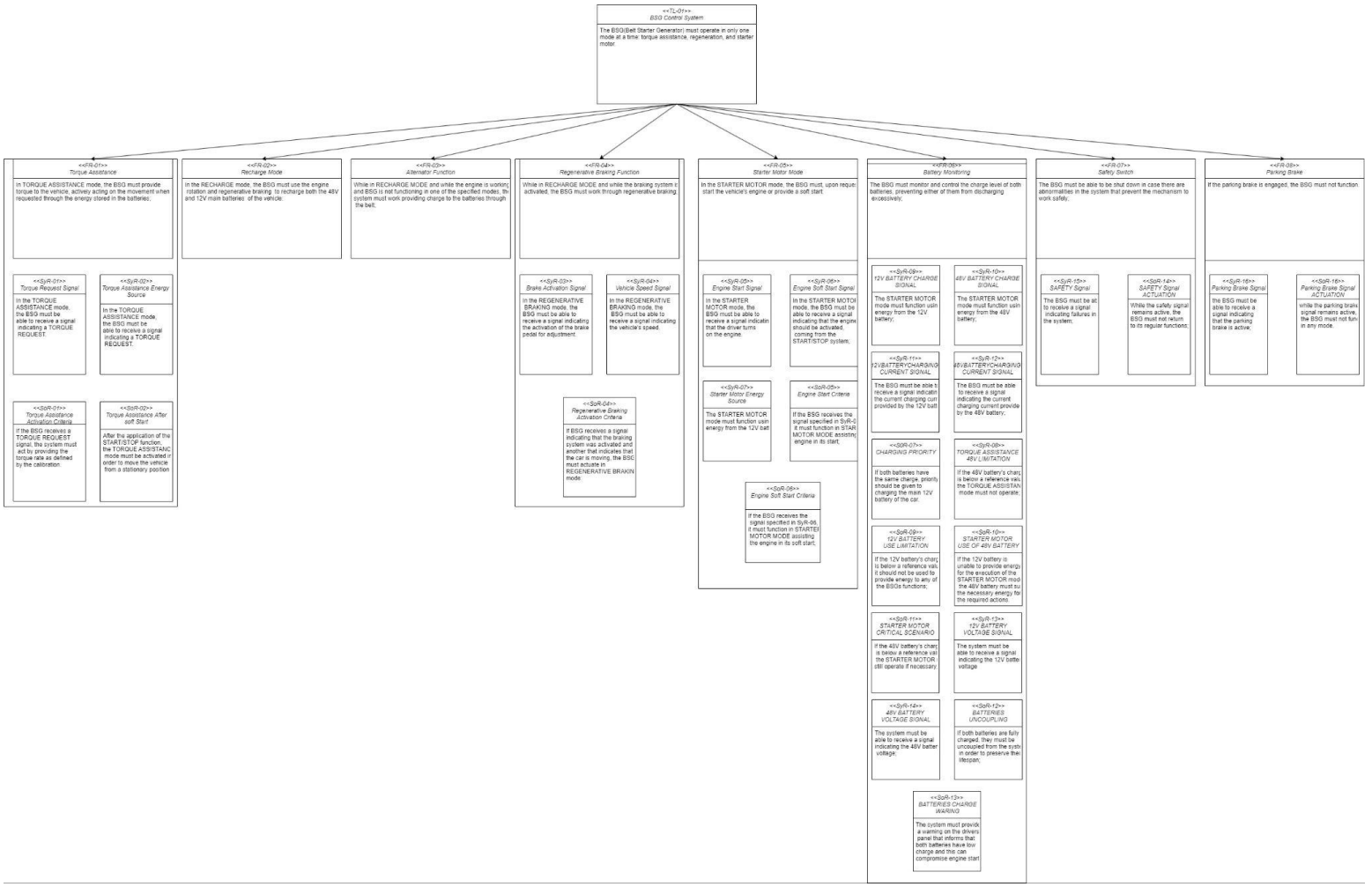
    - **[SoR-14] SAFETY SIGNAL ACTUATION:** While the safety signal remains active, the BSG must not return to its regular functions;

- **[FR-08] PARKING BRAKE**: If the parking brake is engaged, the BSG must not function.

