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Journal of Vibration Engineering

ISSN:1004-4523

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Charging of Electrical Vehicle by Using SwitchedReluctanceMotorDrives

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ABSTRACT

This paper gives a power converter geography coordinated driving and charging capacity of Switched ReluctanceMotor (SRM) drive for Electric Vehicle (EV) application. In the driving mode, the transport voltage can be changedby the front-end buck converter, which meets the prerequisites of the speed open-circle and shut circle control. Inaddition, higher voltage demagnetization can be accomplished by associating the upper freewheeling diodes of theuneven half-span converter to the battery bank, in this way can speed up the demagnetization cycle, expand theabide point and improve the result of the engine. In battery charging mode, a bridgeless rectifier converter isdeveloped by using two-stage windings of the SRM and the current power gadgets of coordinated power converter,without extra inductors and charging units. The battery charging andPower Factor Correction (PFC) control canbeacknowledgedbyshutcircle control ofchargingcurrent.

Key Words—Integrated power converter, high voltage demagnetization, battery charger, electric vehicle, switchedreluctance motor.

I. INTRODUCTION

Electric Vehicle (EV) is an effective solution for decreasing CO2 emission. Currently, EV-related technologies such aselectrical motor drives design and selection, power converters topologies and control algorithms, power source and systemconfigurationareunderextensivedevelopment.Traditionally,permanent-magnetmachinesarepreferredinEVapplications owing to their highpower density and high efficiency. However, the using of large amount of rare-earthmaterials limits the widespread application in mass production market. As a result, developing rare-earth-free machines inEV power drive systems attracts more and more attentions. Among these, switched reluctance motor is a well-knowncompetitive candidate in EV applications due to its robust structure, flexible control, harsh environmental sustaina- bility,excellentfault-tolerantcapability, andhigh startingtorque.

AfewbetterSRMpowerconvertergeographies,forexample,thesecludedfull-spanconverters,detachedsupportCapacitor based converter, C-dump based converters, three-level nonpartisan point diode-braced converter, four levelconverters,Semi Z-source incorporated converter, double stock power converter and soon have been produced for furtherdevelopingtheframeworkfunctionalexecution.

For EV applications, the wide speed guideline capacity, over-burden maintainability, and numerous functional Capabilitymix present difficulties to the SRM power converter framework arrangement. The power converter ought to be used fordriving the engine as well concerning charging the battery source. By and large, a minimized power converter withnumerous energy change capability is profoundly required. Customarily, the unbalanced half bridge converter is used forcontrolling the EV SR drives. In any case, this converter can work in driving mode and regenerative slowing down mode,andalongtheselinesanextrabatterychargeroughttoaddedforcharge.Also,becauseoftheexcitationanddemagnetization voltages are restricted by the proper dc-interface voltage, quick excitation and demagnetization can't beaccomplished. To work on the general execution of the SRM drive framework, a few high level power converters has beencreated for EV application. A lift front-end dc/dc converter, four-stage unbalanced half scaffold converter and buck-supportPFCchargercoordinatedpowerconverterisintroducedinUnderdrivingmode,thetransportvoltagecanbeverymuch controlled and supported by the lift converter, and the winding put away energy can be naturally recuperated back to thebattery source. For the transport voltage is consistently higher than the battery voltage, acknowledging engine speedguidelineexclusivelybycontrollingthefront-endDCconverteristroublesome.Furthermore,becauseofthedemagnetization voltage is lower than the transport voltage, the quick demagnetization can't be guaranteed. In, a Milerconverterwithbatterychargingcapabilitycoordinatedis proposedformoduleHEV,whichutilizesjust fourpowerexchanging gadgets for driving and charging activity. Notwithstanding, because of the utilizing of a typical power switch inthe Miler converter, the stay point ought to be limited to stay away from long demagnetization time and the negative torqueeffects. Ina modifiedMiler converter with front-enddc/dcboost converter fedis constructedwith two three-phaseIntelligent Power Modules (IPMs). This converter can improve the high Speed operation performance and realize batterycharging function with line-drawn power quality. A modular front-end circuit based multilevel converter is developed,whichcanprovideafive-leveldrivingcontroltoaccelerate the excitationand demagnetizationprocesses.

However, the conduction region is restricted within 15° for the three-phase 12/8 SRM. A split power converter with flexiblecharging capability for afour-phase EV SRM is developed. In this converter, the central tapped winding node is utilized forconnecting the phase windings with the converter circuit. In a modular tri-port converter with central-tapped node in eachphase winding is proposed. In this converter, flexible energy flow control between battery, SRM and generator can beachieved, and furthermore the onboard charger for single phase or three phases AC grid can be constructed. The traditionalSRM phase winding structure should be changed accordingly to construct the power converter topology. Besides, the fastdemagnetization cannot be achieved. In a novel multiport bidirectional SRM drive to combine the GCU, battery, PV paneland SRM for flexible driving and charging function with fewer power devices. The dc voltage is boosted and multilevelvoltage is achieved by the battery bank in the GCU driving mode, and by the charge capacitor in the pure battery drivingmode. The excitation and demagnetization processes are both accelerated due to the boosted dc voltage. Besides, veryflexible charging control strategies are developed. However, the bus voltage cannot be adjusted directly. In a modularmultilevel converter (MMC) based switched SR drive with decentralized battery energy system is proposed, which can takeadvantages of the MMCs topology for SRM drives to achieve multilevel phase voltage, flexible dc-bus voltage, modularstructure, and flexible control. However, many additional modularpower devices and driving circuits should be added inthe power converter system.An electric vehicle SR drive powered by a battery/super capacitor having grid-to-vehicle (G2V)and vehicle-to-home (V2H) and vehicle-to-grid (V2G) functions is developed. This converter is formed by a bidirectionalfront-end two quadrant buck/boost dc/dc converter and the SRM asymmetric bridge converter, which can ensure goodacceleration/deceleration, reversible driving, and braking characteristics. In a new converter is integrated by a boost circuit,a switch capacitor with two energy storage systems, battery packs and an SRM. Many driving operation modeswithboosted excitation and demagnetization voltage can be achieved. However, two battery packs or capacitors should be addedin the power converter. A cascaded multiport SR drive for hybrid EV applications is proposed. This converter system canensureflexibleenergyconversionamongthegenerator/acgrid,thebatterybank,andthemotor,andcanalsoachieveBattery Management (BM) function. However, to construct the front-end battery modular circuits, many additional powerswitchesshouldalso beadded.

Generally, to develop a compact battery charger with a simple circuit and flexible control scheme is preferable for EVapplication.Asoflate,manycoordinatedlocallyavailablechargergeographiesarecreatedforEVSRdriveframework.Ina buck-support PFC based battery charger is developed. In this converter, three stage windings of a four stage SRM is used,and a large portion of the power gadgets are chosen from the current driving circuit. Nonetheless, an extra power diodeought to be added. In a coordinated diode span buck-support PFC and buck PFC battery charger are created in a two IPMsbased four-stage full-span converter. A basic buck-support type and buck type accusing converter of equal stage windingsarecreated.Inthemultiportconverterwithmulti-layeredbatterychargingcapabilitiesfromPV,generatorcontrolunit,andaclatticearecreated.Inanycase,thePFCcapabilityisn'taccomplishedinthesegeographies.Inadoublepartedconverteris created for help both the dc and ac charging. While interfacing with an air conditioner power framework, the proposedgeography has a value of the staggered converter, which can guarantee great PFC execution. Nonetheless, the windingsoughttobe splittedand thefocaltappedhuboughttobe remembered fortheconverter.

