iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** V **Month of publication:** May 2025

DOI: https://doi.org/10.22214/ijraset.2025.70842

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Hybrid Energy System Simulation and Modelling Incorporating Wind, Solar, Battery and Fuel Cell Power

PullaMounika[1], Dr.P.Venkata.Prasad[2]
Chaitanya Bharathi Institute of Technology, Hyderabad, India

Abstract: Improving grid-interfaced hybrid generation systems' power transmission capabilities is the primary goal of this work. This hybrid system typically combines wind and solar energy sources. This research suggests the idea of maximum power tracking strategies to obtain the maximum and consistent output power from these renewable energy sources at any given moment. Direct Current (DC) to DC boost converter control is the primary function of this maximum power point tracking controller. Lastly, MatLab/Simulink simulation is used to observe the performance of this hybrid system based on Maximum Power Point Tracking (MPPT).
Keywords: Solarpower,wind/photovoltaic,battery,andfuelcellhybridgeneration,simulationandmodelling,microhydropower, and renewable energy.

I. INTRODUCTION

It is common knowledge that the world's fossil fuel supplies are rapidly depleting. Today's energy needs are mostly met by fossil fuels and nuclear power facilities. Only a small portion comes fromrenewableenergysourcesincludinggeothermal,biomass, solar, wind, and others. The lack of fuel will be serious in the not-too-distant future. According to the energy conservation rules, energy can only be changed from one form to another; it cannot be created or destroyed. Preservingenergyreservesandincreasing energy efficiency are the main areas of current research. Additionally, researchhasbeendoneonhowtoconstructreliableandstudy systems for using non-traditional energy sources. Both of them are abundant sources of renewable energy. Sunlight isregardedasa vital resource since direct solar intensities in many tropical and temperate countries exceed 1000w/m2. A solar cell system uses sunlight to create electricity. Grouped cells are the components that make up panels andmodules. Duetoitsmanyadvantages,suchaslowmaintenancecosts, high reliability, ease of allocation, and no fuel prices, as well as the fact that there are no moving parts, solar cell production is growing inpopularityasarenewableenergysource. Windenergyi sconvertedintousableelectricalpowerby wind turbines. When it comes to powering new buildings, onshore wind is frequently more cost-effectivethanoffshorewind.Small onshore wind turbines provide electricity to remote places. When used, wind energy is clean, renewable, requires little space, and emits no greenhouse gases. The consequences on the environment are often lessseverethanthoseofotherpowersources.Although wind power fluctuates significantly over shorter periods of time,itislargelyconsistentthroughouttheyear.Aregion'sgridwillneed to be modified as wind power increases because mechanical wind turbine models that use synchronous generators will make conventional energy more challenging. When the wind turbine is rotating,thewindwillnotdiffersignificantlyfromthesurrounding air. The value of this can be raised for real-time implementation.

II. SYSTEM MODELING AND PROBLEM STATEMENT

Thisworksuggestsmodellingandsimulatingsolarandwindpowersystemsindependently,thenmergingthemforthetransformer's output AC load in the manner described below:

A. Solar Power System

Solar cell technology is used to turn sunlight into electricity. The most crucial part of the solar cell system is thought tobethesolarcell itself Modules or panels are made up of cells grouped collectively. Many panels can be combined to make large solar arrays. Arrays are solar panels or collections of panels with several cells connected in parallel, series, or both. Mostpeopleareinterestedin modelling solar cell panels or commercial solar cell technology [4]. Our solar PV array module has a 15KW rating.

The average PV cell generates less than 0.4 to 0.5 watts at 400to500mAand1V,hencethecellsonamodulemustbeconnectedin series-parallel configuration to generatesufficienthighpower.Aphotovoltaicarrayisanelectricallyconnectedgroupofsolarmodules that use series and parallel circuits to generate the required current and voltage. [5] [6] To supply the necessary output power, PV modules are then connected in a series-parallel configuration.

A circuit consisting of a diode and a parallel current source can be used to mimic a solar cell. The cell's I through V characteristics are determined by the diode. The amount of solar radiation that reaches the cell is directly connected to the current source output. [7]

The Shockley equation, which describes the relationship between voltage and current in a solar cell, states that the open circuit voltage grows logarithmically.[8].

$I = I_{pv} - I_o[\exp(qU/kT)\ 1]$

$U = kTq\ln 1 - I - I_{pv} I_o$

Where:

photovoltaic current (Ipv) Diode saturation current (Io) and elementary charge (q) are equal to 1.6021 * 1019As. U = voltage ofthe solar cell

k=Boltzmannconstant(1.3806*1023J/K)T=Thetemperatureofthereferencesolar cell.

B. Wind Power System

Harvesting wind energy involves physically connecting a rotor with two or more blades to an electrical generator. The power coefficient'smaximumtheoreticalvalueis0.55.Itisaffectedbypitchangleandtipspeedratio(TSR).Pitchangleistheangleatwhich thebladesofaturbinealignwithitslongitudinalaxis.TSRistherotor'slinearspeedinrelationtowindspeed.TSR,ortipspeedratio.

$\lambda = \omega * R / v_w$ (3)

Where:

thetipspeedisdenotedbyλ

Turbinerotorspeed(rad/s)isrepresentedbytheratioω.

