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Abstract— This paper talks about a system called a "fuel cell-based microgrid," which can provide electricity to remote areas, either when they are disconnected from the main power grid (islanded mode) or when the main grid is working. The microgrid uses different renewable energy sources, like solar panels, wind turbines, and fuel cells, to generate electricity. The fuel cell-based approach allows smart management of electricity production, making it easier to provide power to remote areas. The case study in the paper looks at how this microgrid works in remote areas. A fuel cell can use hydrogen or air as fuel to produce electricity, and this can also be stored in batteries for later use. The main goal of this study is to find out the best size for each type of renewable energy system (solar, wind, fuel cell) in the microgrid, focusing on minimizing costs while ensuring enough power is available for the remote area. In simple terms, it's about designing an efficient and cost-effective system to provide renewable power to remote areas, with the help of technologies like solar, wind, and hydrogen-based fuel cells.

Keywords-Fuel cell based microgrid; hydrogen fuel cell.

I. INTRODUCTION

Traditionally, electricity is generated using fossil fuels like coal, oil, and gas. However, these sources are not good for the environment because they pollute the air, contribute to global warming, and will eventually run out. To avoid these problems, we need to switch to renewable energy sources like solar, wind, hydro, and geothermal power, which are clean and sustainable.

Among these, **solar energy** and **hydrogen fuel cells** are becoming verypopular because theyare efficient, eco- friendly, and have high energy output. The best part is that they don't release harmful pollutants. For example, solar energy doesn’t create any waste, and hydrogen fuel cells only produce pure water as a by-product. Now,one anothersolution to generate electricity in a clean way is a**micro-gridsystem**. A micro-grid is a small, local energy network that can work independently or be connected to the main power grid.It generates electricity from multiple small sources, like solar panels and hydrogen fuel cells, and can store energy in batteries.This system can manage power in a cost-

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effective and environmentally friendly way. It can work in different conditions, like when there's not much sunlight(for solar energy) or when demand for power changes. One approach is to use solar energy and hydrogen fuel cells together. A **control strategy** helps manage energy production and storage to ensure the system works efficiently. For example, when there's a lot of sunlight, the solar panels generate electricity and store some in batteries for later use. The hydrogen fuel cells can provide power when there'snot enough solar energy. A small- scale version of this system has been designed to generate around **50kW** of power. It can work in two modes:

1. **Islanded mode**: The system works on its own , disconnected from the main grid.
2. **Grid-connected mode**: The system is connected to the main power grid, providing electricity when needed.

The system's performance is tested under different conditions to make sure it works well. The hope is that this small-scale model could serve as the foundation for building larger systems in the future.
In short, micro-grids that use solar energy and hydrogen fuel cells are an efficient, clean, and promising way to generate electricity in a sustainable way.

II. PROBLEM DEFINITION

The main problem that are facing in present time , is the challenge of getting electricity to remote areas. These remote areas are usually located far from cities or towns, making it hard to set up electricity lines or power stations that can deliver energy in remote areas.
Without electricity, daily life can become very difficult for the people in remote areas. Simple tasks like cooking, lighting their homes, or using electronic devices become challenging. This lack of electricity can affect education, work, health services, and overall living standards. So, theproblem is not just about power; it also affects many aspects of people's lives.

III. Solution of Problem

A 50 KW, 625 VDC fuel cell stack to design a microgrid is formed virtually. A fuel cell stack is a device that supply power through a chemical reaction, typically using hydrogen and oxygen. In our case, the fuel cell stack has a capacity of 50 kilowatts(KW), which is enough to power multiple homes or small communities. The system generates 625 volts of direct current (DC) electricity, whichis thetype of electricitythat flows in one direction, makingit suitable for use in a microgrid.
We have created a microgrid, which is essentially a small, self-sufficient electrical system that can operateindependently. The microgridcanprovide electricityeven if the main electricitygridis down. This makes it especially useful for remote areas where connecting to the main grid might be impossible or too costly.
With this microgrid powered by the fuel cell stack, electricity supply to remote areas been done, which help to meet the energy needs of people living there. This solution is reliable, efficient, and clean, as fuel cells are an environmentally friendly way to generate electricity.