Inthispaper,afront-endbuckdc/dcconverterbasedEVSRMpowerconverterwithbatterychargingcapabilitycoordinated is proposed for accomplishing different activity modes, for example, driving activity, recovery slowing down,and battery charging.Albeit a buck front-enddc/dc converter is remotely prepared, the on-board charger is coordinatedwith the installed power parts and SRM stage windings. In the driving mode, the DC-transport voltage can be changeddynamically from zero to the battery voltage with the buck converter stage.Accordingly, the speed control and SRMdriving control can be decoupled as the speed open-circle control and shut circle control can be executed exclusively bycontrolling the front-end buck converter, which might further develop the activity proficiency as the power exchanging lossoftheyoustageawryhalfextensioncanbe brought down.Additionally,quickdemagnetizationcanbe accomplished asthe demagnetization voltage is higher than or equivalent to the DC-transport voltage, and the winding put away energy can beconsequently recuperated back to the battery source during demagnetization process. In the charging mode, the powergadgets that were implanted in the SRM converter and two-stage windings are utilized to frame a coordinated bridgelessrectifier to charge the battery from the air conditioner matrix with PFC capability. Tests have been performed with a 1kWSRM model machine. The control plans of the different functional modes are appropriately planned and acknowledged in atypicalARMregulator.Detailed exploratoryoutcomesconfirmtheviabilityofthe proposed techniques.

This paper is coordinated as follows. In Segment II and III, the proposed power converter geography and control plans ofthe various functional modes are introduced. Then, at that point, the exploratory outcomes are examined in Segment IV,withendmade insection V.

II. TOPOLOGYANDOPERATIONALMODESANALYSISOFTHEINTEGRATEDPOWERCONVERTER

A. Topology oftheintegratedpowerconverter

The power train outline of the proposed battery-EV drive framework is displayed in Fig. 1. As contrasted and the powerchart as displayed, just the one power source is utilized. The framework comprises of the battery bank, the coordinatedpowerconverter, andtheSRfootholdengine.

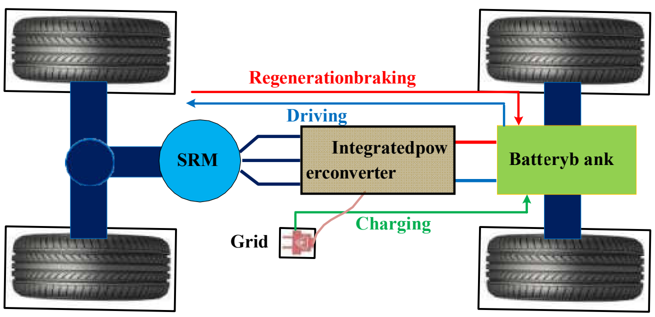


Fig.1Thepowerflowofthebattery-EVpropulsionsystem.

As displayed here, the power streams of three activity modes like the engine driving mode, the regenerative slowing downmode, and the battery charging mode are completely dealt with by the proposed coordinated power converter. In SRMdriving mode, the battery will supply the driving power. In the regenerative slowing down mode, portions of the slowingdown energy will criticism to the battery source with the recovery control of the SRM. Furthermore, in battery chargingmode,thelocallyavailable batterychargergeographywill berecreatedwithoutextra powergadgets,inductors andcapacitors.

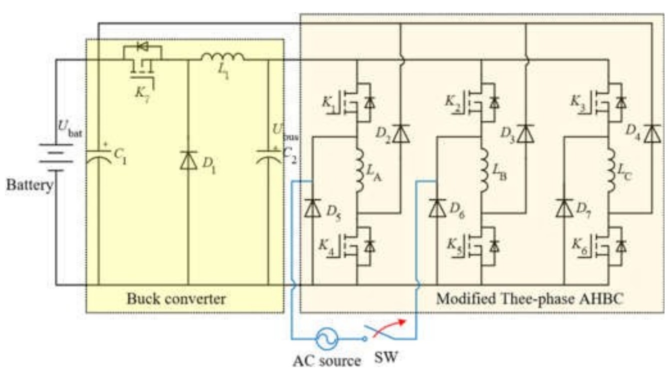


Fig. 2 Topology of the proposed integrated power converter for battery

EVSRMdrivesystem

Fig. 2 shows the topology of the integrated power converter, which is composed of a buck front-end dc/dc converter, amodifiedasymmetricalhalf-bridgeconverter (MAHBC),thebatterysource,theSRMandthesinglephase AC gridconnector.

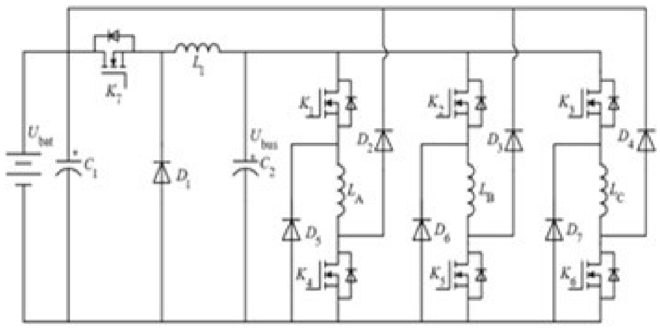


Fig.3(a)TopologyinDrivingmodeandregenerationbrakingmode

As displayed in Fig. 3(a), the buck front-end dc/dc converter is associated in series with MAHBC. In the MAHBC part, theupper freewheeling diodes are associated with the battery source straightforwardly. With this geography setup, the transportvoltage of the MAHBC can be changed from zero to the battery voltage by controlling the buck converter, and thedemagnetization current will input and accuse the battery straight forwardly of diminished demagnetization time length.Under regenerative slowing down mode, the battery can be charged by regenerative current straightforwardly. Besides, asdisplayed in Fig. 3(b), the battery charging can be accomplished by remaking a bridgeless AC-DC rectifier with the existtwo power switches K4 and K5, the four freewheeling diodes D2, D3, D5 and D6, and the windings of An and B stages. Asno extra power parts are included on board battery charger, the power converter has great reconciliation ability. Hence, theEV SRM power drive framework can lessen the dependence on charging stations essentially. The definite examination ofthe functionalmodesistalkedabout intheaccompanying parts.

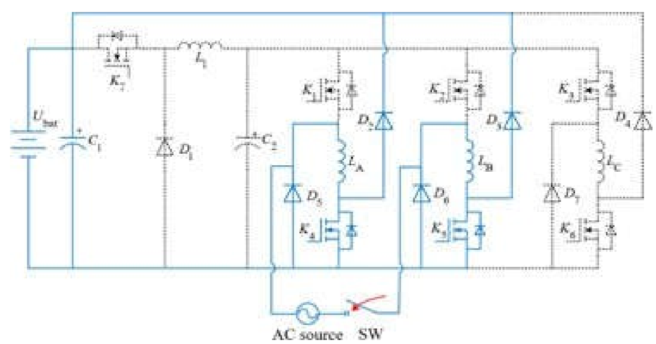


Fig. 3 (b) Topology in battery charging modeFig.3Topologiesunderdifferentoperationmodes

B. DrivingModes

Under driving mode, the battery source energy can be converted to the mechanical energy for SRM driving by the front-endbuckconverterandthe MAHBC.

