

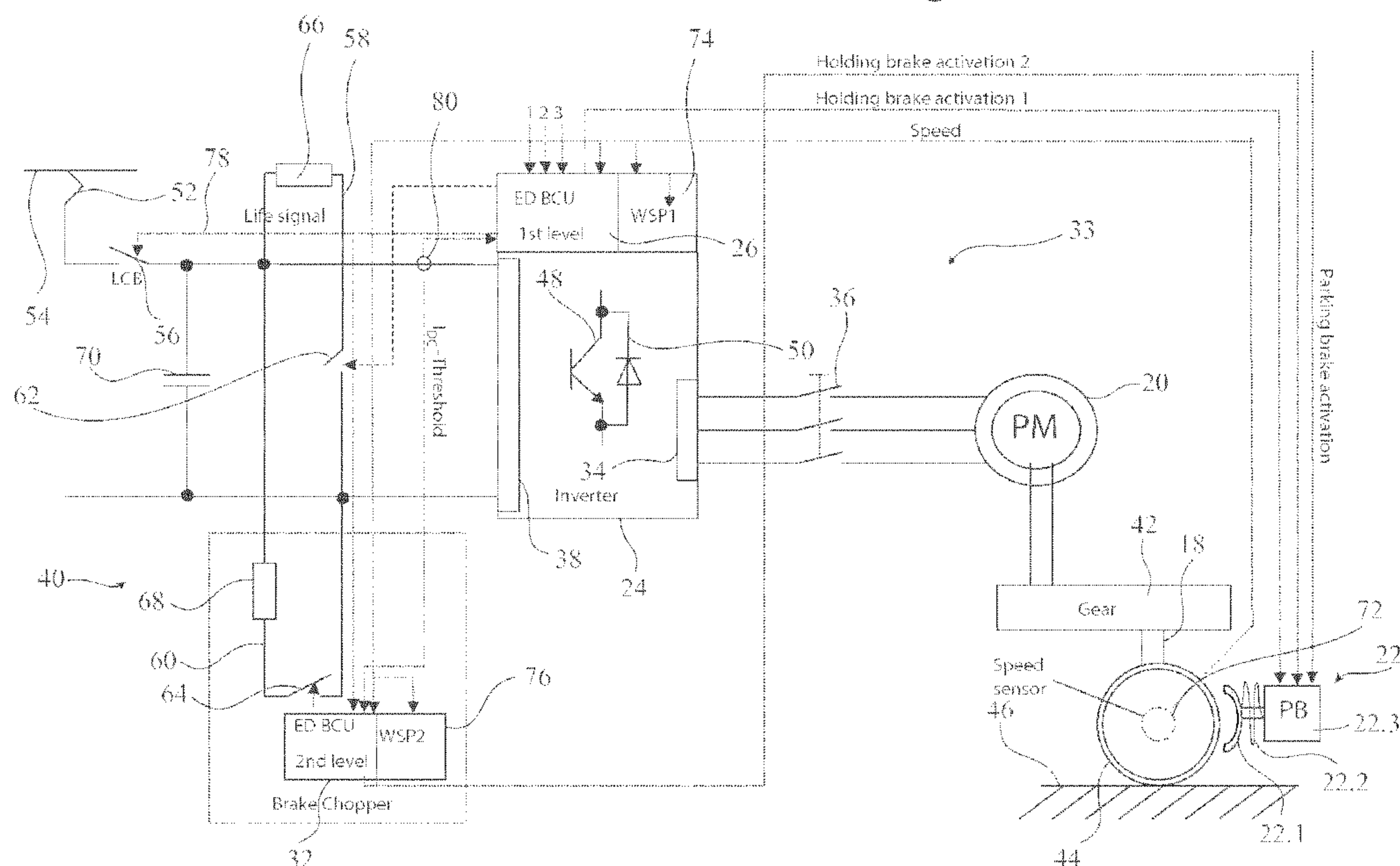


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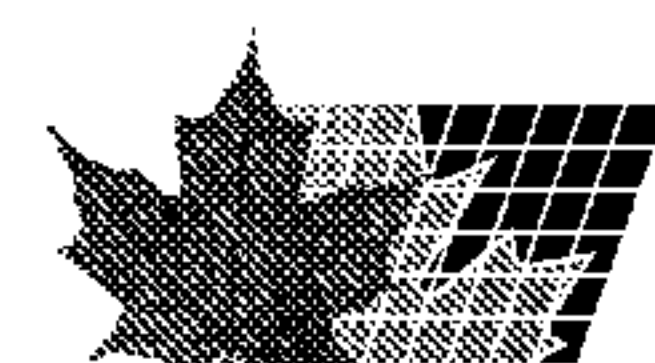
(54) **Titre : PROCÉDE POUR ACTION DE FREINAGE D'UN ESSIEU DE FREIN D'UN VEHICULE FERROVIAIRE ET SYSTEME DE FREINAGE POUR VEHICULE FERROVIAIRE**
(54) **Title: METHOD FOR A BRAKING OPERATION OF A WHEEL AXLE OF A RAIL VEHICLE AND BRAKING SYSTEM FOR A RAIL VEHICLE**

Fig.2



(57) **Abrégé/Abstract:**

A wheel axle (18) of a rail vehicle is provided with an electro-dynamic brake system (33) and with a not fully rated mechanical braking system (22). A braking method for braking the wheel comprises at least a service braking mode carried out solely with the electro-dynamic braking system (33), a parking brake mode carried out solely by the mechanical braking system (22), and an emergency braking mode comprising a first level emergency braking mode carried out solely by the electro-dynamic braking system (33) and a second level emergency braking mode activated when the first level emergency braking mode has a malfunction and carried out solely by the electro-dynamic braking system (33) as long as a low efficiency condition of the electro-dynamic braking system is not met and at least partly by the mechanical braking system (22) when the low efficiency condition of the electro-dynamic braking system (33) is met.



