International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 21 No. 3 (1) 2025

ijerst.editor@gmail.com
editor@ijerst.com

ISSN 2319-5991 www.ijerst.com
Vol. 21, No. 3(1), 2025

Research Paper

POWER QUALITY ENHANCEMENT IN SOLAR–WIND HYBRID EV CHARGING STATIONS INTEGRATED WITH THREE-PHASE GRID

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ABSTRACT

The integration of renewable energy sources, such as solar and wind power, into Electric Vehicle (EV) charging stations presents a promising solution for sustainable transportation. However, ensuring high power quality in these systems is essential for the efficient operation of both the charging stations and the grid. This project compares the power quality improvement in solar and wind-based EV charging stations interconnected with a three-phase grid. Power quality parameters such as voltage stability, harmonics, power factor, and frequency regulation are evaluated for both systems. Solar-based systems, benefiting from predictable energy generation during daylight, generally exhibit superior performance in terms of voltage stability, harmonic reduction, and power factor correction, with the ability to integrate seamlessly with energy storage solutions.

In contrast, wind-based systems offer the advantage of continuous power generation in regions with consistent wind, but they face challenges due to variability in wind conditions and more complex control mechanisms. Both systems contribute to frequency regulation and voltage support, albeit with different levels of consistency. The project concludes that while both solar and wind- based EV charging stations can significantly improve power quality, the optimal solution depends on local environmental factors, grid infrastructure, and the need for energy storage integration

Received: 02-07-2025 Accepted: 16-07-2025 Published: 04-08-2025

1. INTRODUCTION

Electric vehicles' (EVs) popularity has grown in response to growing environmental concerns about pollution and the need to conserve natural resources. The need to create charging stations is a direct result of the increasing demand for electric vehicles. Typically, grid electricity is used to charge the electric vehicle's battery. There is an example of a charger topology that uses the grid to charge an electric vehicle's battery. These layouts charge the electric vehicle battery using the massive amounts of electricity from the grid. Unfortunately, the charger can only accept power going in one way, therefore no active power can flow from the car to the grid. Nevertheless, in times of high demand, the power stored in EV batteries may be used as an energy storage device.

Electric vehicles often have a lot of energy saved up while they're parked. Electric vehicles use their stored energy to fulfil the grid's peak power demand even when they're not in use. The EV charger must be able to accommodate active power flow in both directions for this to be achieved [6]. "Vehicle to grid" refers to the process by which an electric car feeds electricity into the electrical grid. Charging electric vehicles in this way can potentially help the grid with reactive power as well [7–10]. Close to the load end is where the reactive power assistance is supplied. The PV intermittency is mitigated by connecting the charging station to the grid and using the EV battery as buffer storage. The ability to charge the electric vehicle's battery while in motion has been shown. Nevertheless, low-powered batteries may be charged onboard. Consequently, an off-board charger is the better option than the on-board ones. Topics covered include topologies including off-board chargers A grid-connected, off-board, single-stage photovoltaic (PV) EV charging station is shown in this study. You may charge your device in either way using this charging station. A bidirectional converter connects the electric vehicle to the charging station's DC-link. A bidirectional converter's main advantage is that it prevents the DC-link ripples and second harmonic current from damaging the EV battery and shortening its lifespan. The elimination of DC-link voltage dependent on EV battery rating selection is another benefit. To charge or drain the battery, the bidirectional converter's duty cycle is regulated.

In this case, the PV array charges electric vehicle batteries while also supplying the utility with excess power, so reducing the generating demand. Reactive power adjustment is required by the grid and is achieved by means of the VSC. In grid linked mode, the PV based EV charging station enhances the grid power quality. In standalone mode, it functions by using PV array generation to charge the EV battery, which is useful in the event of a grid outage. The system is also evaluated under several dynamic situations, including fluctuations in PV insolation, grid voltage unbalance, and grid reactive power adjustment. When power is back on, the charging station gets back in sync with the system.

Many people believe that electric vehicles (EVs) are the key to reducing transportation-related pollution. The proportion of EVs is also increasing at an exponential rate, thanks to global efforts to promote their use. A big concern is the need to often recharge electric cars while driving due to their limited range. The high price tag and limited range of electric vehicles are two of the main drawbacks of this mode of transportation. Hence, a lot of research is going into the use of renewable energy to power enough electric car charging stations. Here, energy sources including fuel cell stacks, wind turbines, and solar photovoltaic arrays are powering electric car charging stations.

Therefore, to satisfy the power demand and improve environmental conditions, it is essential to employ distributed energy supplies in a hybrid way that balances the unpredictability of each. Furthermore, electric car charging with suitable control algorithms is a major concern right now.

2. ELECTRICAL VEHICLES

When it comes to global financial results and R&D investment, the automotive industry has grown into a formidable rival. More and more, modern vehicles come with cutting-edge safety features meant to bolster the protection of pedestrians and motorists alike. Better still, with more cars on the road, we can travel in relative comfort and speed.

Carbon monoxide (CO), particulate matter (PM), sulphur dioxide (SO2), and nitrogen oxides (NOx) have all tragically increased in concentrations due to this in urban areas. The region accounts for around 28% of total emissions, while street mobility is responsible for over 70% of transportation-related CO_2 emissions, according to an EU study.

Governments in most developed countries are encouraging the purchase of electric vehicles as a means to reduce emissions of carbon dioxide and other greenhouse gases. Specifically, they push for transport policies that are both economical and kind to the environment via a range of initiatives, most often including subsidies for purchases or tax cuts, but often include more novel ideas like free public parking or highway use.

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Electric propulsion alone can propel the 12-kilowatt-hour (kWh) battery-powered Mitsubishi Stranger PHEV for about 50 km. On the other hand, PHEVs must use more petrol than what their manufacturers claim. A hybrid electric vehicle (HEV) combines the power of an electric motor with that of a conventional gas-powered engine.You would understand the distinctiveness of HEVs if you were familiar with module cross breed electric cars (PHEVs). really, the power generated by the gas-powered engine of the car is what really charges the battery of the electric motor. In newer versions, the batteries could be charged by converting dynamic energy into electric energy, which is achieved by slowing down. The fourth-generation Prius crossover includes a 1.3 kWh battery, which theoretically allows it to go 25 km on electric power alone.

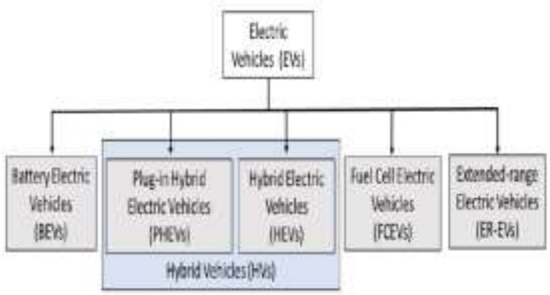


Fig 1: Electric vehicles classification according to their engine technologies and settings

Solar photovoltaic system

Solar cells, often termed photovoltaic cells, are devices that convert sunlight into energy by means of the photovoltaic effect. When the source of energy is not specified, the term "photovoltaic cell" is more typically used than "solar cell" to describe the same kind of device. Arrays of photovoltaic cells, solar panels, or modules are constructed from individual cells. Photovoltaics refers to the scientific study and technical development of methods for converting solar energy into useful power.

Amorphous silicon-based cells have an efficiency of 6%, research lab cells with multiple junctions have an efficiency of 40.7%, and hybrid packages with several dies have an efficiency of 42.8%. Presently available multi crystalline Si solar cells have energy conversion efficiency between fourteen and nineteen percent.

Solar cells may also be integrated into other electrical devices so that they can function only on solar power. Solar phone chargers, bike lights, and camping lanterns are some ways that people may use solar electricity into their daily life.

One further way to save money is to use rechargeable batteries that may be charged using solar power. Smartphones, personal digital assistants, laptops, music players, and many more electrical gadgets may have their power restored using solar battery chargers. So, you won't have to worry about finding an electrical outlet to charge these devices anymore. This is especially helpful since the majority of electricity is produced via hazardous and unsustainable methods.

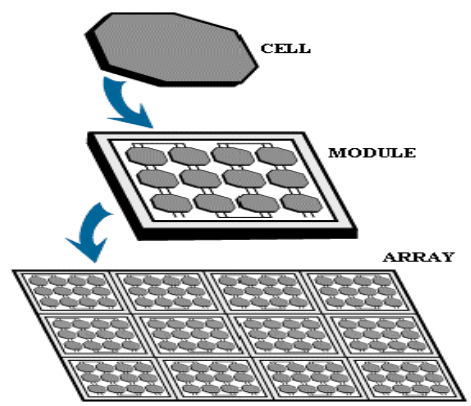


Fig 2: Solar PV Module diagram

An excellent energy source for lowering consumption is a solar battery, which can kick in and keep the lights on in the case that the main power supply goes out. Power outputs from solar battery systems vary widely, from a few watts to several thousand kilowatts. The majority of solar batteries' historical applications have been in power grid reliability or in large-scale solar power facilities. Recently, solar battery module panels installed on outside walls or roofs have become more common.

In order to get a photovoltaic voltage, solar batteries usually have a substrate connected in series with several components that generate photoelectric electricity. An essential component of solar panel batteries, the solar cell is the smallest element of a system that transforms light energy into useful power. An attractive feature of solar cells as an energy harvesting technology is its high conversion efficiency in directly converting solar radiation into electricity. Additionally, solar cells provide almost permanent power at low operating costs and have zero environmental effect.

Wind energy and its importance

Many people around the world believe that utilities should be required to use more renewable energy, regardless of the cost, and that tax incentives should be offered to promote the development and use of renewable energy sources like solar and wind power. Renewable energy investments are expected to provide long-term economic benefits, according to optimistic forecasts. Since each of the various natural energy sources is dependent on your immediate surroundings, it is up to you to choose which one is ideal for your needs. A huge improvement would be to have solar panels or wind turbines installed on every house to increase the electricity supply. Solar panels are being distributed to hundreds of homes by certain governments as a means of experimenting with this energy-saving strategy.

Geothermal energy is a promising resource that will play a significant role in the years to come. Geothermal energy allows you to tap into the earth's natural heat and convert it into hot water or, in more abundant cases, a geothermal power plant. Research into this approach has received massive funding, particularly in the last few years, with the goal of improving the efficacy of the existing technology. Here we have the arguments in favour of using renewable energy sources, which will almost certainly be crucial to the development of our civilisation in the years to come.

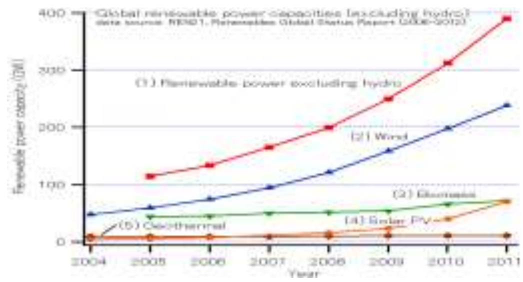


Fig 3: Wind Energy and Wind Power

Fig 4: Wind Farm

It is possible to power wind turbines using airflows. The rated power of modern utility-scale wind turbines can vary from 600 kW to 5 MW, with 1.5-3 MW turbines being the most popular for commercial use. The power that the wind can provide is directly proportional to the cube of the wind speed, meaning that power output grows exponentially with increasing wind speed, up to the maximum output of each individual turbine. The best places to put wind farms are offshore or at high elevations, where the winds are stronger and more consistent. Capacity factors typically range from 20 to 40 percent, with higher values seen in optimal locations.

According to estimates, the technological potential of wind energy on a worldwide scale might be equivalent to 40 times the present demand for power or five times the entire energy output in the world right now. In regions with stronger wind resources, this may necessitate the installation of wind turbines across expansive regions. Because offshore resources are subject to wind speeds that are around 90% higher than land-based ones, they have the potential to generate a lot more energy.

One kind of solar energy is wind power. The sun's uneven heating of the atmosphere, surface imperfections, and the Earth's rotation all work together to generate winds. Topography, water bodies, and plant life all have an impact on how wind patterns develop on Earth. This motion energy, also known as wind flow, may be "harvested" by state-of-the-art wind turbines and utilised to produce power.

3. PROPOSED SYSTEM

Charging station control is built on reference active and reactive power commands. The decision to charge or discharge the EV battery is made by the EV owner using the reference active power command. The reference reactive power is chosen based on the charging station's inductive and capacitive reactive power requirements for continuous operation. The user controls the charging station to select when to charge or discharge their electric vehicle's battery.

G2V refers to the system action that occurs when grid electricity is needed to charge the electric vehicle's battery (Grid to Vehicle). However, the process is called V2G (Vehicle to Grid) if electric vehicles' batteries are discharged to provide electricity to the grid. The charging station may also provide reactive power adjustment, either trailing or leading, depending on the situation.

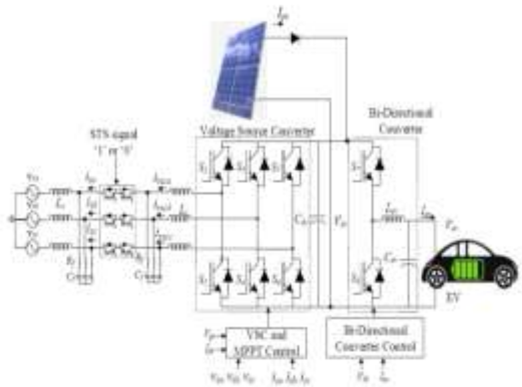


Fig 5: Three-phase Three wire single-stage grid connected PV system with EV

System configuration

Figure 1 shows a simplified block schematic of a single-stage PV-based electric vehicle charging station. The DC electricity produced by the PV array is used only to charge the electric vehicle's battery at a PV-based charging station. The electric vehicle's battery is charged and discharged using a bi-directional converter. The DC-link is directly connected to the PV array. Making the charging station more affordable by doing away with the need for a boost converter. To connect to the grid, a VSC that uses an IGBT to convert DC power into AC power is used. Also based on IGBTs are the static transfer switches (STS) that link the charging station to the grid.

Control scheme

Using the electricity generated by the PV array to charge electric vehicles is the primary goal of this charging station. The PV array's output might be fed into the grid, and the charging station is grid-synchronized. Furthermore, EVs have the capability to both drain and feed electricity back into the grid. Hence, for the charging station to be used more effectively, an intelligent control strategy has to be created. Figure 2 shows the developed control technique. There are essentially two input instructions on the controller.

A. Active Power Reference Command

The need to charge or discharge the EV battery determines this. In order to generate incentives, EV owners may choose to charge or discharge their batteries to provide power to the grid at times of high demand. This active power command is controlled by the owner of the electric vehicle.

B. Reactive Power Reference Command

It specifies the parameters for the quantity and kind of reactive power that may be transferred, whether it capacitive or inductive. There are two main ways in which electric vehicle charging stations (VSCs) and the control of charging and discharging at these stations are categorised: grid linked mode control and freestanding mode control.

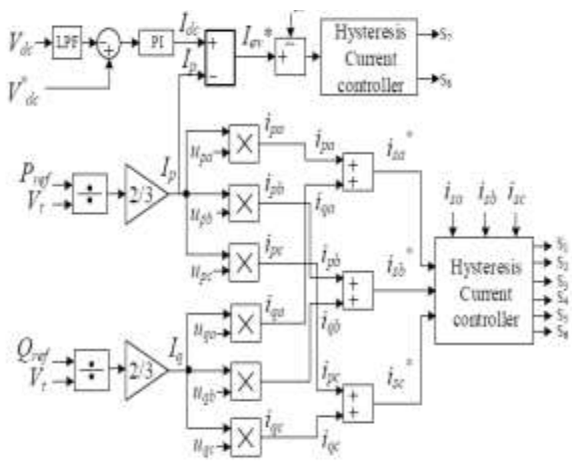


Fig 6: Controller diagram

The VSC switching pulse generation in grid linked mode of operation is influenced by the active power reference command and the reactive power reference command. A DC-DC bidirectional converter regulates the charging and draining of the electric vehicle's batteries. The next section provides a detailed description of the control system.

VSC Control in Grid Connected Mode

Figure 2 shows the grid-connected form of VSC gate pulse production. The active part of the current (Ip) is influenced by the Pref (Active Power Reference Command), while the reactive part (Iq) is influenced by the Qref (Reactive Power Reference Command). Multiplying the active current component (Ip) by the in-phase unit templates (upa, upb, upc) estimates the per-phase active currents (ipa, ipb, ipc). In a similar vein, the reactive current components (Iq) and the quadrature-phase unit templates (uqa, uqb, uqc) are multiplied to estimate the per-phase reactive currents (iqa, iqb, iqc). The following sections provide a more in-depth description of the control.

Right before the PCC is connected to the grid, the control synchronises the grid voltages (vs) with the PCC voltages (vvsc) when the grid is returned from an islanding situation. Fig. 5 shows the control for synchronisation. The factors that determine the operation mode of the system are the grid voltage amplitude (Vt), θe, and grid frequency fs.

The system enters an islanding mode when one of the following conditions is met: the amplitude of the grid voltage at PCC, Vt, must be more than 1.1pu or less than 0.88pu; the phase angle, θg, must be less than or equal to θs; or the grid frequency, fs, must be greater than or equal to 50.5Hz or less than 49.5Hz. The synchronisation control determines whether the system operates in grid linked or islanding mode based on these voltage and frequency circumstances, and it sends a signal of "1" (on) or "0" (off) to the STS (Static Transfer Switches), as shown.

EV Charging/Discharging Control in Standalone Mode

In order to keep the DC-link voltage constant under dynamic situations, the MPPT is used to determine the reference DC-link voltage (Vdc *). The DC-link voltage stays constant regardless of whether an EV is charging or discharging because of the controller's architecture. There is no extra strain on the grid since the quantity of electricity transferred remains constant.

4. SIMULATION RESULTS

Proposed simulation diagram and results

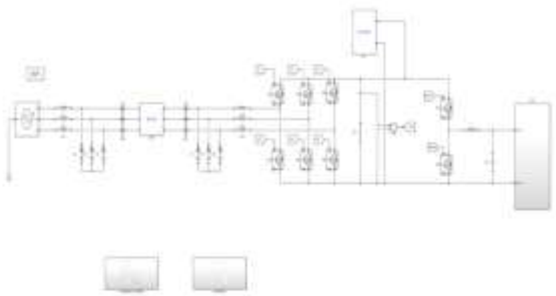


Fig 7: Proposed Circuit Diagram

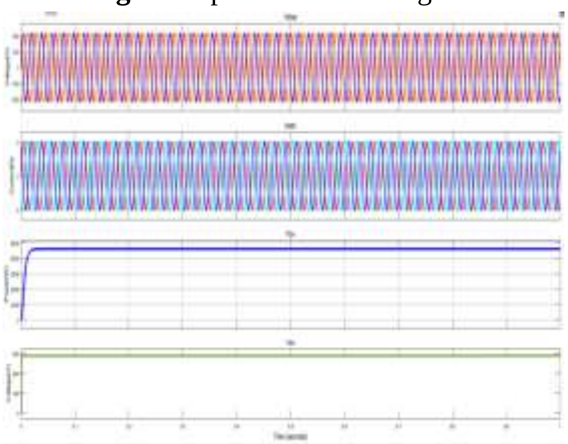


Fig 7(a): Charging Station at Steady State

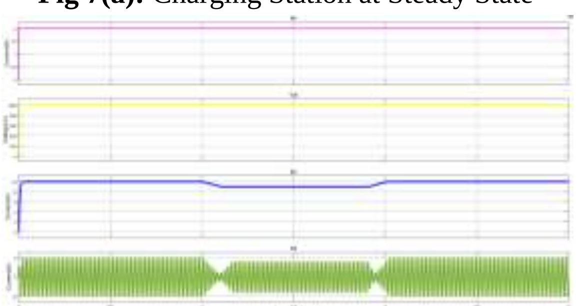


Fig 7(b): Dynamic response of grid connected system at Increase in solar insolation , Fall in PV insolation

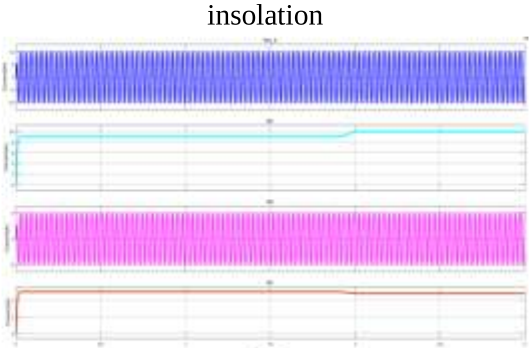


Fig 7(c): Voltage unbalance and rise in PV insolation

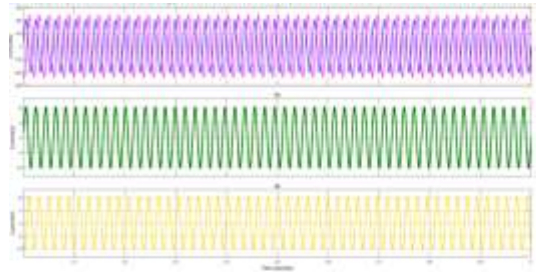


Fig 7(d): source currents and load currents

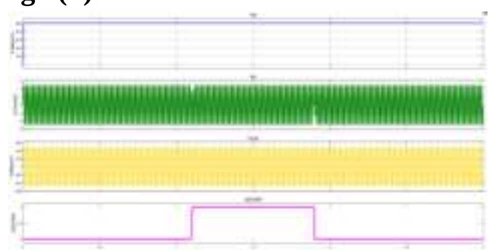


Fig 8 (a,b): DC voltage, source current and VSC voltage

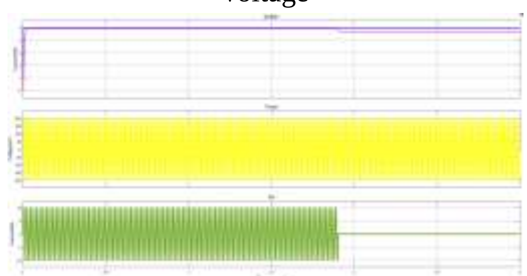


Fig 9(a): PV and EV current and voltages

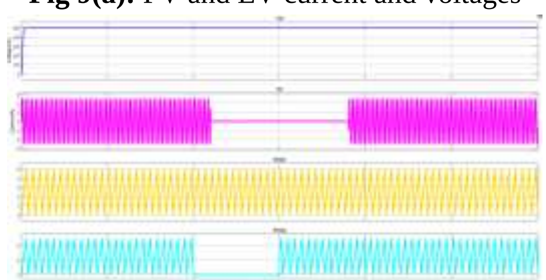
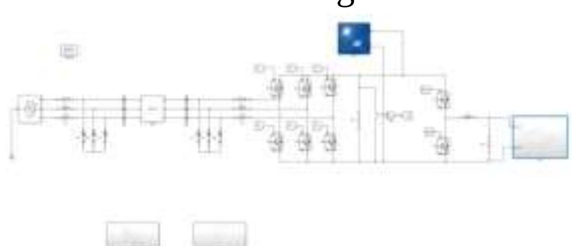


Fig 9(b,c): DC voltage and source current, threts and sag.

Extinction model using Solar



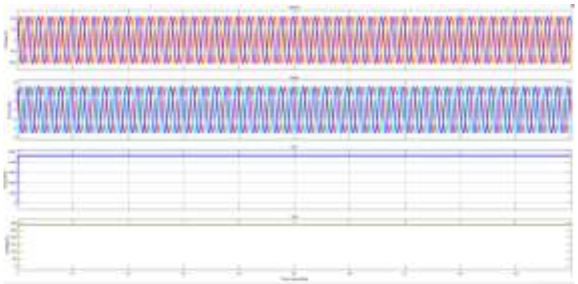


Fig 10(a): Charging Station at Steady State

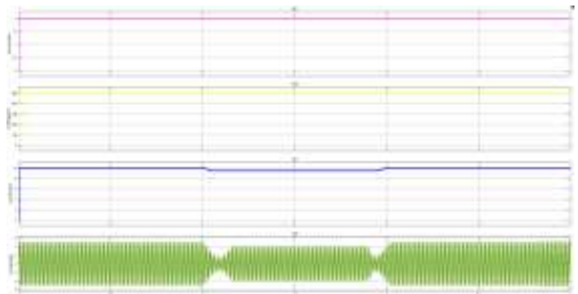


Fig 10(b): Dynamic response of grid connected system at Increase in solar insolation , Fall in PV insolation

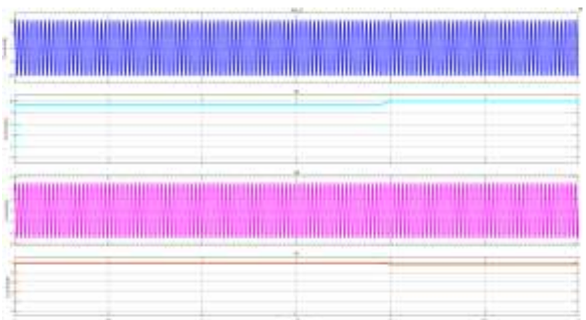


Fig 10(c): Voltage unbalance and rise in PV insolation

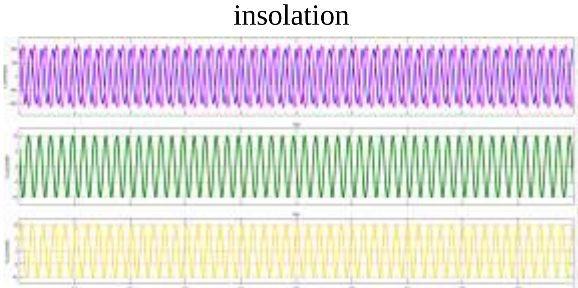


Fig 10(d):source currents and load currents

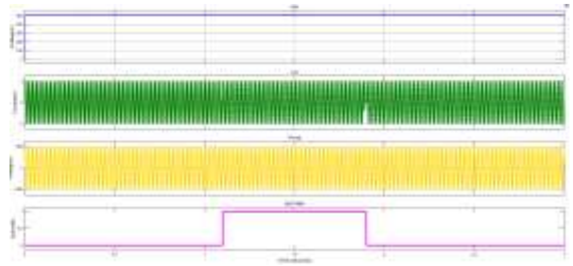


Fig 11: DC voltage, source current and VSC voltage

Extension with solar and wind combination

Fig 12: Solar, PV cogeneration system

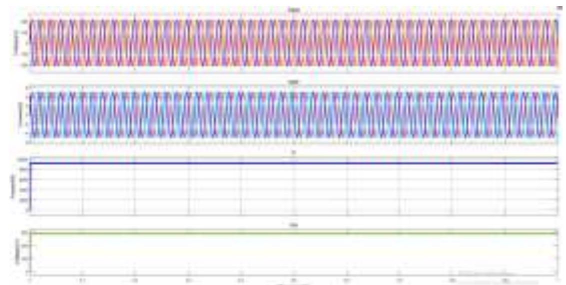


Fig 12(a): Three phase source voltage, currents, EV voltage and PV power

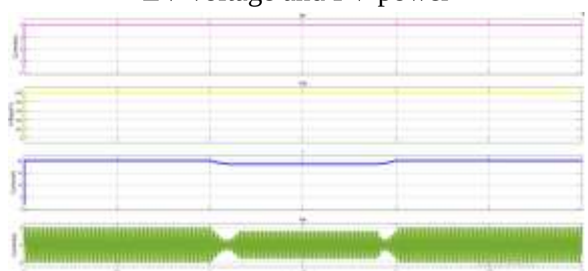


Fig 12(b):EV currents ,DC voltages and Source currents

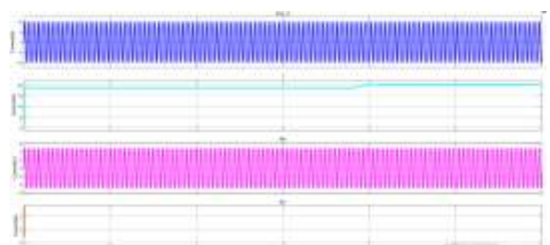


Fig 12(c):VSC currents, source currents EV currents

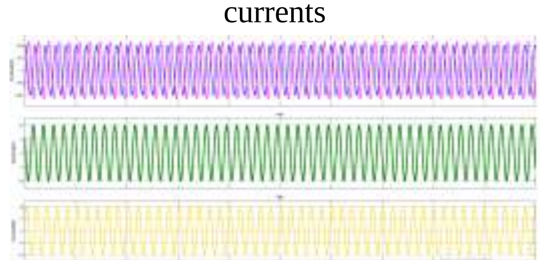


Fig 12(d): Source voltages and currents

5. CONCLUSION

It is possible to create income by selling electricity produced by draining electric vehicle batteries to the grid during peak hours, and a single-stage PV-based EV charging station can synchronise with the grid and transmit its generated power back into the grid. When hooked up to the grid, the charging station has already accounted for reactive power. Both the grid-connected and freestanding modes of operation of the charging station have been tested and found to be good. Once the charging station is in sync with the grid, it may transmit back any surplus power when the grid is available. Experimental findings have shown that the charging station can withstand dynamic situations such grid voltage imbalances, reactive power adjustment, and fluctuations in PV insolation.

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