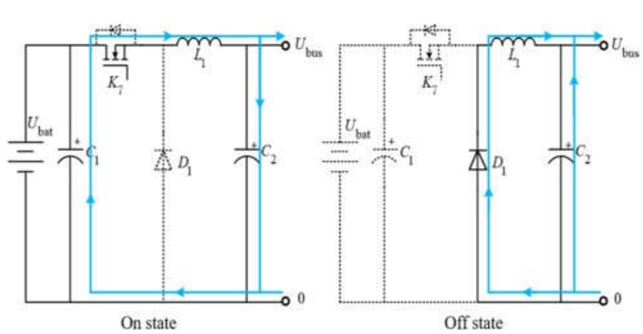
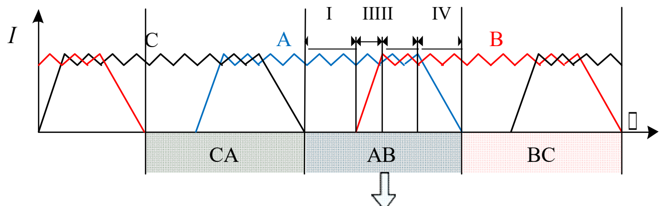


Fig.4Thecontrolstatesofthefront-endbuckconverter

Front-end buck converter activity: By applying PWM signals in K7, the front-end buck dc/dc converter is worked forchangingthetransportvoltageoftheMAHBC.AsdisplayedinFig.4,K7isturnedontoempowertheinductorL1andsend the battery energy to the SRM for creating motoring force. In the off state, K7 is turned off and the energy put away ininductor L1 will be delivered to keep up with the excitation of the SRM stages. In view of volt-second equilibriumguideline,whentheobligationproportionofthe K7isapplied,the transportvoltagecanbeaddressed as

$U_{bus}=DU_{bat}$.



ZoneI:A+, A0	PhaseAconductionalone
ZoneII: A+/B+,A0/B+ **ZoneIII:**A+/B+,A0/B+,A+/B0,A0/B0 **ZoneIV:**A-/B+, A-/B0	PhaseAandBconduction

Fig.5ThecontrolstatesoftheSRMatdifferentregions

MAHBCoperation: Without losing consensus, stage A solitary stage conduction and stages A/B covering conductionstates are chosen for examining the same circuits and the ongoing stream ways of the SRM engine activity. As displayed inFig. 5, taking stage A and B for instance, the conduction locale is separated into four zones I to IV. In zone I, stage A isdirected alone, andindifferentzones, AandBstagearecross-overled.

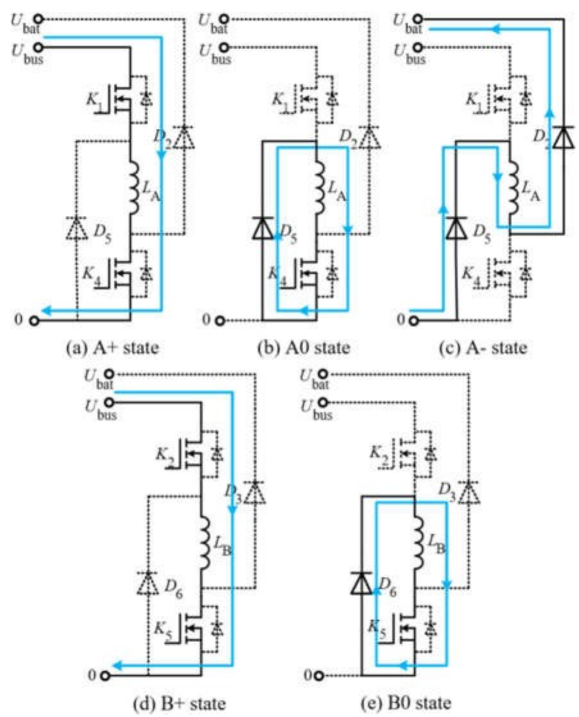


Fig.6 Theexistentcontrolstatesof AandBphaseintheregions(a toe)

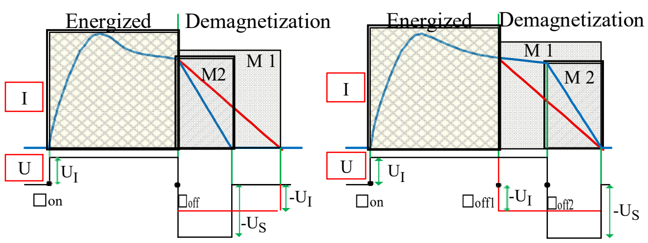
In zone I, stage A is just directed stage, which can worked under excitation mode A+ and freewheeling mode A0. The samecircuitsandtheongoingstreamwaysofA+andA0statesaredisplayedinFig.6(a)and(b)individually.InA+state,K1and K4 are turned on and the transport voltage is applied in the stage winding.In A0 state, K1 is turned off and K4 is turnedon, stage A will work under current freewheeling mode.As should be visible in zero voltage is applied to the stagewindingandthe stagecurrent abatementsasa resultofthenegative back electromotivedrive(backEMF).

In zone II, stage B is worked under excitation mode B+. Consolidating with the activity conditions of stage A, twofunctional modes like A+/B+, A0/B+ are exist. The same circuits and the ongoing stream ways of A+, A0 and B+ aredisplayed in Fig. 6(a), (b) and (d), individually. By consolidating the same circuit of A+ and B+, the manufactured identicalcircuits of the activity mode A+/B+ can be formed. The manufactured comparable circuits of the activity mode A0/B+ canbe createdlikewise.

Inzone III,thestageBcan work underexcitationmodeB+ andfreewheelingmodeB0,which is equivalenttothatinstage A. Subsequently, consolidating the functional conditions of stage A, four functional modes like A+/B+, A0/B+, A+/B0 andA0/B0 would exist. Likewise as that in zone II, the same circuits of these four activity modes can be made by the samecircuitsasdisplayedin Fig.6(a),(b),(d)and(e).

InzoneIV,stageAisworkingunderdemagnetizationmodeA-.AsdisplayedinFig.6(c),K1andK4areturnedoff,andthe freewheeling stage current will criticism to the battery source through the two diodes D2 and D5 byJoining with the twofunctional methods of the stage B, two functional modes, for example, A-/B+ and A-/B0 can be created. Essentially, thesamecircuitsofthesetwomodescanbeformedbythesamecircuitsofA-state, B+stateandB0state.

AsdisplayedinFig. 5, inthezoneI toIV, thereare 8functionalstatesintheMAHBCpart,likeA+,A0,A+/B+,A0/B+,A +/B0, A0/B0, A-/B+, and A-/B0. In this manner, consolidating with the on/off conditions of the front-end buck converter,thereare 16common functionalstatesinthedriving methodoftheproposedconverter.



(a) withthesame turnoffangle **(b)withdifferentturnoffangle**

Fig.7**Comparisonofthetwocontrolstateswithorwithouthigherdemagnetizationvoltage**

Ascontrastedandtheconventionalunbalancedhalfscaffoldconverter,thetransportvoltagecanbechangedfromzerotothebatteryvoltage,whichispotentialforspeedguidelinewiththecontrollabletransportvoltage.Additionally,thedemagnetization voltage is battery voltage, which is dependably higher or equivalent to the transport voltage of theMAHBC.Inthisway,quickdemagnetizationcanbeaccomplished.AsshouldbevisibleinFig.7(a),withhigherdemagnetizationvoltage,thestagecurrentwilldiminishquickerandthenegativeforcebroughtaboutbythedemagnetization current can be brought down. Hence, it can delaythe conduction locale for further developing themotoring force yield. As displayed in Fig. 7(b), the mood killer point is stretched out from θoff1 to θoff2, yet with higherdemagnetization voltage applied, the demagnetization current can be diminished to zero quick, which won't fall behindwhenthe current isdecreased tofocus intheconventional controlstrategy.

C.RegenerativeSlowingdownModes

Under regenerative slowing down mode, the SRM will be controlled as a generator. As displayed in Fig. 8, the astonishingcurrent for age can be developed by changing the excitation area [θon, θoff] of each stage. Taking stage A for instance,when the excitation signal is eliminated, the created current would freewheel through the two diodes D2 and D5 to chargethe battery.The same circuits oftheexcitation and age modes are recorded in Fig.8. As should bevisiblehere,inexcitation mode, both of the two power switches will be turned on to empower the stage winding. In any case, in age mode,both of the two switches will be switched off. In the slowing down mode, when the power switches of each stage arecompletelyswitched off,the stagecurrentwillfreewheeling throughtheupper diodeand criticismtothebatterysource.