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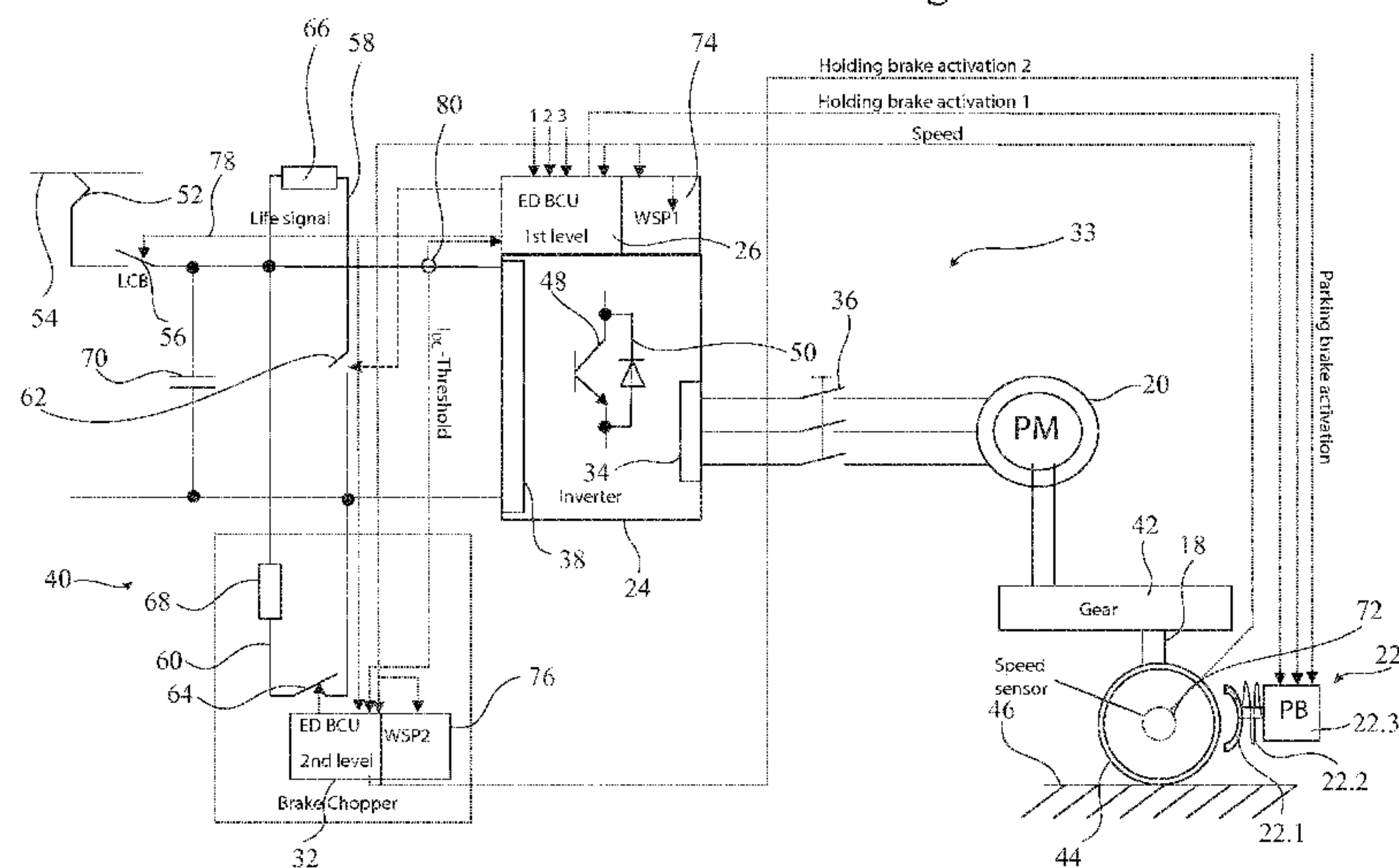
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METHOD FOR A BRAKING OPERATION OF A WHEEL AXLE OF A RAIL VEHICLE AND BRAKING SYSTEM FOR A RAIL VEHICLE

TECHNICAL FIELD OF THE INVENTION

5 **[0001]** The invention relates to electrically driven rail vehicles powered by an overhead line or a third rail. It relates in particular, albeit not exclusively, to electrical multiple unit (EMU) rail vehicles comprising a plurality of coaches and driven by motors, preferably permanently excited synchronous machines, distributed over the length of the vehicle. More specifically, it relates to a braking method and system,
10 which make extensive use of electro-dynamic braking, and completely or almost completely avoids the use of friction brakes in emergency braking situations.

BACKGROUND ART

[0002] Traditionally, rail vehicles are provided with several different braking means, such as mechanical or electro-dynamic brakes. The mechanical brakes are
15 generally pneumatically operated and transform the kinetic energy of the rail vehicle into heat through friction. The electro-dynamic brakes transform the kinetic energy of the vehicle into electric energy, which can be dissipated as heat in rheostats (rheostatic braking) or fed back to the power line, e.g. an overhead catenary line or a third rail (regenerative braking). Usually, electro-dynamic brakes are provided by the
20 electric motors of the electrically driven rail vehicle, which are operated as alternators or generators. Depending on the kind of traction motor used, e.g. DC motors, permanent magnet AC motors or induction motors, the electric machine must be controlled to transfer energy from the rotor to the stator during braking.

[0003] Mechanical and electro-dynamic brakes are applied jointly or separately
25 for different braking functions, in particular for service braking and for emergency braking.

[0004] For service braking, the mechanical brakes and electro-dynamic brakes are usually blended. More precisely, the electro-dynamic brakes supply the required braking torque up to their full capacity, and are supplemented by the mechanical
30 brakes if necessary, so as to minimize wear and optimize energy regeneration.

[0005] On the other hand, electro-dynamic brakes are usually not considered reliable enough to be applied in emergency braking situation. Hence, the whole retarding torque in case of emergency braking is still provided by the mechanical brakes. To provide sufficient performance for emergency braking, the installation of the mechanical brake system requires a number of actuators, which are not permanently used for service braking. The installed mechanical braking means are therefore not used on a regular basis. Increased weight, space for installation of voluminous pneumatic equipment and cost are the consequence.

[0006] A safety braking system for a vehicle with electric traction is disclosed in US 2009/0224706. The safety braking system comprises a first, electric, non-safety brake which is integrated in the traction chain and includes a three-phase permanent magnet motor capable of operating as a voltage generator, a traction inverter capable of being configured as a diode bridge rectifier, an electromechanical switch for connecting the permanent magnet motor to the inverter, and a DC link including a chopper brake resistor, a line filter and a line circuit-breaker. The system further includes a second, safety brake. According to one embodiment, the safety brake includes the diode bridge rectifier of the traction inverter, a terminal load resistor, an auxiliary electromechanical relay connected in series with the terminal load resistor and controlled at an input, the relay and the resistor being interposed in parallel between the chopper and the inverter. A current monitoring device is mounted in series on the DC side of the inverter for monitoring the braking performance of the first brake. Upon detection of a predetermined condition, the current monitoring device triggers the electromechanical relay to switch on the branch of the circuit including the load resistor. In order to avoid motoring, the line circuit breaker is also triggered to open the power line.

[0007] This system is complex as it involves both an electric non-safety brake and an electric safety brake.

[0008] Hence, there is a need for a simpler and more integrated electro-dynamic braking system and method, which make extensive use of electro-dynamic brakes even in the most demanding emergency situations, to avoid the installation of a fully-rated mechanical system.

SUMMARY OF THE INVENTION

[0009] The foregoing shortcomings of the prior art are addressed by the present invention.

[0010] According to a first aspect of the invention, there is provided a method for
5 a braking operation of a wheel axle of a rail vehicle, the wheel axle being provided with an electro-dynamic brake system and with a not fully rated mechanical braking system, the method comprising at least a service braking mode, a high integrity emergency braking mode and a parking brake mode, the service braking mode being carried out solely by the electro-dynamic braking system and the parking brake mode
10 being carried out by the mechanical braking system, wherein the high integrity emergency braking mode is carried out solely by the electro-dynamic braking system as long as a low efficiency condition of the electro-dynamic braking system is not met and at least partly by the mechanical braking system, when the low efficiency condition of the electro-dynamic braking system is met.

[0011] According to another aspect of the invention, there is provided a method
15 for a braking operation of a wheel axle, in particular a drive wheel axle, of a rail vehicle, comprising at least a service braking mode, a high integrity emergency braking mode and a parking brake mode, wherein the service braking mode is carried out solely by an electro-dynamic braking system from the cruising speed of the
20 vehicle down to standstill, the parking brake mode is carried out by a mechanical braking system which is not a fully-rated mechanical braking system, and the high integrity emergency braking mode is carried out solely by the electro-dynamic braking system as long as a low efficiency condition is not met, and is at least partly carried out by the mechanical braking system when the low efficiency condition is
25 met.

