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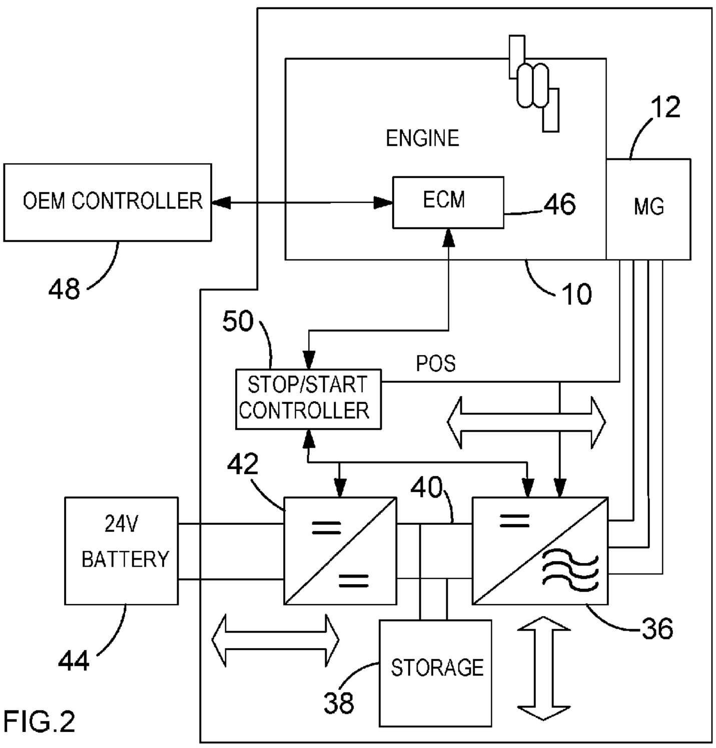

FIG.2

(57) **Abstract**: A stop-start system is disclosed for a vehicle comprising an electrical starter-generator (MG,12) directly coupled to the crankshaft of the internal combustion engine (10). The stop/start system comprises a stop/start controller (50) arranged to vary torque produced by the starter-generator (MG,12) during a stop/start event to at least partially compensate for variations in torque produced by the engine (10).

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VEHICLE WITH A START-STOP SYSTEM WHEREIN THE STARTER-GENERATOR IS DIRECTLY COUPLED TO THE INTERNAL COMBUSTION ENGINE

The present invention relates to a stop-start system for a vehicle, and in particular a vehicle having an integrated engine and electrical machine. The present invention has particular, but not exclusive, application with commercial vehicles such as buses, trucks, lorries and vans.

Hybrid vehicles combine an internal combustion engine with an electrical machine to achieve fuel savings and reduce emissions. Various types of hybrid vehicle are currently in production. A vehicle which can be driven by just the electrical machine is sometimes referred to as a full hybrid, while a vehicle in which the electrical machine is only able to assist the internal combustion engine is sometimes referred to as a mild hybrid. Mild hybrids can have smaller batteries and a less powerful electrical machine than a full hybrid, which allows their cost and weight to be reduced.

Hybrid vehicles usually include a stop-start system, which automatically shuts down and restarts the internal combustion engine to reduce the amount of time the engine spends idling, thereby reducing fuel consumption and emissions. Stop-start systems are also present in some vehicles in which an electrical machine is not used to drive the vehicle, and these vehicles are sometimes referred to as micro-hybrids.

Hybrid vehicles are particularly advantageous in urban environments where frequent stops and starts are encountered and emissions are most harmful. There is therefore an increasing interest in commercial vehicles with some degree of hybridization in order to reduce emissions and fuel consumption.

Currently available commercial hybrid vehicles tend to use parallel hybrid systems, in which the internal combustion engine and the electrical machine are both coupled to the vehicle’s transmission. This usually requires an arrangement of gears and clutches in the drive train, which makes the system expensive and difficult to retrofit. Existing stop/start systems also tend to require special batteries, and suffer from a limit to the frequency at which stop/start events can occur. These drawbacks have to date limited the take-up of hybrid commercial vehicles.

According to a first aspect of the present invention there is provided a stop/start controller for controlling stop/start events in a vehicle comprising an integrated engine and electrical machine, wherein the stop/start controller is arranged to vary torque produced by the electrical machine during a stop/start event to at least partially compensate for variations in torque produced by the engine.

The present invention may provide the advantage that, by varying the torque produced by the electrical machine during a stop/start event to at least partially compensate for variations in torque produced by the engine, the effect of torque pulses produced by the engine may be reduced. This may allow the engine to be stopped and/or started more smoothly, more quickly, and/or more efficiently than would otherwise be the case. This may also allow the frequency at which stop/start events can take place to be increased, and/or allow lower cost components to be used.

By “stop/start event” it is preferably meant either a stop event, or a start event, or both.

Preferably the stop/start controller is arranged to control the electrical machine to vary the torque applied by the electrical machine to the engine. This can allow the amount of torque applied to be tailor to the specific circumstances, and thus allow more efficient operation of the electrical machine. This in turn may reduce the amount of electrical storage required to power the electrical machine.

Preferably the amount of torque applied by the electrical machine is variable within one cycle of the engine. This can allow the electrical machine at least partially to compensate for variations in the torque produced by the engine due to different parts of the engine cycle. Thus the torque applied by the electrical machine may be variable during an engine cycle so as to reduce variations in the torque produced by the engine during the engine cycle. This can allow vibration which is produced by the engine to be reduced.

Preferably the stop/start controller is arranged to at least partially compensate for torque produced by at least one of a compression stroke, an expansion stroke and a combustion stroke.

Preferably the electrical machine is arranged to absorb torque produced by the engine during a combustion stroke and/or an expansion stroke. This may help to reduce vibrations produced by the engine, and may also lead to more efficient operation since the absorbed energy can be used to charge an electrical storage device.

Preferably the stop/start controller is arranged to control the electrical machine such that the electrical machine applies a negative torque to the engine during a stop event. This can allow the engine to be brought to a stop more quickly and/or more efficiently than would otherwise be the case.

The stop/start controller may be arranged to control the electrical machine such that the electrical machine applies a variable torque to the engine during a stop event. This can allow the appropriate amount of torque to be applied, which may lead to more efficient operation.

Usually when an engine is restarted following a stop event, the exact position of the engine's crankshaft is not known. This can lead to a delay and/or judder when starting the engine.

In a preferred embodiment, the stop/start controller is arranged to control the electrical machine such that the engine is brought to a stop in a predetermined position. This preferably involves stopping the engine with the engine crankshaft at a predetermined angle. The predetermined position may be, for example, with a piston at or close to the start of an inlet stroke. With this arrangement, when the engine is restarted, the starting position of the engine is known and the engine can go straight into an inlet stroke. This may make the engine easier to start, and may allow the engine to be restarted more quickly and/or with less vibration.

When an engine comes to a stop, it usually produces vibration as the engine speed reduces, due to movement of the pistons in the engine. In a preferred embodiment, the stop/start controller is arranged to control the electrical machine to produce a variable negative torque to dampen vibrations of the engine during a stop event. For example, the variable negative torque produced by the electrical machine may oppose torque produced by the engine during at least one of a compression stroke and an expansion stroke. This can allow the engine to be stopped more smoothly. Furthermore, the negative torque produced by the electrical machine can be used to charge an electrical storage device.

Preferably the stop-start controller is arranged to vary a negative torque produced by the electrical machine during a stop event such that the negative torque is less during a compression stroke and/or greater during an expansion stroke than at other points in the engine cycle during the stop event. This may allow the effect of pulses of torque produced by the engine during a stop event to be reduced. This may allow the engine to be brought to a stop more smoothly, more quickly, and/or more efficiently than may otherwise be the case.

The electrical machine is preferably used as a starter motor to start the engine during a start event. The stop/start controller may be arranged to control the electrical machine to control starting of the engine. For example, the stop/start controller may be arranged to control the electrical machine such that the electrical machine applies a variable torque to the engine during a start event. This may allow the engine to be started more quickly and/or more efficiently.

When an engine is started, it usually produces vibrations as the engine turns and combustion starts. In a preferred embodiment, the stop/start controller is arranged to control the electrical machine to produce a variable torque to dampen vibrations of the engine during a start event. For example, the variable torque produced by the electrical machine may oppose torque produced by the engine during at least one of a combustion stroke, a compression stroke and an expansion stroke.

Preferably the stop/start controller is arranged to vary a positive torque produced by the electrical machine during a start event such that the positive torque is greater during a compression stroke and/or less during an expansion stroke than at other points in the engine cycle during the start event. This may allow the engine to be started more smoothly, more quickly, and/or more efficiently than may otherwise be the case.

Preferably the stop-start controller is arranged to produce a pulse of negative torque when the engine fires. This may allow the electrical machine to at least partially compensate for a positive torque pulse produced by the engine during the combustion stroke when the engine fires.

According to another aspect of the present invention there is provided a stop-start system comprising a stop/start controller in any of the forms described above.

When an engine is running it continues to produce vibration due discontinuous pulses of torque produced by the pistons. These vibrations may be particularly pronounced in commercial vehicles such as buses and trucks, and at low speeds, and may require the engine to idle at a higher speed than is required by the engine itself.

In a preferred embodiment the stop-start system includes an active torque cancellation controller for controlling the electrical machine to produce a torque which acts so as to reduce variations in the torque produced by the engine while the engine is running. The active torque cancellation controller may be part of or separate from the stop/start controller.

The active torque cancellation controller may be operable at idle speed and/or at other engine speeds. In a preferred embodiment the active torque cancellation controller is arranged to reduce variations in the torque produced by the engine while the engine is idling. This can allow the idle speed of the engine to be reduced, in comparison to the case that no active torque cancellation is used. Thus, in cases where it is not possible for the engine to be stopped, the idle speed may nonetheless be reduced, thereby reducing fuel consumption and emissions.

The active torque cancellation controller may operate the electrical machine alternatively as a generator and a motor within an engine cycle. This may result in an electrical storage device being alternately charged and discharged by the electrical machine. Preferably the active torque cancellation controller is operable to alternately charge and discharge an electrical storage device within an engine cycle such that the net effect is that the electrical storage device remains charged. This may allow a relatively small electrical storage device to be used for the active torque cancellation.

The stop-start system may further comprise a position sensor for sensing the position of the electrical machine and/or engine. The position sensor preferably senses the position of the rotor within the electrical machine. Preferably the stop/start controller and/or active torque cancellation controller is arranged to control the electrical machine in dependence on the sensed position. For example, the torque applied by the electrical machine may be varied in dependence on the sensed position and/or the speed of the engine. This can facilitate application of the torque cancelation techniques described above.

Preferably the stop-start system comprises an electrical storage device for supplying power to the electrical machine when it is operating as a motor. The electrical storage device is preferably a dedicated storage device for controlling stop/start operations of the engine and/or active torque cancellation. This can allow a relatively low capacity storage device such as a high energy capacitor to be used for the storage device, thus reducing cost. Furthermore this arrangement may facilitate integration of the stop/start system with an existing vehicle.

The electrical storage device may comprise at least one capacitor, such as at least one super capacitor, although other types of electrical storage device such as batteries and electric flywheels could be used instead.

Preferably the electrical machine is arranged to charge the electrical storage device when it is operating as a generator. This can help to ensure that the electrical storage device remains sufficiently charged to start the engine.

The stop-start system may further comprise a bi-directional AC/DC converter for connection between the electrical storage device and the electrical machine. The bi-directional AC/DC converter may be selectively operable as an inverter or a rectifier. Preferably the stop/start controller is arranged to control the electrical machine via the bi-directional AC/DC converter.

In one embodiment, the bi-directional AC/DC converter is operable in an overload state when the electrical machine is operating as a motor. This may be possible by reducing the duration of a start and/or stop event using the techniques described herein. This can allow an AC/DC converter with lower rated switches to be used, thereby reducing the cost.

The system may further comprise a DC/DC converter connected to the bi-directional AC/DC converter. The DC/DC converter is preferably bidirectional, and may be arranged convert between an intermediate DC voltage produced by the bidirectional AC/DC converter, and a lower voltage for use by a battery. Thus the DC/DC converter may be arranged for connection to an external battery. This can allow the system to connect, for example, to an existing vehicle battery.

Preferably the electrical storage device rather than the external battery is used to start the engine. This can allow smaller and lower cost DC/DC converter to be used than would otherwise be the case.

When the vehicle is first started after an extended period of rest, there may be insufficient charge in the electrical storage device to start the engine. Thus the external battery may be used to charge the electrical storage device when the system is first started. This can allow the electrical storage device to have a lower capacity than would otherwise be the case, thus reducing the cost of the system.