Ristheturbineblade'sradiusinmeters.Windspeed(m/s)isdenotedbyvw.

Thewindenergyconvertermodelisdevelopedbasedonthefollowingassumption:

- Lessfriction;
- Staticwindflow;
- Longitudinalwindflowwithoutshear;
- Rotationalfreeflow;
- Incompressiblewindflow(ρ=1.22kg/m3)
- Thewindflowsfreelyaroundthewindenergyconverter.

The greatest physically convertible wind energy may be foundusingatheoreticalmodelthatisindependentofthetechnical specifications of the wind energy converter and the presumptions made. There is a lot ofenergyinamovingmassofair.Thisenergy comes from air movement caused by a pressure gradientontheplanet'ssurface.Windturbinesareusedtocreateelectricityusingthis energy [12][13].

Thewindconverter'smaximumpowervalue,whichisdeterminedbytheairmasses'kineticenergy,isgivenbythefollowingequation: $P_{max} = (8/27) * A\rho v^3$ (4)

Thefollowingformulacanbeusedtocalculatethehypotheticalelectricityrepresentedbyapercentageofincidentairflow: $P_{max} = (8/27) * A\rho v^3$

Pwind= 0.5Aρv3

Pmax=Pwind·Cp (5)

Synchronousandinductiongeneratorsaretwotypesofelectricgenerators.Thefollowingformula is used to determine the wind's mechanical power:

$P=0.5\rho A C_p(\lambda,\beta)v_w^3$ (6)

Where:

ρstandsforairdensity.

Cp(λ,β)istherotorsweptareaA.Thefunctionofthepowercoefficient.Theratiooftipspeedtoλ β is the pitch angle. VW-wind speed

Itisinefficienttosetupafreestandingpowersystembecausethe PMSGisutilizedinthiswindpowersysteminsteadofaninductiongenerator,whichrequiresaleadingvoltage to stimulate it. This is often accomplished by connecting the induction machine to the grid. The rotor and magnetic field rotate at the same speed in a synchronous system because the magnetic field is produced by a permanent magnet that is fixed to the shaft. Through the magnetmechanism,electricityisinducedintothestationaryarmature[14]. The wind system has a 60 KW rating.

III. LITERATURE REVIEW

Hybrid energy systems (HES) that integrate wind, solar, battery storage, and fuel cell technologies have emerged as a promising solution for sustainable and reliable power generation, especially in remote or off-grid areas. The variability and intermittency of renewable sources such as wind and solar necessitate the incorporation of energy storage systems like batteries and fuel cells to ensure stable and continuous power supply. Simulation and modelling play a crucial role in designing, optimizing, and evaluatingthe performance of such complex systems. Various software tools have been employed for this purpose, including HOMER, MATLAB/Simulink,TRNSYS,and PSCAD. HOMER is particularly popular for techno-economic analysis and optimal sizing, while MATLAB/Simulink is widely used for dynamicmodellingandcontrolstrategydevelopment. ResearcherssuchasLambertet al. (2006) and Rajkumar et al. (2013) have demonstrated the use of these tools in simulating solar-wind-fuel cell systems to assess theirfeasibilityandreliability. Advancedmodellingtechniques, includingprobabilistic approachesandartificialintelligence (AI)-based optimization methods like genetic algorithms and particle swarm optimization, have also been applied to manage the stochastic nature of renewable sources and to fine-tune system configurations. Recent studies have furtherexploredtheintegrationof hydrogen storage with fuel cells to extend backup duration and improve sustainability. Challenges such as system control complexity, economic viability, and hydrogen handling remain areas of active research. Nonetheless, the growing capabilities of simulation tools and real-time energy management systems indicate a strong potential for hybrid systems to play a central role in future energy infrastructure.

IV. SOLAR, WIND, BATTERY AND FUEL CELL POWER SYSTEM SIMULATION

The wind turbine is the most crucial component of wind power systems. Wind turbines use aerodynamically constructed blades to catch wind energy and convert it into rotating mechanical power. Frequently, three blades are used. The rotating component of an electric generator absorbs this mechanical energy and converts it into electrical energy. A solar photovoltaic array is used in solar systems. Simulating rechargeable and fuel cell power systems entails building computer-based representations and mathematical models to examine howtheseenergysourcesfunctioninvariousscenarios.Theelectrochemicalprocesses,thestateofcharge,voltage behaviour, temperature impacts, and degradation over time are the main topics of simulations in batteries. The electrochemical processes that turn the oxygen and hydrogen into electricity are modelled via simulations forfuelcells,takingintoaccountvariables like system efficiency, water andheatmanagement,andgasflowdynamics.Withouttheneedforexpensivephysicalprototypes,these simulations assistengineersinperformanceprediction,designoptimization,controlstrategytesting,andbatteryorfuelcellintegration into larger systems such as electric vehicles or renewable energy grids. Simulations offer insights into system response, energy efficiency,anddurabilitybyvaryingparameters like load demand, temperature, and operating conditions. This aids in improved design and practical implementation.