[0012] The cruising speed of the vehicle is a speed at which the vehicle or wheel axle is designed to run for long period of times between stations. The cruising speed is in any case above 100 km/h and, in the case of a high speed vehicle, higher than 250 km/h. The parking and holding brake system is basically a mechanical brake
30 system and not a fully-rated braking system, i.e. it is thermally not rated to brake the wheel axle from the cruising speed down to standstill. This means that the braking

system is substantially less complex and bulky than a fully-rated braking system (which, by definition, must be able to brake the wheel axle from the cruising speed down to standstill by itself). The mechanical braking system is only able to brake the vehicle if the vehicle speed is already below a predetermined threshold, which may
5 depend on the weight supported by the wheel axle. The method takes advantage of this available mechanical braking system to supplement or replace the electro-dynamic braking system at very low speed in the high integrity emergency braking mode, when the efficiency of the passively running static converter and of the electro-dynamic braking system becomes insufficient.

10 **[0013]** The low efficiency condition of the electro-dynamic braking system is met when the electro-dynamic braking system becomes unable to transform the kinetic energy at very low speed. This may be the case when the current magnitude in a DC link associated of the electro-dynamic brake system drops below a predefined threshold. Alternatively the low efficiency condition is met when a speed of the rail
15 vehicle or of the wheel axle drops below a predefined threshold (e.g. 5 or 2 km/h). The low current and low speed condition can be used simultaneously. The low efficiency condition should be chosen such as to correspond to a vehicle speed that is below the predetermined threshold of the mechanical braking system mentioned above.

20 **[0014]** Upon deceleration of the wheel axle or rail vehicle from the cruising speed down to standstill in the service braking mode, the electro-dynamic braking system holds the wheel axle and the rail vehicle stationary for a predetermined period of time, e.g. 10s or 1 minute, after which the mechanical braking system takes over and the electro-dynamic braking system is ramped down or faded out. This helps to avoid
25 overloading the electro-dynamic brake converter's switching elements of the electro-dynamic braking system. Hence, in the service braking mode, the electro-dynamic brake system followed by the mechanical brake system are used to bring about the holding brake function, i.e. the function of holding the train at standstill for a short duration.

30 **[0015]** To prevent reverse movements when the rail vehicle starts moving, the mechanical braking system is released only after building up motoring torque.

[0016] After deceleration down to the threshold value in the emergency braking mode, the mechanical braking system progressively takes over. In the high integrity emergency braking mode, a blending of the mechanical brake system and electro-dynamic brake system or the mechanical brake system alone is used for the holding
5 brake function.

[0017] In the high-integrity emergency braking mode, a static converter located between a traction motor and a DC link of the electro-dynamic braking system is run as a passive rectifier, whereas in the service braking mode the static converter is run as an active rectifier. Hence, the risk of a potential malfunction of a control unit in
10 charge of controlling the power semiconductor switches of the static converter is avoided in the high-integrity emergency braking mode.

[0018] The high-integrity emergency braking mode is preferably a second level emergency braking mode and the procedure preferably also includes a first level emergency braking mode.

[0019] In the first level emergency braking mode, the vehicle is preferably decelerated from the cruising speed of the vehicle down to standstill solely by the electro-dynamic braking system. In this respect, the first level emergency braking mode is very similar to the service braking mode, except that the set value for the braking power is maximum at any given time from the cruising speed down to
20 standstill, such that a maximum available deceleration is applied by the electro-dynamic brake system at each instant. In both the service and the first level emergency braking mode, a static converter of electro-dynamic braking system associated with the wheel axle is actively controlled. In particular, if the static converter is provided with power semiconductor switches and freewheeling diodes,
25 the power semiconductor switches are triggered to optimise the power transfer from the electro-dynamic brake associated with the wheel axle to DC link and from there to a power line for generative braking and/or to a brake chopper for dissipative braking. The service braking mode and first level emergency braking mode are preferably jerk limited, which is achieved by a proper control of the electro-dynamic braking system,
30 since no mechanical friction braking is involved.

[0020] The second, high-integrity emergency braking mode is a braking mode of higher integrity but of lower efficiency, in particular at very low speed, and the mechanical braking system is used to complement or replace the electro-dynamic brakes when the braking power of the electro-dynamic brakes becomes insufficient at very low speed, e.g. below 5 or 2 km/h. In particular, in the case of a static converter provided with power semiconductor switches and freewheeling diodes as discussed above, the power semiconductor switches of the static converter are disabled, the circuit operates as a passive rectifier via the freewheeling diodes to transfer power away from the electro-dynamic brakes. Jerk limitation is realised by progressively fading out the electro-dynamic braking system at low speed and taking over with mechanical braking system.

[0021] The second, high-integrity emergency braking mode is preferably carried out upon a malfunction of the first level emergency braking mode. A malfunction condition in the first level brake control mode is detected when the electro-dynamic braking system does not adequately decelerate the wheel axle in presence of an emergency brake demand based on a comparison between an instantaneous target emergency torque value and an actual torque value. According to a preferred embodiment, the instantaneous target emergency torque value is calculated based on an axle load weight sensor signal and a driving wheel axle revolution speed signal.

[0022] The procedure with two emergency braking modes of different priorities ensures that in case of malfunction, the electro-dynamic brake force is not lost completely. Advantageously, the electro-dynamic braking system can be operated both as a regenerative brake and as a rheostatic brake in the service braking mode and in the first level emergency braking mode, and the regenerative brake is given a higher priority than the rheostatic brake. Hence, the procedure takes full advantage of regenerative braking, i.e. of the braking capacity of the power line. The connection to a power line is preferably interrupted in the second level emergency braking mode, such that the electro-dynamic brake performs only as a rheostatic brake.

[0023] According to a preferred embodiment, a wheel slide protection is active during service braking mode, first level emergency braking mode and second level emergency braking mode. The wheel slide protection is preferably applied on a per

axle basis. The wheel slide protection may include a first level wheel slide protection associated to the first level emergency braking mode and a second wheel slide protection associated to the second level emergency braking mode.

[0024] According to a preferred embodiment, a load weighing of the car body
5 influences the service braking, first level emergency braking mode and/or the second level emergency braking mode. Preferably, the load weighing is performed locally, on each bogie or each axle, and the service braking and/or emergency braking modes are load compensated according to this local load weighing.

[0025] According to one embodiment, the first level emergency braking mode is
10 activated when an emergency brake loop is de-energised and the second level braking mode is activated when a life signal from the first level brake control unit fails.

[0026] Preferably, the mechanical braking system is an electrically controlled mechanical braking system. Preferably the mechanical braking system is an energise-
15 to-release braking system, and more preferably a spring-applied braking system.

[0027] According to another aspect of the invention, there is provided a method for braking a rail vehicle provided with a plurality of wheel axles, in particular a multiple unit rail vehicle, each of the wheel axles being provided with an electro-dynamic braking system and a mechanical braking system, each of the wheel axles
20 being individually braked as described above. In particular, the low efficiency condition of each electro-dynamic braking system is individually assessed for each electro-dynamic braking system and each axle.

[0028] The procedure is performed on a per axle (or per motor) basis by opposition to a per bogie or per car basis. This means in particular that the potential
25 malfunction of the first level emergency braking mode is preferably detected at the level of each electro-dynamic braking system or each axle, and that switching to the second level emergency braking mode is performed locally, while other well-functioning brake control units are still in the first level emergency braking mode.