The stop/start controller may be arranged to perform control of stop/start events based on one or more of: an accelerator signal; a brake signal; a vehicle moving signal; and an inhibit signal. This may allow the system to be implemented using existing signals, and thus may facilitate fitting of the system to an existing vehicle.

Preferably the system is adapted for fitting to an existing vehicle.

According to another aspect of the invention there is provided a vehicle power train comprising an engine, an electrical machine, and a stop/start system in any of the forms described above.

The electrical machine is preferably integrated with the engine. For example, the rotor of the electrical machine may be directly connected to the engine crankshaft. This may allow the electrical machine to be connected to the engine without the use of gears or clutches. This may allow a compact and lightweight design to be achieved, and facilitate control of the engine with the electrical machine.

Preferably the rotor of the electrical machine is at least partially supported by the engine bearings. For example, the electrical machine may be located between the engine and a transmission, and its rotor may be supported by the engine bearings and the transmission bearings. This may help to achieve a compact, lightweight, and low cost design.

The electrical machine may be located within the engine’s flywheel housing. In a preferred embodiment, the rotor of the electrical machine replaces the engine’s flywheel. By replacing the flywheel with the rotor, the electrical machine can be permanently connected to the engine without the need for gears or clutches and without significantly increasing the rotating mass.

Thus, an integrated engine/electrical machine may be provided in which the electrical machine replaces the starter motor, alternator and flywheel, and does not require gears or clutches between the engine and the machine. This can allow a compact, lightweight, and low cost design to be achieved.

According to another aspect of the invention there is provided a method of controlling stop/start events in a vehicle comprising an integrated engine and electrical machine, the method comprising varying torque produced by the electrical machine during a stop/start event to at least partially compensate for variations in torque produced by the engine.

Features of one aspect of the invention may be provided with any other aspect. Apparatus features may be provided with method aspects and vice versa.

Preferred features of the present invention will now be described, purely by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a cross-section through part of an integrated engine/electrical machine in an embodiment of the invention;

Figure 2 shows schematically a vehicle stop-start system in an embodiment of the invention;

Figure 3 shows parts of the stop-start system in more detail;

Figure 4 shows schematically various parts of a four-stroke engine combustion cycle;

Figure 5 shows torque against crankshaft angle for one cylinder of a typical four stroke engine;

Figure 6 illustrates a possible variation of the torque of the electrical machine during a stop event;

Figure 7 is flow chart illustrating the processes carried out during a stop event;

Figure 8 illustrates a possible variation of the torque of the electrical machine during a start event;

Figure 9 is flow chart illustrating the processes carried out during a start event;

Figure 10 shows the spectrum of the engine torque for a typical engine;

Figure 11 shows the engine torque and its first harmonic over three engine cycles;

Figure 12 shows an example of an active damping torque;

Figure 13 shows an example of an active damping torque with the addition of a negative torque;

Figure 14 shows a control topology for active torque cancellation in one embodiment;

Figure 15 shows an embodiment of the stop/start controller; and

Figure 16 shows another embodiment of a vehicle stop/start system.

Integrated engine concept

It has been recognised for some time that hybrid vehicle technology would be beneficial for commercial vehicles due to the savings in fuel and reduction in emissions that can be achieved. This is particular relevant for vehicles such as busses and delivery vans operating in urban environments where frequent stops and starts are encountered and emissions are harmful to the population. However cost has been a significant barrier to the introduction of hybrid technology, and hybrid commercial vehicles are often only economically viable with the support of state subsidies.

Embodiments of the invention relate to a new integrated engine concept with reduced fuel consumption and emissions that can replace existing engines while maintaining existing interfaces. An aim is to maximise the ratio of fuel saving to capital cost and in doing so make the technology economically viable.

Figure 1 shows a cross-section through part of an integrated engine/electrical machine in an embodiment of the invention. Referring to Figure 1, the system comprises an internal combustion engine 10 with an integrated electrical machine 12. The integrated engine/machine is connected to the vehicle's driven wheels via a transmission 14 which in this example is an automatic transmission. The engine 10 comprises cylinders 16, a crankshaft 18, and a flywheel housing 20. The electrical machine comprises a rotor 22 which rotates inside a stator 24. The rotor 22 comprises permanent magnets 26, while the stator 24 comprises stator windings 28 and a stator housing 30.

In the arrangement of Figure 1, the electrical machine 12 is located inside the engine's flywheel housing 20. The stator housing 30 is connected to the flywheel housing 20. The rotor 22 of the electrical machine is directly coupled to the engine crankshaft 18 on one side and to the transmission 14 on the other side, and replaces the engine's flywheel. The electrical machine relies on the engine bearings 32 and the transmission bearings 34 to support its rotating mass.

By replacing the flywheel with the rotor of the electrical machine in the way shown in Figure 1, the benefits of an integrated engine and electrical machine can be achieved with a compact and lightweight design. Furthermore, since the rotor of the electrical machine is directly coupled to the engine’s crankshaft, the rotor can be used to control the position of the crankshaft.

Figure 2 shows schematically a vehicle stop-start system in an embodiment of the invention. Referring to Figure 2, the system comprises engine 10 with integrated electrical machine (motor generator) 12. The electrical machine 12 is connected to a bidirectional AC/DC converter 36. The bidirectional AC/DC converter 36 functions either as an inverter or a rectifier depending on whether the electrical machine is operating as a motor or a generator. The bidirectional AC/DC converter 36 is connected on its DC side to an electrical storage device 38 via a DC link 40. Depending on the mode of operation, the electrical storage device 38 can provide electrical power to the DC link, or be charged from the DC link. In this embodiment the electrical storage device 38 is a high energy capacitor or set of capacitors.

A DC/DC converter 42 is also connected on one side to the DC link 40. The DC/DC converter is connected on the other side to an external battery 44. In this embodiment the external battery is the vehicle’s existing battery. The DC/DC converter 42 is bidirectional, and converts between the battery voltage (typically 24V or 12V) and the voltage of the DC link (typically around 300V).

The internal combustion engine 10 is controlled by an engine control module 46, which is connected to an external controller 48. In addition, a stop/start controller 50 is connected to the engine control module 46, and is used to control the stop/start operation of the engine. The stop/start controller 50 also controls the operation of the bidirectional AC/DC converter 36 and the DC/DC converter 42. A position signal POS is fed from the electrical machine 12 to the stop/start controller 50 for use in the control processes.

In the arrangement of Figures 1 and 2, the electrical machine 12 is operable either as a motor or as a generator. This allows the electrical machine to replace the vehicle’s normal alternator and starter motor, and allows stop/start operation of the engine. The electrical storage device 38 is designed to provide the short term, high energy power required to start the engine.

Operation of the system shown in Figures 1 and 2 is as follows.

During normal driving the engine 10 is used to drive the vehicle, and the electrical machine 12 functions as a generator powered by the engine. In this mode the electrical machine generates electrical power which is fed to the bidirectional AC/DC converter 36. The bidirectional AC/DC converter functions as a rectifier, and converts the AC output of the electrical machine 12 to DC for supply to the DC link 40. If the electrical storage device 38 is not fully charged, then it is charged from the DC link 40. In addition, the external battery 44 is charged from the DC link 40 via DC/DC converter 42.

When the vehicle is braking, regenerative braking can be used and this can allow the storage device 38 and/or the battery 44 to be charged using the vehicle's kinetic energy.

When the vehicle is at rest, the stop/start controller 50 checks whether an engine stop event can be initiated. This typically involves checking that the brake pedal is depressed and that the accelerator pedal is not depressed using brake and accelerator signals received from the engine control module 46. The stop/start controller 50 also checks that there is sufficient charge in the storage device 38, and that there is no override signal. If a stop event can be initiated, the stop/start controller 50 signals to the engine control module 46 to cut the engine. In response, the engine control module checks that that conditions are appropriate for stopping the engine (for example, that the engine is warm enough), and, if appropriate, cuts the engine. In this state no fuel is consumed and no emissions produced.

When it is detected that the engine is to be started again (for example based on a signal from the accelerator pedal), the electrical machine 12 functions as a motor, and is used to start the engine 10. This is achieved by operating the bidirectional AC/DC converter 36 as an inverter, in order to covert the DC voltage on the DC link 40 to an AC voltage for driving the electrical machine 12.

In the arrangement described above, the short term, high power electrical energy required for starting the engine is provided by the electrical storage device 38, rather than the external battery 44. Since only a short term energy supply is required, the electrical storage device can be made from relatively low cost components such as capacitors or super capacitors. However other electrical storage devices capable of producing short term, high power electrical energy, such as batteries or electrical flywheels, could be used instead.

Since the external battery 44 is not used to start the engine, the DC/DC converter 42 can be made from smaller, lower cost components than would otherwise be the case. High power DC/DC converters are expensive items and so this can allow significant cost savings to be achieved.

In a preferred embodiment the electrical storage device comprises one or more high energy capacitors. Typically an energy of about 700J is required to start the engine, which would require the capacitors to have a total capacitance of about 80-100mF. Capacitors of these values are commercially available at relatively low cost in comparison to battery storage. It will be appreciated that these values may vary depending on, amongst other things, the size of the engine.

A further advantage of the above arrangement is that the duty cycle of the storage device 38 can be higher than that of a battery. This can allow a stop/start system to be achieved with a higher stop/start capability than would be possible with conventional batteries. For example, in one embodiment up to 60 stop/start events per hour may be achievable using capacitors as the storage device.

When the engine is first started after a stop/start event, the stop/start controller 50 prioritizes charging of the electrical storage device 38, so that the system is ready for the next stop/start event. It has been found that in a practical implementation the electrical storage device can be charged in a few seconds. Once the electrical storage device 38 is sufficiently charged, the external battery 44 can be charged.

In the arrangement described above, when the engine is first started, there may be insufficient charge in the electrical storage device 38 to start the engine. In this case, the electrical storage device 38 is charged from the external battery 44 via the DC/DC converter 42, until there is sufficient charge in the storage device

38 to start the engine. This may require a delay of a few seconds before the engine is first started. However this compromise can allow significantly less expensive components to be used, which can make the overall system more economically viable.

In the arrangement described above, the electrical machine is used as part of a vehicle a stop/start system, to start the engine after a stop event. If desired, the electrical machine could also be used to provide some boost to the engine, for example during acceleration, in which case the vehicle may function as a mild hybrid. The energy required for the boost may come from the electrical storage device 38 and/or the external battery 44.

Although the stop/start system described above stops the engine when the vehicle is at rest, if desired, the engine may also be stopped while the vehicle is coasting but not at rest.

The arrangement shown in Figure 1 can allow an existing engine in a commercial vehicle to be replaced with the integrated engine/machine arrangement, while maintaining existing interfaces. Furthermore, the integrated engine/machine arrangement can connect to the vehicle’s existing battery system, with additional energy capacity being provided by the internal storage device 38. Thus this arrangement can provide a low cost solution for retrofitting to an existing vehicle.

Bidirectional AC/DC converter

Figure 3 shows in more detail parts of the bidirectional AC/DC converter 36. In this embodiment the electrical machine 12 is a three phase machine, although a machine with any number of phases could be used. The bidirectional AC/DC converter 36 is connected on one side to the three phase windings of the electrical machine 12, and on the other side to the DC link 40.

The bidirectional AC/DC converter 36 comprises transistors T1 to T6 and diodes D1 to D6. When the electrical machine 12 is operating as a generator, the diodes D1 to D6 operate as a three phase, full wave bridge rectifier to produce a rectified DC output. The rectified output is smoothed by capacitor C1 and fed to the DC link 40. The AC/DC converter 36 can also be operated in active rectifier mode by controlling transistors T1 to T6 to control current (power/energy) flow from electrical machine 12 to DC link 40.

When the electrical machine 12 is operating as a motor, the transistors T1 to T6 are controlled such that the converter 36 operates as an inverter. In this mode the converter 36 produces a three phase AC output which is fed to the machine 12 in order to drive it as a motor. The AC output for the first phase is produced by operation of the transistors T1 and T2, the AC output for the second phase is produced by operation of the transistors T3 and T4, and the AC output for the third phase is produced by operation of the transistors T5 and T6. Each pair of transistors operates by switching the voltage on the DC link to the respective output so as to produce the desired waveform at the output.

The transistors T1 to T6 are operated under control of a switching control circuit 52. When the converter 36 is acting as a rectifier, a voltage sensor 54 senses the DC link voltage, and current sensors 56 sense the output currents of each phase of the AC power output. The sensed voltage and currents are fed back to the switching control circuit 52. This enables the converter 36 to operate as an active rectifier to produce a stable DC link and control the power drawn from the electrical machine 12.

When the controller 36 is acting as an inverter, current sensors 56 sense the output currents of each phase of the AC power output, and the voltage sensor 54 senses the DC link voltage, and the sensed currents and voltage are fed back to the inverter/rectifier controller 52. In addition, a position sensor 58 senses the position of the rotor 22 of the electrical machine 12, and feeds the sensed position to the switching control circuit 52 as well as the stop/start controller 50. The position sensor can be a resolver, or any other type of position sensor for sensing the rotational position of the rotor. The sensed currents are compared to three reference signals representing the desired output frequency and voltage of each phase. The controller 52 then controls the transistors T1 to T6 so that the three AC output signals substantially match the reference signals, in order to produce the required AC output signals for driving the electrical machine.

The switching control circuit 52 receives signals from the stop/start controller 50 in order to switch between operation as a rectifier and an inverter, and to control operation in each mode.

Stop events

Usually when an engine is stopped it is allowed to come naturally to rest and the exact rotational position of the crankshaft is not known. This can lead to a momentary delay and/or judder when stopping and starting the engine.

In the arrangement shown in Figures 1 and 2, the rotor 22 of the electrical machine 12 is directly connected to the engine crankshaft 18. In preferred embodiments, the electrical machine is used to control the position of the engine crankshaft during a stop event.

Figure 4 shows schematically the various parts of a four-stroke engine combustion cycle. Referring to Figure 4, the cycle comprises intake stroke 60, compression stroke 62, combustion stroke 64 and exhaust stroke 66. The highest position of the piston is referred to as top dead centre (TDC) and the lowest position of the piston is referred to as bottom dead centre (BDC).

Figure 5 shows torque against crankshaft angle for one cylinder of a typical four stroke engine. As shown in Figure 5, a large pulse of torque is produced once for every two rotations of the crankshaft. This pulse of torque corresponds to the combustion stroke. In addition, a small pulse of negative torque is produced during the compression stroke.

In the case that fuel is not ignited, a small positive pulse of torque (not shown in Figure 5) is produced after the compression stroke due to expansion of gas in the cylinder.

The positive and negative pulses of torque produced by the engine may cause the engine to vibrate. This may be particularly noticeable at low engine speeds. In particular, as the engine stops and restarts, the low engine speed may cause a noticeable judder which may transfer to the vehicle body. This may be unpleasant for occupants of the vehicle and may require the vehicle to have mechanical damping or more robust parts than would otherwise be the case.

In a preferred embodiment, when a stop event is triggered, the electrical machine is used to bring the engine to a stop more quickly than would otherwise be the case. This is achieved by operating the electrical machine as a generator, to produce negative torque (i.e. a braking torque). Furthermore, the engine is brought to a stop as close as possible to its ideal stopping position. In addition, active torque cancellation techniques are applied to reduce vibration during the stop event.

Figure 6 illustrates a possible variation of the torque of the electrical machine during a stop event. In Figure 6, the engine speed is shown in the dotted line, while the torque produced by the engine is shown in the solid line. The engine torque fluctuates over time due to the compression strokes and subsequent expansion strokes.

In Figure 6, the negative (braking) torque to be applied by the electrical machine is shown by the dashed line. The magnitude of the negative torque is approximately proportional to the speed of the engine. However the amount of negative torque varies within an engine cycle, in order to cancel the variable torque of the engine.

Figure 7 is flow chart illustrating the processes carried out by the stop/start controller 50 during a stop event in order to control the position of the engine crankshaft.

Referring to Figure 7, in step 70 a stop event is triggered. This typically occurs when the stop/start controller 50 determines that the vehicle is at rest, and various other conditions are satisfied, such as the electrical storage device 38 being sufficiently charged. When a stop event is triggered, in step 72 the stop/start controller sends a signal to the engine control module 46 requesting it to stop the engine.

When the engine control module 46 receives a request to stop the engine, it first checks that the engine is able to be stopped. This may involve checking various parameters such as engine temperature, outside temperature etc. If the engine control module determines that the engine can be stopped, it sends a confirmation signal to the stop/start controller 50. The engine control module 46 then stops the engine by cutting the fuel and performing any other shut down procedures.

In step 74, the stop/start controller waits for confirmation of the stop event from the engine control module. If no confirmation is received, or if the engine control module indicates that the engine cannot be stopped, the process is terminated without stopping the engine.

If the engine control module 46 confirms the stop event, then in step 76 the stop/start controller 50 obtains the position of the electrical machine's rotor 22 from the position sensor 58. In step 78 the current rotor position is compared to previous rotor positions to obtain the rotor speed. Since the rotor is directly connected to the engine's crankshaft, the speed and position of the crankshaft 18 can be obtained from those of the rotor 22.

In step 80 the stop/start controller determines whether the engine has stopped at the start of an inlet stroke, using the calculated position and speed of the engine crankshaft. If the engine has stopped at the start of an inlet stroke, then the process terminates.

If the engine has not stopped at the start of an inlet stroke, then in step 82 the stop/start controller determines a torque which is to be applied to the engine via the electrical machine. The torque to be applied is that needed to bring the engine to a stop quickly and smoothly, and in a position which is as close as possible to the ideal stopping position. For example, the torque to be applied may be that shown by the dashed line in Figure 6. This torque can be obtained by accessing a look up table stored in memory to determine the required torque for a given engine speed and crankshaft position.

In step 84 the stop/start controller 50 instructs the switching control circuit 52 to apply the appropriate torque to the engine 10 using the electrical machine 12. Processing then returns to step 76 where a new value of the rotor position is obtained.

Since the engine and the electrical machine will initially have rotational inertia, the torque which is applied is mainly a braking torque. However, as the engine speed approaches zero, a small positive torque may be applied. For example, if the engine has stopped just short of or just beyond the ideal stopping position, the appropriate positive torque in either a forwards or backwards direction may be applied to bring the engine to its ideal stopping position.

By applying the processes described above, the electrical machine 12 can bring the engine to a stop with the engine crankshaft at or close to the ideal position for restart. In practice this will usually mean stopping the engine such that a piston is at the start of an intake stroke, as indicated by line 68 in Figure 4. This can allow the piston to go directly into an intake stroke when the engine is restarted. Furthermore, since the engine control module 46 has knowledge of the starting position of the crankshaft, it can determine more quickly the appropriate timings for injection of fuel into the cylinders. This can allow the engine to restart more quickly and more efficiently than would otherwise be the case. Thus this arrangement can help to enhance the stop/start capability of the system.

During a stop event the fuel supply to the engine is cut, and thus the engine does not produce the pulses of torque normally associated with a combustion stroke. However the engine crankshaft continues to rotate until the engine is at rest. During this time, the engine will continue to produce a negative pulse of torque during a compression stroke, followed by a positive pulse of torque during an expansion stroke, as shown in Figure 6. By varying the negative (braking) torque applied by the electrical machine during a stop event such that the braking torque is less during a compression stroke and/or greater during an expansion stroke, the effect of the pulses of torque produced by the engine can be reduced. This can allow the engine to be brought to a stop more smoothly, more quickly, and/or more efficiently than may otherwise be the case.

It will be appreciated that during the stop event described above the electrical machine applies a braking torque to the engine to bring it to a stop. This involves the electrical machine operating as a generator. The thus generated electrical energy can be used to charge the electrical storage device 38. Thus this arrangement can allow the electrical storage device to have a lower capacity than would otherwise be the case, thereby further reducing costs.

Start events

In a preferred embodiment, when the engine is started active torque cancellation is applied to the engine by the electrical machine as part of the process of bringing the engine up to speed.

Figure 8 illustrates a possible variation of the torque of the electrical machine during a start event. In Figure 8 the engine speed is shown by the dotted line, while the torque produced by the engine is shown by the solid line. Initially the engine torque fluctuates with time due to cylinder compression strokes and subsequent expansion strokes before the fuel is ignited. After the first few cycles, the fuel is ignited producing combustion strokes. The combustion strokes lead to larger peaks in the engine torque. The positive (turning) torque to be applied by the electrical machine in order to start the engine and cancel out the fluctuations is shown by the dashed line.

Typically the electrical machine is used to bring the engine up to a speed of about 600 RPM before the cylinders are fired. During this time, the engine will continue to produce a negative pulse of torque during a compression stroke, followed by a positive pulse of torque during an expansion stroke, as shown in Figure 8. By varying the positive (turning) torque applied by the electrical machine during a start event such that the turning torque is greater during a compression stroke and/or less during an expansion stroke, the effect of the pulses of torque produced by the engine can be reduced. Furthermore, when the engine fires the electrical machine may produce a pulse of negative (braking) torque pulse to at least partially compensate for the positive torque pulse produced by the engine during the combustion stroke. This can allow the engine to be started more smoothly, more quickly, and/or more efficiently than may otherwise be the case.

Figure 9 is a flow chart showing the processes carried out by the stop/start controller 50 during a start event. Referring to referring to Figure 9, in step 86 the stop/start controller 50 triggers a start event. This typically occurs when the brake is released or when the accelerator pedal is depressed, or when electrical power is required for example to charge the storage device 38 or the battery 44. When a start event is triggered, in step 88 the stop/start controller sends a signal to the engine control module 46 to indicate that the engine is to be restarted.

When the engine control module 46 receives a request to start the engine, it first checks that the engine is able to be started. If the engine control module determines that the engine can be started, it sends a confirmation signal to the stop/start controller 50. The engine control module 46 then begins the process of starting the engine, including determining the appropriate timings for injection of fuel into the cylinders. Since the engine control module 46 has knowledge of the starting position of the crankshaft, it can determine more quickly when fuel should be injected. In addition, the engine control module may use the position signal obtained from the position sensor 58 to determine engine timings.

In step 90, the stop/start controller checks whether confirmation of the start event has been received from the engine control module. If no confirmation is received, or if the engine control module indicates that the engine cannot be started, the process is terminated without starting the engine.

If the engine control module 46 confirms the start event, then in step 92 the stop/start controller 50 obtains the position of the electrical machine's rotor 22 from the position sensor 58. In step 94 the current rotor position is compared to previous rotor positions to obtain the rotor speed. Since the rotor is directly connected to the engine's crankshaft, the speed and position of the crankshaft 18 can be obtained from those of the rotor 22.

In step 96 the stop/start controller determines a torque which is to be applied to the engine via the electrical machine. The torque to be applied is that needed to rotate the engine, while cancelling out as far as possible any vibrations produced by the engine as it is started. For example, the torque to be applied may be that shown by the dotted line in Figure 8. This torque can be obtained by accessing a look up table stored in memory to determine the required torque for a given engine speed and crankshaft position.

In step 98 the stop/start controller 50 instructs the switching control circuit 52 to apply the appropriate torque to the engine 10 using the electrical machine 12. In order to achieve this, the bi-directional AC/DC converter 36 acts as an inverter and the electrical machine 12 acts as a motor. The relatively short term, high power electrical energy needed to turn the engine is supplied by the electrical storage device 38. At the same time the engine control module 46 performs the processes required to start the engine such as supplying fuel and if necessary starting the ignition.

In step 100 the stop/start controller 50 determines whether the engine has started. This may be done based on engine speed, or by receiving a signal from the engine control module 46. If the engine has not started, then processing returns to step 92 where a new value of the rotor position is obtained. If the engine has started, then the engine start process terminates, and the engine control module 46 controls the running of the engine in a conventional manner.

It will be appreciated that during the start event described above the electrical machine applies a turning torque to the engine in order to rotate it. This involves the electrical machine operating as a motor, during which time electrical power is supplied by the storage device 38. However, when a combustion stroke is produced by the engine, the electrical machine may act temporarily as a generator in order to absorb the torque of the combustion stroke. During this period the generated electrical energy can be used to charge the electrical storage device 38.

A further advantage of the arrangement described above is that the bidirectional AC/DC converter 36 may have a lower rating than would otherwise be needed. Referring back to Figure 3, the rating of the transistors T1 to T6 depends upon the maximum power which they are required to switch. The maximum power will normally be required when the electrical machine 12 is turning the engine 10 in order to start the engine. By minimising the time required to start the engine using the techniques discussed above, it may be possible to use transistors with a lower rating than would otherwise be the case. In particular, by minimising the duration of a start event, it may be possible to operate the transistors temporarily in an overload state when starting the engine.

Thus the overload capability of silicon switches may be exploited to allow transistors with a lower rating to be used. This can allow the overall cost of the system to be further reduced.

Active torque cancellation

In one embodiment, during normal running of the engine, the electrical machine 12 is operated with variable torque in order to provide active damping of vibrations generated by the engine 10.

Figure 10 shows the spectrum of the engine torque for a typical engine. In Figure 10 the first harmonic is equivalent to a complete engine cycle, and thus has a frequency equal to the engine speed (in rpm) divided by 120. Figure 11 shows the engine torque and its first harmonic over three engine cycles.

The discontinuous pulses of torque produced by the engine may resonate with the body of the vehicle, producing vibrations. These vibrations may be particularly pronounced in commercial vehicles such as buses and trucks, and at low speeds, and may require the engine to idle at a higher speed than is required by the engine itself. This in turn may lead to higher fuel consumption, more emissions, and more noise.

In order to reduce the vibrations produced by the engine, the electrical machine 12 may be driven so as to produce a torque which dampens at least some of the harmonics of the engine torque.

Figure 12 shows an example of the active damping torque which is generated by the electrical machine 12. In Figure 12, the first harmonic is damped by 33%, the second harmonic by 17% and the third harmonic by 8%. In this example the first harmonic is damped the most, and the amount of damping is reduced with increasing harmonic number. This is because the system inertia acts as a low pass filter for the vibration, so higher harmonics are better damped by the inertia.

In Figure 12 the electrical machine 12 produces positive torque during one part of the cycle, and negative torque during another part of the cycle. This means that the machine is operating alternately as a generator and a motor. In Figure 12 the average torque (area under the curve) is zero. Thus the net effect is that electrical power is neither generated nor consumed, and the electrical storage device 38 and the battery 44 are neither charged nor discharged.

If it is desired to charge the electrical storage device 38 and/or the battery 44, then the electrical machine can be driven with a net negative torque, so that the net effect is to generate electrical power. Figure 13 shows an example of an active damping torque with the addition of a small negative torque. This negative torque is used to generate electricity to charge the storage device 38 and/or battery 44.

Conversely, if it is desired to provide some power assist to the engine, then the electrical machine 12 can be driven with a net positive torque. However the torque may still vary within an engine cycle in order to dampen the vibrations.

It will be appreciated that the spectrum of the engine torque will vary with engine speed. Thus the frequency of the active damping torque produced by the electrical machine 12 may be varied with engine speed. Furthermore, the shape of the active damping torque waveform may also vary with speed. For example the amount of damping of each harmonic may be varied as the speed of the engine varies. In this way, the appropriate damping is provided at each engine speed.

An active torque cancellation (ATC) controller is used to control the machine torque. The ATC controller may be part of the stop/start controller 50, or a separate module. The ATC controller calculates the amount of torque which is required to dampen the vibrations produced by the engine. The torque calculation may be based on, for example, calculation of the engine average torque and measurement of the engine speed. The optimum active vibration torque amplitude and phase shift can be mapped during calibration on a calibration test-rig, and programmed in on a real system as a function of engine speed and average engine torque. An alternative method can be based on a dynamic regulator which can calculate actual active damping torque demand. Such a regulator employs a mathematical model to estimate cancellation torque in real time.

By applying the active torque cancellation techniques described above, it may be possible to run the engine at a lower idle speed. Thus, if the vehicle is at rest but it is not possible to stop the engine for some reason, the idle speed of the engine may nonetheless be reduced by using active damping, thereby reducing fuel consumption, emissions, and noise.

Figure 14 shows the control topology for active torque cancellation in one embodiment. In the arrangement of Figure 14, the engine output power is fed to active torque cancellation (ATC) controller 102. The ATC controller 102 may be part of the stop/start controller 50 shown in Figure 2, or it may be a separate module. ATC controller 102 calculates the active torque which is to be applied based on engine output power, using the techniques discussed above.

In Figure 14, the voltage measured by the voltage sensor 54 is compared to a reference voltage V_{DC} in comparator 104. The output of the comparator is fed to proportional integral (PI) controller 106. The output of PI controller 106 is a value T_{VR}, which is the torque required to ensure that the electrical storage device 38 remains fully charged. The value T_{VR} is added to the ATC torque produced by ATC controller 102 in adder 108. The total required torque is then applied to the regulator (switching control circuit) 52. The regulator 52 controls the switches in the bi-directional AC/DC converter 36 such that the electrical machine 12 applies the required torque to the engine 10.

Stop/Start Controller

Figure 15 shows an embodiment of the stop/start controller 50. Referring to Figure 15, the stop/start controller comprises a processor 110 with associated memory 112. The processor 110 is programed to perform the various functions described above, where appropriate using values stored in the memory 112.

In addition, an interface 114 is provided for communicating with the engine control module 46, and an interface 116 is provided for communicating with the bi-directional AC/DC converter 36, DC/DC converter 42, and position sensor 58.

Alternatively, the stop/start controller could be implemented using analog control circuitry.

In a preferred embodiment, the stop/start controller 50 performs control of stop/start events based on the following signals:

- Accelerator signal
- Brake signal
- Vehicle moving signal
- Inhibit signal

The accelerator signal indicates whether or not the accelerator pedal is depressed. The brake signal indicates whether or not the brake pedal is depressed. The vehicle moving signal indicates whether or not the vehicle is moving. The inhibit signal indicates whether stop/start events should be inhibited, for example, because power is required for other purposes. These signals may be provided by the engine control module 46 and/or by sensors in the vehicle, such as sensors on the brake or accelerator pedals.

With knowledge of the above four signals, it can be decided whether or not a stop event and/or a subsequent start event should be initiated. This may be done using the following truth table.

Override	Vehicle stopped	Accelerator depressed	Brake depressed	Operation
0	0	0	0	normal
0	0	0	1	charge energy storage
0	0	1	0	discharge energy storage
0	1	0	1	stop engine
0	1	1	0	fast start
1	1	0	1	low speed idle

By controlling stop/start events based on the above four signals, the stop/start controller can be easily integrated with an existing engine control module, without requiring additional signals or sensors. Thus this arrangement can facilitate fitting of the stop/start system to existing engines or vehicles.

In the arrangements described above it should be noted the OEM controller 48 interfaces with the engine control module 46, while the 24V battery is part of the existing vehicle system. The stop/start functionality is managed partly by the stop/start controller 50 and partly by the ECM 46. The mode of operation consists of an initial “first start” where the DC/DC converter 42 takes energy from the vehicle battery 44 which charges the storage device 38. The DC/DC converter 42 is sized for low power to manage cost. Once the energy storage 38 is charged the engine 10 is able to start by passing energy from the energy storage through the bi-directional AC/DC converter (inverter) 36 to the electrical machine 12. Once in operation the energy for start stop is predominately circulated between the electrical machine 12 and the energy storage 38.

Another embodiment of a vehicle stop/start system is shown in Figure 16. In the arrangement of Figure 16, parts corresponding to those of Figure 2 are given the same reference numeral and are not described further. This topology removes the need for energy storage thus removing a cost contributor at the expense of a larger DC/DC converter and system efficiency. Furthermore, engine speed and/or position is obtained from the engine control module 46.

In the embodiments described above an electrical machine is integrated within an internal combustion engine. This can increase the robustness of the system, and allow for direct management of the crankshaft. This can enable the following features:

- Fast soft start/soft stop, achieved by managing the combustion cycle through crank position, fuelling and torsional cancellation.
- Low idle speed. Low speeds achieved through torsional cancellation. Torsional cancellation will be managed by the electrical machine, power electronics and energy storage
- Limited Torque Assist
- Regenerative energy storage charging.

This arrangement can provide a “micro” parallel hybrid that is centred on the engine. This can provide a system that directly replaces existing engines providing a mass market route to the commercialisation of hybrid technologies. This arrangement can also facilitate further electrification such as:

- Replacing engine alternators
- Providing electrical power to electrical ancillaries around the vehicle
- Plug in electric
- Electrical energy recovery, either from the exhaust stream or as part of an Organic Rankin Cycle system

By integrating the electrical machine with the engine, the engine can be packaged so as to be as transparent as possible in terms of form for vehicle applications. This can allow the system to be used with various different engine platforms as well as various different vehicle OEM’s (original equipment manufacturers).

In the above description, preferred features of the invention have been described with reference to various embodiments. It will be appreciated that features of one embodiment may be used with any other embodiment. Furthermore, the invention is not limited to these embodiments, and variations in detail may be made within the scope of the appended claims.

CLAIMS

1. A stop/start controller for controlling stop/start events in a vehicle comprising an integrated engine and electrical machine, wherein the stop/start controller is arranged to vary torque produced by the electrical machine during a stop/start event to at least partially compensate for variations in torque produced by the engine.

2. A stop/start controller according to claim 1, wherein the stop/start controller is arranged to control the electrical machine to vary the torque applied by the electrical machine to the engine.

3. A stop/start controller according to claim 1 or 2, wherein the amount of torque applied by the electrical machine is variable within one cycle of the engine.

4. A stop/start controller according to any of the preceding claims, wherein the stop/start controller is arranged to at least partially compensate for torque produced by at least one of a compression stroke, an expansion stroke and a combustion stroke.

5. A stop/start controller according to any of the preceding claims, wherein the electrical machine is arranged to absorb torque produced by the engine during a combustion stroke and/or an expansion stroke.

6. A stop/start controller according to any of the preceding claims, wherein the stop/start controller is arranged to control the electrical machine such that the electrical machine applies a negative torque to the engine during a stop event.

7. A stop/start controller according to claim 6, wherein the stop/start controller is arranged to control the electrical machine such that the electrical machine applies a variable torque to the engine during a stop event.

8. A sto/-start controller according to claim 6 or 7, wherein the stop/start controller is arranged to control the electrical machine such that the engine is brought to a stop in a predetermined position.

9. A stop/start controller according to claim 8, wherein the predetermined position is at or close to the start of an inlet stroke.

10. A stop/start controller according to any of the preceding claims, wherein the stop/start controller is arranged to control the electrical machine to produce a variable negative torque to dampen vibrations of the engine during a stop event.

11. A stop/start controller according to claim 10, wherein the variable negative torque produced by the electrical machine opposes torque produced by the engine during at least one of a compression stroke and an expansion stroke.

12. A stop/start controller according to any of the preceding claims, wherein the stop/start controller is arranged to vary a negative torque produced by the electrical machine during a stop event such that the negative torque is less during a compression stroke and/or greater during an expansion stroke.

13. A stop/start controller according to claim 10, 11 or 13, wherein the negative torque produced by the electrical machine is used to charge a storage device.

14. A stop/start controller according to any of the preceding claims, wherein the stop/start controller is arranged to control the electrical machine to control starting of the engine during a start event.

15. A stop/start controller according to claim 14, wherein the stop/start controller is arranged to control the electrical machine such that the electrical machine applies a variable torque to the engine during a start event.

16. A stop/start controller according to claim 14 or 15, wherein the stop/start controller is arranged to control the electrical machine to produce a variable torque to dampen vibrations of the engine during a start event.

17. A stop/start controller according to claim 16, wherein the variable torque produced by the electrical machine opposes torque produced by the engine

during at least one of a combustion stroke, a compression stroke and an expansion stroke.

18. A stop/start controller according to any of the preceding claims, wherein the stop/start controller is arranged to vary a positive torque produced by the electrical machine during a start event such that the positive torque is greater during a compression stroke and/or less during an expansion stroke.

19. A stop/start controller according to any of the preceding claims, wherein the stop-start controller is arranged to produce a pulse of negative torque when the engine fires.

20. A stop-start system comprising a stop/start controller according to any of the preceding claims.

21. A stop-start system according to claim 20 further comprising an active torque cancellation controller for controlling the electrical machine to produce a torque which acts so as to reduce variations in the torque produced by the engine while the engine is running.

22. A stop-start system according to claim 21, wherein the active torque cancellation controller is operable at idle speed.

23. A stop-start system according to claim 21 or 22, wherein the active torque cancellation controller is operable to alternately charge and discharge an electrical storage device within an engine cycle such that the electrical storage device remains charged.

24. A stop-start system according to any of claims 20 to 23, further comprising a position sensor for sensing the position of the electrical machine and/or engine.

25. A stop-start system according to claim 24, wherein the stop/start controller is arranged to control the electrical machine in dependence on the sensed position.

26. A stop-start system according to claim 24 or 25 when dependent on claim 21, 22 or 23, wherein the active torque cancellation controller is arranged to control the electrical machine in dependence on the sensed position.

27. A stop-start system according to any of claims 20 to 26, further comprising an electrical storage device for supplying power to the electrical machine when it is operating as a motor.

28. A stop-start system according to claim 27, wherein the electrical storage device is a dedicated storage device for controlling stop/start operations of the engine and/or active torque cancellation.

29. A stop-start system according to claim 27 or 28, wherein the electrical storage device comprises at least one capacitor.

30. A stop-start system according to any of claims 27 to 29, wherein the electrical machine is arranged to charge the electrical storage device when it is operating as a generator.

31. A stop-start system according to any of claims 27 to 30, further comprising a bi-directional AC/DC converter for connection between the electrical storage device and the electrical machine.

32. A stop-start system according to claim 31 wherein the bi-directional AC/DC converter is selectively operable as an inverter or a rectifier.

33. A stop-start system according to claim 31 or 32, wherein the stop/start controller is arranged to control the electrical machine via the bi-directional AC/DC converter.

34. A stop-start system according to any of claims 31 to 33, wherein the bi-directional AC/DC converter is operable in an overload state when the electrical machine is operating as a motor.

35. A stop-start system according to any of claims 31 to 34, further comprising a DC/DC converter connected to the bi-directional AC/DC converter.

36. A stop-start system according to claim 35, wherein the DC/DC converter is arranged to be connected to an external battery.

37. A stop-start system according to claim 36 wherein the electrical storage device is used to start the engine.

38. A stop-start system according to claim 36 or 37, wherein the external battery is used to charge the electrical storage device when the system is first started.

39. A stop-start system according to any of claims 20 to 38, wherein the stop/start controller is arranged to perform control of stop/start events based on one or more of: an accelerator signal; a brake signal; a vehicle moving signal; and an inhibit signal.

40. A stop-start system according to any of claims 20 to 39, wherein the system is adapted for fitting to an existing vehicle.

41. A vehicle power train comprising an engine, an electrical machine, and a stop/start controller according to any of claims 1 to 19 or a stop/start system according to any of claims 20 to 40.

42. A vehicle power train according to claim 41, wherein the electrical machine is directly connected to the engine crankshaft.

43. A vehicle power train according to claim 41 or 42, wherein the electrical machine is connected to the engine without the use of gears or clutches.

44. A vehicle power train according to any of claims 41 to 43, wherein the rotor of the electrical machine is at least partially supported by the engine bearings.

45. A vehicle power train according to any of claims 41 to 44, wherein the electrical machine is located within the engine’s flywheel housing.

46. A vehicle power train according to any of claims 41 to 45, wherein the rotor of the electrical machine replaces the engine’s flywheel.

47. A method of controlling stop/start events in a vehicle comprising an integrated engine and electrical machine, the method comprising varying torque produced by the electrical machine during a stop/start event to at least partially compensate for variations in torque produced by the engine.

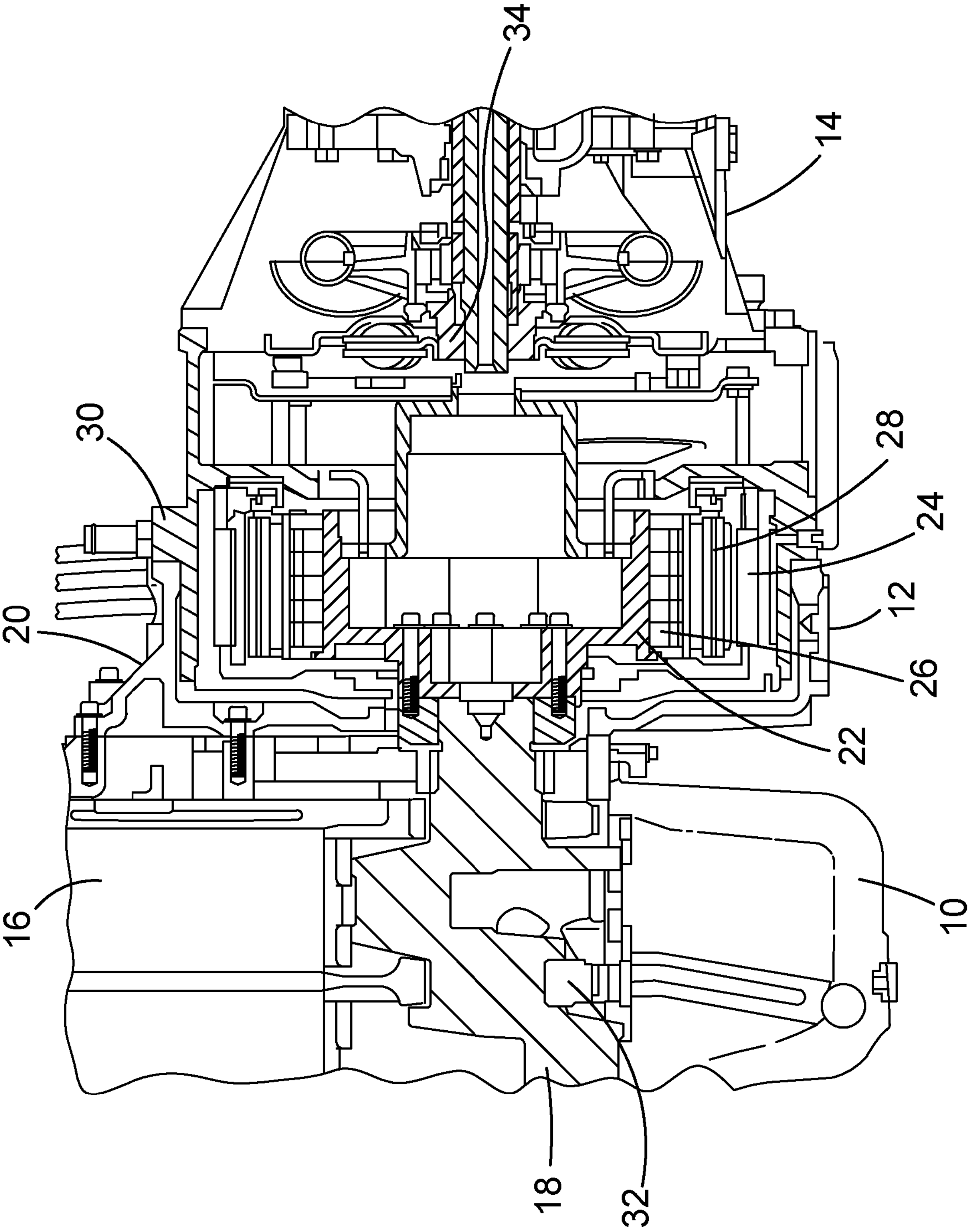


FIG.1

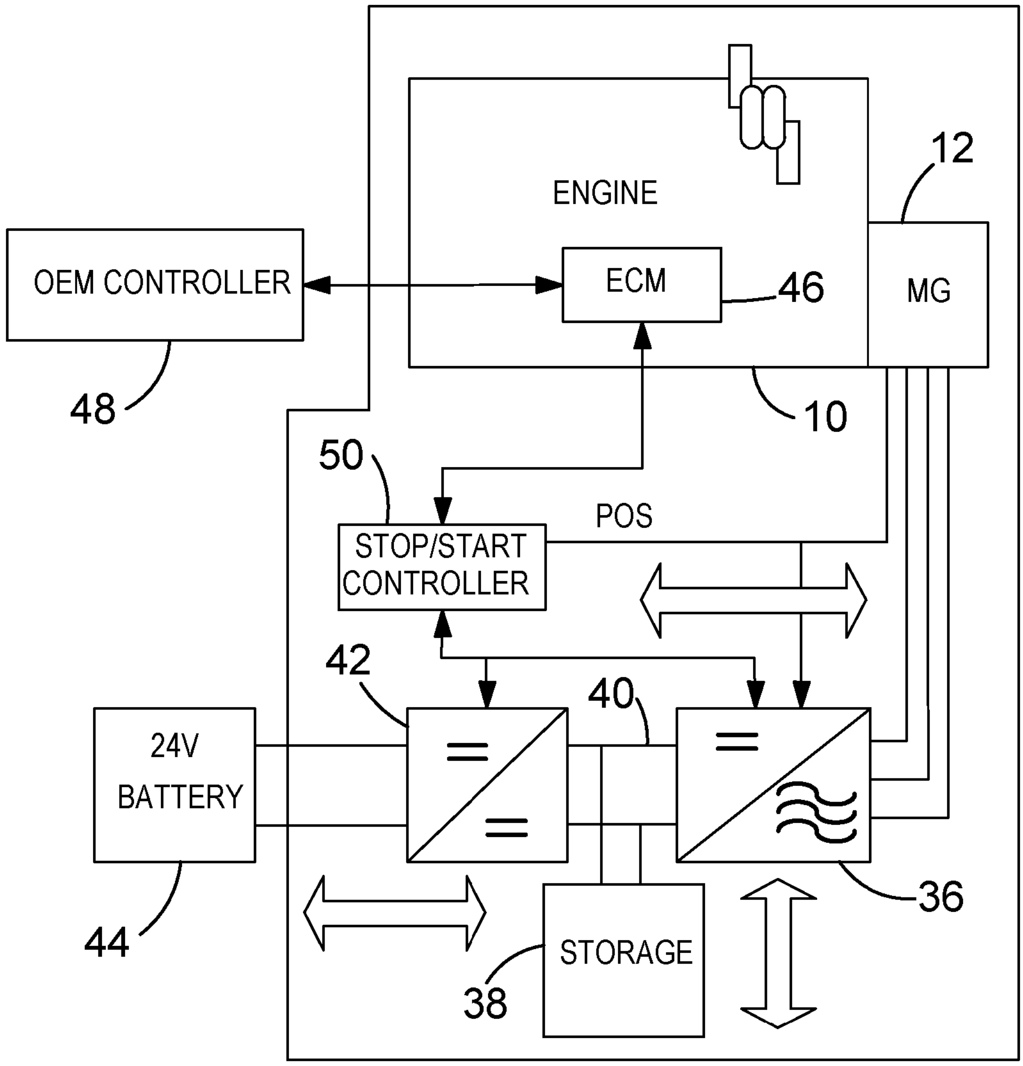

ENGINE
12
OEM CONTROLLER
ECM
46
MG
48
10
50
POS
STOP/START CONTROLLER
42
40
24V BATTERY
36
44
STORAGE
38

FIG.2

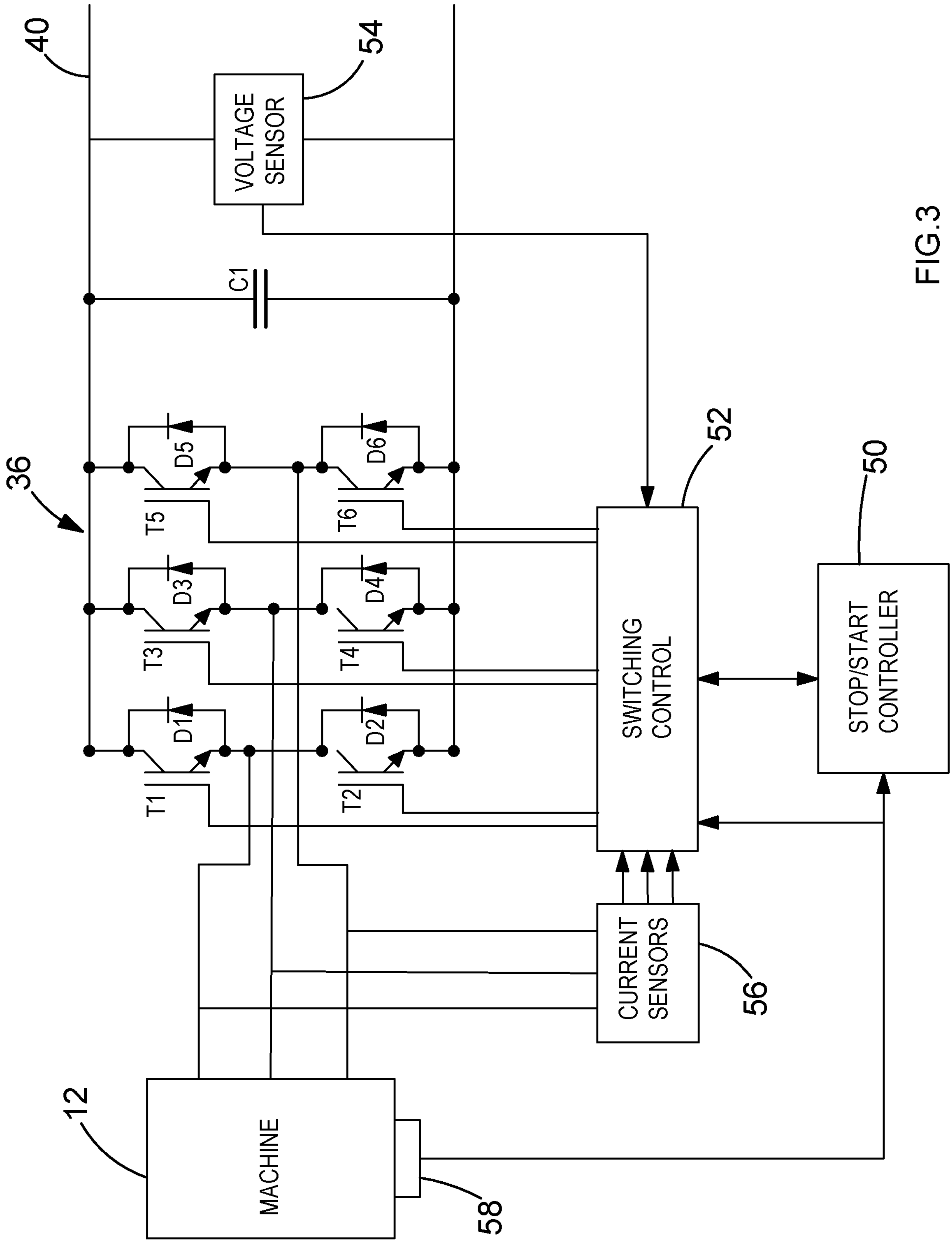

40
54
VOLTAGE SENSOR
C1
36
T1
D1
T2
D2
T3
D3
T4
D4
T5
D5
T6
D6
52
SWITCHING CONTROL
50
STOP/START CONTROLLER
CURRENT SENSORS
56
12
MACHINE
58

FIG.3

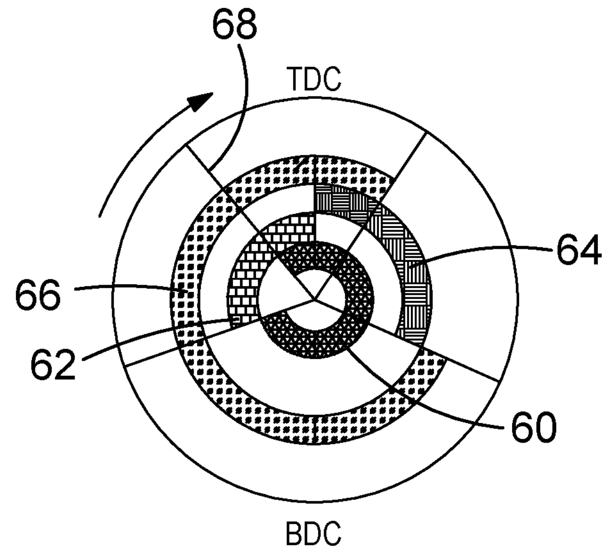

68
TDC
64
66
62
60
BDC

FIG.4

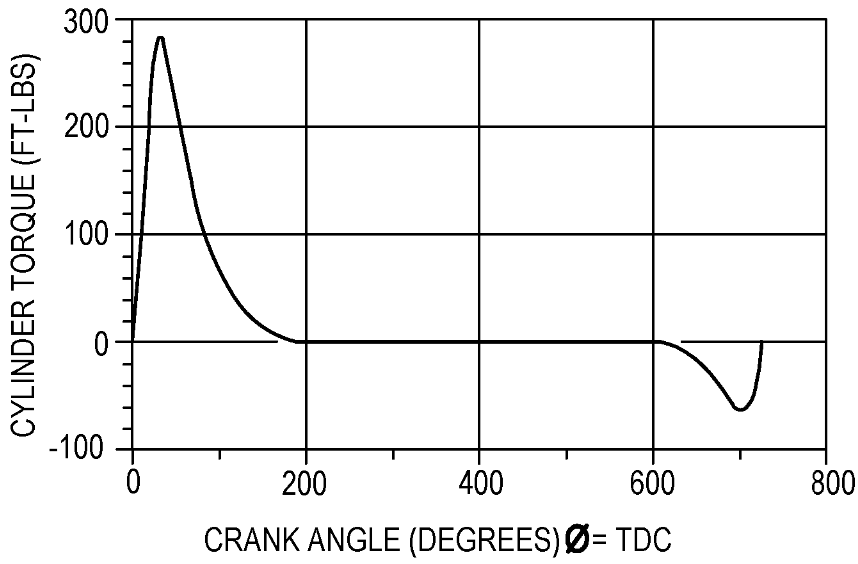

300
200
100
0
-100
CYLINDER TORQUE (FT-LBS)
0
200
400
600
800
CRANK ANGLE (DEGREES) Ø= TDC

FIG.5

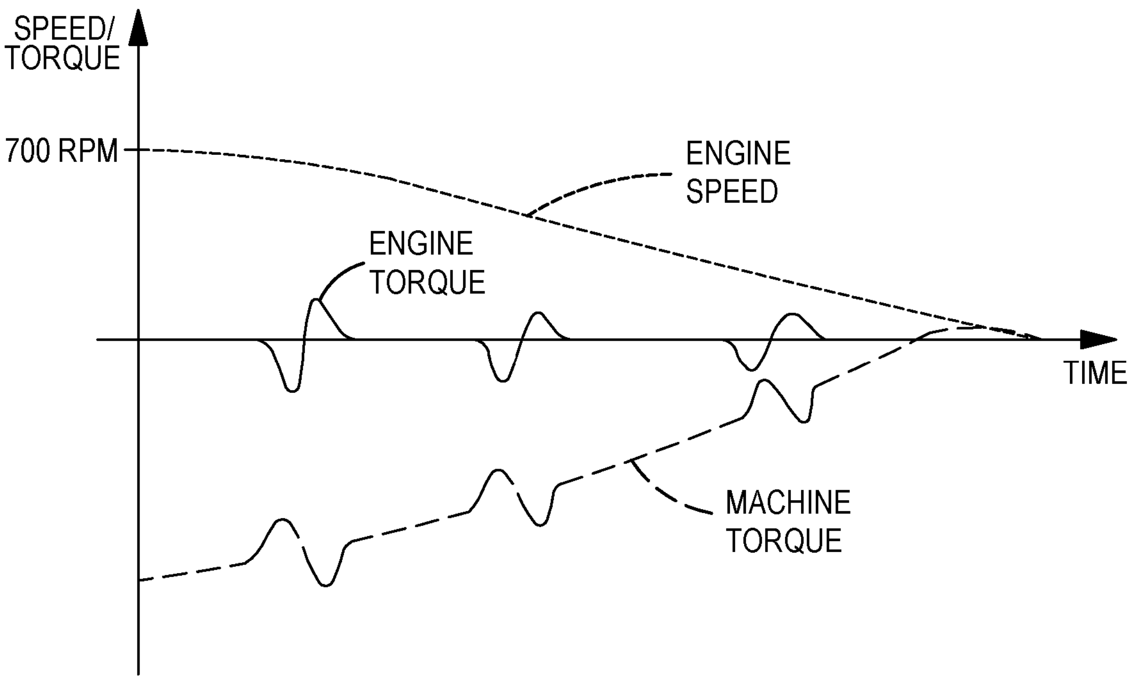

SPEED/
TORQUE
700 RPM
ENGINE
SPEED
ENGINE
TORQUE
TIME
MACHINE
TORQUE

FIG.6

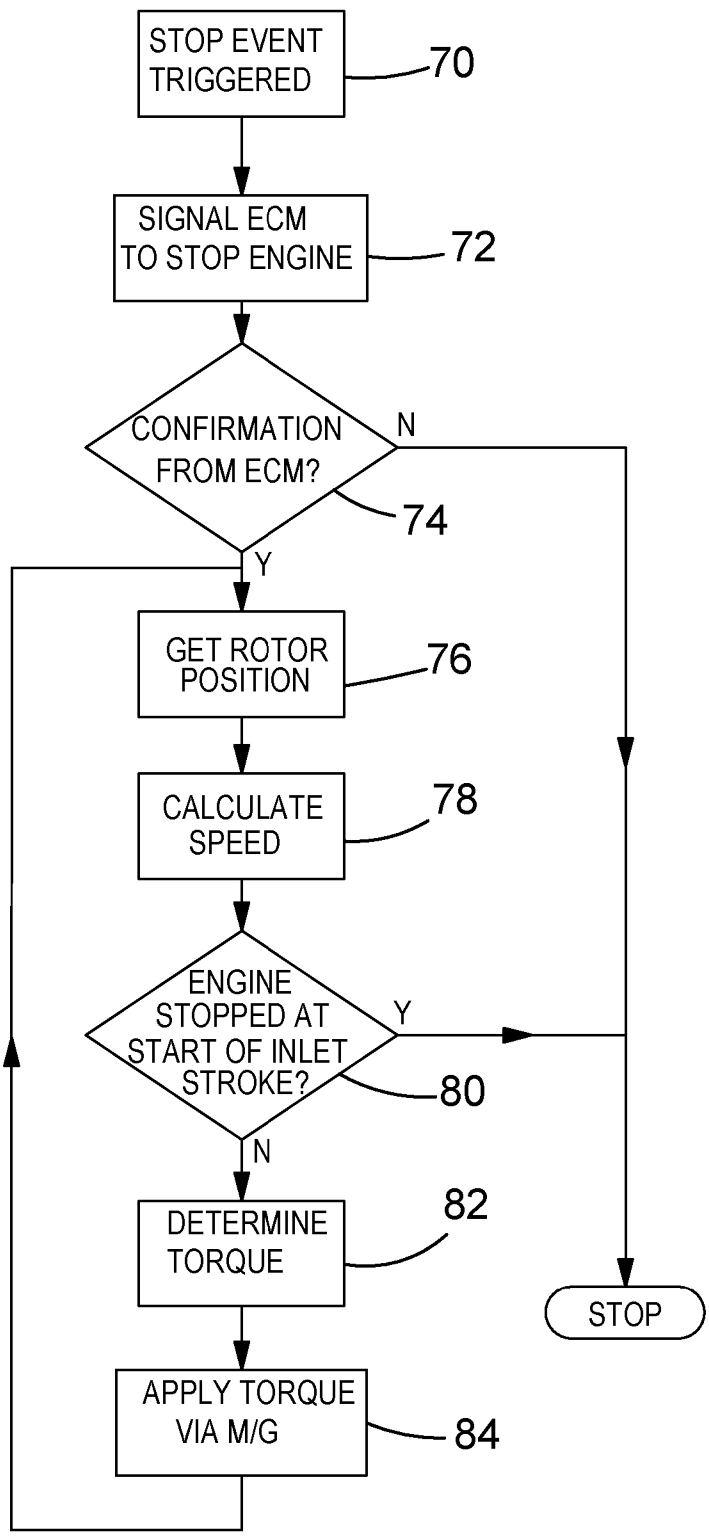

STOP EVENT TRIGGERED
70
SIGNAL ECM TO STOP ENGINE
72
CONFIRMATION FROM ECM?
N
74
Y
GET ROTOR POSITION
76
CALCULATE SPEED
78
ENGINE STOPPED AT START OF INLET STROKE?
Y
80
N
DETERMINE TORQUE
82
STOP
APPLY TORQUE VIA M/G
84

FIG.7

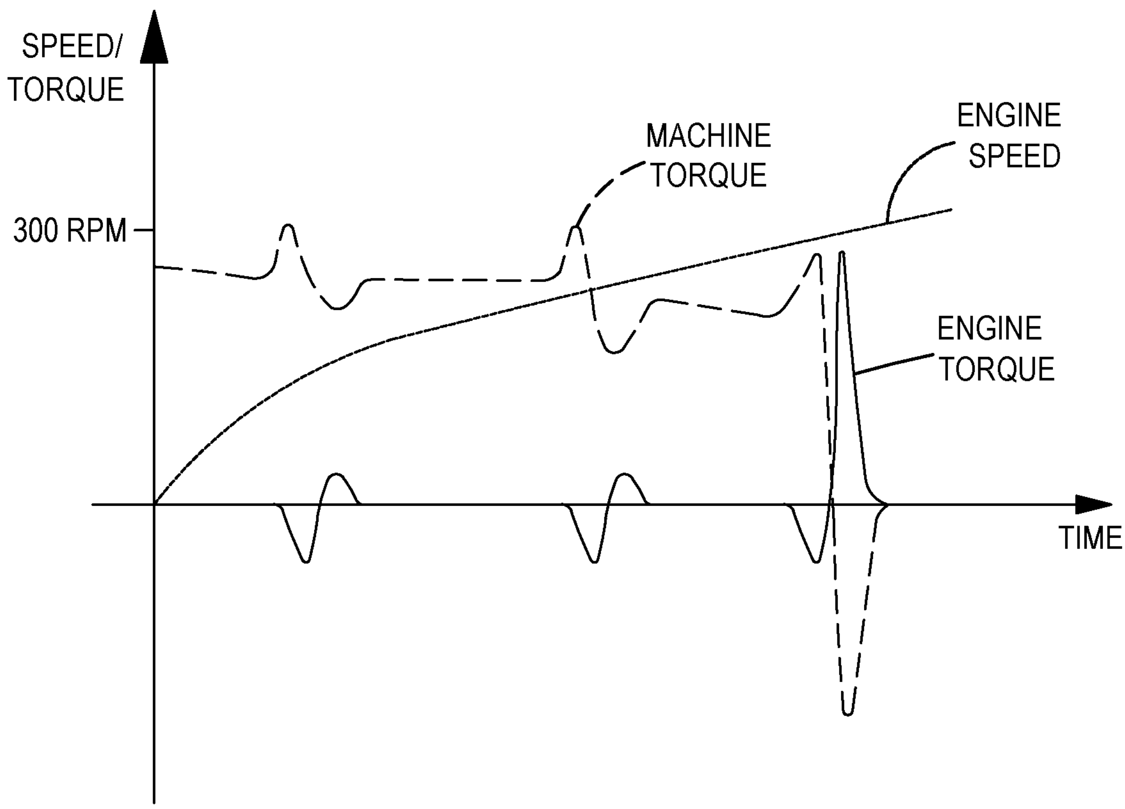

SPEED/
TORQUE
300 RPM
MACHINE
TORQUE
ENGINE
SPEED
ENGINE
TORQUE
TIME

FIG.8

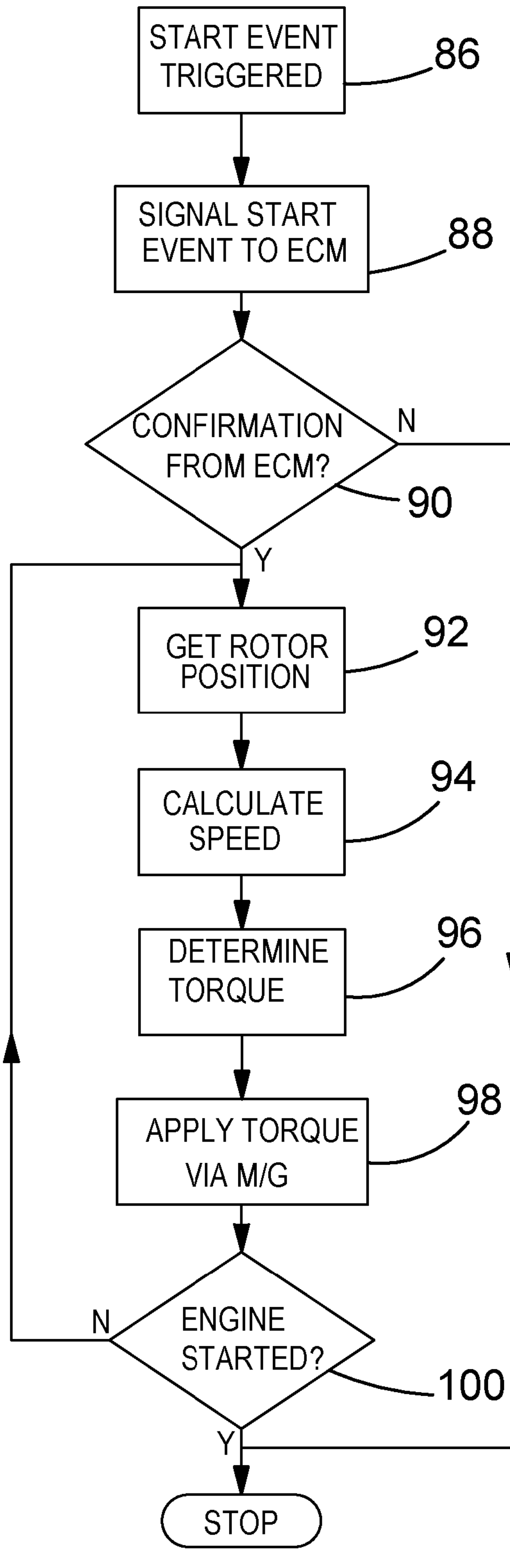

START EVENT TRIGGERED
86
SIGNAL START EVENT TO ECM
88
CONFIRMATION FROM ECM?
N
90
Y
GET ROTOR POSITION
92
CALCULATE SPEED
94
DETERMINE TORQUE
96
APPLY TORQUE VIA M/G
98
ENGINE STARTED?
N
100
Y
STOP

FIG.9

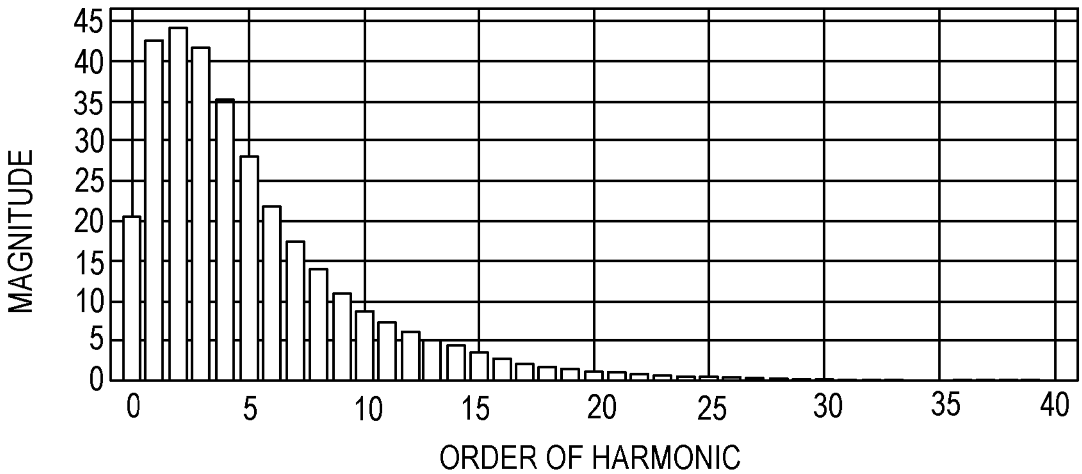

MAGNITUDE
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
ORDER OF HARMONIC

FIG.10

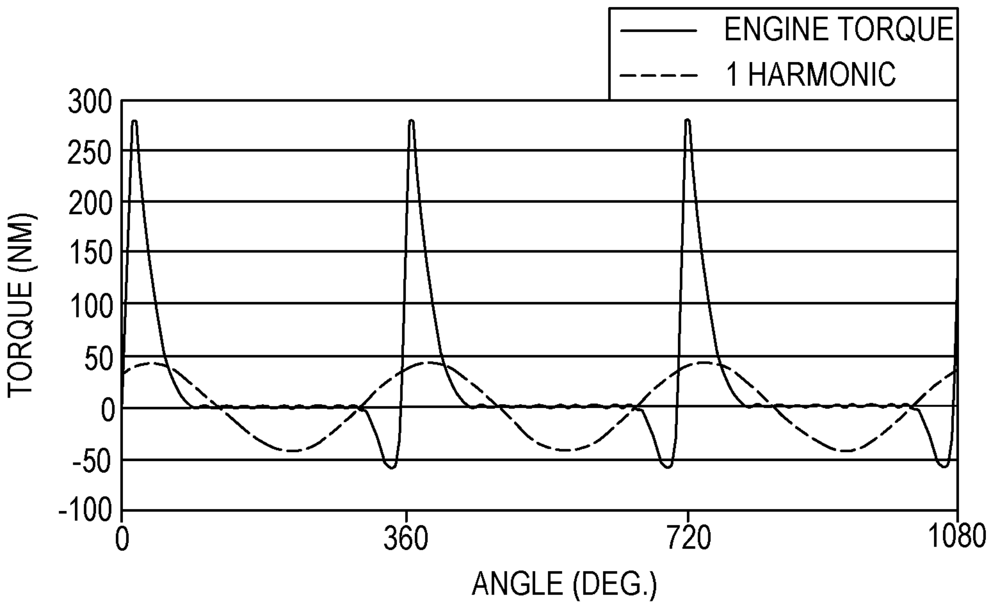

ENGINE TORQUE
1 HARMONIC
TORQUE (NM)
300
250
200
150
100
50
0
-50
-100
0
360
720
1080
ANGLE (DEG.)

FIG.11

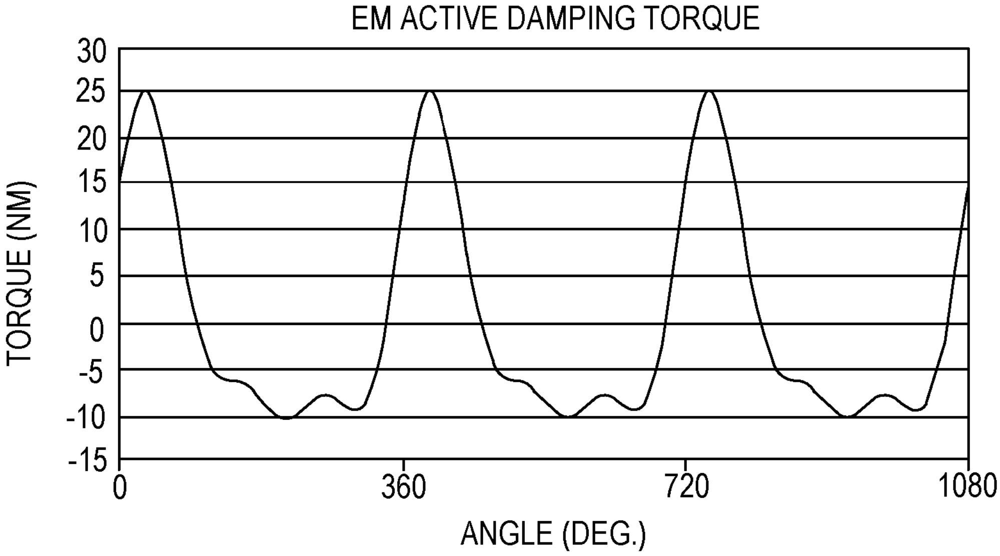

EM ACTIVE DAMPING TORQUE
30
25
20
15
10
5
0
-5
-10
-15
TORQUE (NM)
0
360
720
1080
ANGLE (DEG.)

FIG.12

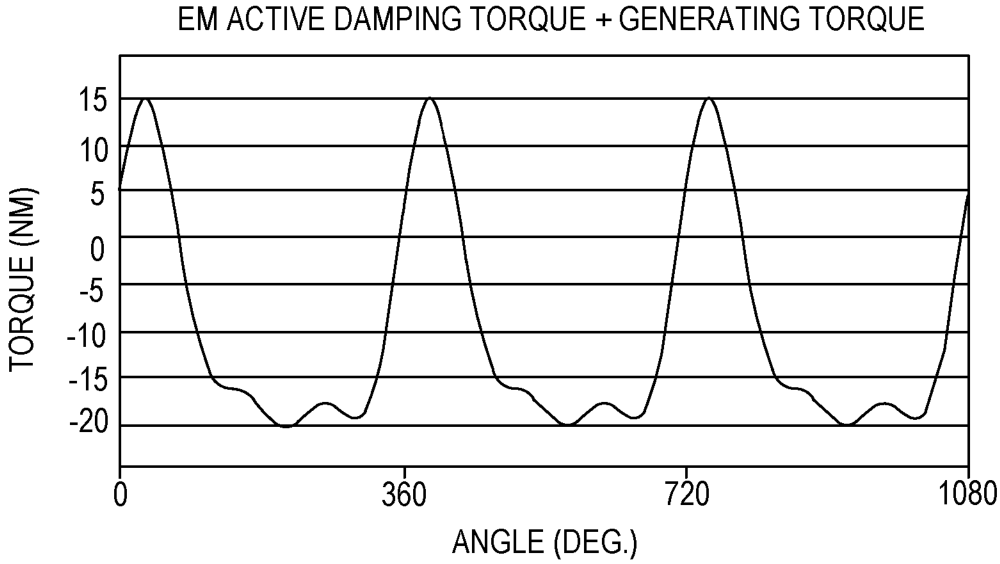
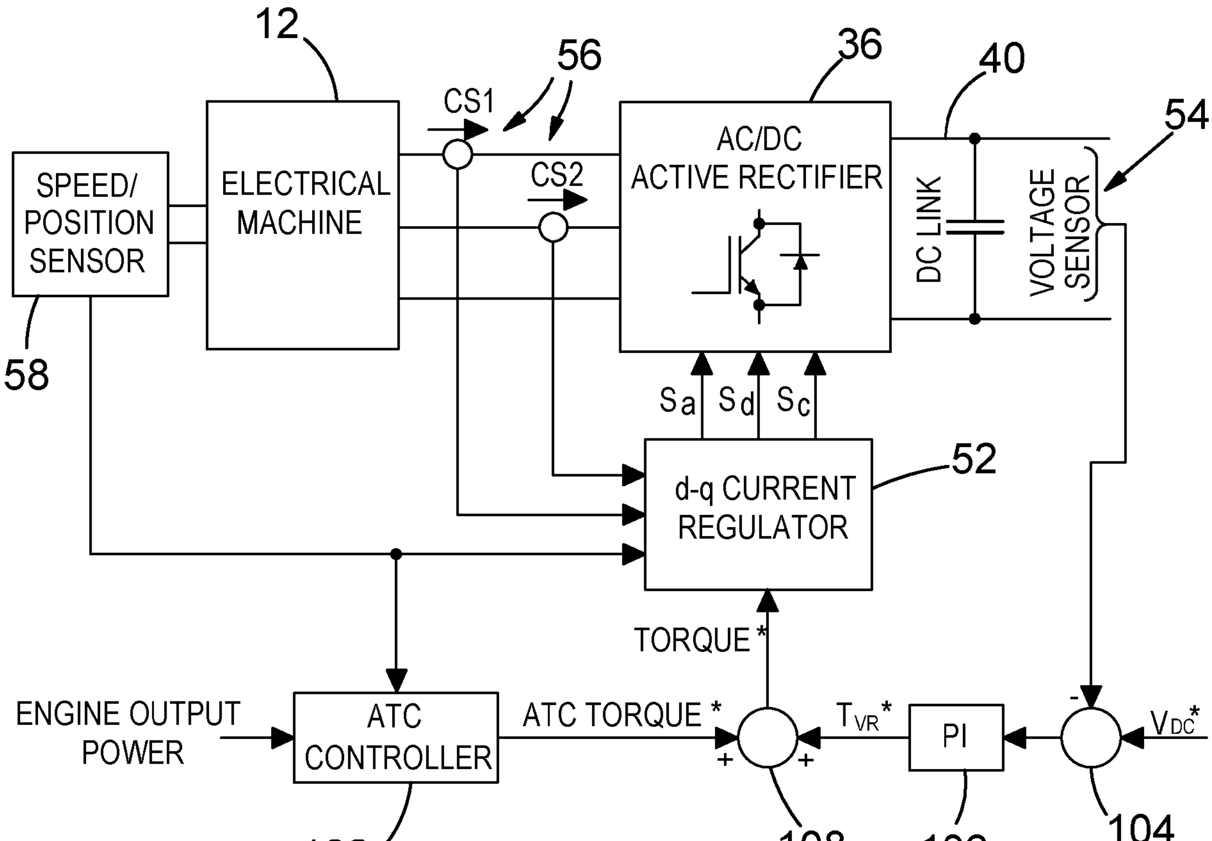
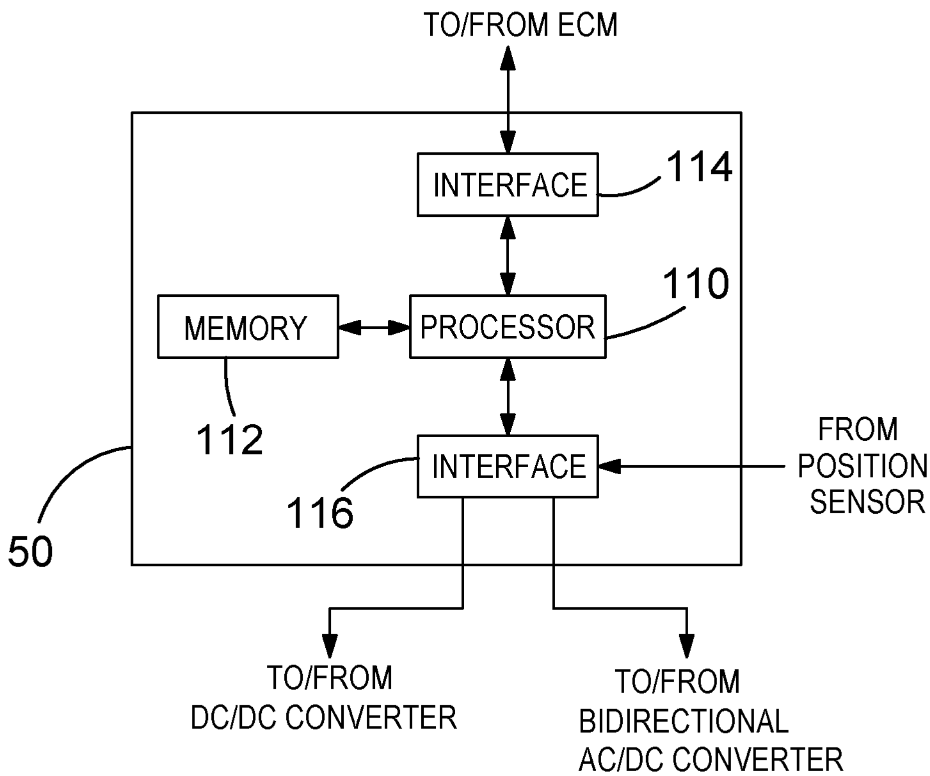

EM ACTIVE DAMPING TORQUE + GENERATING TORQUE
15
10
5
0
-5
-10
-15
-20
TORQUE (NM)
0
360
720
1080
ANGLE (DEG.)

FIG.13



12
56
36
40
54
CS1
CS2
SPEED/
POSITION
SENSOR
ELECTRICAL
MACHINE
AC/DC
ACTIVE RECTIFIER
DC LINK
VOLTAGE
SENSOR
58
Sa
Sd
Sc
d-q CURRENT
REGULATOR
52
TORQUE *
ENGINE OUTPUT
POWER
ATC
CONTROLLER
ATC TORQUE *
TVR*
PI
VDC*
102
108
106
104

FIG.14



TO/FROM ECM
INTERFACE
114
MEMORY
PROCESSOR
110
112
INTERFACE
116
FROM
POSITION
SENSOR
50
TO/FROM
DC/DC CONVERTER
TO/FROM
BIDIRECTIONAL
AC/DC CONVERTER

FIG.15

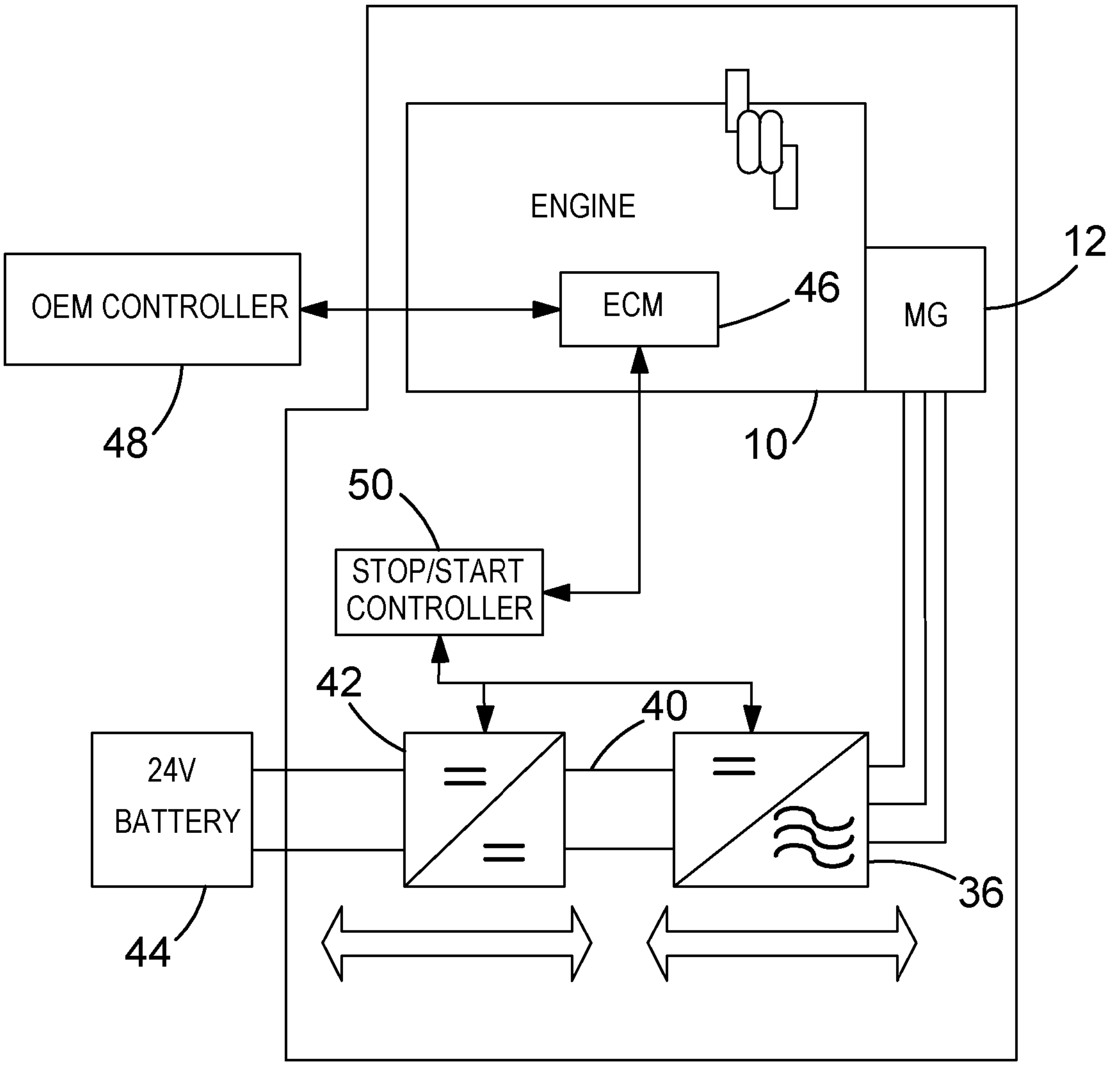

ENGINE
OEM CONTROLLER
ECM
46
MG
12
48
10
50
STOP/START
CONTROLLER
42
40
24V
BATTERY
36
44

FIG.16

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2015/051272

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02N11/04 B60K6/26 B60W10/06 B60W10/08 B60W30/20
H02K7/18 F02B75/06 F02N11/08 B60K6/485 F16F15/18
F02D41/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F02N B60K B60W H02K F02B F16F F02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 177 734 B1 (MASBERG ULLRICH [DE] ET AL) 23 January 2001 (2001-01-23) abstract; figures 1-5 column 1, line 60 - column 3, line 29 column 9, line 10 - column 11, line 38 column 13, line 24 - column 14, line 29 column 15, line 31 - column 17, line 5 -----	1-47
X	EP 1 829 725 A2 (PEUGEOT CITROEN AUTOMOBILES SA [FR]) 5 September 2007 (2007-09-05) abstract; figures 1-5 paragraphs [0005], [0045] - [0047] -----	1-28,30, 39-47
X	DE 197 48 665 A1 (ISAD ELECTRONIC SYS GMBH & CO [DE]) 6 May 1999 (1999-05-06) abstract; figures 1-4 ----- -/--	1-28,30, 39-47

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 July 2015	30/07/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Mineau, Christophe

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 365 170 A1 (BAYERISCHE MOTOREN WERKE AG [DE]) 26 November 2003 (2003-11-26) abstract; figures 1-3 -----	1-28,30, 39-47
X	WO 01/14944 A1 (SIEMENS AG [DE]; SCHAEFER HEINZ [DE]) 1 March 2001 (2001-03-01) abstract; figures 1-4 -----	1-28,30, 39-47
A	WO 2010/106560 A1 (ALENIA AERONAUTICA SPA [IT]; ANASTASIO VINCENZO [IT]; SBUTTONI ANTONIO) 23 September 2010 (2010-09-23) abstract; figures 1-4 -----	1-47
A	DE 10 2007 047427 A1 (BOSCH GMBH ROBERT [DE]) 9 April 2009 (2009-04-09) abstract; figure 1 -----	1-47

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2015/051272

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-47

   Compensation of the torque variations produced by an engine by the electrical machine in a vehicle with start-stop function

1.1. claims: 1-7, 9-13, 19-26, 39, 40, 47

   Compensation of the torque variations produced by an engine by the electrical machine in a vehicle with start-stop function during a stop event

1.2. claim: 8

   Stop the engine in a particular position with the help of the electrical machine

1.3. claims: 14, 15

   Accelerate the engine start with the help of the starter-generator

1.4. claims: 16-18

   Compensation of the torque variations produced by an engine by the electrical machine in a vehicle with start-stop function during a start event

1.5. claims: 27-38

   Supply the starter-generator with a high-voltage capacitor in addition to the vehicle battery

1.6. claims: 41-46

   Provide a direct connection between the starter-generator and the engine crankshaft

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2015/051272

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6177734 B1	23-01-2001	US 6177734 B1	23-01-2001
		US 6365983 B1	02-04-2002
EP 1829725 A2	05-09-2007	EP 1829725 A2	05-09-2007
		FR 2898082 A1	07-09-2007
DE 19748665 A1	06-05-1999	DE 19748665 A1	06-05-1999
		EP 1027546 A1	16-08-2000
		JP 2001522023 A	13-11-2001
		WO 9923396 A1	14-05-1999
EP 1365170 A1	26-11-2003	DE 10223426 A1	04-12-2003
		EP 1365170 A1	26-11-2003
WO 0114944 A1	01-03-2001	DE 19939250 A1	22-03-2001
		EP 1203270 A1	08-05-2002
		WO 0114944 A1	01-03-2001
WO 2010106560 A1	23-09-2010	NONE	
DE 102007047427 A1	09-04-2009	NONE	