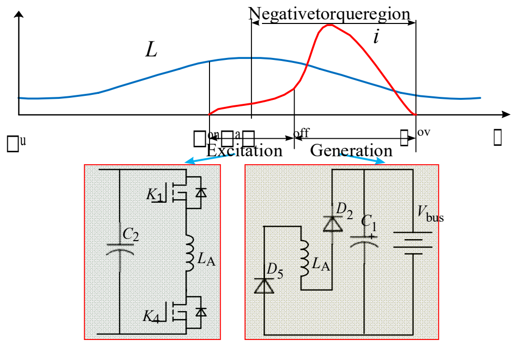


Fig.8Operationalstatesunderregenerativebrakingmode

Assuming the misfortune energy of the freewheeling circuits isn't thought of, all the slowing down energy will be input tothe battery source, andhence the slowing down energy can be recovered. Furthermore, as the producing current streams intheinductancediminishinglocale,negativeslowingdownforcewillbe createdtomakethespeed declinerapidly.

D.BatteryChargingMode

As displayed in Fig. 3(b), in the event that all power switches keep up with turned off with the exception of K4 and K5, thewindings of An and B stages, the exist two power switches K4 and K5, the four freewheel diodes D2, D3, D5 and D6 areused for developing the bridgeless AC-DC rectifier in light of board battery charger. In this manner, no extra power gadgetsought to be added to understand the charging capability. Be that as it may, as the stage windings of two neighboring stagesare chosen for utilizing as the energy-stockpiling inductors of the bridgeless rectifier, it is important to stay away from thevarietyofthestageinductancebroughtaboutbyrevolutionandattractive immersionimpacts.

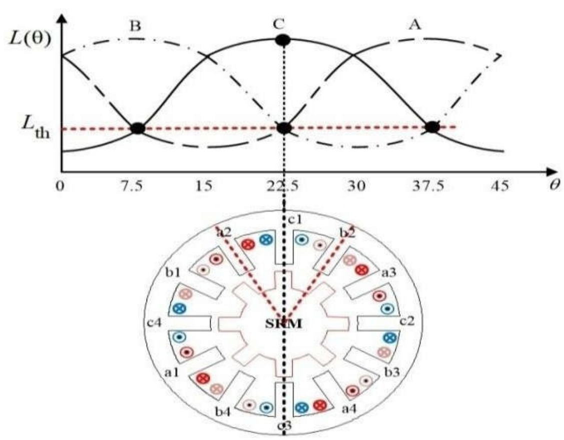
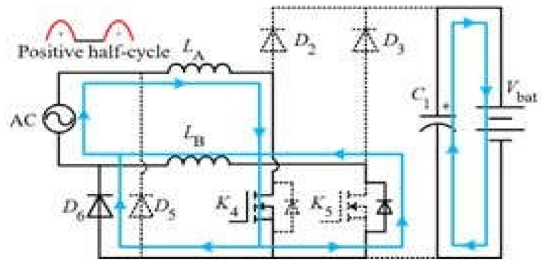


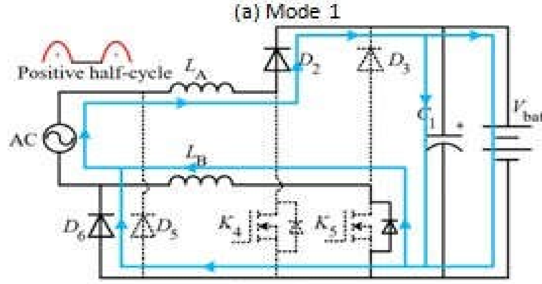
Fig.9Lockpositionselection

As displayed in Fig. 9, by astonishing stage C alone, the rotor will pivot to the C-stage adjusted position, where the middlelines of the rotor shafts are lined up with the middle lines of the C-stage stator posts. Subsequently, to secure the rotor herewith a mechanical installation, the winding inductance worth of stage An and B are equivalent. As should be visible in Fig.9, their inductances are equivalent to L_{th}, which is the inductance esteem in the lower crossing point position of the threestage unsaturated inductance attributes. Moreover, in the C-stage adjusted position, both of the A and B stages are foundclose bytheir unaligned positions exclusively. Accordingly, theirstage inductancewill not delicate to theattractiveimmersions,despitethefactthat thereare highinfoflowsmovingthroughthewindings.

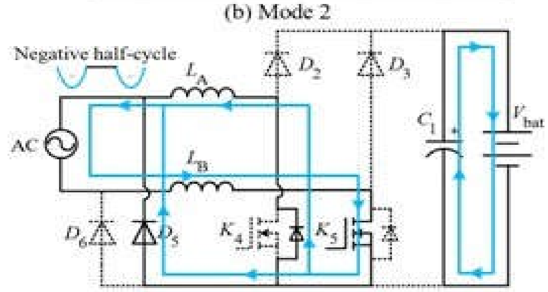
The essential functional methods of the developed bridgeless rectifier are displayed in Fig. 10. As should be visible in Fig.10(a) and (b), during the positive half-pattern of the air conditioner source, the dc/dc help circuit LA-K4-D2 is dynamicthroughdiodeD6,theantiparalleldiodeofK5,andLB.Likewise,duringthenegativehalf-patternoftheairconditioner source, the other dc/dc support circuit LB-K5-D3 is dynamic however the diode D5, the antiparallel diode of K4, and LA.,which is displayed in Fig. 10(c) and (d). The control is rearranged as the two power switches can be driven by a similarPWM signals. Moreover, Power Factor Amendment (PFC) capability can be acknowled --ged by controlling the inductorscurrent of every half-cycle drawn from the mains and molding it like the information voltage waveform. The point by pointexaminationofthe controlprocedureswillbetalkedabout inSegment III.