ThefollowingisthecompleteSimulinkdesignmodel:

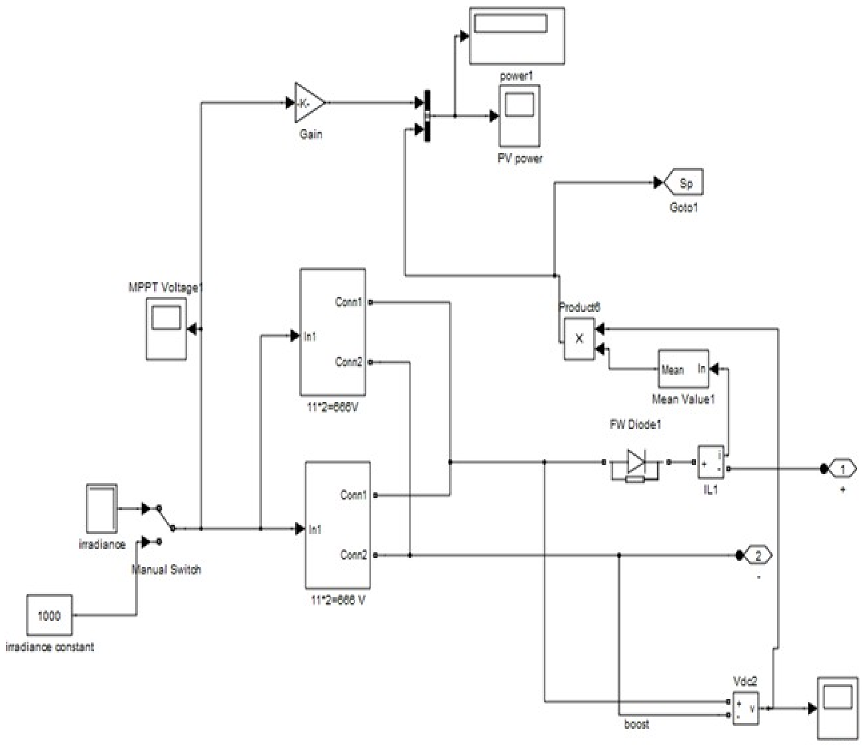


Figure-1: SimulinkDiagramofSolarpowersystem.