[0029] The method takes advantage of the fact that on a multiple unit vehicle, the odds of having a simultaneous malfunction of all the local brake control units is almost inexistent. Hence, running some of the electro-dynamic braking systems in a failsafe degraded mode is acceptable, since the well-functioning brake control units will ensure that the overall braking performance of the vehicle is as expected.

[0030] According to a another aspect of the invention, there is provided a braking system for braking a rail vehicle provided with a plurality of drive wheel axles, each drive wheel axle comprising an associated electro-dynamic braking system and an associated mechanical braking system that is not fully rated, each drive wheel axle comprising an associated first level brake control unit for carrying out at least a service braking mode solely with the associated electro-dynamic braking system from the cruising speed of the vehicle down to standstill, and for carrying out a parking braking mode at standstill solely with the associated mechanical braking system, each drive axle further comprising an associated second level brake control unit for carrying out a high integrity emergency braking mode solely with the associated electro-dynamic braking system as long as a low efficiency condition is not met, and at least partly with the mechanical braking system when the low efficiency condition is met. Preferably all the wheel axles of the vehicle are drive wheel axles as described hereinbefore. Alternatively, the vehicle may also include trailer axles.

[0031] The first level brake control unit and the second level brake control unit are preferably each connected to a mechanical brake activation unit associated to the drive wheel axle. In the service braking mode (and, if available in the first level emergency braking mode), the first level brake control unit triggers the activation of the mechanical brake system after a predetermined time at standstill. In the high integrity emergency braking mode, the second level brake control unit triggers the activation of the mechanical brake system as soon as a low efficiency condition is met.

[0032] The not fully rated mechanical braking system is preferably the only friction brake associated with each of the drive wheel axle. In other words, the drive wheel axles are not provided with fully rated mechanical braking system, which is a major advantage in terms of weight and space.

[0033] The mechanical braking system is preferably an energise-to-release, preferably a spring applied, braking system. According to a preferred embodiment the mechanical braking system is electrically controlled and actuated, which involves that no pneumatic or electro-pneumatic control system is necessary. Again this is a major advantage in terms of complexity.

[0034] Preferably each mechanical braking system is provided with a mechanical brake activation unit. The first level brake control unit and the second level brake control unit are each connected to the mechanical brake activation unit.

[0035] According to a preferred embodiment, the braking system comprises a power line and, for each of the wheel axles, the associated electro-dynamic braking system comprises at least one traction motor operable as an alternator during braking operation, at least one inverter connected to the motor and operable as a rectifier during braking operation, at least a first wheel slide protection unit, and a signal transmission system with sensors. The first level brake control unit is connected to the inverter and to the first wheel slide protection unit and the second level brake control unit is connected to the first level brake control unit and to a second wheel slide protection unit. The service braking mode and, if available, the first level emergency braking mode are carried out by the first level brake control unit, while the second level emergency braking mode is carried out by the second level, high integrity brake control unit.

[0036] The power line is preferably a DC power line and the braking system comprises a DC link with at least one brake chopper connected to the second level brake control unit and to the inverter, and the motor is a synchronous motor.

[0037] Preferably, the signal transmission system comprises a first connection from the first level brake control unit to an emergency brake loop and a second connection from the first level brake control unit to a load weight sensor.

[0038] Preferably, the signal transmission system comprises a live signal connection from the first level brake control unit to the second level brake control unit and to the line circuit breaker and/or at least one separation contactor.

[0039] According to one embodiment, the sensors comprise one or more speed sensors associated to the wheel axle, wherein each of the first level brake control unit, the first wheel slide protection unit, the second level brake control unit and a second wheel slide protection unit is connected to at least one of said one or more speed sensors.

[0040] According to one embodiment, the sensors include one or more current sensors in the DC link, wherein each of the first level brake control unit and the second level brake control unit is connected to at least one of said one or more current sensors.

[0041] According to another aspect of the invention, there is provided a wheel axle of a rail vehicle, in particular for carrying out the methods described above, the wheel axle being provided with an electro-dynamic braking system and a mechanical braking system which is not fully rated, the electro-dynamic braking system comprising a traction motor associated with the wheel axle and operable as alternator during braking operation, an inverter connected to the motor and operable as a rectifier during braking operation, wherein the inverter is provided with a first level brake control unit connected to a first wheel slide protection unit and a second level brake control unit connected to the first level brake control unit and to a second wheel slide protection unit. The wheel axle is not provided with any fully-rated mechanical braking system.

[0042] According to another aspect of the invention, there is provided a braking system for an electrical multiple-unit vehicle, in particular for carrying out the method described above, comprising a power line, a plurality of carriages, each driven by one or more traction motors each associated with one traction wheel axle and operable as alternator during braking operation, a plurality of inverters each connected to one of the traction motors and one only and operable as a rectifier during braking operation, wherein each of the inverters is provided with a first level brake control unit connected to a first wheel slide protection unit and a second level brake control unit connected to the first level brake control unit and to a second wheel slide protection unit.

[0043] The wheel slide protection is carried out as a per axle control and is available during both service brake and emergency brake. Due to low to medium integrity level required for service brake (low to medium integrity) and first level emergency brake (medium level integrity requirement) the wheel slide protection is performed by the first level brake control unit. Whenever the second level emergency brake mode is active the wheel slide protection is performed by a second level wheel slide protection of higher integrity associated to the second level brake control unit.

[0044] Preferably, each traction wheel axle is provided with an electro-mechanical braking system, preferably a spring-applied braking system.

10 **[0045]** According to one embodiment, the inverter is connected to a DC-link provided with a current sensor, and the second level brake control unit triggers the application of the electro-mechanical braking system when a current signal detected by the current sensor is below a predetermined, preferably strictly positive threshold.

15 **[0046]** According to one embodiment, each driving wheel axle is provided with at least one rotation sensor connected to the second level brake control unit, which triggers the application of the electro-mechanical braking system when a rotation speed signal detected by the rotation sensor is below a predetermined, preferably strictly positive threshold, corresponding e.g. to a ground speed of about 3 to 5 km/h.

20 **[0047]** According to another aspect of the invention, there is provided a braking system for a rail vehicle, comprising:

- an electric power line;
- an emergency brake loop which is energised in the absence of an emergency brake demand and de-energised in presence of the emergency brake demand;
- 25 - driving wheel axles each provided with
 - at least one parking brake,
 - at least one electro-dynamic brake,

- a static converter having AC terminals connected to the electro-dynamic brake and DC terminals, the static converter including a circuit of power semiconductor switches and freewheeling diodes, the circuit being such that when the power semiconductor switches are disabled, the circuit operates as a passive rectifier via the freewheeling diodes to transfer power from the AC terminals to the DC terminals,
 - a DC-link for connecting the DC terminals of the static converter to the power line, the DC-link including one or more braking chopper,
 - a first level brake control unit connected to the emergency brake loop and at least responsive to the emergency brake demand to generate trigger signals to control the power semiconductor switches of the static converter and at least one of the one or more braking choppers, and
 - a second level brake control unit for controlling at least one of the one or more braking choppers in presence of an emergency brake demand and of a malfunction condition of the first level brake control unit.
- 20 **[0048]** The braking system takes advantage of the failsafe degraded passive operative mode of the static converter to transfer the braking power of the electro-dynamic brakes back to the DC link and to the braking chopper to achieve a higher integrity level emergency braking whenever the first, lower-level brake control unit proves inefficient.
- 25 **[0049]** According to a preferred embodiment, the braking system further comprises a service brake demand line, the first level brake control unit being responsive to a service brake demand signal on the service brake demand line to control deceleration of the axle down to zero. No friction braking is involved at all in the service braking mode, even at very low speed. Hence, there is no need to equip

the vehicle with heavy and bulky full-rate friction brakes and the vehicle does not include such full-rate friction brakes. At standstill, the holding torque delivered by the electro-dynamic brakes is preferably calculated as a function of an assessed or measured load weight, preferably a load weight measured locally on the wheel axle
5 corresponding to the electro-dynamic brake or on the bogie or running gear to which this wheel axle belongs.