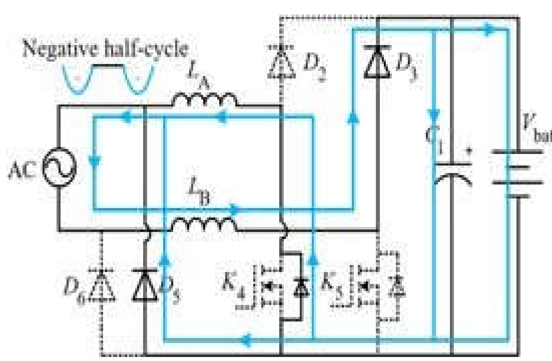
(a) Mode 1



(b) Mode 2



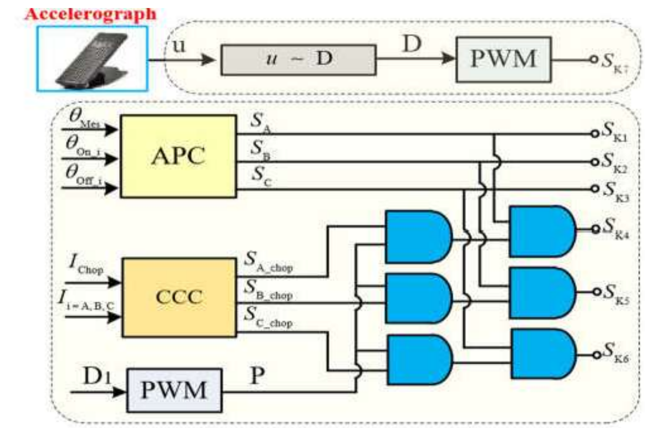
(c) Mode 3



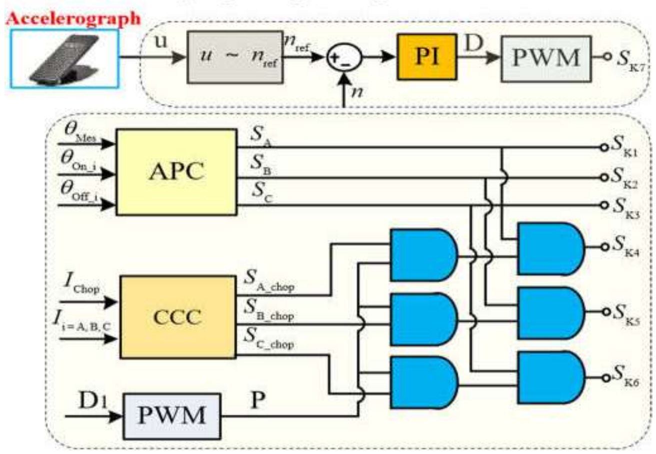
(d) Mode4

Fig.10Operationalmodesofthereconstructedbridgelessrectifier

It ought to be noticed that because of the inconsistent current in the two stages, inconsistent force would be created, whichmight bring about certain vibrations during the charging system. During the positive and negative half pattern of AC sourcevoltage, separately, the all out force during the charging system isn't zero. However, by and large, for EV application, thecharging power is a lot of lower than the force of the foothold engine. The allout force created during charging cycle wouldbetiny.



(a) Speed open-loop control



(b) Speedclosed-loopcontrol

Fig.11PrinciplediagramofthedrivingcontrolstrategiesCONTROLSTRATEGIES

A. Drivingcontrolstrategies

As talked about in the past segment, the combination of the front-end buck converter makes the transport voltage of theMAHBC movable. Hence, it is achievable to change the rotational speed of the EV-SRM by controlling the front-end buckconverter. The standard outlines of the speed open-circle and shut circle control calculations are displayed in Fig. 11(a) and(b), separately. As should be visible in Fig. 11(a), by changing over the result voltage of the EV accelerograph into theobligation proportion of the PWM control sign of the power switch K7 straightly, the front-end buckconverter can becontrolled straightforwardly to yield a variable transport voltage to help the MAHBC and drive the EV-SRM. In theMAHBC part, the Conventional Current slashing Control (CCC), Angle Position Control (APC) and PWM control can bejoined for creating the control signs of the six power switches K1-K6. To be noted here, just the lower switches of eachstage leg are directed for producing the zero voltage freewheeling state in the conduction districts. In speed shut circlecontrol, the result voltage of the EV accelerograph is changing over into the reference rotor speed straightly. The speeddeviation is taken care of to a PI regulator to create the obligation proportion ofthe PWM sign of K7. Hence, the rotorspeed will be controlled to follow the reference by changing the transport voltage of the MAHBC. This is the main contrastas contrasted and the open-circle control calculation. The stage recompense and current guideline control will likewise bedealt with bythe MAHBC.

It ought to be noticed that the obligation proportion D1 as displayed in Fig. 11(a) and (b) can be set to 1 straightforwardly,in light of the fact that the speed control is completely dealt with by the control of the front-end converter. Consequently,the rotor speed control can be decoupled from the essential engine driving control calculation like the APC and CCCcontrol.Nonetheless,inthecustomaryawryhalfscaffoldconverter,thetransportvoltageisfixed,subsequentlytochange the rotor speed, no less than one power switch of each stage leg ought to participate in the PWM guideline of the appliedvoltage of each stage winding. Consequently, the switch recurrence of the MAHBC will be a lot of lower than that inconventional topsy-turvyhalfextensionconverter.

B. Regenerativebrakingcontrolstrategy

Inregenerativeslowingdownmode,theSRMiscontrolledasagenerator.Thecontrolblockchartiscomparativeasthatfor the speed open-circle driving control, which is displayed in Fig. 11(a). The main distinction is that the excitation localefor age energizing current development ought to be chosen close by the adjusted position. As displayed in Fig. 11(a), in thispaper the excitation district is fixed at [20°, 35°] for a 12/8 construction SRM model and the obligation proportion D1 is setto1.Forthissituation,theappliedexcitationvoltageforageinvigoratingcanbeconstrainedbycontrollingtheacceleroographphysically.

After excitation, the creating current will input to the battery straightforwardly through the two free wheel diodes. In theinterim,thenegativeforcewillcreatedforbrake.

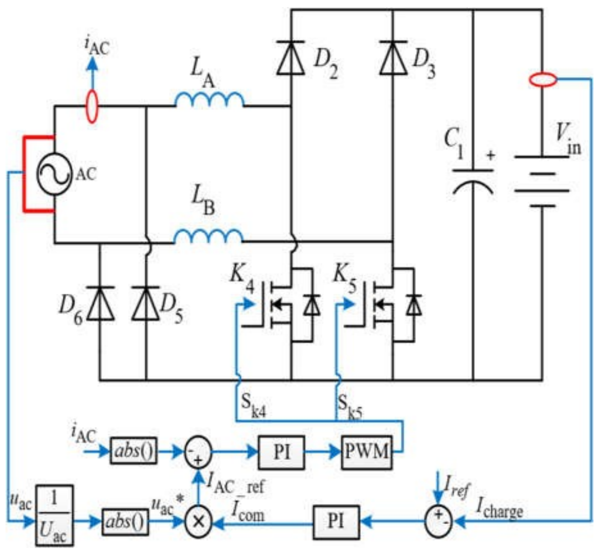


Fig.12Principlediagramofthebatterychargingcontrolstrategy

C. Batterychargingcontrolstrategy

Under battery charging mode, the bridgeless converter is developed as an on-board charger without adding extra powergadgets and inactive parts. In this paper, a steady typical current charging control conspire is created. As displayed in Fig.12, the charging plan can be carried out with a twofold current circle control calculation. The external circle is the chargingcurrent criticism circle, in which a PI regulator is used for controlling the blunder between the reference current and thecriticism charging current. To accomplish PFC capability, an AC input current controlled inward circle is additionallyadded. The AC Input Current Reference $I_{AC_ref}$is created by increasing outright worth of unit ac source voltage U_{ac}* withthe external circle control order I_{com}. The following blunder between the$I_{AC_ref}$and the outright worth of the directestimated AC input current $i_{AC}$is additionally managed with another PI regulator and the produced PWM signals areutilized for controlling the two power switches all the while. Through these control technique, in every half pattern of theAC period, the typical battery charging current can follow the reference current, and in the mean time the information accurrentcanbecontrolled assinusoidalcurrentsynchronized with theACvoltage.

IV. EXPERIMENTALRESULTS

To check the legitimacy of the proposed incorporated power converter and its control methodologies, tests have beenexecuted ina12/8 designSRD.Thefundamental particularofthemodelmachineisrecordedintableI.

