Peer-to-Peer Energy trade in Smart Grid

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Abstract — This implemented work Peer-to-Peer (P2P) energy trading in smart grids is a game changer in the old energy distribution model, allowing prosumers (entities that both produce and consume energy) to directly sell surplus energy with other users. P2P trading improves grid efficiency, energy democratization, and consumer empowerment by utilizing modern technologies such as blockchain, the Internet of Things (IoT), and smart contracts. This decentralized strategy promotes local energy balance, lowers transmission losses, and stimulates the use of renewable energy sources. The article examines the architecture, benefits, and challenges of integrating peer-to-peer energy trading into smart grid frameworks, with an emphasis on system design, market models, security concerns, and regulatory implications. It also includes case studies and pilot projects to demonstrate the practicality and potential impact of this novel energy trading paradigm.

Keywords: Peer-to-Peer Energy Trading, Smart Grid, Prosumers, Blockchain, IoT, Smart Contracts, Decentralized Energy Systems, Renewable Energy Integration, Energy Market, Grid Optimization

I. INTRODUCTION

The notion of peer-to-peer (P2P) energy exchange has emerged as a game changer in the smart grid ecosystem, allowing families and businesses to create, consume, and trade energy in a decentralized manner. P2P energy exchange platforms can enable secure transactions between prosumers by leveraging block chain technology, IOT devices, and advanced data analytics, allowing them to monetize their excess energy production and gain greater control over their energy age patterns, thereby optimizing energy efficiency and reducing reliance on traditional grid infrastructure.

This change to a decentralized and democratized energy system has the potential to transform our understanding of energy production and consumption, paving the way for a more sustainable, resilient, and community-driven energy future. In his context, the concept of P2P energy exchange is poised to play a vital role in the transition towards a low carbon economy, enabling households and businesses to take ownership of their energy needs and contribute to a sustainable energy future, where individuals are no longer just passive consumers, but also active producers and traders of energy, fostering a culture of cooperation and mutual support, where energy surplus from one household can be shared with neighbours. In addition to giving people more control over their energy use and costs, this move toward a decentralized energy system has the potential to de-emphasize energy access, advance energy democracy, and give households new economic opportunities that they can use to boost local economic growth and help build a more resilient and sustainable electrical infrastructure, which will ultimately result in a cleaner, more dependable, and more equitable energy system for everybody.

II. MODELLING OF THE SYSTEM

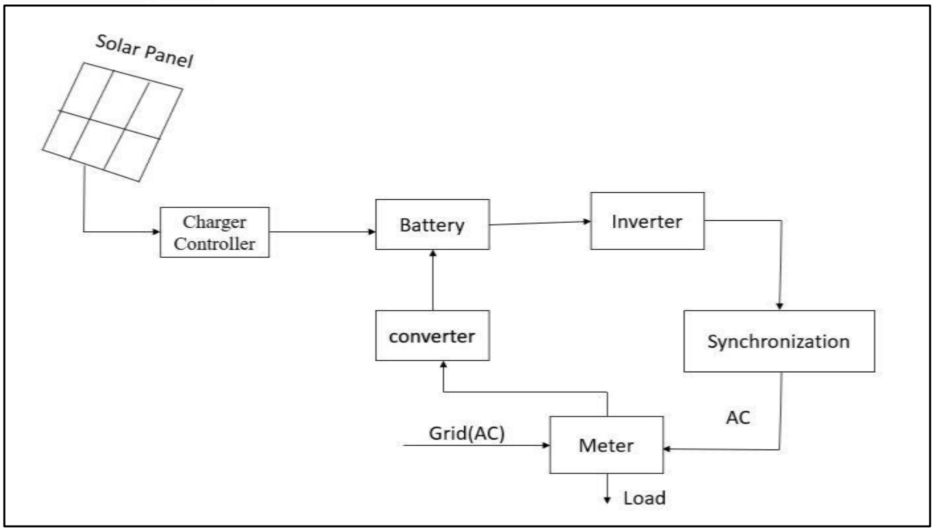

Fig 3.1: Block Diagram of peer-to-peer energy exchange prosumer driven solutions for smart grid.

Grid-Connected Solar Photovoltaic System Architecture with Battery Backup. To improve energy reliability and maximize the use of renewable energy sources, the suggested system, as shown in Figure is a grid-connected solar photovoltaic (PV) energy system coupled with a battery storage unit. The following are the main parts are:

A. *The architecture:*

Solar Panel: The main energy source is the solar PV array, which produces direct current (DC) electricity from incident solar irradiation. Through power conversion stages, this clean energy source provides power to the load and charges the battery.

1) Controller for Charge: By managing the voltage and current output from the PV array, the charge controller controls the battery's charging process. It prolongs battery life, avoids overcharging, and guarantees safe and effective charging. Under different irradiance circumstances, energy harvesting can be maximized by using Maximum Power Point Tracking (MPPT) algorithms.
2) Energy Storage System for Batteries (BESS): Excess energy produced by the PV array is stored in the battery and made available during times of peak demand or low solar generation. Both charging (from the grid or solar) and discharging (to supply the inverter/load) are made possible by the bidirectional flow capabilities.
3) Converter in both directions: This converter connects the DC bus and battery system to the AC grid. When solar power is insufficient, it permits grid-to-battery charging. Depending on the system architecture, it may also permit battery-to-grid discharge. Power flow regulation and proper voltage conversion are guaranteed by the converter.
4) The inverter: The battery or solar array's DC electricity is transformed into alternating current (AC) via the inverter so that it can be used for consumer loads and grid integration. Maintaining phase and frequency alignment with the power grid requires a synchronized inverter.
5) Unit of Synchronization: To enable secure and reliable parallel operation, the synchronization unit makes sure the inverter's AC output is phase-matched with the grid. To avoid grid disruptions, this involves synchronizing the phase angle, frequency, and voltage magnitude.
6) The Energy Meter: The energy flow between the system and the grid is recorded by the meter in both directions. By measuring both imported and exported energy, it facilitates billing and incentive systems and enables net metering operations.
7) Fill up: Residential, business, or industrial consumers are represented by the load. Solar and battery power are given priority by the system, with grid support added as needed.
8) The Grid of Utility: When rules allow it, the system's connection to the traditional utility grid allows for the feeding of excess solar energy and allows for a continuous power supply during solar deficiencies.

B. Circuit diagram:

The working peer-to-peer energy exchange functions as a prosumer-driven smart grid solution. With this technology, prosumers can generate, store, convert, synchronize, and trade energy while maintaining effective integration with the main power grid. Solar panels are used to generate energy at the start of the process, converting sunlight into direct current (DC) electricity. The system uses this energy as its main input. The first component of the system is a solar panel, which absorbs sunlight and transforms it into DC electrical energy. Typically, this output is uncontrolled and varies according to the amount of sunshine. Before being fed into the voltage regulator, the voltage from the solar panel is smoothed out by a capacitor. After that, an XL6009 boost converter IC receives the voltage from the solar panel. In order to charge the battery, this chip raises the voltage level to the appropriate level. It performs effective DC-DC conversion in conjunction with a Schottky diode and an inductor.

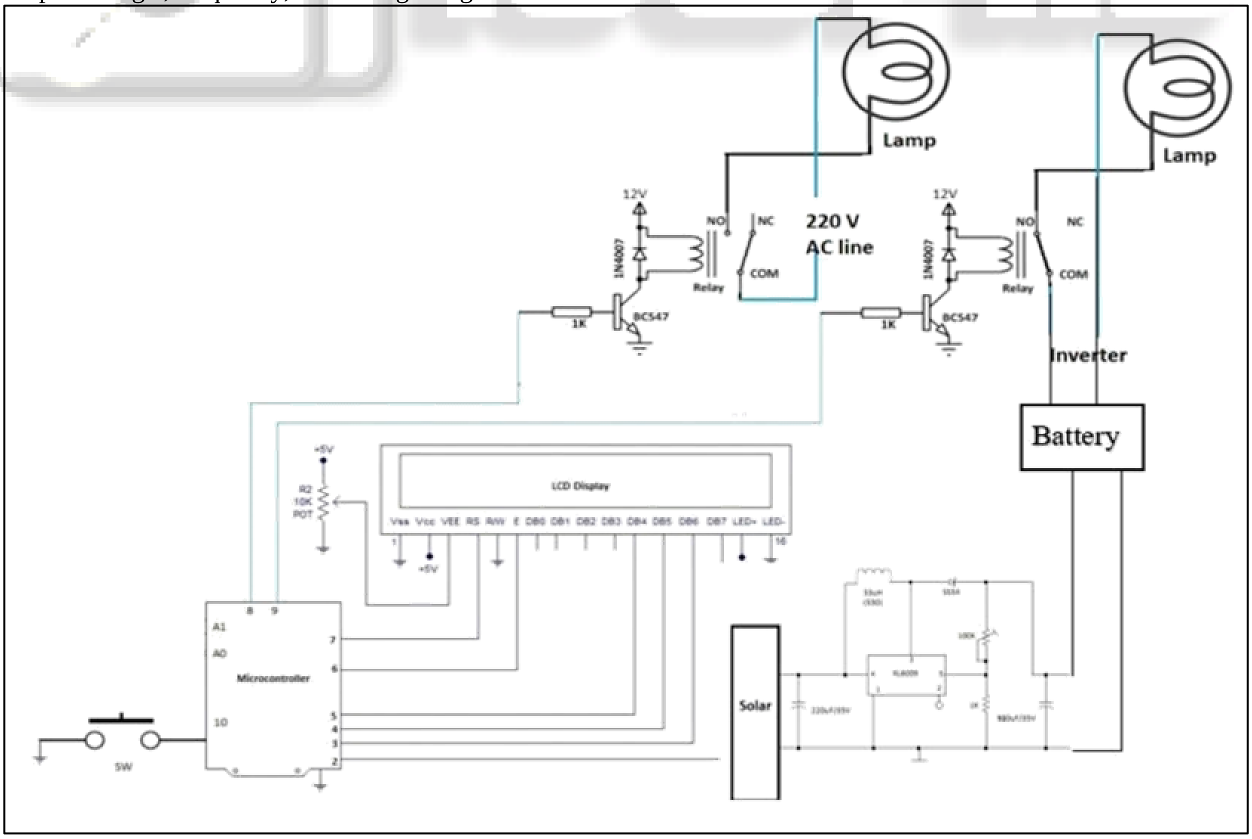

Fig. 3.2: Circuit diagram of peer-to-peer energy exchange prosumer driven solutions for smart grid.

The controller sends excess energy to a battery for storage if it is not immediately needed for home appliances. When solar generation is minimal, like at night or on overcast days, this stored energy serves as a backup that can be used. By acting as an energy buffer, the battery helps prosumers preserve their energy independence while promoting grid stability. Energy must be converted from direct current (DC) to alternating current (AC), which is compatible with the majority of appliances and the grid, before it can be used for domestic appliances or exported to the grid. The inverter does this conversion. An inverter that is linked to the battery transforms the DC power it has stored into 220V AC. AC appliances, like the lamps in the circuit, can be powered by this output. The control system only turns on the inverter when necessary. Power is switched between the solar inverter and the main AC power line using two relay modules, each powered by a BC547 NPN transistor and an IK base resistor. Depending on the control signal, the relays determine whether the lighting will run on AC power or inverter power. The relays are made to alternate between contacts that are normally closed and those that are normally open. At the center of the decision-making process is a 28 microcontroller. It regularly checks the battery's charge state and the amount of solar power available. It transmits control signals to the transistors, which then switch on or off the relays based on the circumstances. To indicate system information including voltage levels, the power source being used, and battery condition, an LCD display is attached to the microprocessor. It is powered by a 5V supply and utilizes data pins D0 through D7.

III. DC-AC INVERTER

One essential electrical equipment that transforms direct current (DC) into alternating current (AC) is an inverter. It is essential to contemporary electronic systems where energy must be converted from DC to AC for practical usage in homes, businesses, and electrical grids. Examples of these systems include batteries, solar panels, and fuel cells. In order to achieve high efficiency, minimal storage, and accurate output control, modern inverters employ sophisticated semiconductor switching devices such as MOSFETs, IGBTs, and microcontroller-based control systems.

Inverters are now more crucial than ever in providing seamless and effective energy conversion and consumption due to the growth of renewable energy and electric mobility. Applications for inverters are numerous and include motor drive systems, off-grid power solutions, electric cars, renewable energy systems, and uninterruptible power supplies (UPS). An inverter's main job is to convert a DC input source into an AC output with the appropriate voltage, frequency, and waveform quality. In order to create an alternating waveform, an inverter switches semiconductor devices like MOSFETs or IGBTs that are managed by electronic circuits or microcontrollers.

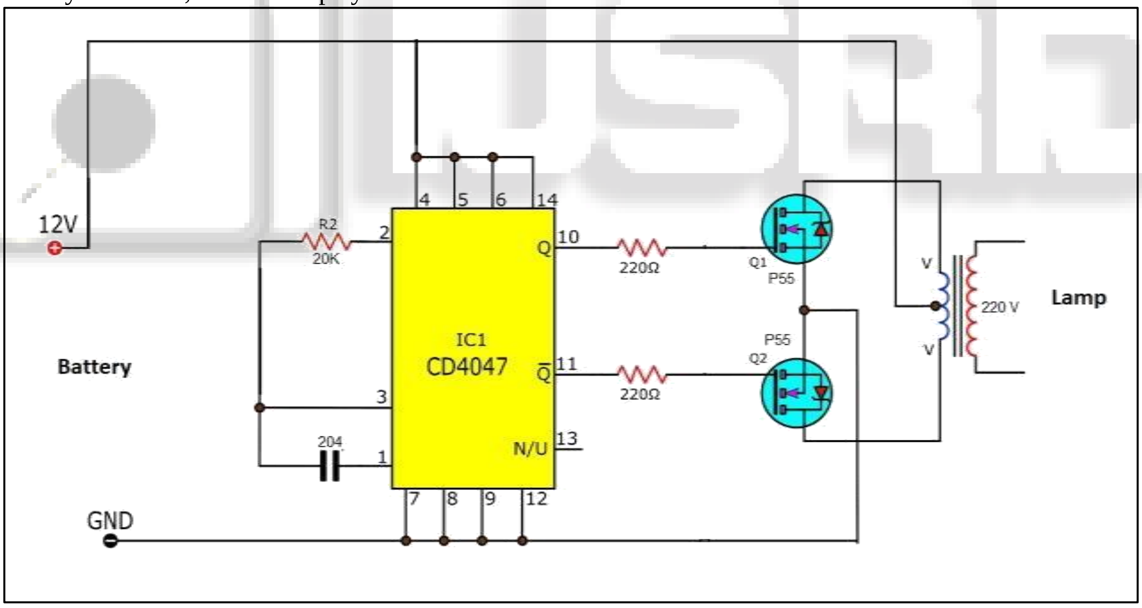

Fig. 3.3: DC-AC inverter

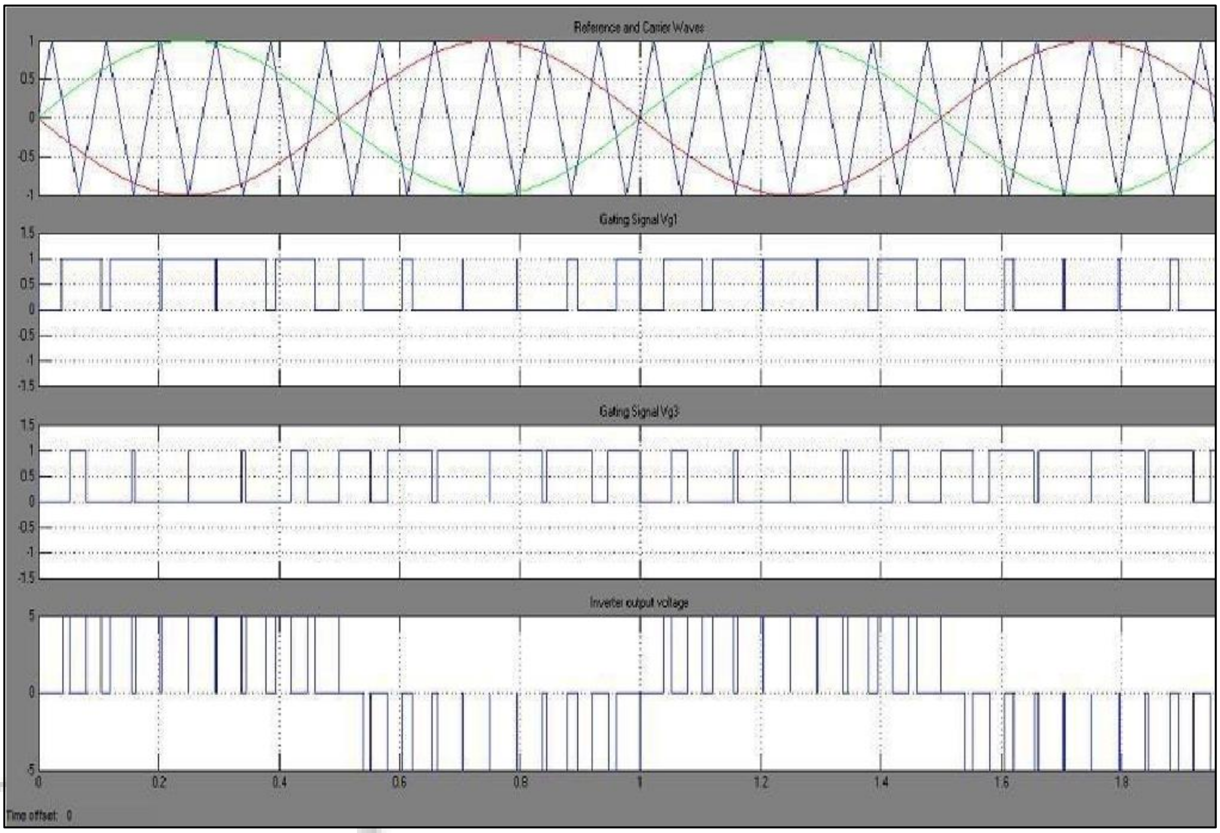

Fig. 3.4: Gating Signals and Output Voltage of DC-AC inverter

A. *DC-DC Converter*

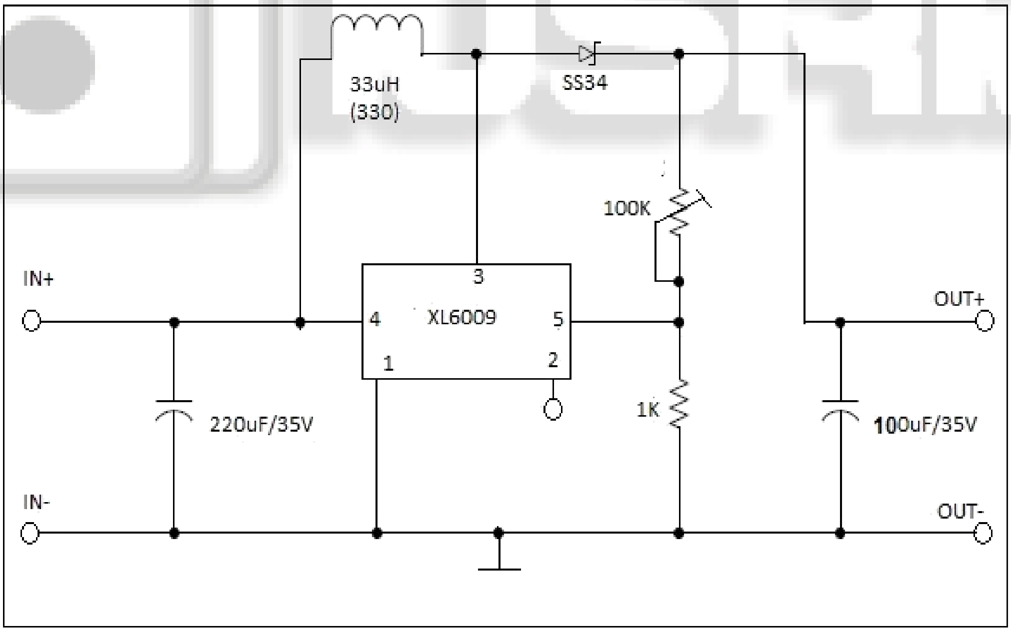

Fig. 3.4: DC-DC Converter

From portable electronics to renewable energy systems, a DCDC Boost Converter is a crucial power electronic circuit that is used in many different applications. It is an essential part of systems where the input voltage must be increased to power a load that needs a higher voltage because its main purpose is to step up or boost a given DC voltage level to a higher one. The energy storage and release mechanism utilizing inductors, capacitors, diodes, and switches forms the basis of the boost converter's operation.

The idea of energy transfer between magnetic and electric fields is how a DC-DC boost converter works. Current passes through the inductor during operation, storing energy in its magnetic field when the switch (usually a transistor) is closed. The diode and capacitor work together to raise the voltage when the switch opens, releasing the energy that has been stored in the inductor. The output voltage can be adjusted to reach a desired voltage level and is dependent on the switch's duty cycle. The operation of a boost converter is rooted in the principle of energy transfer between magnetic and electric fields, leveraging components such as inductors, capacitors, diodes, and semiconductor switches (typically transistors). When the switch is closed, current flows through the inductor, storing energy in the form of a magnetic field. Upon opening the switch, this stored energy is released. The inductor resists sudden drops in current, causing the voltage across it to rise. This elevated voltage, combined with the input, is directed through the diode and stored in the output capacitor, resulting in a higher output voltage.

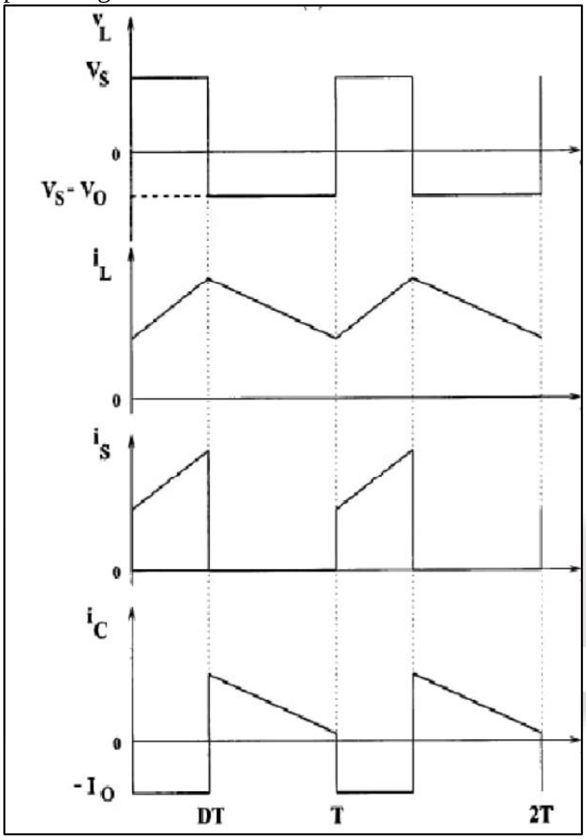

Fig. 3.5: DC-DC Converter Waveform

IV. RESULTS AND DISCUSSION

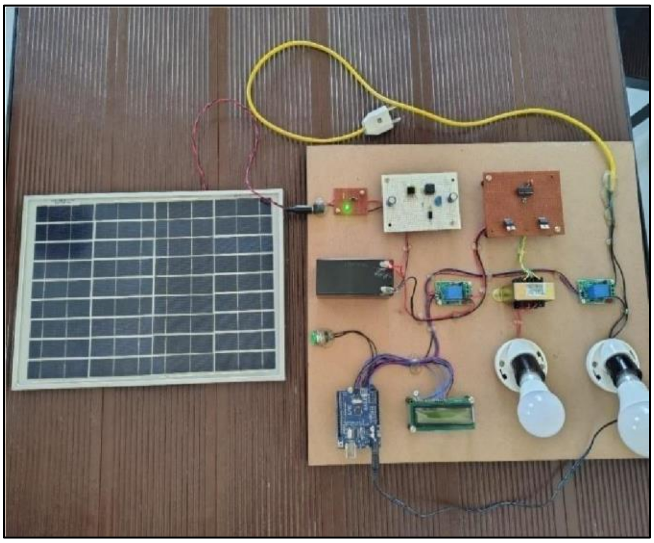

Fig. 4.1: Model of peer-to-peer energy exchange prosumer driven solutions for smart grid

This project, which is probably intended for instructional or demonstrative purposes, shows a small-scale setup illustrating a fundamental energy generation and consumption principle. A solar panel, which transforms light energy into electrical energy (DC), is the main component. This 20 is the source of energy generation in this configuration. a circuit board that contains a number of electronic parts, maybe including a microcontroller, resistors, capacitors, and diodes. The energy system is controlled and managed by this board. The energy system is controlled and managed by this board. The batteries' presence indicates that the system has the capacity to store the energy produced by the solar panel. Later, when solar generation is scarce or non-existent (for example, at night), this stored energy can be used. Light Bulbs: The load or energy-consuming devices are represented by the two light bulbs. They use the electrical energy that is either stored in the batteries or produced by the solar panel. The energy transmission from the solar panel to the battery, control circuit, and lightbulbs is depicted by the interconnected wires.

Fig. 4.2: Measurement of P2P energy exchange under No-Load Condition

P2P energy exchange refers to the decentralized sharing of energy among prosumers (producers-consumers) without relying heavily on centralized grids. Measuring P2P energy exchange under a no-load condition—where no significant load is connected—helps in analyzing baseline energy flow, losses, and system stability.

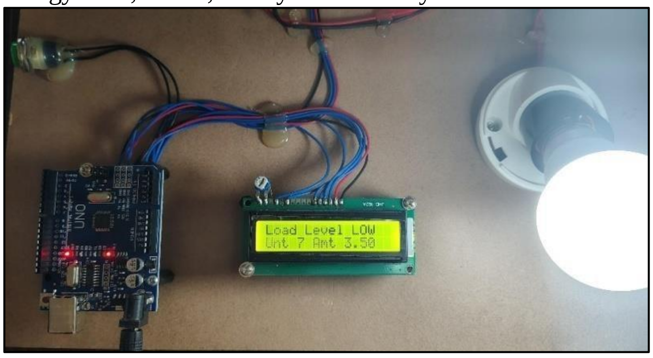

Fig. 4.3: Measurement of P2P energy exchange under Low load condition

Peer-to-peer (P2P) energy exchange under load situations is measured by assessing grid stability and the energy transfer between decentralized energy producers and consumers. Whilst loads take into account the influence of related. This procedure guarantees effective distribution of load energy.

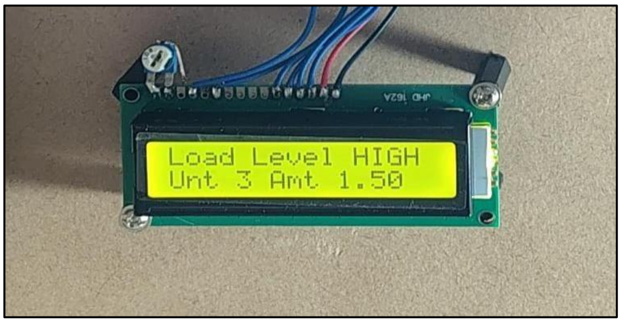

Fig. 4.4: Measurement of P2P energy exchange under High Load condition

High load situations usually occur during periods of high consumption, such as the evening when homes use several appliances at once or during severe weather when heating or cooling systems are running at maximum efficiency. In these situations, the amount of power generated by solar or other renewable sources could not be enough to meet demand, requiring more power from the main grid, energy storage devices, or the demand itself.

V. Conclusion

To sum up, the future of P2P energy exchange with prosumer-driven smart grid solutions is bright and expected to increase significantly. This approach has the potential to change the way energy is produced, used, and traded as the globe moves toward cleaner, decentralized energy systems. P2P systems can increase grid efficiency, promote sustainability, and give customers new economic opportunities by integrating developing technology. The continuous developments in these fields indicate that P2P energy exchange will be essential to creating a more resilient, sustainable, and egalitarian energy future, even though regulatory frameworks and market structures will need to adapt. In order to support P2P energy exchanges, regulatory frameworks will change, creating precise guidelines for pricing, data security, and market structure. Finally, by supporting net- zero aims and possibly incorporating carbon credit trading mechanisms into P2P platforms, the move toward decentralized energy models will help achieve sustainability goals and further align financial incentives with environmental Sustainability.

VI. Future scope

Your project's future scope on P2P energy exchange with prosumer-driven smart grid solutions has enormous promise in a number of areas. Decentralized energy trading will become more necessary as the use of renewable energy sources increases, creating new chances for regional energy markets and infrastructure modernization. Blockchain and smart contract integration can facilitate automated, transparent, and safe energy transactions, decreasing the need for middlemen and increasing energy efficiency.

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