[0050] According to a preferred embodiment, each driving axle is further provided with a parking brake, which is preferably a spring applied, electrically released friction brake. It should be understood that unlike service friction brakes,
10 which should be dimensioned such as to dissipate in heat most or all of the kinetic energy of the rail vehicle decelerating from its cruising speed down to standstill, parking brake are dimensioned to merely hold the wheel axle at standstill.

[0051] Preferably, the first level brake control unit automatically activates the mechanical brake and deactivates the electro-dynamic brake when the vehicle has
15 been at standstill for a predetermined time. Preferably, the electro-dynamic brake is progressively decreased down to zero after the mechanical brake has been applied.

[0052] If the second level brake control unit is automatically activated to carry out high integrity emergency braking, the parking brake may be activated when a low efficiency condition of the electro-dynamic braking system is reached because the
20 combination of the passive rectifier and braking chopper does not provide sufficient braking power at very low speed. The low efficiency condition of the electro-dynamic braking system is preferably one condition out of the following set of conditions:

- the speed of the rail vehicle is less than a predetermined, strictly positive threshold value;
- 25 - the current amplitude in the DC link is less than a predetermined, strictly positive threshold value.

[0053] When the condition is reached, the mechanical brake release system becomes de-energised and the mechanical brake automatically applies.

[0054] According to one embodiment, the first level brake control unit includes a first level wheel slide protection controller for setting an instantaneous torque limit as a function of at least the revolution speed of the axle and for preventing that the actual braking torque exceeds the instantaneous torque limit.

- 5 **[0055]** Preferably, the second level brake control unit includes a second level wheel slide protection controller for setting an instantaneous torque limit as a function of at least the revolution speed of the axle and for preventing that the actual braking torque exceeds the instantaneous torque limit.

- 10 **[0056]** According to a preferred embodiment, the first level brake control unit of each driving axle is connected to a load weight sensor for measuring the load weight on said driving axle or on a couple of axle including said driving axle, and determines a target service deceleration torque based on a load weight value measured by the load weight sensor.

- 15 **[0057]** The first level brake control unit of each driving axle is connected to a load weight sensor for measuring the load weight on said driving axle or on a couple of wheel axles including said driving axle, and determines a target service deceleration torque based on a load weight value measured by the load weight sensor.

- 20 **[0058]** The electro-dynamic brake is using a permanently excited synchronous motor, in particular a permanent-magnet motor used as traction motor for the rail vehicle. Thanks to the operative principle of this kind of motor, an automatic locking protection is achieved, since at 100 % slide (wheel locked) the motor braking torque is zero.

- 25 **[0059]** The power line is provided with at least one line circuit breaker. According to a preferred embodiment, a trigger circuit of the line circuit breaker is connected to the first level brake control unit or to the supervision unit to open the line circuit breaker if a regenerative mode abortion condition is met. In practice, motoring of the electro-dynamic brakes during braking will trigger the opening of the line.

[0060] Each driving axle is advantageously provided with one or more sensors included in a list of sensors consisting of a driving wheel axle revolution speed sensor, an axle load weight sensor and an actual brake torque sensor.

[0061] According to an embodiment, a malfunction condition of the first level
5 brake control unit is detected when the first level brake control unit does not adequately decelerate the wheel axle in presence of an emergency brake demand based on a comparison between an instantaneous target emergency torque value and an actual torque value. According to a preferred embodiment, the instantaneous target emergency torque value is calculated based on an axle load weight sensor
10 signal and a driving wheel axle revolution speed signal.

SHORT DESCRIPTION OF THE DRAWINGS

[0062] Other advantages and features of the invention will become more clearly apparent from the following description of specific embodiments of the invention given as non-restrictive example only and represented in the accompanying drawings
15 in which:

- Fig. 1 is a schematic view of a rail vehicle provided with a braking system according to one embodiment of the invention,
- Fig. 2 is a schematic view of the braking system of Fig. 1.

[0063] Corresponding reference numerals refer to the same or corresponding
20 parts in each of the figures.

DETAILED DESCRIPTION OF AN EMBODIMENT

[0064] Referring to Fig. 1, a rail vehicle, in this example an electrical multiple unit vehicle comprises a number of coaches **10**, each of which runs on one or more two-axle bogies **12**. Each bogie **12** is provided with a secondary suspension installed
25 between the coach body and a bogie frame **13**. The secondary suspension may include a levelling system **14** and a load weighing sensor **16**. The local load weighing sensor is e.g. a pressure sensor associated to the pneumatic or hydro-pneumatic levelling system **14**. A pressure sensor attached to the gas reservoir delivers the load signal.

[0065] At least some of the wheel axles **18**, in the example all of them, are drive axles each individually linked to a dedicated permanently excited synchronous motor **20**. Each wheel axle is also equipped with an electrically controlled mechanical parking brake system **22** consisting of one or more friction brakes **22.1**. Each parking
5 brake **22.1** is biased towards the braking position by a spring **22.2** and released by an electrically controlled actuator **22.3**. The parking brakes are not rated for braking the vehicle above a very-low speed limit of e.g. 3 to 5 km/h. Remarkably, the wheel axles **18** are not provided with other friction brakes rated for mechanically transforming into heat all the kinetic energy of the rail vehicle.

[0066] Each permanently excited synchronous motor **20** is individually connected to a dedicated static converter **24** which can be operated alternatively in an inverter mode for powering the associated permanently excited synchronous motor **20** and in a rectifier mode for braking the permanently excited synchronous motor **20**. As will explained in more detail below, a first level brake control unit **26**
15 controls the static converter in both service braking and emergency braking situations. The first level brake control unit **26** is connected to an emergency braking loop **28** and to a service braking line **30**. A second level brake control unit **32** of higher integrity takes over the control of the electro-dynamic braking in case of failure of the first level brake control unit **26**.

[0067] The permanently excited synchronous motor **20**, static converter **24**, first level brake control unit **28** and second level brake control unit **32** together constitute an electro-dynamic braking system **33** associated to the wheel axle **18**. As illustrated in Fig. 2, each static converter **24** has AC terminals **34** connected to the associated permanently excited synchronous motor **20** via a three-phase circuit breaker **36** and
25 DC terminals **38** connected to a DC-link **40** associated with the first level brake control unit **26**. The rotor of the motor **20** is mechanically linked to a wheel axle **18** of the rail vehicle via a gearing **42**. The steel wheels **44** of the wheel axle **18** close the electric circuit and allow the current to flow back to the feeder station via the track **46** connected to the earth. The static converter **24** includes a circuit of power semiconductor switches **48** and freewheeling diodes **50**. The power semiconductor
30 switches **48** of the static converter **24** are controlled by the first level brake control

unit **26** and can be operated alternatively in an inverter mode for powering the permanently excited synchronous motor **20** and in a rectifier mode for feeding back energy from the permanently excited synchronous motor **20** to the DC terminals **38** of the static converter **24**. The circuit of the static converter **24** is such that when the power semiconductor switches **48** are disabled, the circuit operates as a passive rectifier via the freewheeling diodes **50** to transfer power from the AC terminals **34** to the DC terminals **38**.