IV. System Modelling

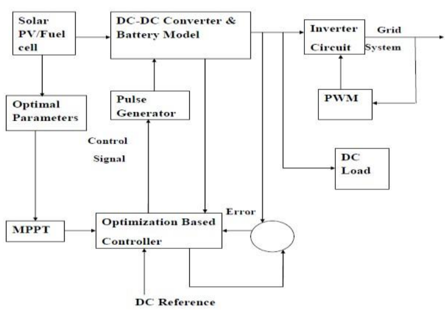

Figure1.The Block Diagram Of Microgrid

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Figure 1 represents block diagram a of microgrid which have a two source of generating electricity , oneis solarPVand other oneis Fuelcell. FirstofalltheybothsourcegenerateVariableDC andafter that we convert this Variable DC to Fixed DC by using DC-DC Converter and also used battery to stored generating power in battery for emergency conditions. After conversion we supply generating power to DC load, and also used controller to control this overall phenomena or to minimize error. This controller also provide pulse signal to converter. Controller also takes DC power to control this system. Optimal Parameters are used to filter an harmonics which comes from the source, and MPPT device is used to trace maximum value of voltage and current.

A. SolarPV

In aPV system, thesolar energyis converted toelectrical energybyusing oneor morePV modules.Mainly, the system consists
of panels, and various mechanical electrical connectors in order to produce the desired output. The panels are connected in series and parallel connection to provide the desired amount of voltage and current.

B. Fuel Cell

The most common fuel cell among other fuel cell is proton exchange membrane fuel cells (PEMFCs). It is very commonbecause it can operate at a lowertemperature (-20 to 1000C) and can startitsoperation veryfast from itsidle condition tofullload condition.Thebasicprincipleofa fuel cell is that it reactshydrogen with oxygen tocreate electricity. Thereaction produces water asa by-product, but the main goal is to produce electricityin a clean and efficient way.

Fuelcell equation-

$2H_2(g) \rightarrow 4H^+ + 4e^-$ ⟶ AtAnode
$O_2(g)+4H^++4e- \rightarrow 2H_2O$ ⟶ At

Cathode
$2H_2(g)+O_2(g) \rightarrow 2H_2O$+Energy(ElectricalandThermal) ⟶ OverallReaction

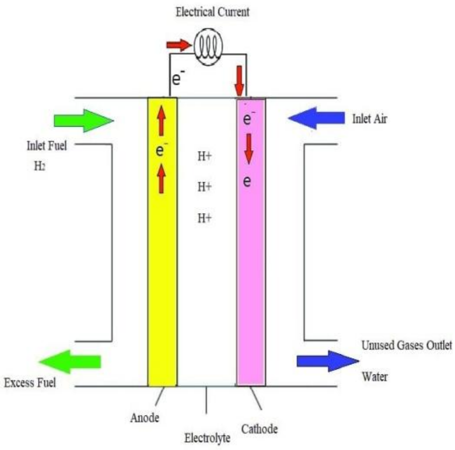

Figure2. Diagram of fuel cell

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Table1.SPECIFICATIONS OF DIFFERENT TYPES OF FUEL CELL

TechnicalTerms	Solid Oxide FCs	Phosphoric AcidFCs	Alkaline FCs	MoltenCarbonate FCs	DirectMethanolFCs
Efficiency(%)	50-65	40-45	45-60	53-57	10-40
CellVoltage(V)	0.8-1.0	1.1	1.0	0.7-1.0	0.2-0.4
Lifespan (h)	1000	>50,000	8000	7000-8000	29.9-274
PowerDensity(kWh/m^(3))	4.20-19.25	0.8-1.9	~1.0	1.05-1.67	-0.6
Temperature (degreeC)	800-1000	150-220	60-120	600-800	70-100

C. Battery Model

Due to high efficiency, high density of energy and environment-friendly nature compared to lead acid or NiCd battery, Li-ion batteryis chosen here for the proposed work. The available battery model in the Sim Power System is utilized in the work.

D. Controller

Controllers are responsible for managing voltage, current, and power flow under both grid-connected and islanded modes. They must handle the dynamic behavior of fuel cells, battery storage, and other distributed energy resources (DERs) while maintaining reliable power quality.

TABLE 2. DIFFERENCE BETWEEN PD, PI AND PID CONTROLLER

Terms	**PIController**	**PDController**	**PIDController**
Work	Combinestheproportionalandintegralactionstoeliminatesteady-state error .	Combinestheproportionalandderivative actionstoprovidefasterresponses and helpreduceovershoot	Combinesproportional,integral, and derivativeactions to handle a widerange of system dynamics,offeringabalancedresponse.
Advantages	Eliminatessteady-state error andprovidesbetter response	Reducesovershootandimprovessystemresponse speed.	Providesexcellentcontrolbyeliminatingsteady-stateerror, reducing overshoot, andimprovingresponsetime.
Disadvantages	Canstillhavesomeovershoot .	Do not eliminatesteadystateerror.	Morecomplextoimplementandtune.

E. MPPT

Maximum Power Point Tracking(MPPT)in simulation refers to the technique used to optimize the power output of renewable energy systems, particularly solar panels. MPPT algorithms adjust the operating conditions (voltage or current) of solar panels to extract the maximum possible power from them, given the varying environmental conditions like sunlight intensity and temperature.MPPT are used to model and test the performance of solar power systems under different conditions before real-world implementation. Simulating MPPT helps optimize energygeneration, system efficiency, and response to changing environmental factors.

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F. Inverter Circuit

An inverter circuit is used to simulate the conversion of Direct Current (DC) to Alternating Current (AC), which is a fundamental process for renewable energysystems, especially in solar, wind, and battery-powered applications. The inverter takes power from a DC source (like a solar panel or battery) andconvertsit intoan ACoutput suitable for powering householdappliances, feedinginto the grid. Simulation of inverter circuits helps in analyzing their performance, efficiency, andcontrol under different conditions, ensuring the design meets .

G. PWM

Pulse Width Modulation (PWM) is used to represent and analyze systems that rely on PWM signals for controlling power, voltage, or current. These PWM controller interacts with devices like motors, lights, or heating elements in a digital or analog system. PWM are critical for designingand testing systems before physical implementation, ensuring efficiency, performance, and reliability.

V. Methodology

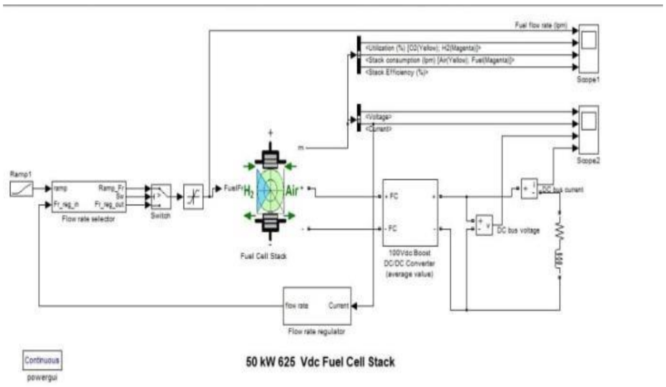

Figure3.The Simulink Model Of Fuel Cell Based Microgrid

Figure 3 represents a Simulink Model of 50 kW, 625 V DC Fuel Cell Stack integrated with a DC/DC boost converter, designed to simulate andanalyze the behavior of a fuel cell system under varying load conditions. The fuel cell stack generates electricity by reacting hydrogen (H_2) with oxygen from the air, producing a DC output. The fuel flowrate selector and regulator dynamically adjust the hydrogen input to optimize fuel utilization and efficiency. A DC/DC boost converter stabilizes the variable output voltage of the stack, converting it to a constant DC bus voltage required by the load. The system monitors key parameters such as fuel utilization, hydrogen consumption, stack efficiency, voltage, and current through connected scopes. The simulation methodology involves regulating hydrogen supply, converting chemical energy to electricalenergy, and stabilizing output voltage, enabling performance evaluation and control strategy development.

Components of Simulink Model

1. **Ramp Signal -** In Simulink, the Ramp Signal block is used to generate a signal that increases or decreases linearly over time.

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It is commonly used in simulation models where a gradual change in input is needed, such as for testing control systems, simulating gradual input variations, or creating a reference signal in dynamic system simulations. In Simulink model following assumptions are considered
slope=10, Start time=10, Initial Output =0

2. DC/DC boost converter-The DC/DC boost converter is a device that takes the variable voltage output from the fuel cell stack and increases ("boosts") it to a stable and constant voltage that can be used by the connected load (like a motor, battery, or other electricaldevices). Theoutputfromthefuelcellisnotconstant-it can change depending on the load or conditions, so the boost converter ensures that the voltage remains steady at the required level.

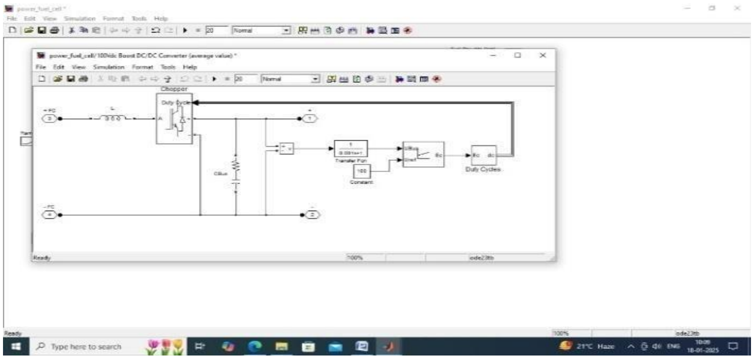

Figure4. Circuit diagram of DC-DC boost converter

3. **Fuel Flow rate selector and regulator-**It controls that how much hydrogen is supplied to the fuel cell. The systemcan adjust this flow rate based on demand to make sure the fuel cell is operating as efficiently as possible. By doing this, the systemcan optimizefuel usage, ensuring it doesn't waste hydrogen and maintains high performance.

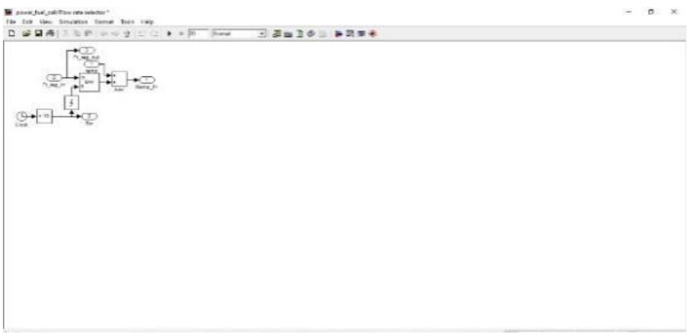

Figure 5. Circuit Diagram Of Flow Rate Selector

4. **Fuel Cell Stack-** Fuel Cell Stack is a device that generates electricity by a chemicalreaction. It specifically uses hydrogen(H_2) and oxygen from the air. The fuelcellstackinthis modelproducesa DC(direct current) output at625voltsand can provide a maximum of 50 kW of power. Proton exchange membrane fuel cells (PEMFCs) is most common fuel cell. It is very common because it can operate at a lower temperature (-20 to 1000C) and can start its operation very fast from its ideal condition to full load condition.

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PEFMC Fuell Cell Equation

$H_2(g) \rightarrow 2H^{+}+2e^{-}$

$0.5O_2(g)+ 2H^{+}+2e- \rightarrow H_2O$

Table 3. SPECIFICATIONS OF FUEL CELL STACK

TechnicalTerms	Values
EfficiencyofFuelCellStack (%)	55
AirFlowRate(Ipm)	300
OperatingTemperature(Celsius)	65
SupplyPressure[Fuel(bar),Air(bar)]	[1.51]
%ofH2used	99.56
FuelCellResistance(ohms)	0.07833
FuelCellStackpower(Watt)	5998.5
Numberofcells	65

5. **Saturation Block-**A saturation block is a concept typically used in various fields such as electrical engineering, control systems, and signal processing. The idea behind saturation is that a system or component has limits to the range of values it can handle, and once these limits are exceeded, it "saturates" and cannot process higher or lower values.
6. **Switch-**Switch is used as a control mechanism that allows the model to choose between different paths or actions based on certain conditions or logic. This can help in making decisions, handling different scenarios, and controlling the flow of the simulation.
7. **Scopes-**The main purpose of a scope is to provide a real-time plot of signals so that engineers or researchers can monitor thesystem's behavior during thesimulation. It helps to visualize time-domain signals, making it easier to observe patterns, fluctuations, peaks, and other important signal characteristics like stability, periodicity, or response to input changes.

Table 4. SPECIFICATIONS OF SIMULINK MODEL

Parameters	Values
RampSignal	Slope=10,Starttime=10
Switch	Sampletime=-1
SaturationBlock	Sampletime= -1,Upperlimit=85,Lower limit = 0
FuelCellStack	PEMFC-6Kw-45Vdc
BoostDC/DC Converter(averagevalue)	100Vdc
FlowRateRegulator	%H2Utilization=99.56,Fuel Pressure= 1.5bar
SeriesRLCBranch	R=100*100/6000(Ohms); I= 100*100/6000(Henry)

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VI. RESULTS AND DISCUSSION

The fuel cell stack is designed to generate 50 kW of power using hydrogen (H_2) and oxygen. It operates at 625 VDC and uses Proton Exchange Membrane Fuel Cells (PEMFCs), which work efficiently and start quickly. The fuel cell's efficiency is about 55%, and it uses 99.56% of hydrogen supplied. The converter stabilizes the fuel cell's variable DC output to a constant voltage suitable for the load (like batteries or devices). The boost converter ensures that the output voltage stays at the required level, even if the fuel cell's output fluctuates. The system dynamically adjusts the hydrogen flow rate to optimize fuel usage and ensure the fuel cell runs efficiently without waste. The fuel flow rate selector helps maintain the correct fuel supply based on the demand. The simulation model uses a Ramp Signal, which gradually increases over time to test how the system responds to changing load demands. A Switch mechanism in the simulation controls which path or action to take, depending on the conditions. The microgrid is designed to work in two modes: islanded (off-grid) or connected to the main grid. The system efficiently manages renewable energy sources (solar and fuel cells) and stores power in batteries for later use. With the help of controllers, the system ensures smooth operation, adapting to changing conditions and minimizing power loss.