TableIMotors
pecifications

Phasenumber	3
Statorpoles	12
Rotor poles	8
Ratedpower	1000W
RatedVoltage	48V
Ratedspeed	3000rpm
Maximumphase inductance	4.52mH
Minimumphase inductance	0.56mH

As should be visible in Fig. 13, the proving ground comprises a 48V lead-corrosive battery bank, incorporated powerconverter,ARMbased regulator,theSRMmodelandthedynamometer.Itemizedexaminationsareasperthefollowing:

Fig.13Experimentalsetup

Under driving controlmode, both of the speed open-circle control and shut circle control procedures are tried. Fig. 14(a)and (b) show the fundamental stage current and voltage waveforms under APC and PWM control. In these tests, the PWMrecurrence of the buck converter is set as f1=10kHz, the PWM recurrence of the MAHBC part is set as f2=6kHz, D1=1 andD1=0.5 are chosen to test the APC and PWM control of the SRM separately. As displayed in Fig. 14(a) and (b), bycontrolling the accelerograph, the applied voltage under conduction areas can be changed lower than the battery bankvoltage, however the demagnetization voltage is fixed at the battery bank voltage. The directed inductor current waveformsof the front-end buck converter under APC and PWM control are likewise shown Fig. 14(c) and (d), separately. It very wellmaybeseenthatthecontroloffront-endbuckconverterandMAHBCconverterisrelativelyindependent.Theseexperimentaloutcomesareinconcurrencewiththeessentialactivitycapabilityoftheproposedcoordinatedpowerconverter geography. As the voltage sign of the accelerograph can be changed over completely to the PWM obligationproportion in speed open-circle control methodology, and it can likewise be utilized as a speed order for speed shut circlecontrol. By controlling the accelerograph, the front-end buck converter can be controlled and in this way battery-bankvoltage will be kicked to supply the MAHBC. In any case, in MAHBC part, the upper diode of each stage leg is associatedstraightforwardly to battery bank, which makes the demagnetization voltage equivalent to battery bank voltage. As theapplied voltage of each stage twisting in the conduction locales is kicked and is bring down the demagnetization voltage,quick demagnetization can be guaranteed. As displayed in Fig. 14(f), with the speed shut circle regulator, the transportvoltage can be changed by the front-end buck converter at various speed references, and in the mean time the rotationalspeed canfollowthereferencespeedwell.

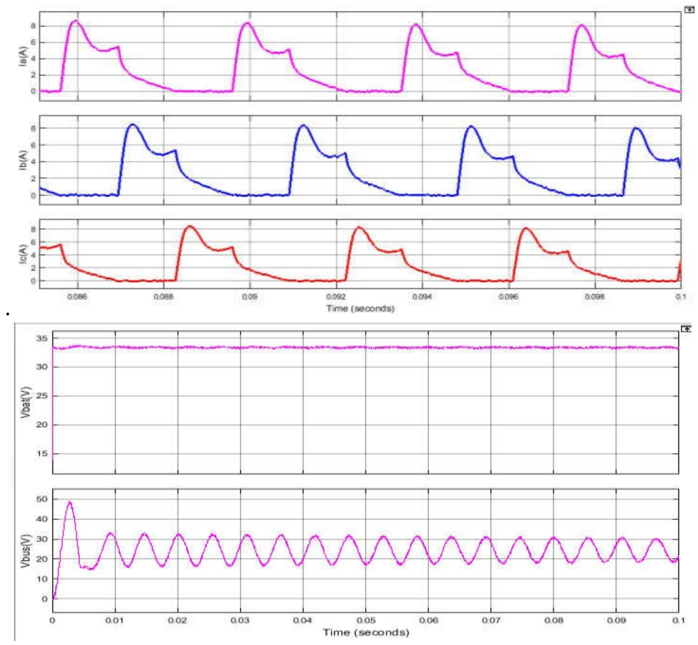


Fig14(a)PhasecurrentandvoltageunderAPCcontrolwithD1=1andTL=0.5N.m.

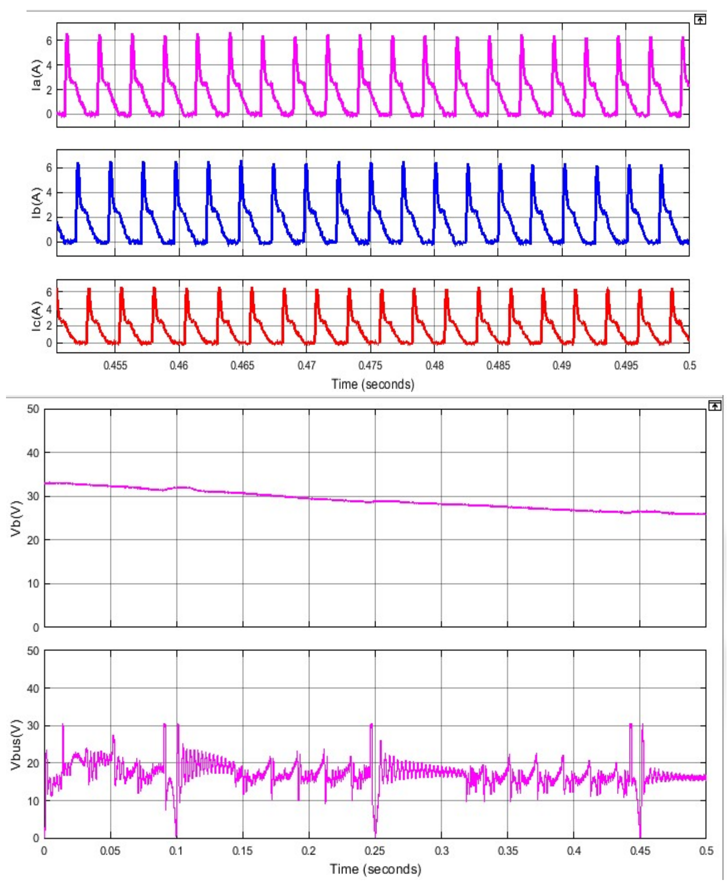


Fig.14(b)PhasecurrentandvoltageunderPWM controlwithD1=0.5andTL=0.5N.m.

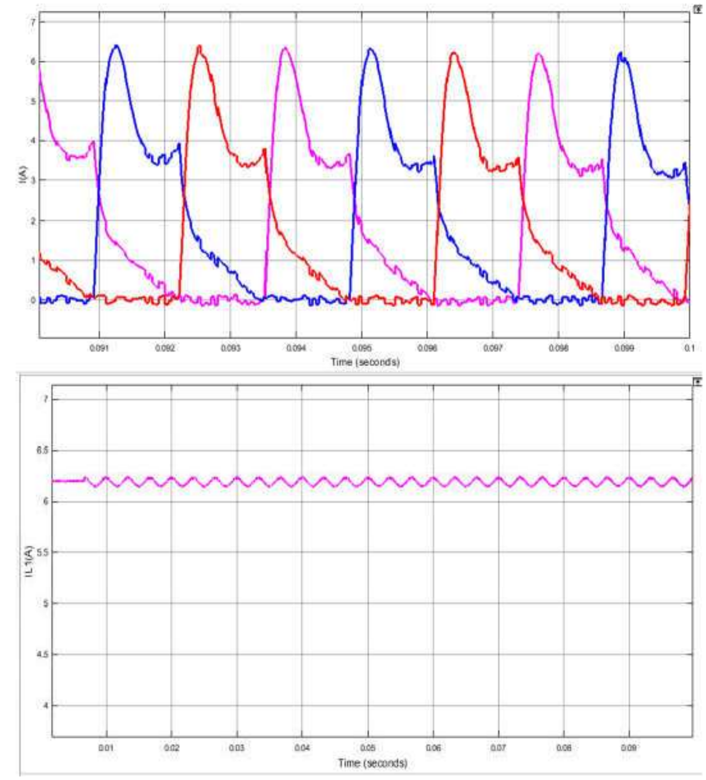


Fig.14(c) PhasecurrentandinductorcurrentunderAPCcontrolwithD1=1andTL=1.5N.m.

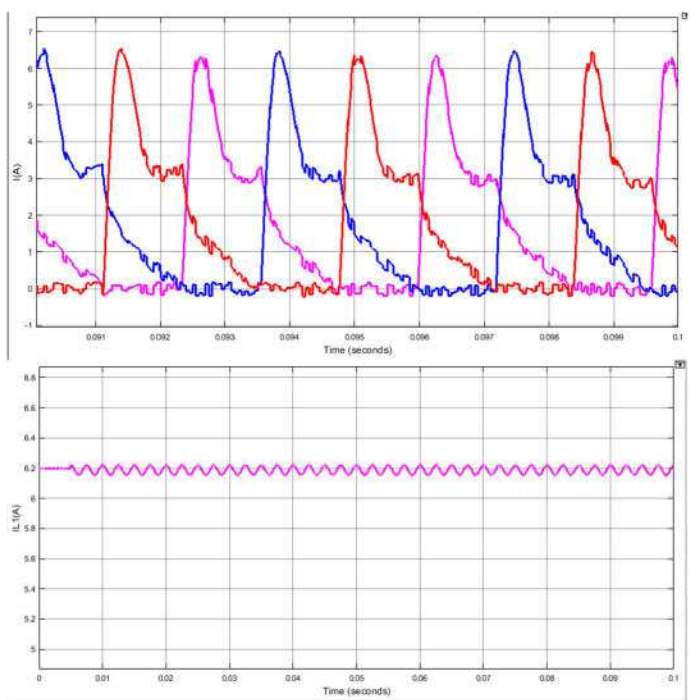


Fig.14(d)PhasecurrentandinductorcurrentunderPWMcontrolwithD1=0.5andTL=1.5N.m.

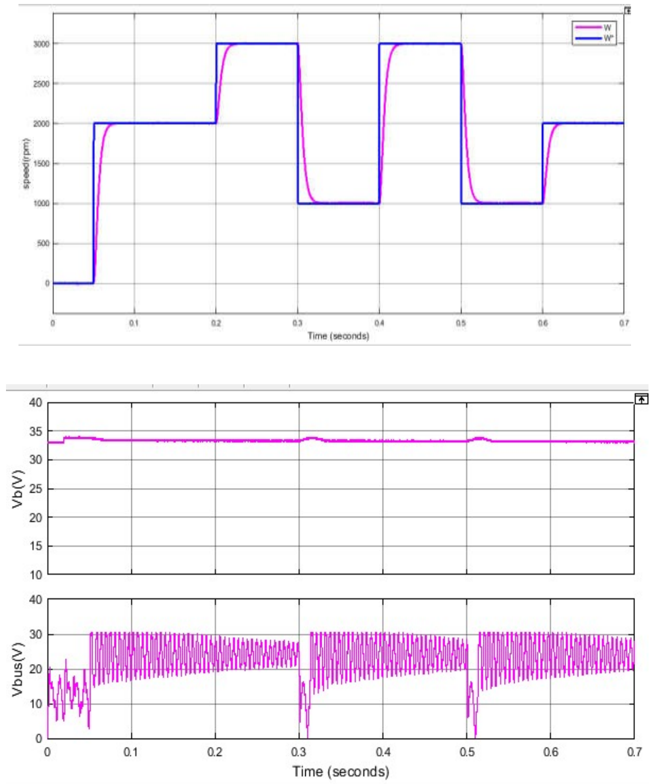


Fig.14(f)Speedclosedloopcontrol

Fig.14TheSimulationresultsunderdrivingcontrolmodes

Inregenerativeslowingdownmode,theexcitationdistrictischangedto[20°,35°]andtheobligationproportionD1issetto 1. In the excitation area, the stage winding is empowered, and when the stage is switched off, the stage will enter the agemode. The changing of stage current waveform between motoring activity and age activity should be visible in Fig. 15(a).As the generative current streams in the inductance diminishing district, negative force would be produced for slowingdown, which will make the rotor speed decline quickly. It ought to be noticed that the producing current is input and chargethe batterystraightforwardly.

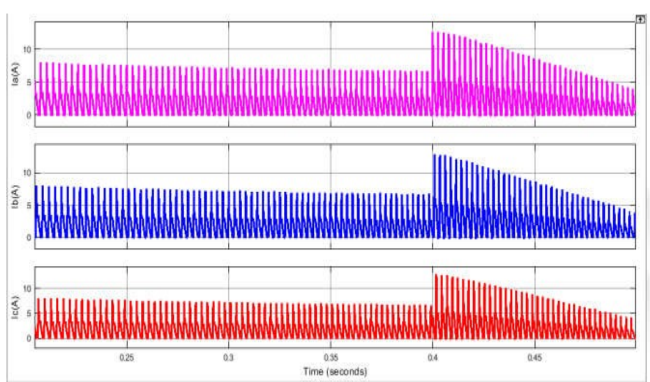


Fig.15 (a)Dynamicchangeofthreephasecurrentat thetransitionstatebetweendrivingandbrakingoperation

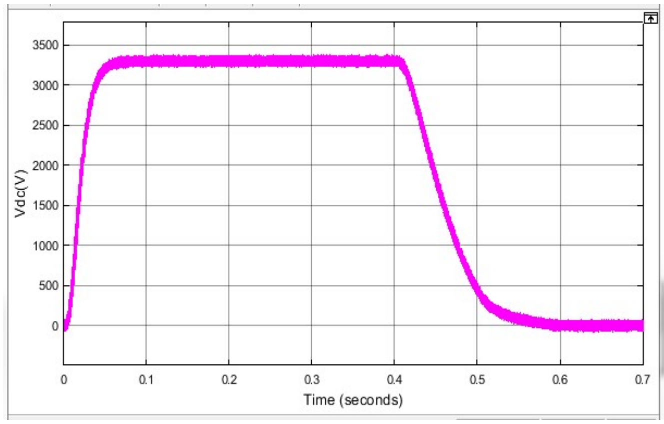


Fig.15(b)Thechangeofrotorspeedatdifferentoperationstates Fig.

15 Thetestresultoftheregenerativebrakingcontrol

As should be visible in Fig. 15(b), the rotor speed will diminish quickly once the slowing down activity order isapplied. In the test, a rotor speed limit 800r/min is set as correlation banner for eliminating the slowing down activity order.As displayed in Fig. 15(b), when the rotor speed is lower than 800r/min, the activity state is changed from regenerativeslowing down activity to free-running activity. At free-running state, all exchanging signals are switched off. As contrastedand theslowingdownactivityexpress,the rotor speed isdiminisheda lot moreslowin free-runningstate.

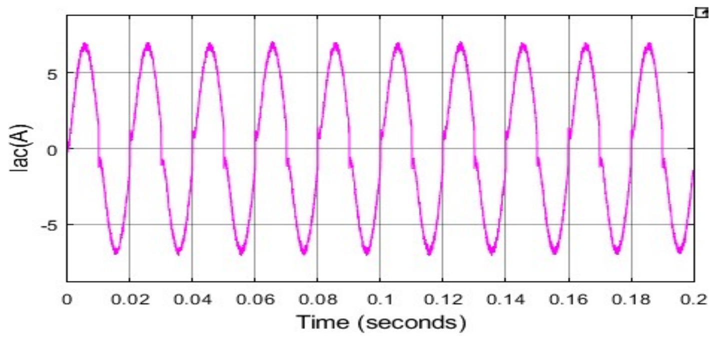
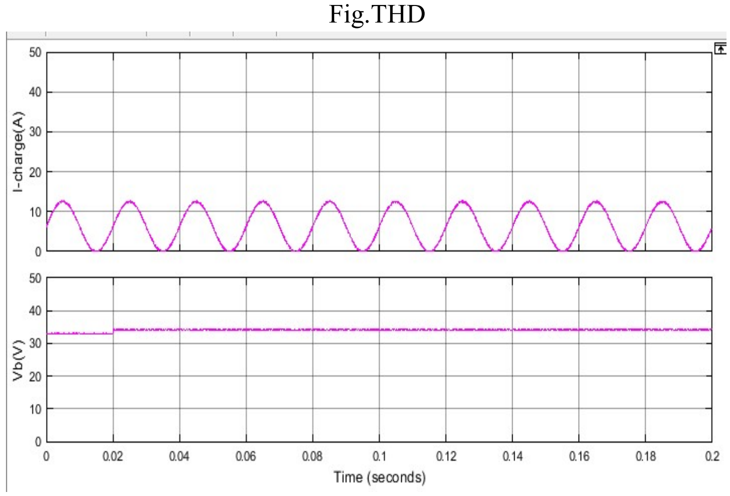


Fig.THD



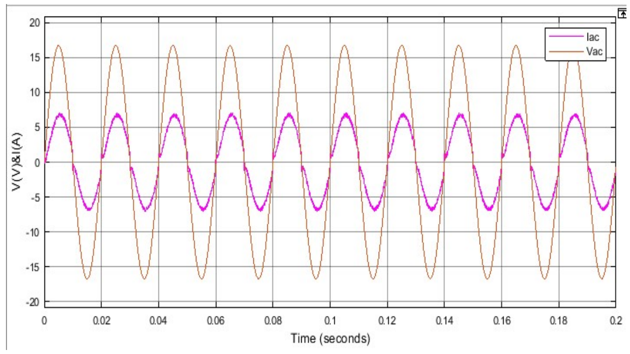


Fig.16Thetestresultsofthebattery chargingcontrol

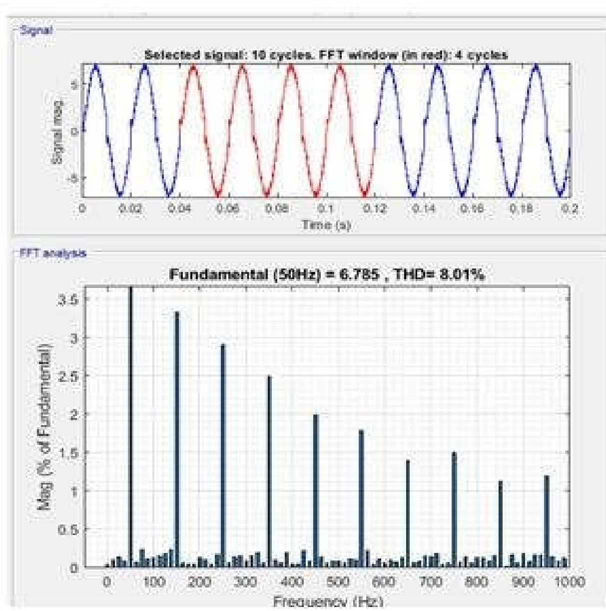


Fig.17FFTanalysisresultof theinputACcurrentIac

Under battery charging mode, the bridgeless rectifier is built as the on-board battery charger. To guarantee the balance oftwo stage windings inductance, the stage C is eager to carry the rotor to the C-stage adjusted positions. In charging mode,the SRM ought to keep halt. For the most part, to keep the rotor without pivoting, a mechanical installation ought to beutilized. However, in the event that the charging current isn't high, when the decent position is chosen, the rotor canbesloweddownbysettingahighloadinthedynamometer.Asthenormalchargingcurrentinthistestisjust2A,bysettinga 30N.m force in the dynamometer, the SRM can be slowed down. Also, as the result voltage of the bridgeless rectifier issupported when contrasted with the air conditioner source voltage, in this way to guarantee solid 48V-battery charging, theair conditioner source voltage is brought down to 22V (RMS voltage) with the autotransformer. In the examinations, a 48V20AH lead corrosive battery pack is utilized as the power source and the exchanging recurrence is fixed at 30kHz. As thegreatest normal charging current for battery back is 3A, a 2A reference current is chosen for testing. The battery chargingtests has been executed by the essential charging plan as shown in Fig. 12. As displayed in Fig. 12, the result current of thebridgeless rectifier is separated by the capacitor C1, and afterward charge the battery. As should be visible in Fig. 16, theaccusing current Icharger differs of a 100Hz recurrence (two times of the air conditioner voltage). It ought to be noticed thatIcharger isn't a wave current, the normal worth of which can follow the given reference current 2A. Plus, the info ac currentiscontrolled asasinusoidalcurrentandissynchronizedwiththeACvoltage.

To evaluate the PFC performance, the power factor (PF) and the Total Harmonic Distortion (THD) are analysed andmeasured.Intheory,the powerfactorPFcanbecalculatedby

$$PF = \frac{P}{\sqrt{P^2 + Q^2}}$$

Where, P is the dynamic power, Q is receptive power. In the trial, the power factor is estimated with a solitary stage electricboundary analyzer. The deliberate PF is higher than 0.99For the most part, the THD of the airconditioner source currentcanbedeterminedby

$$THD = \frac{\sqrt{I_2^{\ 2} + I_3^{\ 2} + \cdots + I_n^{\ 2}}}{I_1}.$$

Where,I1istheRMSworthofthecrucialcurrent,IntheRMSworthofthenthsymphonious.TodecidetheTHD,followingstrategiescanbechosen:

1) TheTHDcanbeestimatedbycertain instrumentslikethe poweranalyser,powerqualityanalyserandetc..
2) TheTHDcanbedeterminedintheregulatoronlinebyutilizingthe Fouriercalculation.
3) The THD can be determined disconnected in Matlab devices utilizing the recorded current information. In this paper, thetechnique is chosen for deciding the THD. As displayed in Fig. 17, the THD is disconnected determined in view of the FFTexamination.ThedeterminedTHD withagatheringof4cycle currentinformation is8.01%.

Inthetrials,thechargingproductivityisdeterminedby

$$\eta = \frac{I_{\text{charge}} U_{\text{bat}}}{I_{\text{ac-RMS}} U_{\text{ac-RMS}}}.$$

where, Iac-RMS and Uac-RMS are the RMS current and voltage of the input ac source.$I_{charge}$is the average charge current ofthe battery,U_{bat}isthe batteryvoltage.Inthetestexperiments,the chargingefficiencyreaches0.96.

V. CONCLUSIONS

Inthispaper,acoordinatedSRMpowerconverterwithonboardbatterychargingcapabilityisproposedforEVapplication. The comparing functional modes and control systems are explored and confirmed exhaustively with tests. Theprincipalelements ofthis converter areasperthe following:

1) A buck front-end dc/dc converter is incorporated with the deviated half scaffold converter, which can make the DC-transport voltage movable, and decouple the rotational speed control and the SRM driving calculation. By controlling thefront-end buck converter, adaptable speed open-circle control and shut circle control can be understood. Albeit the buckconverterisremotelyprepared,a bridgelessrectifierinviewofboardchargercan likewisebe coordinated.

2) Indrivingmode,thewindingputawayenergycanbenaturallyrecuperatedbacktothebatterysourceduringdemagnetization process. The demagnetization voltage is the battery voltage, which is higher than or equivalent to the DC-transportvoltage,hence canguaranteequickdemagnetization.

3) In battery charge mode, the on-board battery charger is framed by a bridgeless rectifier, which is developed with theimplanted power gadgets and the two stage windings. All comprised parts of the chargers are put installed, and no remotelyadded circuit parts are required. The incorporated bridgeless rectifier can be controlled to accuse the battery of good PFCexecution.Itought to benoticed that the batterycharger actuallyhas a fewpotentialrestrictions.

Forexample,

(1) As the bridgeless charger is a lift converter, the air conditioner source ought to be chosen in a lowerlevel voltage. Inthis way, for low voltage battery source application, the air conditioner matrix can't be straightforwardly utilized forcharging.Inanycase,forhighvoltagebatterysource application,itwould be morereasonable.

(2) Inconsistentpromptforceswouldbeproducedinthechosetwostages,whichmightcauseafewvibrationsintheSRMduringthe chargingsystem.

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