[0068] The rail vehicle includes one or more current collectors **52** for connecting the vehicle to a DC catenary line **54** or a third rail. Each static converter **24** is individually connected to the current collector **54** via the DC link **40** and a line circuit breaker **56**. The DC link **16** is connected to the DC terminals **38** of the static converter **24** and includes a first level braking chopper unit **58** and a second level braking chopper unit **60**, each of which includes a braking chopper **62**, resp. **64** and a braking chopper resistance **66**, resp. **68** connected in parallel with the static converter **24**. The DC link further comprises a DC link capacitor **70** connected in parallel with the braking chopper units **58**, **60** and with the DC terminals **38** of the static converter **24**. The braking chopper **62** or the first level braking chopper unit **58** is controlled by the first level brake control unit, while the braking chopper **64** of the second level braking chopper unit **60** is controlled by the second level brake control unit **32**.

[0069] The first level brake control unit **26** receives inputs from emergency brake commands, e.g. a binary input connected to the emergency brake loop **28**, a brake pipe or an emergency pushbutton. The first level brake control unit **26** also receives a load weight signal from the load weight sensor **16** of the bogie **12** corresponding to the drive wheel axle **18**. Additionally, the first level brake control unit **26** receives a revolution speed signal from a rotation sensor **72** associated to the drive wheel axle **18**.

[0070] The same revolution speed signal is fed to the second level brake control unit **32**. Each of the first level and second level brake control units **26**, **32** is provided with a wheel slide protection unit **74**, resp. **76**, which is also fed with the revolution speed signal. Both the first and second level brake control units **26**, **32** are connected

to a life line **78** which triggers the line circuit breaker **56** and to a current sensor **80** that measures the current flowing in the DC link between the DC terminals **38**.

[0071] When the static converter **24** operates in the inverter mode and the permanently excited synchronous machine **20** runs as a motor to propel the vehicle, the electric current flows between the DC link **40** and the DC terminals **38** of the static converter **24**.

[0072] When a service brake signal is present on the service brake demand line **30**, braking is performed by the permanently excited synchronous machines **20** only and combines regenerative and rheostatic braking, with priority to the former. More specifically, the first level brake control unit **26** receives the signal from the service brake demand line and controls the power semiconductor switches of the static converter to operate the static converter **24** in the rectifier mode such that the permanently excited synchronous machine **20** runs as alternator to deliver power through the static converter **24** to the DC link **40**. The DC voltage of the static converter **24** is controlled via the first level brake control unit **26**, based on the revolution speed signal, the load weight signal, the service brake signal and a slide protection signal from the wheel slide protection unit **74**. If the power line allows it, power is fed back to the power line. Otherwise, the first level brake control unit **26** opens the line circuit breaker **56** such that the power is directed through the closed braking chopper **62** and braking chopper resistance **66** of the first level braking chopper unit **58**. Remarkably, the control of the DC voltage during service braking is carried out locally on a per axle basis.

[0073] If the service brake signal is maintained, the vehicle is decelerated down to standstill by the permanently excited synchronous motors **20** as described above without applying any friction brake.

[0074] After the vehicle has reached standstill, a holding torque is maintained by the permanently excited synchronous motors **20**. The holding torque is controlled by the first level brake control unit **26**. The holding torque is preferably a function of the load weight locally measured by the load weight sensor **16**.

[0075] After a predetermined time at standstill, e.g. 10 seconds or 1 minute, the parking brakes **22** are applied and the holding torque applied by the permanently excited synchronous motors **20** is faded out to avoid overheating of the power switches **48** of the static converter **24**.

5 [0076] As will be understood to those skilled in the art, the holding brake function in a standard mode, i.e. when the vehicle decelerates according to a service brake mode, is initially performed by the electro-dynamic brakes only (i.e. the permanently excited synchronous motors **20**), before the mechanical brakes **22** take over.

10 [0077] The friction brake **22.1** is also automatically applied whenever the electrical auxiliary energy feeding the actuator **22.3** drops below a certain threshold. In that case the auxiliary energy is not sufficient to keep the parking brake in release status. Subsequent application of auxiliary energy releases and the parking brake and reinstate normal operation.

15 [0078] The friction brake **22.1** can also be applied or released by the driver actuating a parking brake push button.

[0079] To prevent reverse movements when the rail vehicle starts moving, the mechanical braking system is released only after building up motoring torque. When motoring torque is present the parking brake **22** receives release signal and the electromechanical release device of each mechanical brake **22** is actuated to build up
20 counterforce against the spring to move and keep the friction elements in the release position.

[0080] The emergency brake loop **28** is energised in the absence of an emergency brake demand. If the emergency brake loop is de-energised, the first level brake control unit **26** switches to a first level emergency brake mode, which is comparable
25 to the service brake mode, except that the deceleration is the highest achievable. The first level wheel slide control unit **74** is still active in the first level emergency braking mode.

[0081] In case of malfunction of the first level control unit **26** in response to an emergency braking demand, the second level brake control unit **32** takes over.

Remarkably, the switching from the first level emergency braking mode to the second level emergency braking mode is performed on a per axle basis. The malfunction corresponds to an actual braking torque lower than a given threshold, which is calculated at each instant. In the second level emergency braking mode, the gate drive
5 units of the power semi-conductor switches **48** are blocked and a life signal becomes zero. The static converter **24** operates in a passive rectifying mode via the freewheeling diodes **50**. While the braking efficiency is less in the second level emergency braking mode than in the first level emergency braking mode, a degraded deceleration performance with high integrity is still available. The second level brake
10 control unit controls the braking chopper **64** of the second level braking chopper unit **60**.

[0082] When the speed decreases below a given threshold, the second level braking chopper unit **60** linked to the static converter **24** which operates as a passive rectifier cannot provide sufficient braking torque. Hence, the second level control unit
15 is linked to the electromechanical parking brake and de-energises the electromechanical brake (i.e. applies the brake) to decelerate the wheel axle from a low speed, e.g. 3 to 5 km/h down to standstill by friction. The DC current in the second level braking chopper unit **60** is proportional to the braking torque of the permanently excited synchronous motor **20**. Hence, the application of the friction
20 brake **22** can be triggered by a current threshold measured by the current sensor **80** located in the DC link **40**, or by the rotation sensor **72**.

[0083] A number of modifications can be envisaged. The overhead power line or third rail can be an AC power line.

[0084] The combined electric drive and brake system of the rail vehicle can be
25 provided with a single line circuit breaker or with one common line circuit breaker and a line circuit breaker in each DC link.

[0085] Obviously, the speed sensor **72**, current sensor **80** and/or line circuit breaker **56** can be duplicated for higher reliability, with different sensors of each type being associated to the first level and second level brake control units or with all
30 sensors being associated to the first level and second level brake control units **26**, **32**.

[0086] A single, common braking chopper unit can replace the first level and second level braking chopper units. In that case, the first level brake control unit and second level brake control unit both control the common chopper.