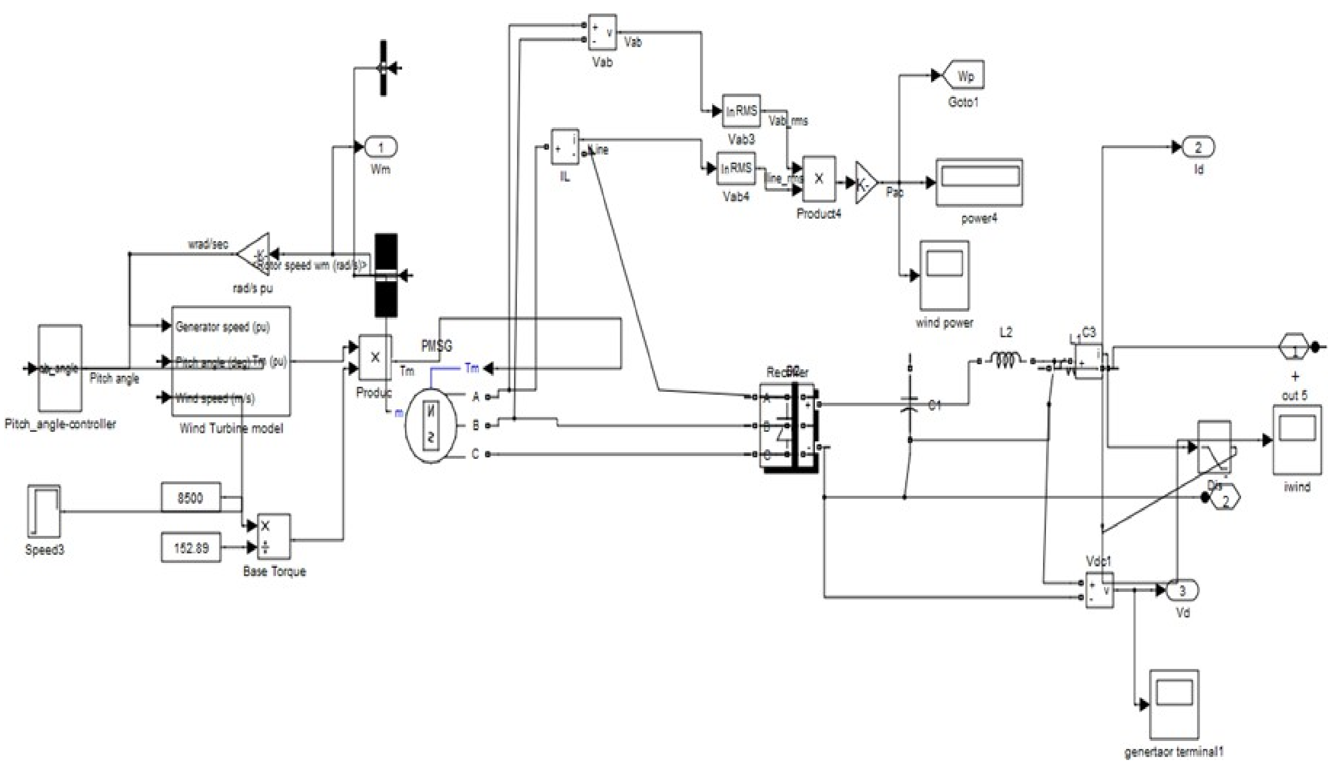


FIGURE2:Simulinkdiagramofwindpowersystem

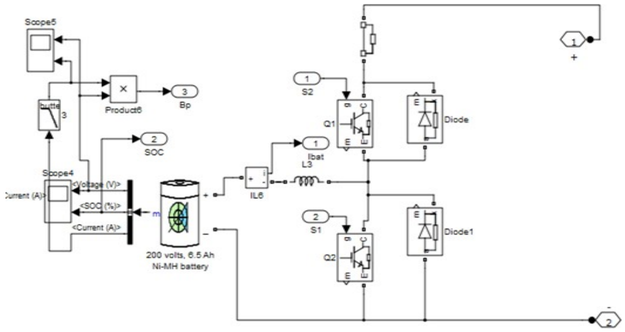


FIGURE3:SimulinkdiagramofBattery

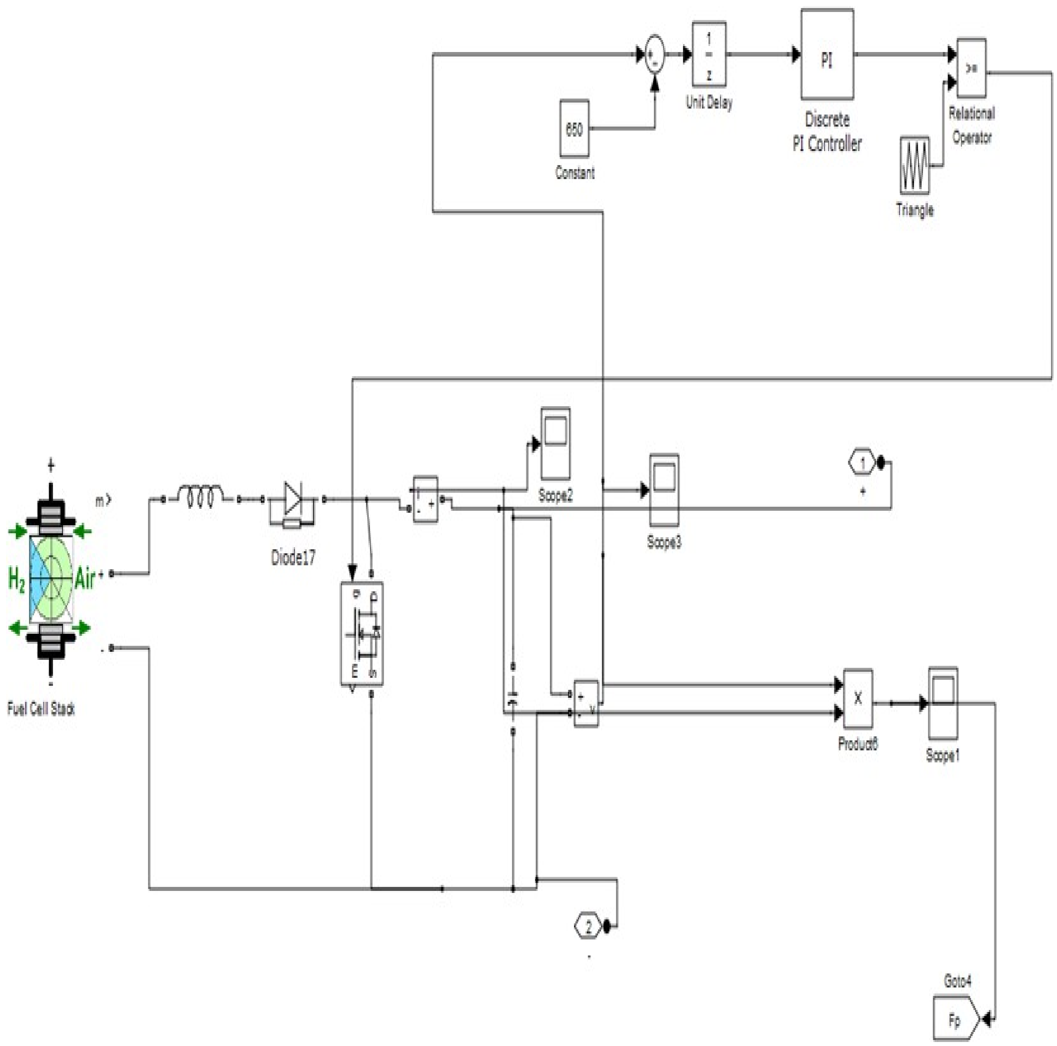


Figure-4: : SimulinkDiagramoffuelcellpowersystem

TheSimulinkmodelofasolarpowersystem,comprisingaPVarray,boostconverter,andMPPT,isdisplayedinFigure1.
ThewindpowerSimulinkmodel,whichincludeswindturbinesimulation,PMSG,rectifier,andDc-Dcboostconverter,isdisplayedinFigure2.
The Simulink model of a battery which includes a bidirectional switch in figure 3.
The Simulink model of a fuel cell which includes PI controllers, diode and unit delay in fig 4.
TheSimulink modelwhich showsthe overall powersystem likesolar, wind,battery and fuelcells shownin fig 5.