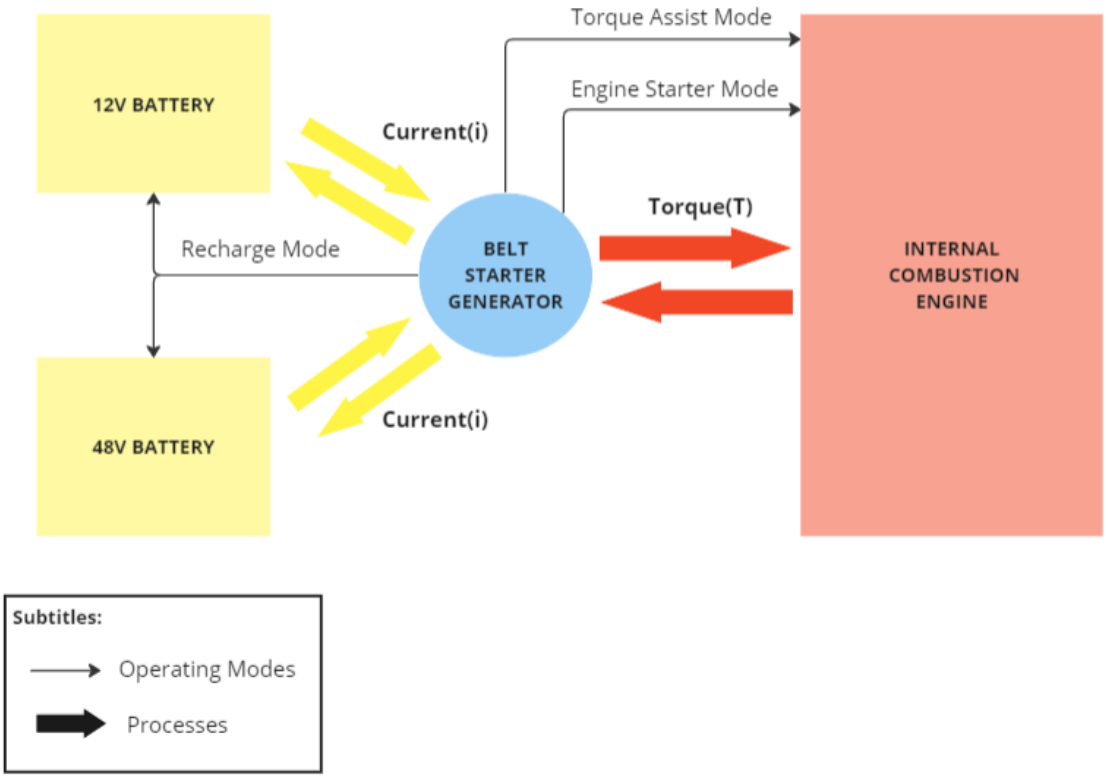
    - **[SyR-16] PARKING BRAKE SIGNAL:** the BSG must be able to receive a signal indicating that the parking brake is active;

    - **[SoR-15] PARKING BRAKE ACTUATION:** while the parking brake signal remains active, the BSG must not function in any mode