[0087] Technical features disclosed in connection with one aspect or embodiment
5 of the invention can be combined with other aspects or embodiments.

CLAIMS

1. A method for a braking operation of a wheel axle (18) of a rail vehicle (10), the wheel axle (18) being provided with an electro-dynamic brake system (33) and
5 with a not fully rated mechanical braking system (22), the method comprising at least a service braking mode, a high integrity emergency braking mode and a parking brake mode, the service braking mode being carried out solely by the electro-dynamic braking system (33) and the parking brake mode being carried out by the mechanical braking system (22), characterized in that the high integrity
10 emergency braking mode is carried out solely by the electro-dynamic braking system (33) as long as a low efficiency condition of the electro-dynamic braking system (33) is not met and at least partly by the mechanical braking system (22), when the low efficiency condition of the electro-dynamic braking system (33) is met.
15
2. A method according to claim 1, characterized in that after deceleration down to standstill in the service braking mode, the electro-dynamic braking system keeps the wheel axle stationary for a predetermined time, after which the mechanical braking system takes over and the electro-dynamic braking system is ramped
20 down or faded out.
3. A method according to claim 1 or 2, characterized in that in the high integrity emergency braking mode, the mechanical braking system progressively takes over and the electro-dynamic braking system is ramped down or faded as soon as
25 the drive wheel axle has decelerated to the threshold value.
4. A method according to any one of the preceding claims, characterized in that in the high-integrity emergency braking mode, a static converter located between a traction motor and a DC link of the electro-dynamic braking system is run as a
30 passive rectifier, whereas in the service braking mode the static converter is run as an active rectifier.

5. A method according to any one of the preceding claims, characterized in that, in the high integrity emergency braking mode, a connection to a power line (54) is interrupted and the electro-dynamic braking system is operated only as a rheostatic brake.
5
6. A method according to any one of the preceding claims, characterized in that the high-integrity emergency braking mode is a second level emergency braking mode and the method also includes a first level emergency braking mode, wherein the second level, high-integrity emergency braking mode is preferably carried out upon a malfunction of the first level emergency braking mode.
10
7. A method according to claim 6, characterised in that the first level emergency braking mode is carried out solely by the electro-dynamic braking system from the maximum or cruising speed of the vehicle down to standstill with a maximum available deceleration.
15
8. A method according to claim 6 or claim 7, characterised in that the electro-dynamic braking system (33) is operated as a regenerative brake or as a rheostatic brake in the service braking mode and in the first level emergency braking mode, wherein the regenerative brake has a higher priority than the rheostatic brake.
20
9. A method according to any one of claims 6 to 8, characterized in that a wheel slide protection (74, 76) is active during service braking mode, first level emergency braking mode and second level emergency braking mode.
25
10. A method according to any one of claims 6 to 9, characterized in that a load weighing of the rail vehicle influences the first level emergency braking mode and/or the second level emergency braking mode.
30

11. A method according to any one of claims 6 to 10, characterized in that the first level emergency braking mode is activated when an emergency brake loop is de-energised and the second level emergency braking mode is activated when a life signal from a first level brake control unit fails.

5

12. A method according to any one of the preceding claims, characterized in that the low efficiency condition of the electro-dynamic braking system is met when a current magnitude in a DC link (40) associated to the electro-dynamic braking system (33) or a speed of the rail vehicle (10) or of the wheel axle (18) drops below a predefined threshold.

10

13. A method according to any one of the preceding claims, characterized in that the mechanical braking system (22) is an electrically controlled mechanical braking system, preferably an energise-to-release braking system, preferably a spring applied braking system.

15

14. A method for a braking operation of a rail vehicle comprising a plurality of wheel axles (18), in particular of a multiple unit rail vehicle, each of the wheel axles (18) being provided with an electro-dynamic brake system (33) and with a not fully rated mechanical braking system (22), characterized in that each of the wheel axles (18) is individually braked according to the method of any one of claims 1 to 13.

20

15. A braking system for braking a rail vehicle provided with a plurality of drive wheel axles (18), each of the drive wheel axles (18) comprising an associated electro-dynamic braking system (33) and an associated mechanical braking system (22) that is not fully rated, each of the drive wheel axles (18) comprising an associated first level brake control unit (26) for carrying out at least a service braking mode solely with the associated electro-dynamic braking system (33) from the cruising speed of the vehicle down to standstill, and for carrying out a parking braking mode at standstill solely with the associated mechanical braking system (22), each drive axle (18) further comprising an associated second level

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brake control unit (32) for carrying out a high integrity emergency braking mode solely with the associated electro-dynamic braking system (33) as long as a low efficiency condition is not met, and at least partly with the associated mechanical braking system (22) when the low efficiency condition is met.

5

16. A braking system according to any of claim 15, wherein the not fully rated mechanical braking system (22) is the only friction brake associated with each of the drive wheel axle.

10 17. A braking system according to any of claims 15 or 16, wherein the mechanical braking system (22) is an energise-to-release, preferably a spring applied braking system.

15 18. A braking system according to any of claims 15 to 18, characterised in that each mechanical braking system is provided with a mechanical brake activation unit (22.3), wherein the first level brake control unit (26) and the second level brake control unit (32) are each connected to the mechanical brake activation unit (22.3).

20 19. A braking system according to claim 15, characterized in that the braking system comprises a power line (54), and for each of the wheel axles (18), the associated electro-dynamic braking system comprises at least one traction motor (20) operable as a generator during braking operation, at least one inverter (24) connected to the traction motor and operable as a rectifier during braking
25 operation, at least a first wheel slide protection unit (74, 76) and a signal transmission system with sensors (80, 72).

20. A braking system according to claim 19, characterized in that the first level brake control unit (26) is connected to the inverter (24) and to the first wheel slide protection unit (74) and the second level brake control unit (32) is connected to
30 the first level brake control unit (26) and to a second wheel slide protection unit (76).

21. A braking system according to claim 19 or claim 20, characterized in that the power line (54) is a DC power line and for each drive wheel axle, the associated electro-dynamic braking system comprises a DC link (40) with at least one brake
5 chopper (60, 62) connected to the second level brake control unit (32) and to the inverter (24), and in that the motor (20) is a synchronous motor.

22. A braking system according to any one of claims 19 to 21, characterized in that the sensors include one or more current sensors (80) in the DC link, wherein each of
10 the first level brake control unit (26) and the second level brake control unit (32) is connected to at least one of said one or more current sensors (80).

23. A braking system according to any of claims 15 to 22, characterized in that the signalling system comprises a live signal connection from the first level brake
15 control unit (26) to the second level brake control unit (32) and to the line circuit breaker (56) and/or to at least one separation contactor.

24. A braking system according to any of claims 15 to 23, characterized in that the sensors comprise one or more speed sensors (72) associated to the wheel axle
20 (18), wherein each of the first level brake control unit (26), the first wheel slide protection unit (74), the second level brake control unit (32) and a second wheel slide protection unit (76) is connected to at least one of said one or more speed sensors (72).

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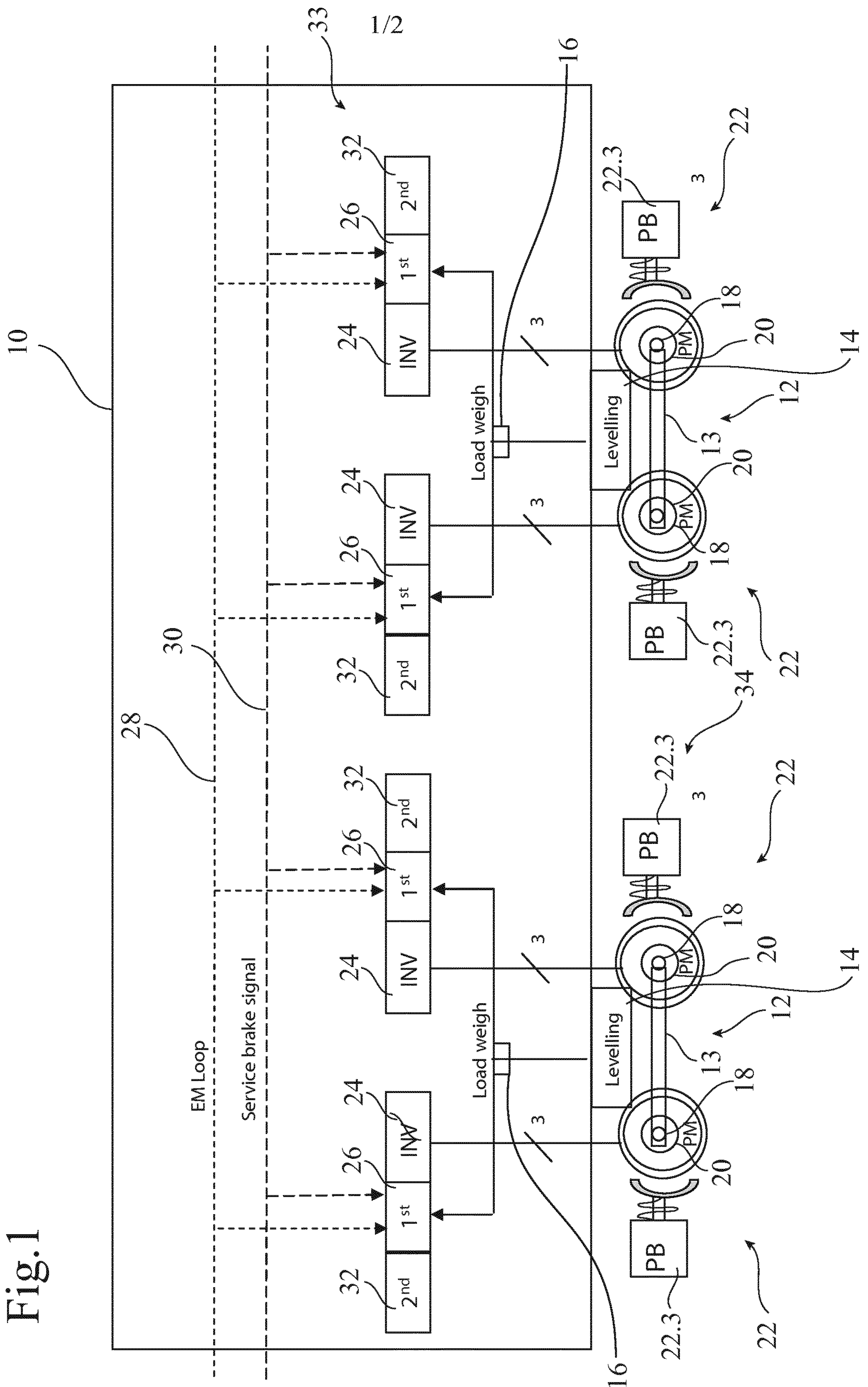


Fig. 2

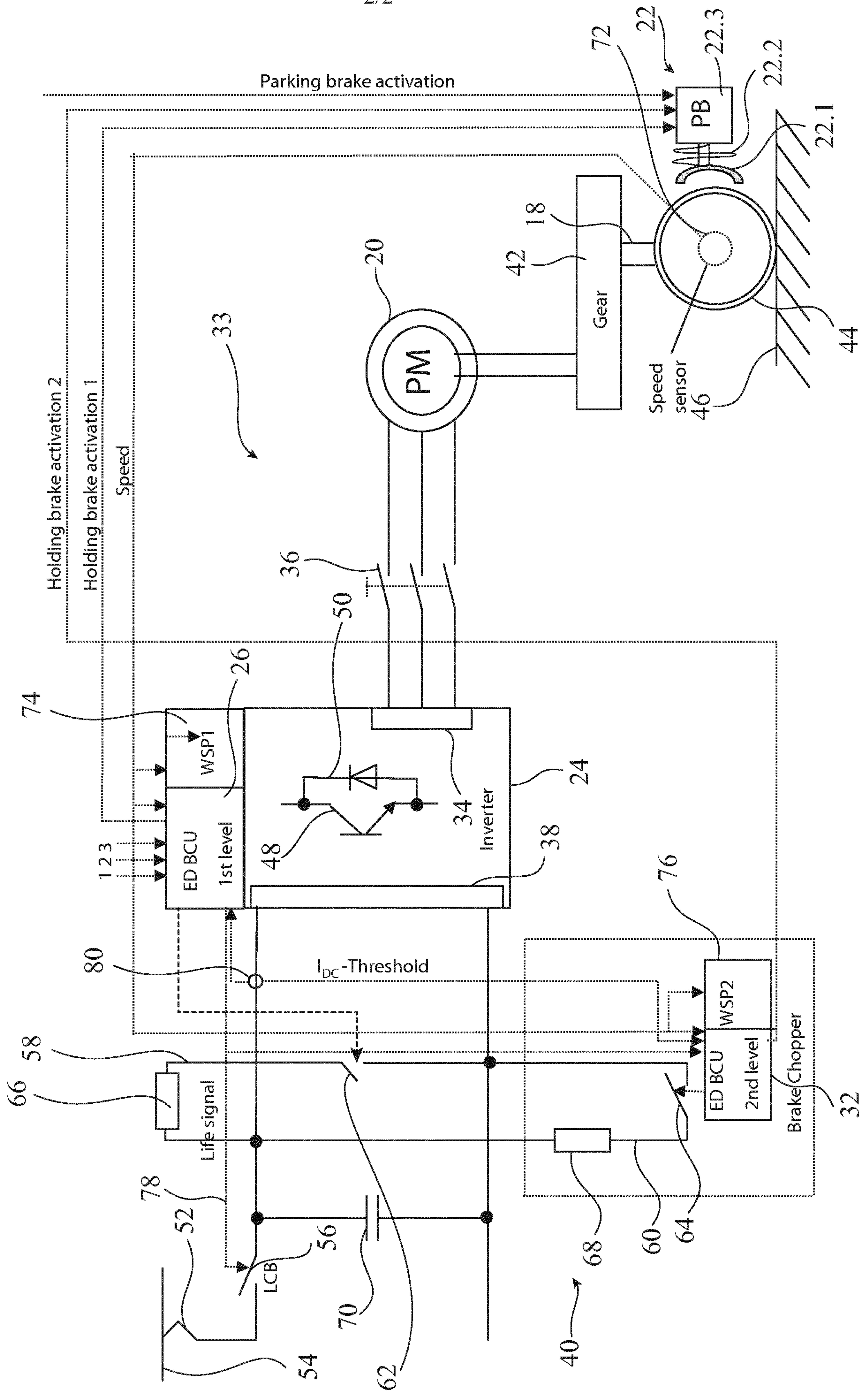


Fig.2