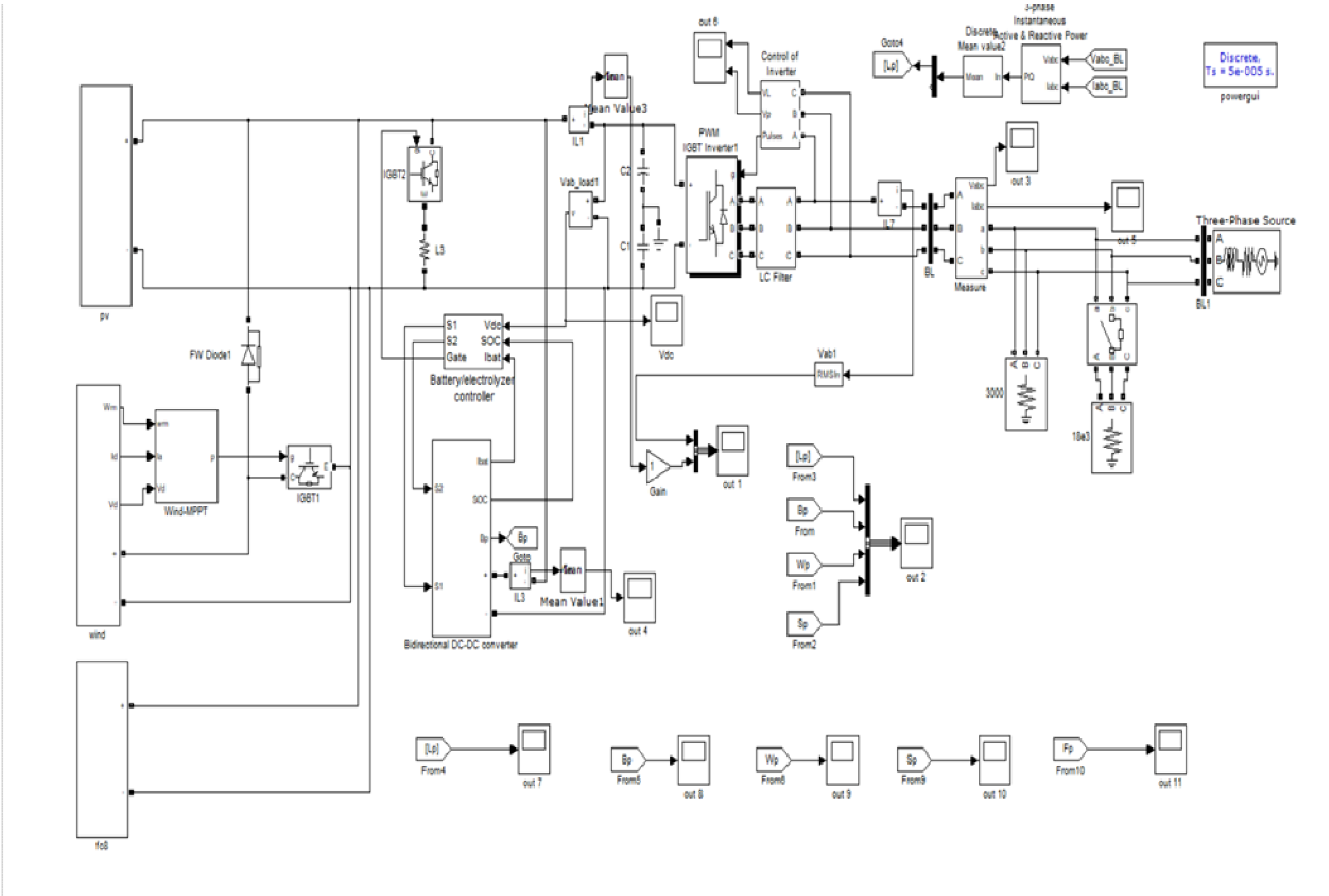


Figure-5:SimulinkDiagramofsolar,wind,batteryandfuelcellhybrid system.

Theboostconverter,whichisusedforsolarsystems,isdesignedtoraisetheDCvoltagefromafluctuatingsolarpanel to ahigher,constantvalue.Italsousesvoltagefeedbacktokeepthewindgenerator'soutputvoltageconstant,sothatat lower wind speeds, the voltage is lower and at higher wind speeds, it is higher. Due to their intrinsic unpredictability, thesesources'poweroutputvarieswiththeweatherandthetimeofday.However,becauseboostconverterscanhandle a broad range of input voltages, and the energy generated by both sources can be fully utilized. Changes in energy generation can lead tovariationsinvoltagelevels.Boostconvertersassistconnectedloadsinreceivingaconsistentandreliable power supply by stabilizing the output voltage. The voltage generated by solar panels and wind turbines might not always be sufficient for the load or batteries. Boost converters can be used to adjust voltage levels to meet the specific needs of the system.

V. RESULTSANDDISCUSSION

The hybridphotovoltaic-windsystemwithanACloadisthefocusofthestudy.Eachsourceisadaptedtothelocalclimate,takinginto account factors like radiation and wind speed. A current as well as voltagesensorisalsorequiredforeachoftheseinordertoensure that the optimum amount of electricity produced is maintained in spite of environmental changes. The system's independence is ensured by these two sources in conjunction with an AC load. Compared to typical systems that only use one source, the hybridsystem uses two linked sources, which results in a higher effective rate.

