HBCC With Fuzzy Logic Technic For Three-Phase PWM AC Chopper FedInduction Motor Drive System For Power Factor Correction

P. KAVYASRI
M.Tech student
Department of EEE
BonamVenkatachalamayya Engineering Collage (A),Odalarevu, East Godavari District

ABSTRACT

In this paper, a new control strategy for aninduction motor (IM) drive system fed from three-phase pulse width modulation (PWM) AC chopper isproposedwithhbccandfuzzytechnic.Themainobjectiveoftheproposedcontrolschemeistoachieveinput powerfactorcorrection (PFC)of theIM drive system under different operating conditions.PFC is achieved by continuously forcing the actualthree-phase supply currents with the correspondingreference currents, which are generated in phase withthe supply voltages, using fuzzy with hysteresis bandcurrentcontrol(HBCC)technique.Theproposedcontrol strategy has two loops; inner and outer loop.Outputoftheouterloopisthemagnitudeofthesupply reference current resulting from either speedcontroller or startup controller, whereas output of theinner loop is PWM signals of the AC chopper. Theproposed AC chopper features a smaller number ofactivesemiconductorswitches;fourIGBTs,withonly two PWM gate signals. As a result, the proposedsystem is simple, reliable, highly efficient and cost-effective.TheIMdrivesystemismodeledusingMATLAB/SIMULINKwasbuiltand tested.

INDEXTERMS:

Hysteresisbandcurrentcontrol,inductionmotor drive,powerfactorcorrection,pulsewidthmodulation,three-phaseACchopper.

I.INTRODUCTION

ACvoltageregulators,alsocalledasACvoltage controllers, are used in various applicationsthat require a regulated AC voltage. Lighting controlusingdimmercircuits,domesticandindustrialheating,speedcontrolandsoftstartersfortheinduction motors are examples of such applications[1], [2]. Different topologies with different controlmethodsoftheseregulatorsinsinglephaseapplications and also in three phase applications arepresented. The purpose of AC voltage controller is tovary the root mean square (RMS) value of its outputthatappliedtotheloadcircuit.Therearethreecontrol methods are offered to achieve this objective;ON/OFF method, phase angle (PA) method and pulsewidth modulation (PWM) method. All three controlmethodscanbeimplementedinbothsingle-phaseandthree-phaseapplications.InON/OFFcontrolmethod,thyristors (i.e.silicon-controlledrectifiers) are used as power switches to connect/disconnect thecircuitoftheloadto/fromtheACvoltagesourcecontinuously.Connectionisoccurredforafewintegral cycles and disconnection for the nextfewcyclesofthefeedingvoltage.Adjustingthenumberof conducted and interrupted cycles controls the RMSmagnitude of the output voltage. In ON/OFF method,the generated harmonics by the switching actions arereducedassilicon-controlledrectifiers(SCRs)areswitched ON at zero voltage and switched OFF atzerocurrent.However,undesirablesub-harmoniccomponentsmaybe produced[3].

Applications of this method is restricted toheating and temperature control systems due to thediscontinuityofthepowersourceatlowdemandlevels. In PA control method, the output of the ACvoltage controller is regulated by adjusting the firingangles of SCRs. The power circuit of a single-phaseregulatorwithPAcontrol methodisgenerallyconsisted of two thyristors which are joined back toback betweentheAC source andthe loadcircuit,whilethree-phaseregulatoriscomposedofthreepairs of SCRs. In [4], [5], soft starting for inductionmotor (IM) fed from a thyristorized voltage regulatoris presented. The artificial techniques are utilized toadjust the motor voltage by varying the firing anglesof the thyristors at certain operating instant of speedand torque commands.

In [6], a voltage ramp technique is presentedfor starting of an AC motor. The voltage, in ramptechnique,isincreasedgraduallybyadjustingtheSCRsfiring anglesduring starting of themotor. In[7], [8], a closed loop current control approach thatdetermines the firing angles of thyristors required tokeep the motor current at starting instantwithin alimitvalueispresented.Intheseapproaches,asmoothstart-upoftheIMisobtained.However,numerous sensors and zero crossing detection (ZCD)circuits are required which make these controllers arecomplicatedandexpensive.Inaddition,thethyristorizedACvoltagecontrollerprovidessignificantharmonicsandlowinputpowerfactor(PF)eveniftheloadisapureresistive.Recentdevelopmentsinsemiconductorswitchesmakeitpossibletoreplace SCRsbymodernpowersemiconductor switches like MOSFETs and IGBTs.UsingPWMcontrolmethodwiththemodernpower switches, the AC voltage regulators performance canbe enhanced in terms of harmonics, filter size, inputPF and voltage control range [9], [10]. In [12], aspeed control of two-phase IM fed from single phasePWMACchopperispresented.Thechopperhaspo wercircuit thatconsists of fourIGBTswitches.The RMS value of the motor voltage is controlled bychanging the duty ratio of the chopper IGBTs andhence the motor speed is adjusted. This chopper isworking in buck mode. Buck and boost modes arepresented in [13]. Performance of single phase PWMAC chopper can be further improved using voltageharmoniceliminationtechniques.

An approach using a genetic algorithm (GA)ispresentedin[14].Aphaseshiftingmethodforenha ncing the input PF of a single phase PWM ACchopper is presented in [15]. Phase shifting oftheoutputvoltageisachievedusingasymmetricalpulse widthmodulation(APWM)asacontrolstrategy.Perform ancecomparisonbetweenconventional,symmetrical and asymmetricalPWMtechniquesispresented.However,p haseshifting method decreases the control range of thechopper output voltage. Optimal values of the PWMsingle phase AC chopper parameters were selected toachieveaunityPF.Anextinctionanglecontrol technique for PF improvement of a single-phase AC voltage controller fed an IM is presented. Different topologies of three phase PWM ACchopperindifferentapplicationsarepresented.Athre ephasePWMACchopper,haseightIGBTs,feeds an is presented. A configuration of thethree-phase chopper with six IGBTs for soft startingof three phase IM is presented, while a four-IGBT configuration is presented. However,theseconfigurationshavelowPF.Amethodofd etermining the operating PF of the three-phase IMusing only the measured current and the manufacturerdata of the motor is presented, a newasymmetricalpulsewidthmodulated(APWM)contr oller for AC chopper fed three-phase IM drive isproposed. A hysteresis band current control(HBCC) approach is used to control the switching ofthethree-phasechopperfedthreephaseACload.UsingHBCCtech nique,balancedthreephasesinusoidal currents are obtained. However, the powercircuit of this system uses six IGBTs with six gatepulseswhichmakethesystemcomplexandexpensiv e. Furthermore, the input PF of this approachislow. AlthoughresearchersfocusedonPFCofsingle-phasePWMACchoppers,theyhavebeengivenalittleatte ntionofPFCofthree-phasechoppers. PFC is important in order to comply withthenecessariesoftheinternationalstandards.Ontheo therside,thereductionintheamountofsemiconductordev icesandintroducingnew control strategies are essential for control simplicity,reliability,higherefficiencyandlowercost .Inthisarticle, new control strategy for PFC of three phasePWM AC chopper using HBCC technique fed threephase squirrel cage IM with soft starting and speedcontroloperatingmodesisproposed.Thepowercir cuitoftheproposedcontrolstrategyissimple,reliable,hig hefficiencyandlowcostasithasreducednumberofpower semiconductorswitches.

The three phase PWM AC chopper consistsof four IGBTs. A new closed-loop control strategy,thatusesonlytwogatepulsestodrivethefourIGB Ts, is achieved. The proposedcontrol strategyhas three main control objectives: soft starting, speedcontrolandinputPFC,whichareachievedbyadjusti ng the RMS value of the input voltage fed theIMterminals.Theproposedcontrolstrategyisinvestig ated,analysedandsimulationresultsareobtainedunderdi fferenttestingconditions.Alaboratory prototype model is implemented based onthe proposed control strategy. The experimental setupconsistsofa1.5HPsquirrelcageIMcoupledmechan icallywithaDCgeneratorforloadingpurpose, a four-switch PWM AC chopper and a DSPDS-1104 control board. The experimental waveformsareobtainedandcomparedwithcorrespondin gsimulationwaveforms.Therestofthearticleisorganized as:first,descriptionandoperatingmodesof the proposed control strategy is discussed. Then,mathematicalanalysisoftheproposedcontrolstrat egyisintroduced.Finally,thesimulationandlaboratoryw aveformsarecollectedandthearticlefindingsare concluded.

II. POWERQUALITY

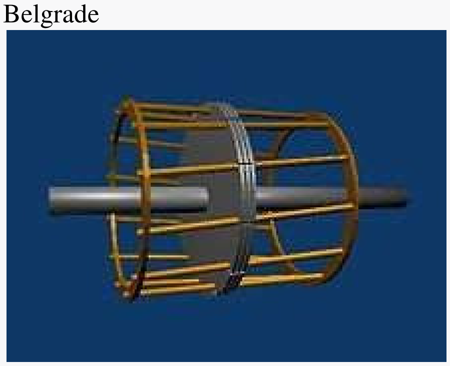
Thecontemporarycontainercraneindustry, like many other industry segments, is oftenenamoredbythebellsandwhistles,colorfuldiagnos ticdisplays,highspeedperformance,andlevels of automation that can be achieved. Althoughthese features and their indirectly related computerbasedenhancementsarekeyissuestoanefficien tterminal operation, we must not forget the foundationuponwhichwearebuilding.Powerquality is themortarwhichbondsthefoundationblocks.

Power quality also affects terminal operatingeconomics,cranereliability,ourenvironment, andinitialinvestmentin powerdistributionsystemstosupport new crane installations. To quote the utilitycompanynewsletterwhichaccompaniedthelastm onthlyissueofmyhomeutilitybilling:‘Usingelectricityw iselyisagoodenvironmentalandbusiness practice which saves you money, reducesemissions from generating plants, and conserves ournaturalresources.’Asweareallaware,containercrane performance requirements continue to increaseatanastoundingrate.

III. INDUCTIONMOTOR

An**induction motor** or **asynchronousmotor** is an AC electric motor in which the electriccurrent inthe rotor neededtoproducetorqueisobtained by electromagnetic induction fromthe magneticfield ofthe stator winding.[1]Aninductionmotorcanthereforebemadewith outelectricalconnectionstotherotor.[a]Aninductionmotor'srotorcanbeeither woundtype or squirrel-cagetype. Three-phase squirrel-cage inductionmotorsarewidelyusedasindustrialdrivesbecausetheyarerugged,reliableandeconomical.Single-phaseinductionmotorsareusedextensivelyforsmallerloads,suchashouseholdapplianceslikefans.Althoughtraditionallyusedinfixed-speedservice,inductionmotorsare increasingly being usedwith variable-frequencydrives (VFDs)invariable-speedservice.VFDsofferespeciallyimportantenergysavingsopportunitiesforexistingandprospective induction motors in variable-torque centrifugal fan,pumpandcompressorloadapplications. Squirrel cage induction motors are verywidelyusedinbothfixed-speedand variable-frequencydrive(VFD) applications.

AmodelofTesla'sfirstinductionmotor,inTeslaMuseum, Belgrade



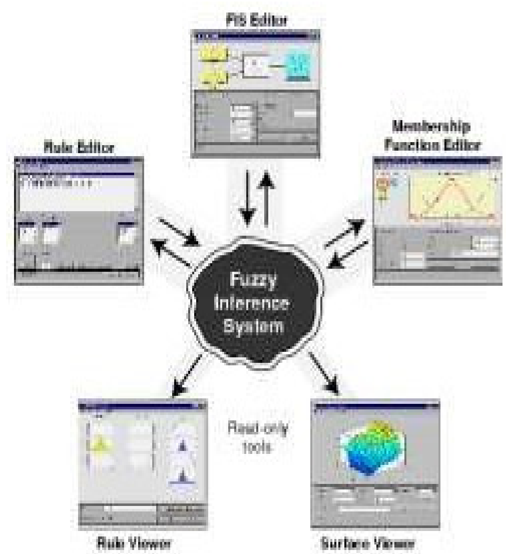
Squirrelcagerotorconstruction,showingonlythecenter three laminations

IV.INTRODUCTIONTOFUZZY

In recent years, the number and variety ofapplicationsoffuzzylogichaveincreasedsignificantly. The applications range from consumerproductssuchascameras,camcorders,washingmachines, and microwave ovens to industrial processcontrol,medicalinstrumentation,decisionsupportsystems, and portfolio selection. To understand whyuseoffuzzylogichasgrown,youmustfirstunderstandwhatismeantbyfuzzylogic.

Fuzzy logic has two different meanings. In anarrow sense, fuzzy logic is a logical system,whichis an extension of multivalve logic. However, in awider sense fuzzy logic (FL) is almost synonymouswith thetheory of fuzzy sets,atheory which relatestoclassesofobjectswithunsharpboundariesinwhichmembershipisamatterofdegree.Inthisperspective,fuzzylogicinitsnarrowsenseisabranch of FL. Even in its more narrow definition,fuzzylogicdiffersbothinconceptandsubstancefromtraditionalmultivalvelogicalsystems.

The fuzzy logic toolbox is highly impressivein all respects. It makes fuzzy logic an effective toolfor the conception and design of intelligent systems.Thefuzzylogictoolboxiseasytomasterandconvenient to use. And last, but not least important, itprovides a reader friendly and up to date introductionto methodology of fuzzy logic and its wide rangingapplications.



TheprimaryGUItoolsofthefuzzylogictoolbox

V. PROJECTDISCRIPTIONANDCONTROL DESIGN

5.1SYSTEM DESCRIPTION AND OPERATIONPRINCIPLE

Fig. 1 represents a schematic diagram of the proposedthreephasePWMACchopperfedanIM.Th echopper iscomposed

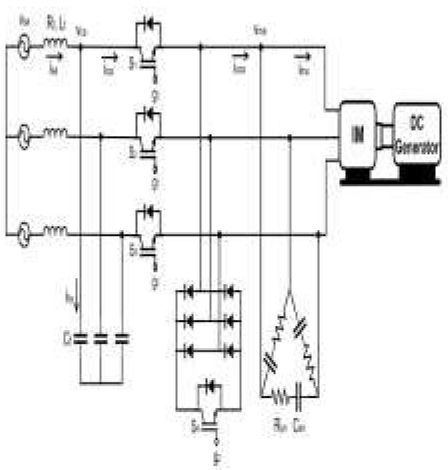


FIGURE 1. Power circuit of the proposed three-phase PWM AC chopper fed an IM drive system.

onlyoffourpowerelectronicsswitches(S1,S2,S3andS4) thatareillustratedinthefigure.Thethreepowerswitches(S1, S2andS3) are series-connectedwiththemotor.While,thepowerswitch(S4)isp arallel-connectedviaapoly phasebridgerectifierwiththemotor.Theseries-connectedswitchesareutilizedtocontinuouslyconnecta nddisconnectthemotortoandfromtheACsupply,respect ively.Hence,theyregulatethedeliveredpowertothemoto r.Whiletheparallel-connectedswitch(S4)offersafreewheelingwayfordisch argingtheenergykept in the motor windings when the series-connectedswitchesareturnedOFF.Asseriesandparallel devicesoperateinacomplementaryway,adeadtimeisintr oducedtoavoidthecommutationproblems.Therearethre eoperatingstages:active,freewheelinganddeadtime.Ind eadtimeperiod,allfourdevicesareturnedOFF.Thecurren tspathsoftheproposedPWMACchopperfedIMinitsthre eoperatingstagesareillustratedbyFig.2.AthreephaseΔ-connected snubbercircuit,whichhasaresistance RsnandacapacitanceCsnperphase,isusedtominimizehi ghvoltagespikesatIMterminalsduetoswitchingofthech opperaswellasprovidingthecurrentpathofIMduringthe deadtimeperiod.Theinputfilteriscomposedofthreeinductors (whoseresistanceisRfandinductanceisLfperphase)andY-connectedthreecapacitors(whosecapacitanceCfperphase).T heLCinputfilterisusedwiththeproposedPFCtechniqueinord ertoreducetheharmonicsofthesupplycurrentduetoswitching ofthechopper.Theproposedcontrolcircuit onlygeneratestwoPWMcomplementarygatepulses(g1andg 2)whichareusedtodrivethechopperIGBTsinordertoprovidet he three main tasks of the proposed control strategy.

5.2PROPOSEDCONTROL STRATEGY

Theproposedcontrolstrategyhasthreemaincontrolo bjectives:softstarting,speedcontrol,andinputpowerfactorco rrection(PFC).Thisstrategy is depending on the control of the appliedvoltage across IM terminals using AC chopper. Fig. 3illustratestheschematicdiagramoftheproposedcontrol strategy. It has two control loops. The innercontrol loop uses HBCC to force the chopper actualcurrent signals to track their command current signalsto achieve input PFC, whereas the outer control loopdetermines the magnitude of the reference currentseitherfromstartingmodeorspeedcontrolmode.Asa result, the inner loop controls the phase and theouterloopcontrolsthemagnitudeofthechoppercurrents.In thefirst,thesoftstartingmodeisworking,andbygivingaswitch ingpulsetotheselector switch, the speed control mode is activatedand thesoftstarting mode isturnedoff.

A.SOFTSTARTINGMODE

The role of the soft starting mode is to generate thereference value of the supply current in a manner thatlimits the starting current of the IM at a preset value.The actual current of IM (Im) is measured and itsRMSvalueisevaluatedbyRMSdetector.Thecomman d or preset value of the motor current (Im*)anditsactualvalue(Im)arecompared.Thecompari sonresultederrorispassedintoaproportional integral (PI) controller to generate thecommand motor current (Is*). Limiting the startingcurrent provides a smooth acceleration and reducesthetorquepulsationsofIMduringsoftstartingperi od.

B.SPEEDCONTROLMODE

Thereareseveralmethodsforcontrollingthespee dof three-phase IMs. These methods can be classifiedinto two main categories according to the control sideoftheIM:a)speedcontrolmethodsthroughthestators uchaschangingtheappliedfrequency,changing the applied voltage, changing the number ofthe stator poles and voltage/frequency (v/f) control,and b) speed control methods through the rotor suchasrotorresistancecontrolandrotorslippowerrecove ry.Variable frequency drives (VFDs) are thecommercial drives. Speed control by VFDs is basedon changing both the stator voltage and frequency oftheIM.VFDsarewidelyusedforwide-rangevariable-speedIMapplications.However,theyarevery expensive and hence not convenient when theyareusedforlimited-rangevariable-speedIMapplications.Sincetheproposedspeedcontrolstrategy depends on changing the stator voltage only,soit is simple, low cost andmore convenientforlimited-range variable-speed IM application which isintendedinthisresearch.Theroleofthespeedcontrolmodeistogeneratethereferencecurrentvalue (Is*) in a way that makes themeasuredspeedofIM(ωm)followsthecommand speed(ωm*).Commandandmeasuredspeedarecomparedandthedifference is used as an input signal to a PI speedcontrollertogenerate Is*.

C.PFCCONTROL

Since PWM AC/AC choppers can only modify themagnitude of the applied voltage, they are normallynegatively viewed; when they are used in IM drivesystems,fortheirlowPF.Therefore,themaincontributionoftheproposedcontrolstrategyisachieving high PF approximately unity as in case ofresistiveloads.TheproposedPFCstrategywasimplementedduringstartingandspeedcontroloperatingmodesof IMdrivewhileusingACchopper. The principle of harmonic minimization ofthe proposed control strategy depends on using PWMtechnique. Whereas, the principle of reactive powermanagementistoobtainPFCdependsontheproposedcurrentcontroltechnique;inwhichtheactualsupplycurrentsareforcedtotracktheirreferencecurrentsthatareinphasewithsupplyvoltages. The role of PFC block is to continuouslycorrecttheinputPFduringIMoperation.Fig.4shows the proposed PFC using HBCC technique.Thereferencevalueofthestatorcurrent(Is*)is utilizedtoobtain the three phase reference supplycurrents (isa*,isb* and isc*) by multiplying the value(Is*) by unit vectors of the supply voltages (usa, usband usc)as:

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = I_s^* \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_{sa} \\ u_{sb} \\ u_{sc} \end{bmatrix} \quad (1)$$

The unit vectors (usa, usb and usc) are generated bymeasuring the phase voltages of the supply (vsa, vsband vsc) and by using three zero crossing detection(ZCD) circuits and three lookup tables as shown inFig.4.Thereferencecurrentsofthesupply(isa*,isb*andisc*),arecomparedwiththeircorrespondingactualvalues(isa,isbandisc)respectively. The resulted errors are passed throughthree hysteresis bands (HBs) and their outputs are thethree switching signals (S1, S2 and S3). Operation ofHBCCtechniquetoobtaintheswitchingsignal(S1)isexplainedbyFig.4.Thelogiccontrolsignalsblock is utilized to find the higher value of the supplyphase voltages. The switching signal F is generatedfrom the three switching signals (S1, S2 and S3) andthethreelogiccontrolsignals(q1,q2 and q3)as:

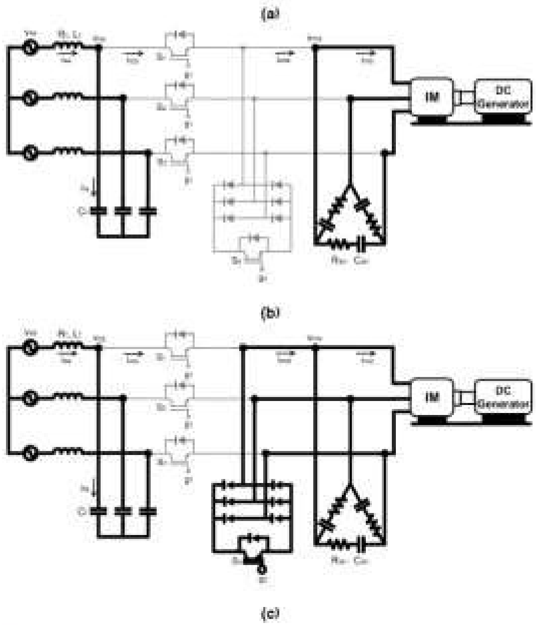


FIGURE 2. The currents paths of the proposed PWM AC chopper fed IM. (a) Active stage. (b) Dead time stage. (c) Freewheeling stage.

The switching signal F and its complementary signalarepassedthroughadeadtimeblockinorderto obtain the two PWM complementary signals (g1 andg2) that are usedtodrive the chopperIGBTs. TheideaoftheproposedPFCtechniqueistoforcecon tinuouslytheactualsupplycurrentstofollowstheir corresponding command currents which are inphase with supply voltages in both the two controlmodes. Considering a sinusoidal supply voltage, thePF at which a converter system operates is defined asfollows:

$$PF = \frac{I_{S1}}{I_S} DPF \qquad (3)$$

FIGURE3.a)ProposedPFCusingHBCCtechnique, (b)Generationofswitchingsignal S1.

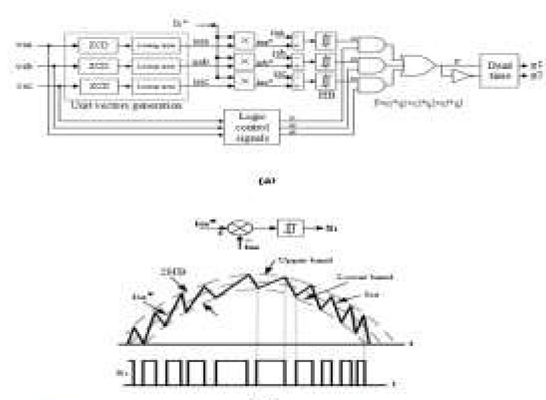


FIGURE 4. a) Proposed PFC using HBCC technique. (b) Generation of

VI. SIMULATIONRESULTS

TheproposedACchopperissimulatedinthe MATLAB/Simulink environment and a prototypemodel is implemented. The simulation was used toconfirm the proposed control strategy theoretically.Threetestcasesareexamined.Correspondingsimulationresultsareobtainedandcompared.Parameters of the system under study are given in theappendix.

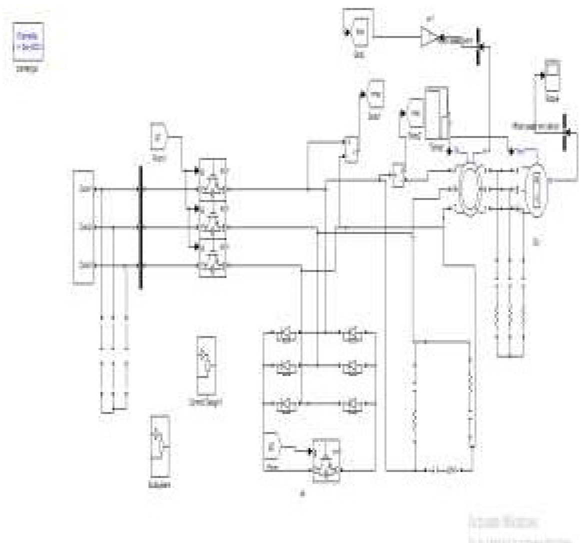


Fig4:ProposedSimulationdiagram

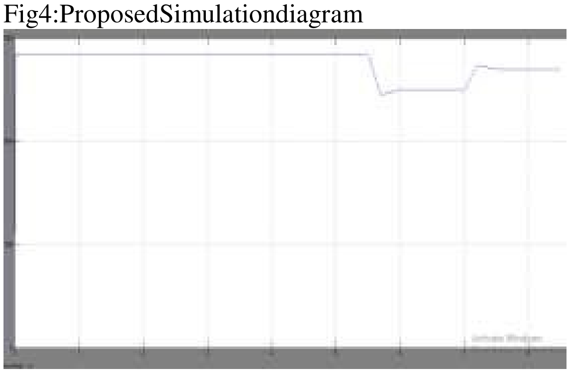


Fig5:Wm

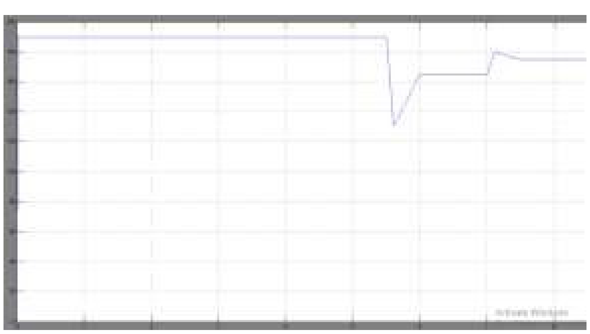


Fig6:Vma

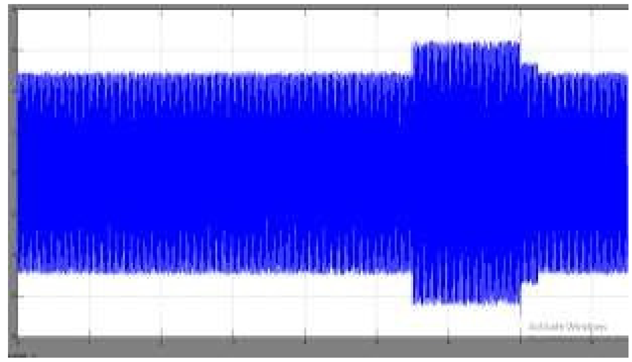


Fig7: Ima

Fuzzy based Variation of the motor speed,currentandphasevoltageatstepchangeinthereferencespeed.

VII. CONCLUSION

Anewcontrolstrategyofthree-phasesquirrel cage IMfedfromPWM AC chopperhasbeensimulatedandlaboratoryimplementedusingFuzzywithHBCCcontrol.ThemaincontrolobjectiveistocorrecttheinputPFwithdifferentoperatingconditionsoftheinductionmotordrivesystem. Input PFC is achieved by forcing the actualcurrentsofthechoppertotracktheirreferencecurrentsthatareinphasewiththeinputvoltagesusingFuzzywithHBCCtechnique.TheproposedcontrolstrategyusesonlytwoPWMsignalsfordriving the active switches of the AC chopper. Theproposed system is simple, reliable and low cost as ithas only four IGBT switches. Operation principle andmathematicalanalysisoftheproposedsystemareintroduced.ThesystemwassimulatedusingMATLAB/SIMULINKwasimplemented.Theeffectivenessoftheproposedcontrolstrategyhasbeen tested at starting, reference speed change andloadtorquevariation.Performanceofthesystemwithout PFC is roughly compared in accordance withconcerning the proposed PFC technique during thethree test cases. Comparative results illustrate that thesystemwiththeproposedPFCtechniquehasacorrectedPFand henceabetter performance

APPENDIX

TABLE II
PARAMETERS OF THE SYSTEM

Symbol	Parameter	Value
V_s	supply voltage	220 V
f	Line frequency	50 Hz
R_f	filter resistor	0.5 Ω
L_f	filter inductor	6 mH
C_f	filter capacitance	7 µ
V_s	IM rated voltage	220 V/ph
P_n	rated power of IM	1.5 hp
N	IM rated speed	1420 rpm
P	No. of poles	4
T_l	Rated load torque	7 N.m
R_s	Stator winding resistance	7.4826 Ω/ph
L_{ls}	Stator leakage inductance	0.0221 H/ph
R_r	Rotor winding resistance	3.6840 Ω/ph
L_{lr}	Rotor leakage inductance	0.0221 H/ph
L_m	Mutual inductance	0.4114 H
β	Motor friction	0.008
J	IM moment of inertia	0.02 kg.m^2

FUTURESCOPE:

Inthiswork,Theproposedsystemissimple,reliablean dlowcostasithasonlyfourIGBTswitches .In Future, I will use Artificial IntelligentTechnictocompensatereactivepowerandhar monics.

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