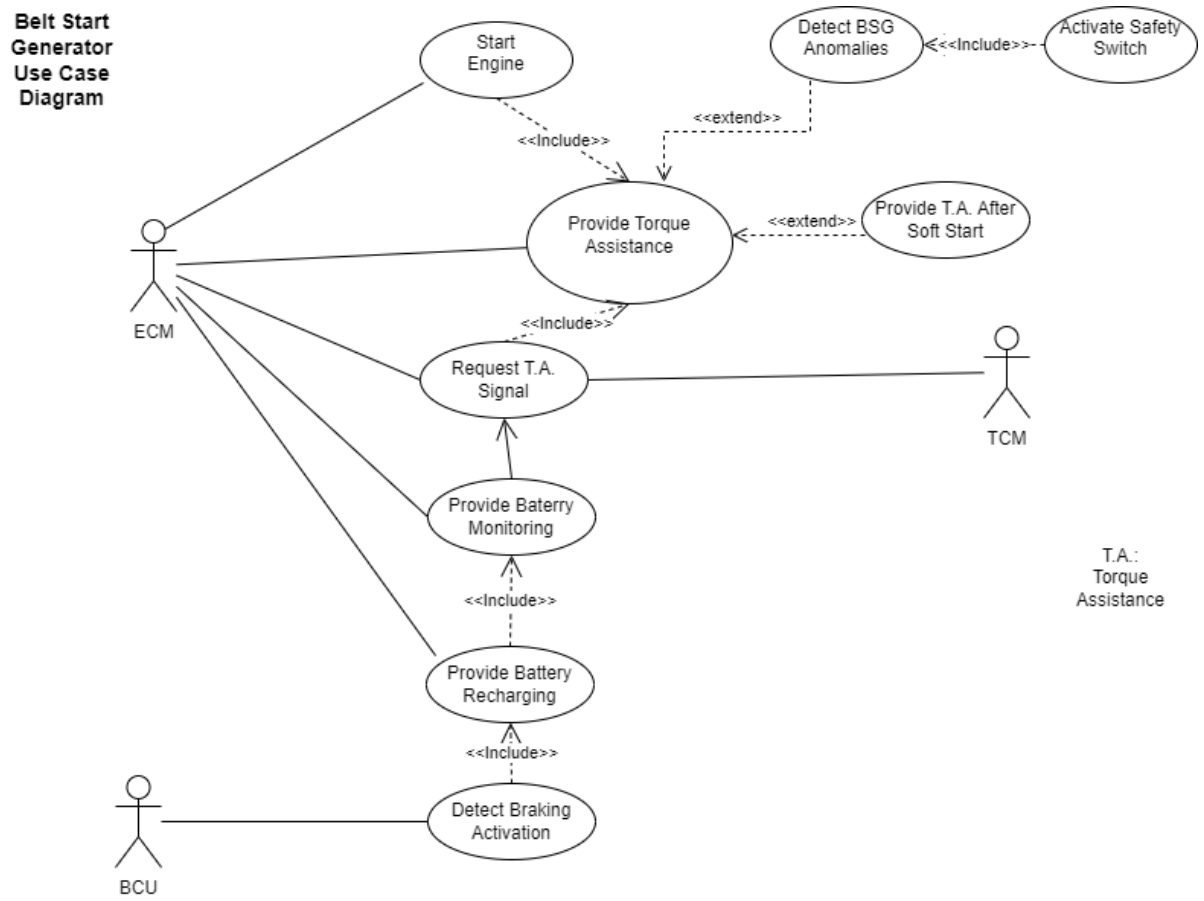
3. Requirements Diagram



3.1 Operating Modes Diagram



3.2 Use case Diagram



3.3 Requirements traceability table

Req.	Affected Requirements							
TL-01	FR-01	FR-02	FR-03	FR-04	FR-05	FR-06	FR-07	FR-08
FR-01	FR-03	FR-04	FR-06					
FR-02	FR-03	FR-04	FR-06					
FR-03	FR-02	FR-04						
FR-04	FR-02	FR-03						
FR-05	FR-06							
FR-06	FR-01	FR-02	FR-03	FR-04	FR-05	FR-07	FR-08	
FR-07	FR-01	FR-02	FR-03	FR-04	FR-05	FR-08		
FR-08	FR-01	FR-02	FR-03	FR-04	FR-05			