The simulation findings demonstrate the robust performance of the proposed solar and wind combined energy source across a variety of operating conditions.Thedynamicmodellingandanalysisemphasizethesystem'sabilitytoseamlessly integrate and benefit from the complementary features of solar and wind resources. The enhanced stability and dependability of power generation observed with protective schemes indicates a considerable improvement in the overall performance of the hybrid system.

Figure6displaysthesolarpowersystem'soutput,includingthesystem'svoltage,current,anddiodecurrent.

Figure7illustratestheoutputofwindpowersystemsusingapermanentmagnetsynchronousgenerator(PMSG)coupledtowindturbines.

Figure8showstheoutputofthefuelcell.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Figure9displaysthepoweroutputofabatterypowerwithSOC(stateofcharge)andoutpowerincludingtime. Figure10displaystheoutputofoverallpoweroutputfromthesolar,wind,batteryetc.

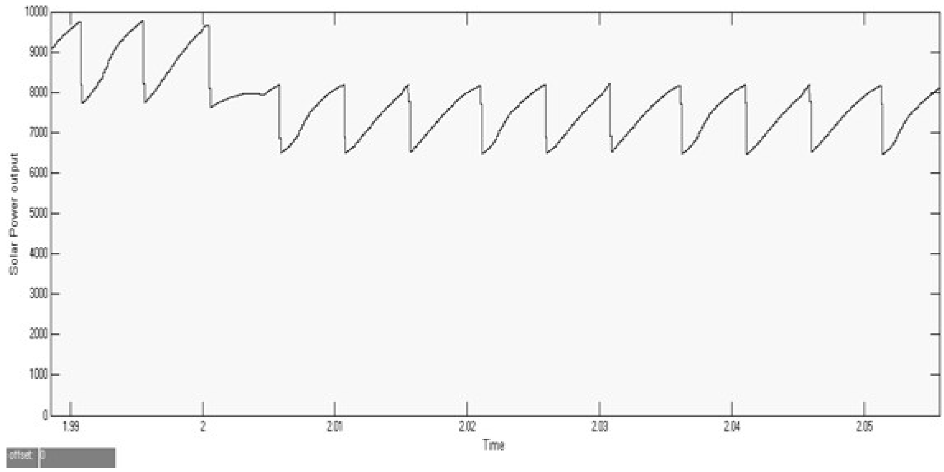


Figure 6: Solarsystemoutput.