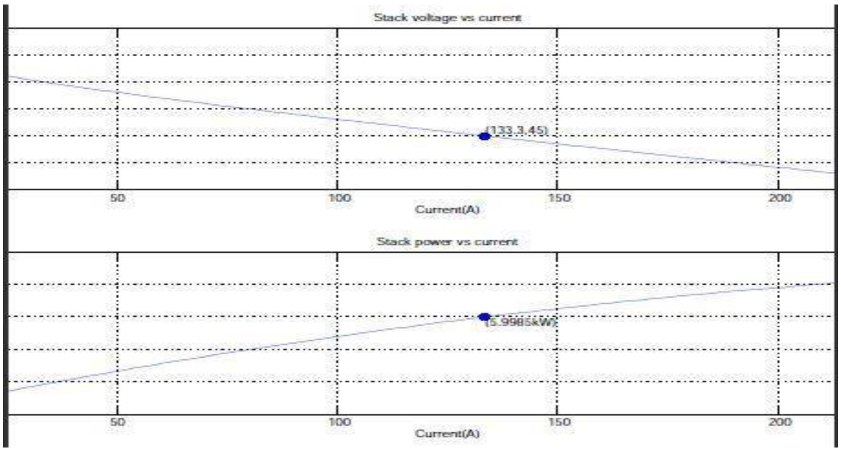

Figure6. VI & PI characterstics of fuel cell stack

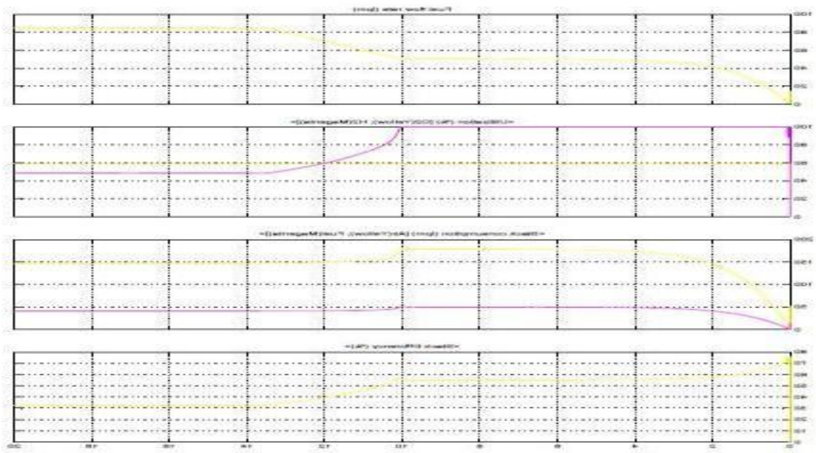

Figure7. Output wave form of Fuel Flow rate (Ipm),Utilizationofh2ando2,Stack Consumption Of Air And Fuel In (Ipm) , Stack Efficiency **(%)**

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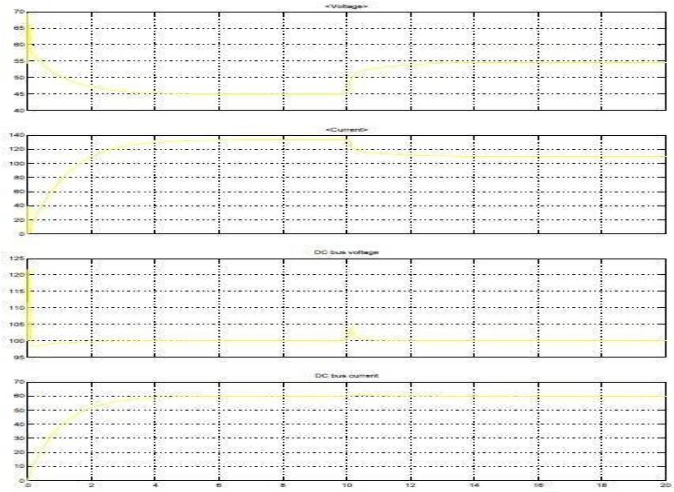

Figure8. Output wave form of voltage, Current, DC bus voltage and DC bus current

VII. CONCLUSION

This study presents a fuel cell-based microgrid system designed to provide reliable electricity to remoteareas. It uses renewable energy sources like solar power and hydrogen fuel cells, along with battery storage. The system can operate both connected to the grid and independently. Simulation results show the system maintains stable voltage and power under different conditions. It also efficiently uses hydrogen with high energyconversion. Thesystem is designed to adapt to varying conditions and provide continuous power, improving the quality of life in remote areas bypowering essential activities. This approach is eco-friendly, cost-effective, and scalable for larger application.

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