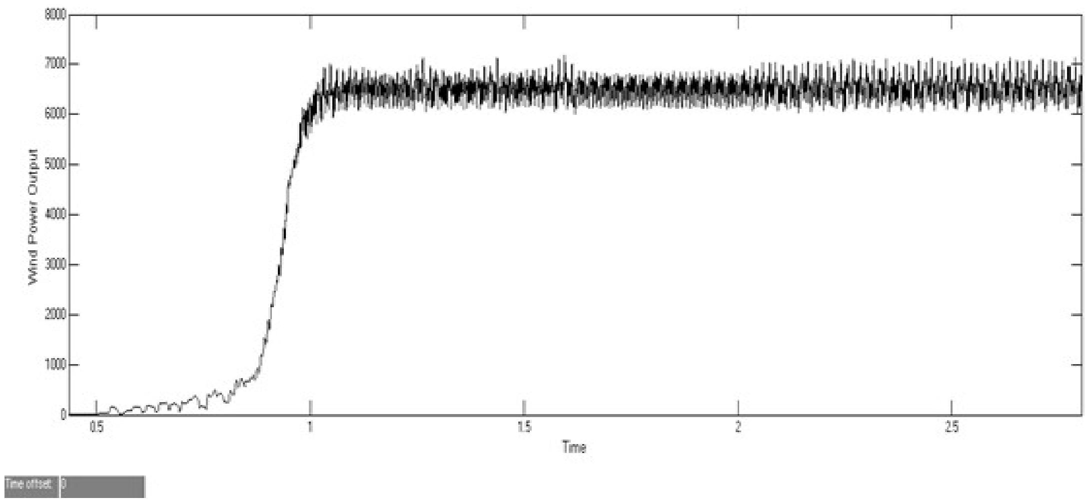


Figure 7:WindPoweroutput

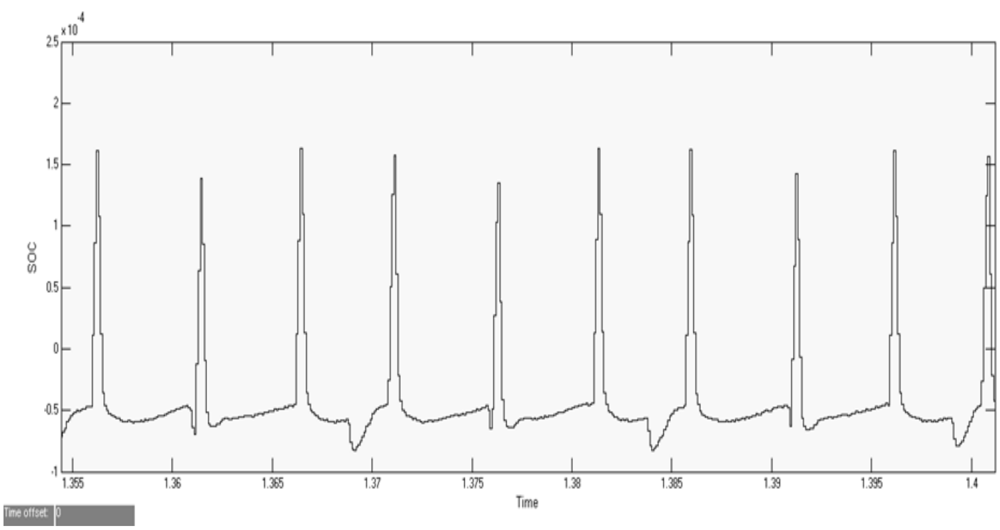


Figure-8:Fuelcelloutput

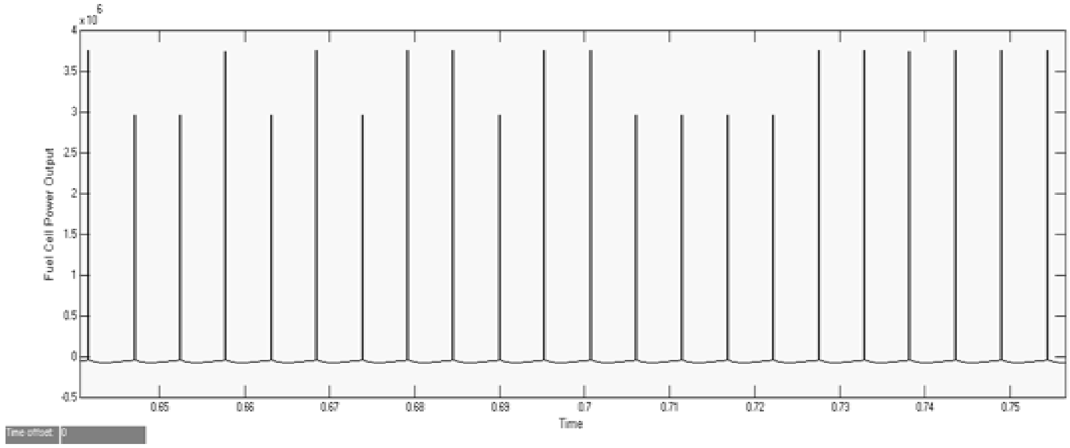


Figure9-BatteryOutput

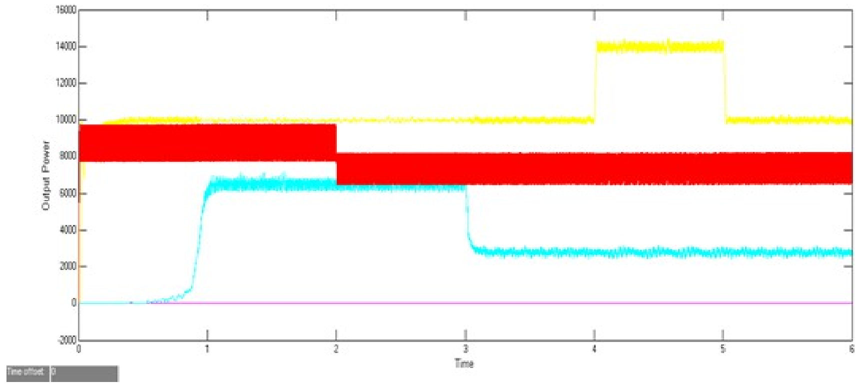


Figure-10:OutputsofLoadpower,WindandSolar power

VI.CONCLUSIONS

ThenewcontrolmethodforPV-WIND-SMESsystemsbasedonfuzzylogiccontrol(FLC)hasbeenproposedin this paper. The proposed FLC method maintains higher reliability of the SMES device by takingintoaccountitsstateof charge (SOC). Additionally, the proposed controller eliminates the fluctuated nature of the PV generation and wind generation through local load management. Additionally,theproposedFLCmethodmaintainsalongerlifetimeoftheDC link capacitors by avoiding high operating voltages due to deep charge anddischargeoperations.Theoutputfromsolar and wind systems is converted into AC power output using an inverter, and acircuitbreakerisconnectedintheallotted time. The hybrid system is adjusted toprovidethemaximumoutput powerunderall operating conditionsinordertofulfill the load. In order to satisfytheload,thebattery supportsthewindorsolarsystem. Itcanal sooperatesimultaneouslyfor the same load..

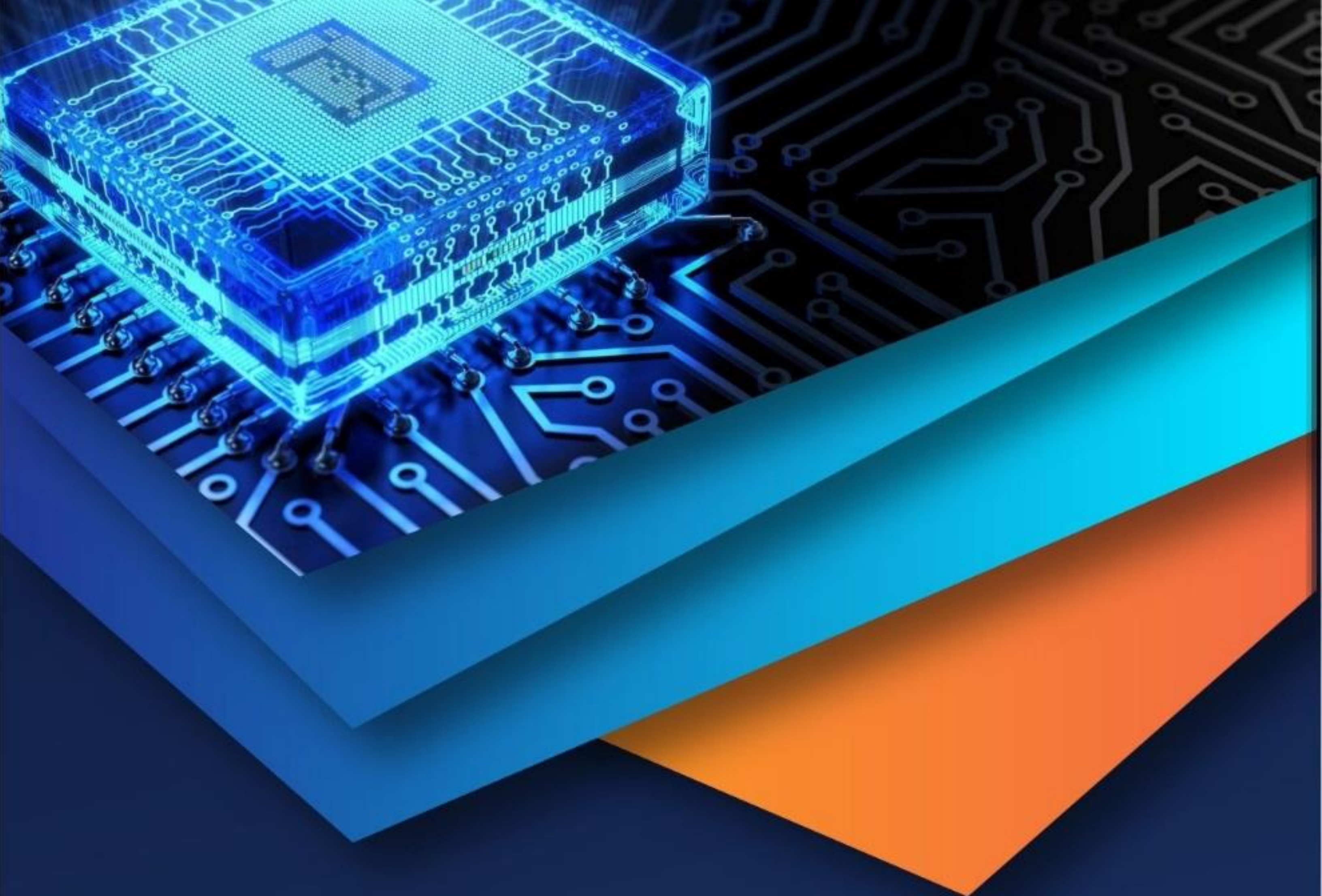
V. ACKNOWLEDGMENT

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Chaitanya Bharathi Institute of Technology Hyderabad for its support.

REFERENCES

[1] J.Kasera,A.ChaplotandJ.K.Maherchandani,"ModelingandsimulationofwindPVhybridpowersystemusingMatlab/Simulink," 2012 IEEE Students' Conference on Electrical, Electronics and Computer Science, Bhopal, India, 2012, pp. 1-4.
[2] Rai,PradeepandRoshanNayak."ModelingandSimulationofThree
[3] PhaseGridConnectedSolarPVSystem."InternationalJournalofCurrentEngineeringandTechnology8(2018)
[4] Shivam,GuptaandT.DeepakKumar."ModellingandSimulationof3PhaseGridconnectedSolarPVSystemwithPowerQuality Analysis." (2018).
[5] Cen,Z.(2017).ModelingandSimulationforan8kWThree-PhaseGridConnectedPhoto-VoltaicPowerSystem.OpenPhysics,15(1), 603-612. https://doi.org/10.1515/phys-2017-0070

[6] HamidonF.Z.,AbdAzizP.D.andMohdYunusN.H.,PhotovoltaicarraymodelingwithPandOMPPTalgorithmsinMATLAB, International Conference on Statistics in Science, Business and Engineering, 1-5 (2012).
[7] MasoudFarhoodnea,AzahMohamed,HussainShareefandHadiZayandehroodi,Powerqualityanalysisofgridconnectedphotovoltaic systems in distribution networks, PrzeglądElektrotechniczny, 89(2), 208-213 (2013).
[8] PrietyandVijayKumarGarg,"ToPerformMatlabSimulationofBatteryChargingUsingSolarPowerWithMaximumPowerPoint Tracking(MPPT)", International Journal of Electronic and Electrical Engineering, vol. 7, no. 5, 2014, ISSN 0974-2174.
[9] Seul-KiKim,Eung-SangKimandJong-BoAhn,"ModelingandControlofaGrid-connectedWind/PVHybridGenerationSystem," 2005/2006 IEEE/PES Transmission and Distribution Conference and Exhibition, Dallas, TX, USA, 2006, pp. 1202-1207.
[10] A.Kadri,H.MarzouguiandF.Bacha,"MPPTcontrolmethodsinwindenergyconversionsystemusingDFIG",20164thInternational Conference on Control Engineering and Information Technology (CEIT), pp. 1-6, 2016.



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY