Optimization of Renewable Energy Integrated Electric Vehicle Charging Stations with Flywheel Energy Storage

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Abstract: *The transportation sector faces critical challenges, including rising fuel prices and environmental concerns stemming from fossil fuel dependence. As a major contributor to greenhouse gas emissions, the transportation industry necessitates urgent decarburization efforts. This paper explores the integration of renewable energy sources into electric vehicle (EV) charging infrastructure, aiming to mitigate environmental impacts and enhance energy efficiency. Specifically, the study focuses on designing hybrid solar-wind charging stations with flywheel energy storage, employing advanced control algorithms for optimal power management. Simulation and methodology encompass AI-assisted power management schemes, converter control system architectures, renewable energy resource modeling, and wind energy system modeling. Results and discussion highlight the performance of the proposed system under varying input conditions, emphasizing the efficacy of the optimized power flow genetic algorithm in regulating power distribution and ensuring grid stability.*

Keywords: *Renewable energy, electric vehicle charging infrastructure, flywheel energy storage, optimization, power management, hybrid solar-wind system, AI-assisted control.*

I. INTRODUCTION

The transportation industry confronts numerous noteworthy challenges, which involves increased fuel prices and growing usage of energy. The main factor that has harmed these areas is the dependency on fossil fuels as the main energy source. When incorporating the environment into account, the transportation industry is primarily held accountable for producing a large amount of CO2, which greatly increases greenhouse gas emissions (GHG). Certain reports from 2019 [1] claim that transportation contributes to US greenhouse gas emissions. Transportation is the second-largest source of greenhouse gas emissions in Canada, contributing 23% of total emissions, and accounts for 35% of the country's energy demand [2]. Studies on air pollution in major cities reveal that the transportation industry is primarily responsible for the issue. Many internal combustion engines (ICEs) run on diesel fuel, whereas spark-ignition engines work mainly on gasoline [3]. .

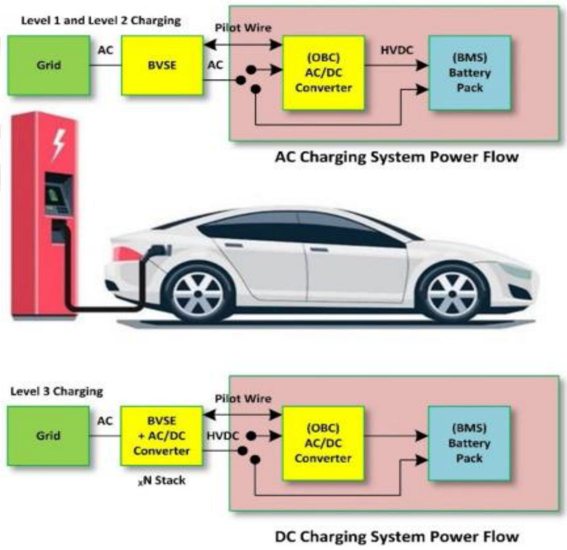

Fig. 1.1 Modes of charging at different levels [4]

A. Renewable Energy

Numerous technical approaches have been recommended to mitigate the effects of climate change (CC). Nuclear energy, increased energy efficiency, mechanical and biological carbon dioxide removal (CDR) techniques, and different solar geoengineering (SG) approaches are on the list. (The most discussed SG tactic involves adding sulphate aerosols to the lower stratosphere to minimize insolation.) RE sources have been thoroughly studied as an alternative because they have the potential to replace fossil fuels (FFs) with low-carbon substitutes. One such is geothermal energy, as Gizzi stated. [5].

However, there are other major ecological problems we are addressing as well, like global climate change, all of which call for quick action. One of the other factors is the overall deterioration of the oceanic environment [6], as evidenced by the growing number of hypoxic regions (over 400 by 2008), the largest of which spans 70,000 km2 [7]. The ocean's pH went down from 8.20 to 8.04 over the past 70 years, indicating that ocean acidification is getting worse. More than half of marine organisms have shells made of the mineral aragonite; however, these organisms cannot form shells if pH falls below 7.95, and this harmful pH level could happen as early as 2040 [8]. Another challenge that is faced by the ocean is a reduction in phytoplankton. As it continues its long-term decline, the entire ocean biomass is currently declining at a rate of roughly 1% annually [9]. Plastic and chemical pollution in the ocean and on land continues to increase [10]. To put it simply, the oceans are dying.

B. Electric energy storage systems

EESS has been divided into magnetic and electrostatic systems. The SMESS is a magnetic system, but the capacitor and the ECC are electrostatic systems [11].

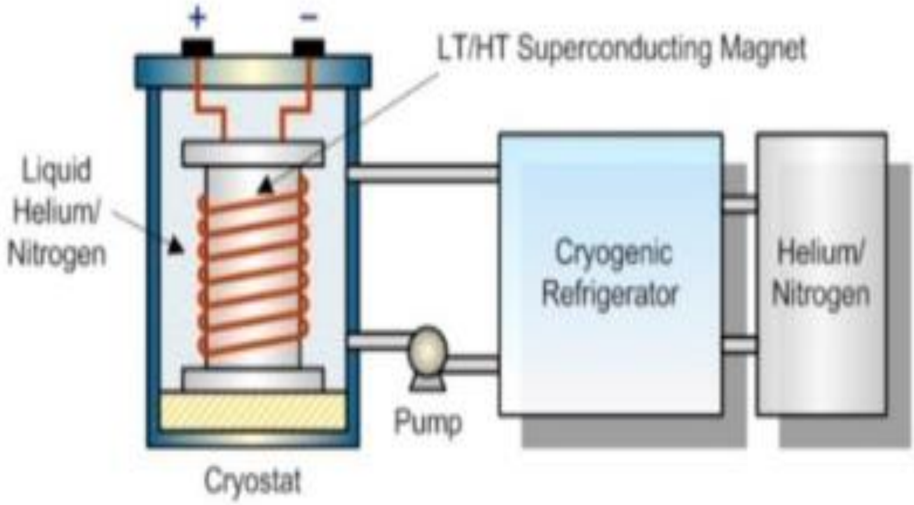

Fig. 1.2 Superconducting magnetic energy storage [11]

C. Electric Vehicles Charging Infrastructure

Fifty-five percent of the world's oil consumption and almost 25% of CO2 emissions are attributable to the conventional transportation sector. At the moment, one of the most important initiatives for the direct reduction of CO2 emissions is the development of electric vehicles, or EVs. The energy crisis and environmental problems, such as local air pollution and global warming, are the main factors behind the development of EVs, especially in urban areas. The study explains how one decarbonization strategy is to electrify active buildings using EVs. EVs can participate in demand-side response programs to operate as prosumers in electric systems. Electric vehicles (EVs) have technical, environmental, and economic ramifications. The vehicle-to-grid (V2G) technology that facilitates the power exchange between EVs and the grid has an economic impact. In exchange for payment to EV owners, V2G diminishes the share of expensive generators, like gas turbines, during peak-load hours, which benefits both EV owners and the power system. The total of the electricity manufactured to power EVs and the direct tailpipe emissions of EVs is what establishes an EV's environmental impact over its lifetime.

In opposition to previous review studies concerning the location of EV charging stations, the current work offers the following contributions:

• The planning models for the placement of charging stations are categorized.

• By giving a brief overview of the planning models, the mathematical formulations and simulation results are elaborated.

• A comparison of the planning models is given, outlining the salient characteristics, benefits, and drawbacks of each model.

• Suitability of the planning models for different areas is advised.

• A summary of how the charging station operates and how it will be scheduled is provided.

• A summary of the global charging infrastructure planning scenario is provided, along with information on the standards, laws, rules, and current business model. [12]

D. Flywheel

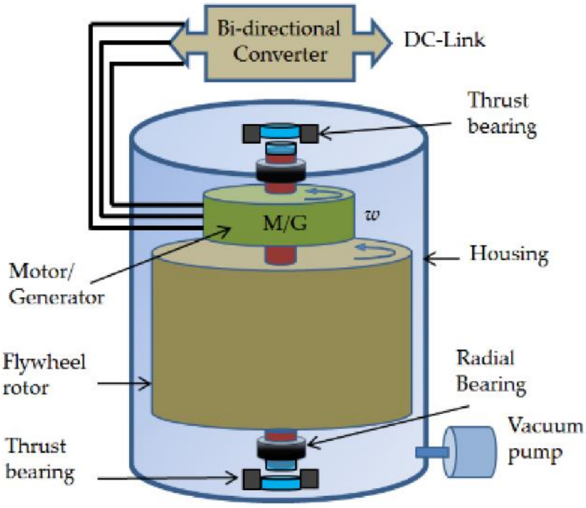

Fig. 3 Structure and components of a flywheel

The use of fossil fuels in all facets of our lives has a severe detrimental effect on the environment, as demonstrated by the ensuing health issues and climate change [13, 17]. Scientists have put forth a variety of solutions to lessen the serious issues brought on by the various fossil fuels. These consist of recycling waste heat [18], creating effective energy conversion systems with little to no environmental impact [19-22], transitioning from fossil fuel resources to renewable energy resources [23], and, lastly, CO2 capture [24-25]. The capacity of renewable energy sources has grown dramatically over the past ten years, creating a pressing need for energy conversion and storage systems that can effectively use and store this increased energy. Fuel cells are efficient energy conversion devices that run on renewable fuels like bio hydrogen biogas or other biomass resources. They have a high potential to replace conventional energy conversion systems in a number of applications, including aviation, water desalination transportation and portable applications. The four kinds of energy storage systems are mechanical, electrical, electrochemical, and thermal.

II. LITERATURE REVIEW

Lei Shen et al. (2020) propose a hybrid energy storage solution for DC micro-grid systems in photovoltaic (PV) power generation electric vehicle (EV) charging stations. This system combines battery and flywheel energy storage to manage power fluctuations. They employ a lithium iron phosphate (LiFePO4) battery to balance reference power and recommend a hierarchical coordinated control scheme based on DC bus voltage monitoring. Simulation analysis using MATLAB/Simulink demonstrates the effectiveness of the control strategy, ensuring flexibility and reliability in various working conditions.

S.S. Kholerdi et al. (2021) introduce an Interactive Time-of-Use (ITOU) model for demand response (DR) programs. This model optimizes performance by selecting off-peak hours for industrial subscribers based on production and sales profiles. The study evaluates program outcomes, highlighting economic benefits for industrial customers through reduced energy consumption during peak hours. The ITOU model proves more successful than traditional approaches in achieving program objectives.

P.H. Cheng (2020) explores demand-side management (DSM) in smart grids, focusing on Plug-in Electric Vehicle (PEV) integration. Utilizing particle swarm optimization (PSO), a fairness plan is devised to share PEV batteries within communities, reducing peak-to-average ratio (PAR) and overall electricity costs. Simulation results demonstrate the effectiveness of the DSM system in lowering PAR and individual household costs.

K. Kouka (2020) presents an energy management strategy for home electric vehicle charging stations (EVCS) with grid-connected photovoltaic power and energy storage systems. Their real-time coordination maximizes PV power utilization while meeting EV requirements. Simulation results validate the efficacy of the strategy in dynamic charging scenarios and varying irradiance conditions.

L.S.A. Grande et al. (2018) examine the technical and financial feasibility of off-grid photovoltaic-battery energy storage systems (PV-BESS) for EV charging. Using HOMER software and meteorological data, they demonstrate the reliability and profitability of off-grid PV-BESS, offering a sustainable alternative to grid-connected charging points.

M. Bornapour (2017) models a micro grid comprising PV, wind turbine, and fuel cell units, focusing on optimal scheduling considering renewable energy uncertainties. A multi-objective firefly algorithm optimizes market profit, emission production, and energy supply. Simulation results validate the effectiveness of the approach in a distributed network micro grid.

Muhammad Shahid Mastoi (2022) discusses the need for IT-enabled infrastructure for electric vehicle charging, emphasizing grid integration and optimal allocation. The study evaluates current infrastructure, challenges, and emerging trends, advocating for standardized and renewable energy-based charging stations.

Gizzi, M (2021) presents simplified closed-loop system models for utilizing geothermal resources in Italian oilfields. The study demonstrates the potential of geothermal electricity generation from dismissed hydrocarbon wells, offering opportunities for various sectors.

Georgian, S et al. (2022) reiterate concerns about global ecosystem destruction, particularly focusing on ocean health. They highlight activities contributing to degradation and propose mitigation measures, emphasizing ecosystem health in international policies.

Dryden, H et al. (2021) discuss the importance of restoring ocean and land ecosystems to mitigate climate change. They emphasize the role of marine life in carbon sequestration and warn against ocean acidification's devastating effects. The study underscores the urgent need for ecosystem restoration to combat climate change effectively.

III. OBJECTIVES

- Designing of a hybrid solar-wind based charging station in combination with hybrid storage system comprising of battery and PMSM based energy storage devices in order to optimize the DC bus voltage balance.
- Development of hybrid algorithm driving DC/AC converters at the station to improve the performance at the PMSM point and allow grid integration.
- Study over all charging structure under various input conditions to both solar and wind energy systems.

IV. SIMULATION AND METHODOLOGY

The effect of electric vehicles on the grid load increases day by day due to increasing the numbers of electric and plug-in hybrid vehicles on the road. While electric vehicles are not considered as the main vehicle for people a few years ago, however, today, electrical and hybrid vehicles are used as main vehicles. Besides the use of electric and hybrid vehicles for personal purposes, they are commonly used for the purpose which is public and commercial transportation. As the shares of the electric and hybrid vehicles in the market are increasing and the electrical demand depending on electric and hybrid vehicles is increasing considerably, too. While hybrid vehicles do not have any problem with their range, electric vehicles still have a range problem. Higher ranges require a high-capacity battery module and this issue increases the cost of the vehicle. Fast charging plays a critical role to solve this problem. Fast charging requires high-power energy demand and this higher demand is an important problem for the grid load. Energy storage plays an important role to reduce this higher demand. Energy storage methods have one of the high-potential solutions for decreasing the losses in the system, increasing the system efficiency, reducing the peak energy demand, and balancing mismatch in the energy supply and demand. Flywheels, one of the mechanical energy storage types, are being used for high-power and low period electricity storage. With developing flywheel technology, they have become a significant energy storage method and they are used in many sectors.

This works gives takes an AI assisted CS power management scheme for applications in power systems and its control during the EV charging station development whose architecture is described in figure 1. Due to the specific challenges and characteristics of power electronic systems, e.g., high tuning speed in control, high sensitivity in condition monitoring for aging detection, etc., the implementation of met heuristics algorithms based on AI in power electronics has still areas left to be explored for further improvement. The AC/DC control designing at the grid end has been proposed with a PQ approach in combination with the met heuristic algorithm so as to improve the grid side system parameters. The designing can be done in dq0 reference frame to ease the study of the elemental parts and their respective changes. The system shall continuously keep a check on the variable parameters and updates as per the requirement.

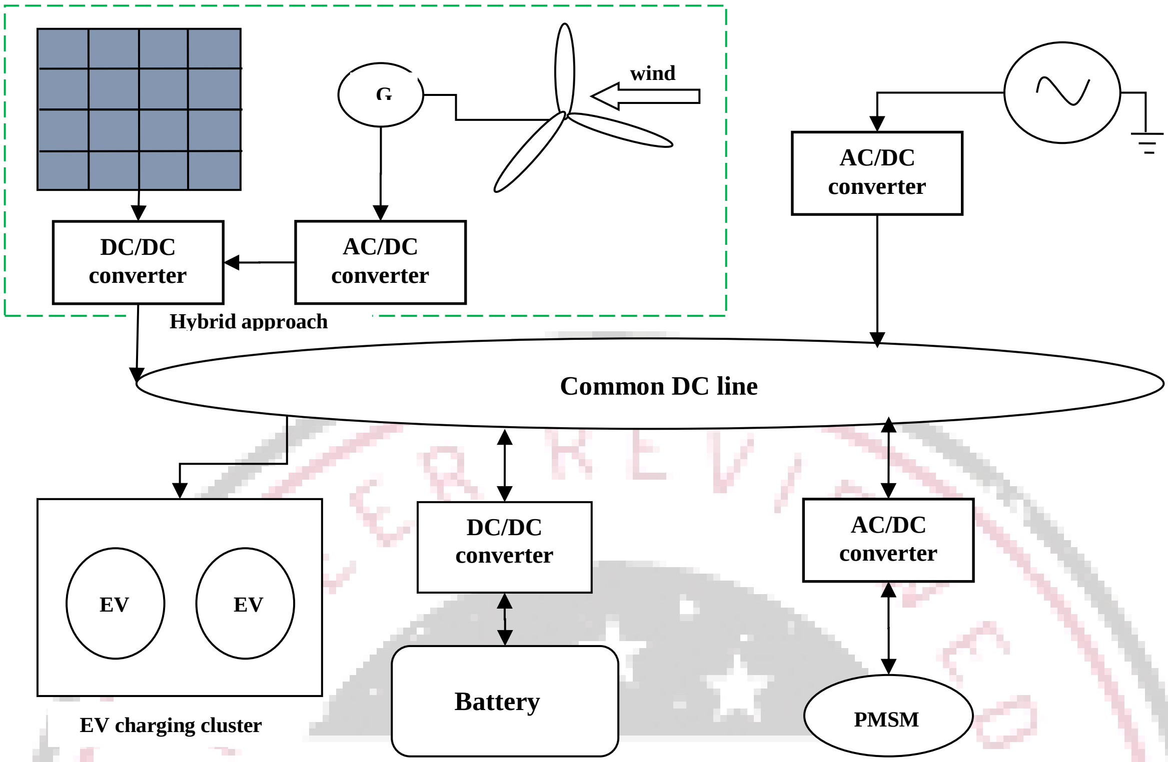

Fig. 4 Hybrid approach at the charging station

4.2 Modelling of flywheel energy storage system in MATLAB

Equivalent circuits of the motors are used for study and simulation of motors. From the d-q modeling of the motor using the stator voltage equations the equivalent circuit of the motor can be derived. Since the wheel motor is a synchronous permanent magnetic machine (PMSM), the electromagnetic torque expressed in the d-q rotating frame is given by:

$$T_e = \frac{3p}{2}[\Psi_{PM} i_q + i_q i_d (L_d - L_q)]$$

Where p is the number of pole pairs; Ψ_{PM} is the flux produced by the permanent magnet; L_d and L_d are respectively the direct and quadrature components of the wheel motor inductance. i_q is the quadrature axis current and i_d is the direct axis current.

The equations for a flywheel energy storage system can be modelled in MATLAB using rotational dynamics. The kinetic energy stored in a flywheel is given by:

KE = (1/2) * I * ω^2

Where KE is the kinetic energy, I is the moment of inertia of the flywheel, and ω is the angular velocity of the flywheel.

4.3 Converter Control system DC/AC Architecture control Designing

A typical converter with a motor consists of a power converter, a motor, and a control system. The power converter is responsible for converting a DC voltage into a three-phase AC voltage, which is then supplied to the motor. The motor is responsible for converting the electrical energy into mechanical energy, which can be used to drive a load.

Voltage Source Inverters are devices that convert a DC voltage to AC voltage of variable frequency and magnitude. They are very commonly used in adjustable speed drives and are characterized by a well defined switched voltage wave form in the terminal. Regulators for AC drives are complex because an AC current regulator must control both the amplitude and phase of the stator current. The AC drive current regulator forms the inner loop of the overall motion controller. As such, it must have the widest bandwidth in the system and must have zero or nearly zero steady-state error.

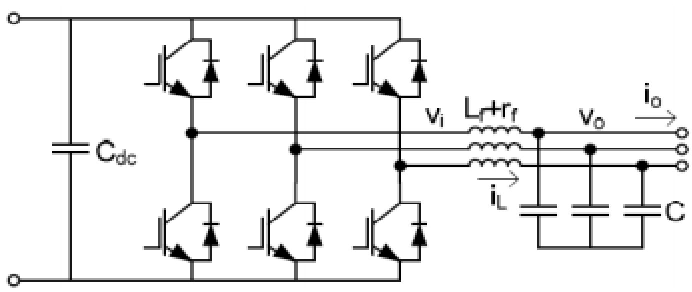

Figure 4.2: Block diagram of three phase inverter.

Table 4.1: Inverter Parameters

Power electronic device	IGBT/Diodes
Snubber resistance	5000 ohms
Forward voltages	0
Ron	$1x10^{-3}$ ohms

4.3 Power flow genetic algorithm (OPGA) Description for Converter Control

In a conventional scheme, the controller parameters are fixed. These fixed parameters are not suitable for dynamic references. Unsuitable parameter specifications will sometimes cause the system to become unstable. Thus, it is important to select suitable parameters for the scheme. The optimization algorithms based on artificial intelligence is widely used to solve optimal problems because of its excellent optimization efficiency and global search capabilities. These algorithms are programmed to imitate nature's selection process and obtain the optimal solution based on several bio-inspired operators.

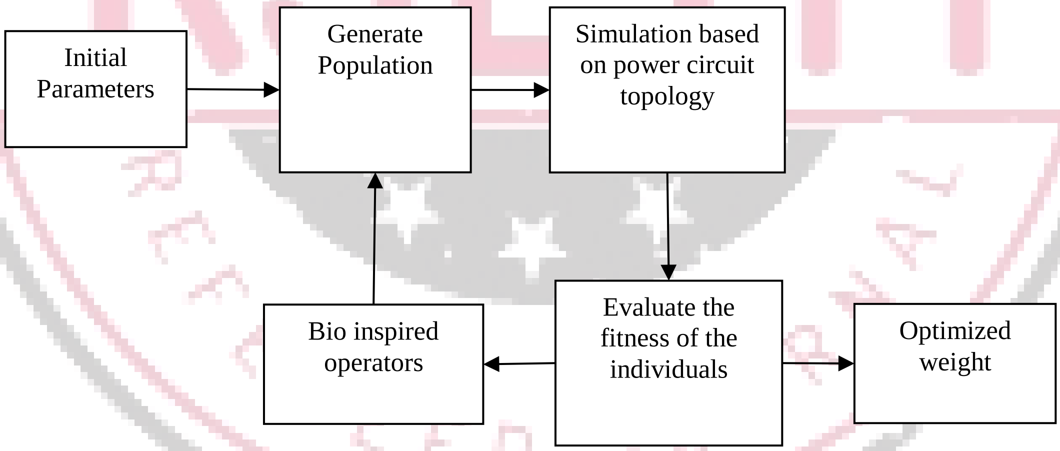

Fig. 5 Operation of the optimization scheme

After an iterative calculation, the optimal result can be obtained. , the aim of the optimization problem is to find a group of initial weights that can minimize the suppression/evaluation time and overshoot. This means that the optimization process should shorten the suppression time as much as possible and limit the amplitude of the overshoot. the performance of the converter could be improved to a greater extend by selecting an optimum PID gain which guarantees a better dynamic and steady state response. With the aim of optimizing the systems dynamic and steady state behaviour under disturbances, the objective function is selected for minimization and the PID gains are tuned so as to minimize/maximize the objective function, thus guaranteeing the desired dynamic performance.

A new metaheuristic approach which has GA optimized weights for logic controller, has been proposed for the power balancing equations and quality improvement in a charging station fed by renewable energy power resources. A block model of the developed genetic algorithm could be easily adapted to different systems and could save time when designing these systems. The developed approach could provide the possibility to make changes, through entering the model content into the controller.

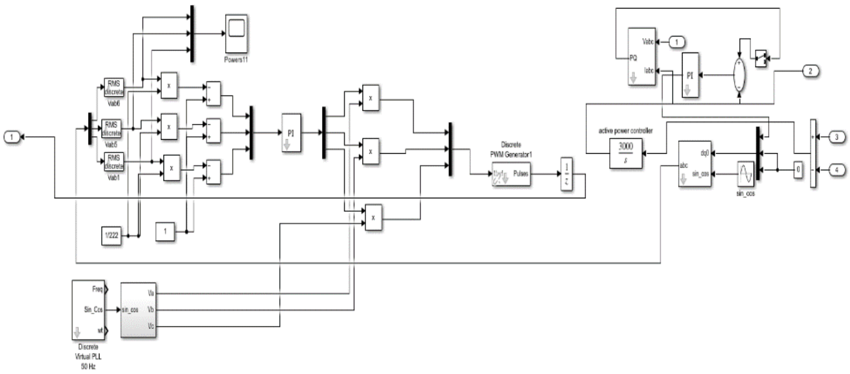

Fig. 6 Control Logic Implementation in solar based CS

4.5 Renewable energy resources modelling

Matlab is a powerful tool for modelling renewable energy systems based Charging systems, as it allows for complex simulations and analyses of system performance. The following are some general steps for modelling a renewable energy system using Matlab:

- Determining the system components: The first step is to determine the components of the renewable energy system, such as the solar panels, wind turbines, batteries, inverters, etc.
- Defining the equations: Next, the equations for each component need to be defined. For example, for a solar panel, the equations for the output voltage and current can be derived using the model equations mentioned in this chapter.
- Developing the model: Using the defined equations, the Matlab code can be written to develop the model of the renewable energy system.
- Simulating the system: Once the model is developed, it can be used to simulate the system under different conditions, such as varying levels of solar radiation or wind speed. The simulation can provide insights into the performance of the system and help identify potential issues.
- Analysing the results: The simulation results can be analysed to optimize the system design and identify potential improvements.
- Visualising the results: The results of the simulation can be visualized using graphs and charts to provide a better understanding of the system performance.

4.6 Wind Energy system Modelling

There are different sources of renewable energy for the energy system. Wind energy is one of the fastest growing renewable energy sources as it is the most economical clean energy and requires less installation time. Wind energy has long been used on farms to grind grain or pump water into a wind turbine. The principle is to convert the kinetic energy of the wind into mechanical energy. This principle applies to wind energy in the electricity grid. A wind turbine captures the kinetic energy of the circulating air and converts it to mechanical energy. A generator installed in the wind turbine converts mechanical energy into electrical energy.
A wind turbine typically consists of several components and subsystems like generator, rotor hub and blade, gearbox, and a tower.

a) Rotor Hub and Blade

The interaction between wind and rotor blade is the important factor for the production of power. The rotor consists of large turbine blades and hub. Blades resemble the wings of an aero plane. Blades are normally large in size. Generally three bladed wind turbines are used in practice. Another component of rotor is pitch drive, which is used to keep the rotational speed of rotor blades at desired operational range of 1000 - 3600 RPM (revolution per minute).

b) Generator

The energy in the wind turns two or three Propeller like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. Thus generator converts mechanical energy of wind turbine rotor into electrical energy
Model of wind turbine with PMSG Wind turbines cannot fully capture wind energy. The components of wind turbine have been modeled by the following equations [8-10].

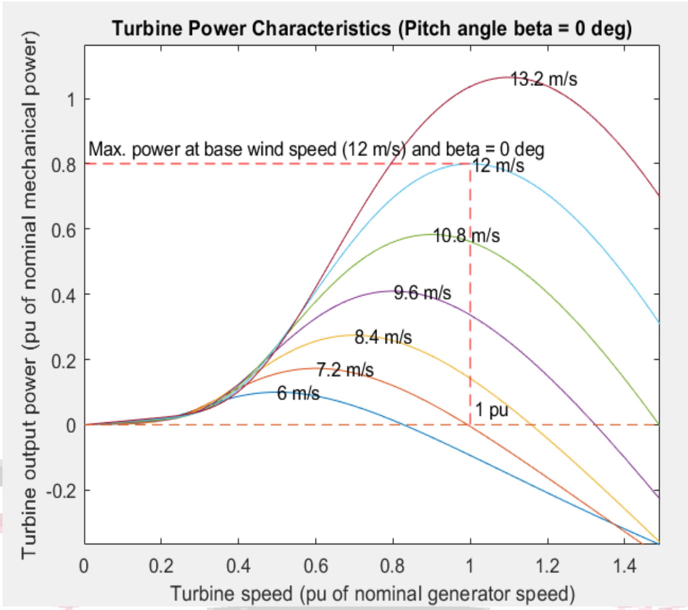

Fig. 7 Wind Turbine characteristic cure used in MATLAB at different wind speeds

Table 4.2: Permanent magnet synchronous generator parameters

Wind speed	variable
Stator Phase Resistance Rs (ohm)	0.425
Armature Inductance (H)	0.000835
Frequency	50 hertz
Flux linkage	0.433
Friction factor	0.01
Pole pairs	4
Viscous Damping	4.5

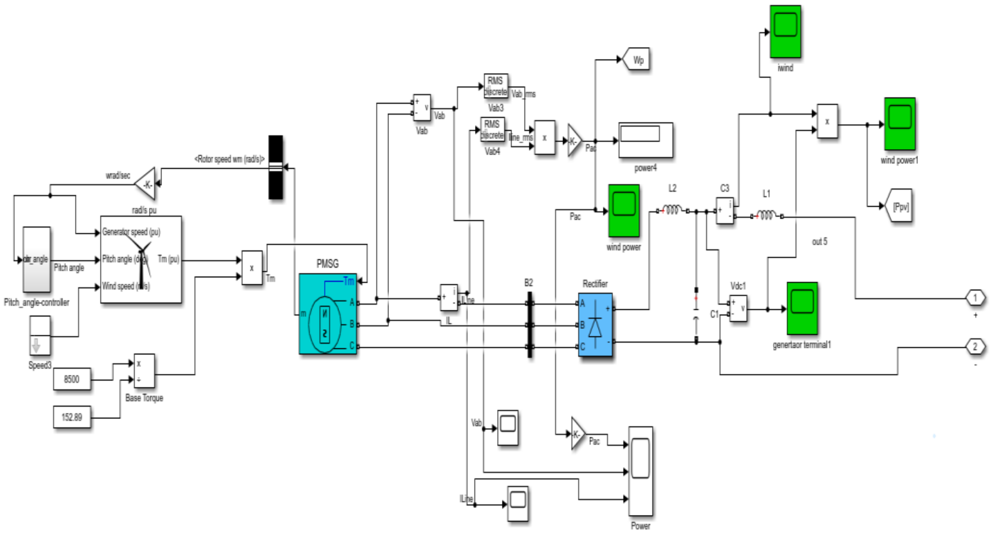

Fig. 8 modelled Wind system

This mechanism uses the variable torque output w_m and tries to optimize the output current and voltage waveform to its maximum value. In addition to the power output equation, other equations can be used to model different aspects of a wind turbine system, such as the mechanical and electrical components, the control systems, and the interaction with the electrical grid. These models can be used to analyze the performance of the system, optimize its design, and develop control strategies to maximize its efficiency and reliability.

V. RESULTS AND DISCUSSION

Charging station with solar energy as input resource of 25KW has been proposed and developed in the MATLAB/SIMULINK. The charges station designed has two storage devices, fly will energy storage systems and battery storage systems. During modelling there are two types of loads that are considered DC loads of 5KW and 2 AC loads of 5KW each. For AC loads DC/AC inverters are employed which whose outputs and power are being controlled by the proposed genetic algorithm operated by controllers. The flywheel energy storage systems are modelled for storage capacity of 5 kilowatt. The battery selected for EV have initial SOC percentage at 60%.

The DC link voltage is tried to be maintained at 600V stable condition. The discussion is done to compare the outputs from the two controllers namely standard voltage modulation control (VMC) and the modified optimised Optimized power flow genetic algorithm (OPGA) in the system for driving the DC/AC converts in the system. During the analysis the solar system of 25KW power capacity is being used as energy source to the charging station. The entire CS architecture when studied with solar is then modified with another renewable energy resource wind system which is also incorporated and the power distribution strategy is studied. For simplification of the study the entire modelling and power distribution capability of the proposed controller has been divided into two main systems depending upon the type of control system brought to use for providing signals to the DC/AC converters:

System 1: Renewable energy based Charging station having standard voltage regulation controllers for converters

System 2: Charging station converters driven by Optimized power flow genetic algorithm (OPGA) based controllers for converters.

The proposed approach that uses the genetic algorithm in multi stage configuration helps in determining the optimised parameters for driving the DC/AC converters and thereby providing better power quality at the loading points as well as maintaining the DC link voltage to a more stable level.

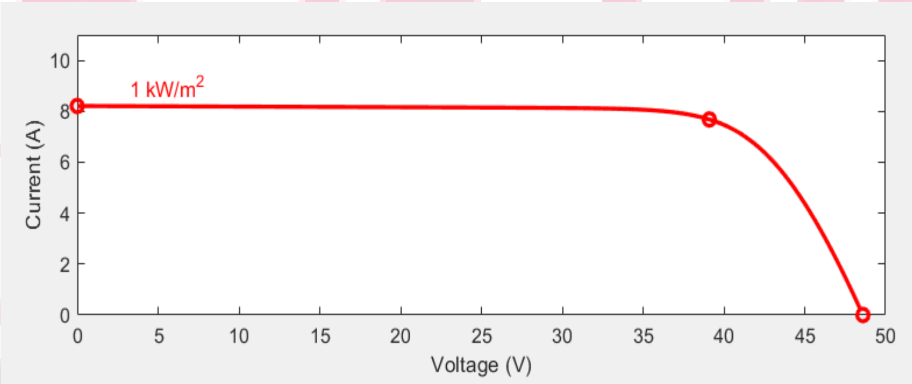

Fig. 9 I-V characteristic of the solar module at 1000 W/m^2

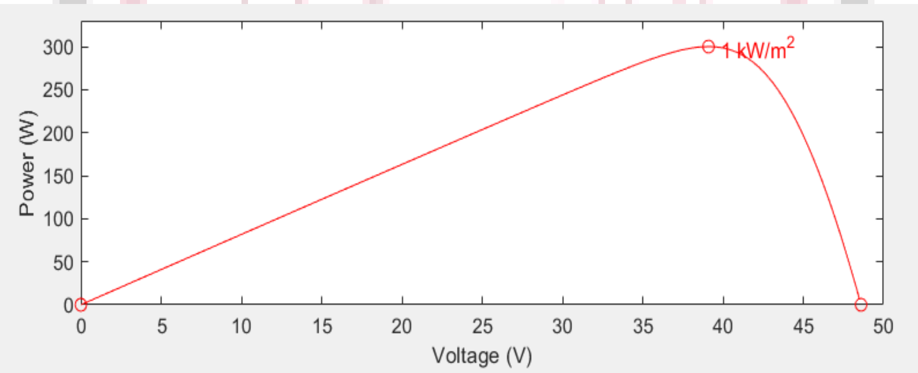

Fig. 10 P-V characteristic of the solar module at 1000 W/m^2

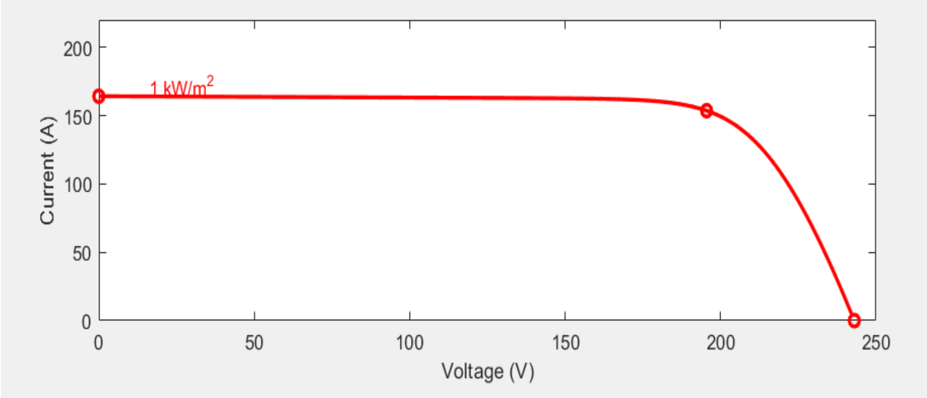

Fig. 11 I-V characteristic of the solar array at 1000 W/m^2

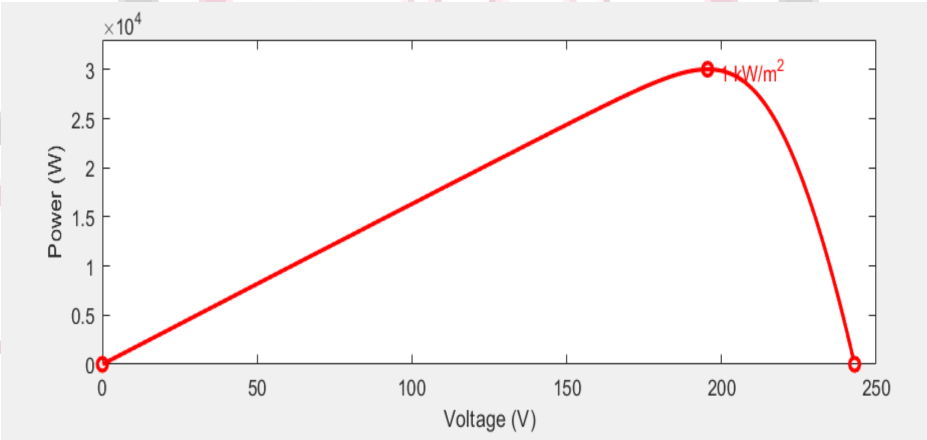

Fig. 12 P-V characteristic of the solar module at 1000 W/m^2

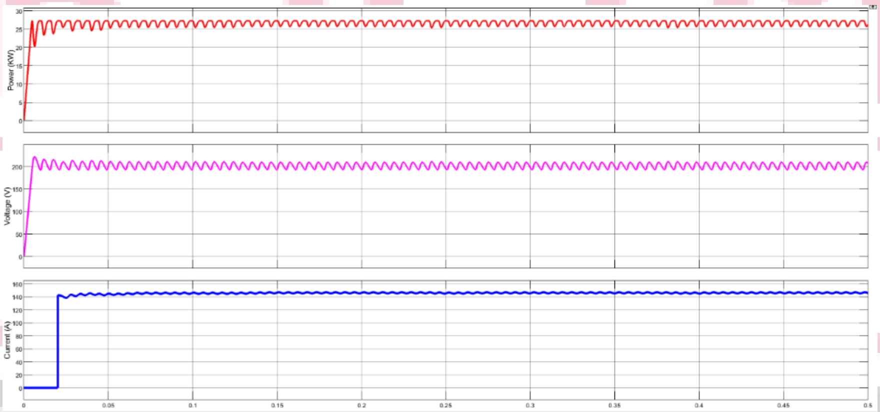

Fig. 13 Output from the solar array with 1000W/m^2 feeding in the charging station (a) Power Output in KW (b) Voltage (c) Current Output

The irradiation levels of the solar inputs is made variable in between 400W/m^2 to 1000 W/m^2. Change in Irradiance affects the photon generated current, corresponding change on the open circuit voltage is less. The short circuit current (Isc) is directly proportional to the solar insolation (Irradiation). During simulation the irradiation input tot the solar system is reduced to 600W/m^2 at 0.1 second of the simulation. Then the irradiation level is again reduced to 400W/m^2 at 0.3 second of the simulation time. The analysis of the system is then extended to the

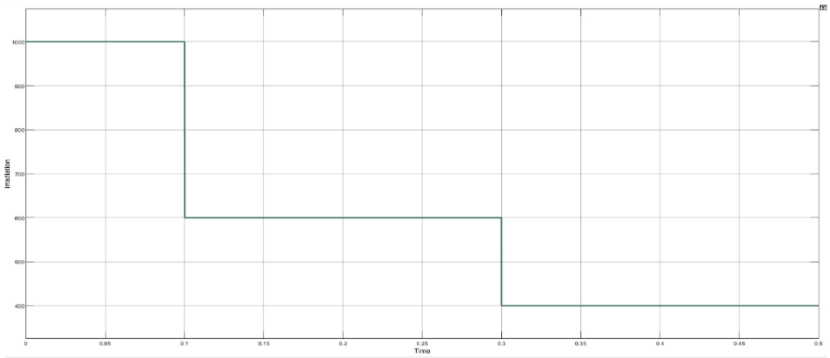

Fig. 14 Variable Irradiation input to the solar system-based CS

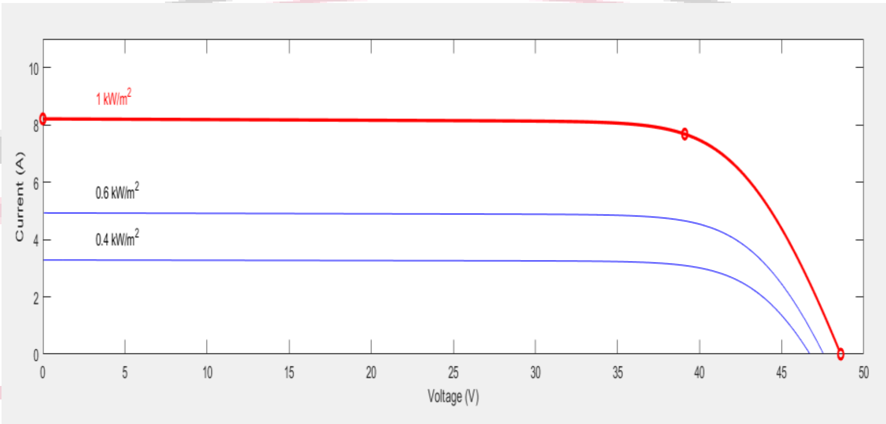

Fig. 15 I-V characteristic of the solar module at 1000 W/m^2, 600 W/m^2, 400 W/m^2

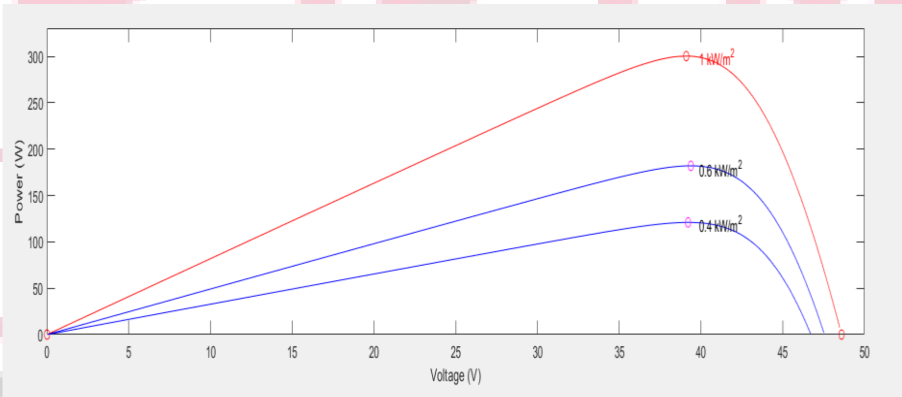

Fig. 16 P-V characteristic of the solar module at 1000 W/m^2, 600 W/m^2, 400 W/m^2

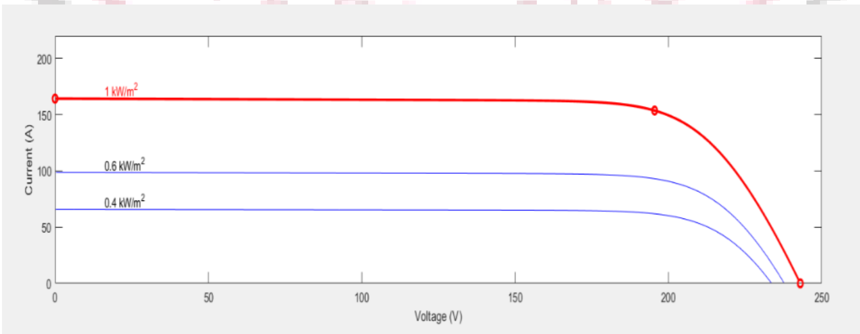

Fig. 17 I-V characteristic of the solar array at 1000 W/m^2, 600 W/m^2, 400 W/m^2

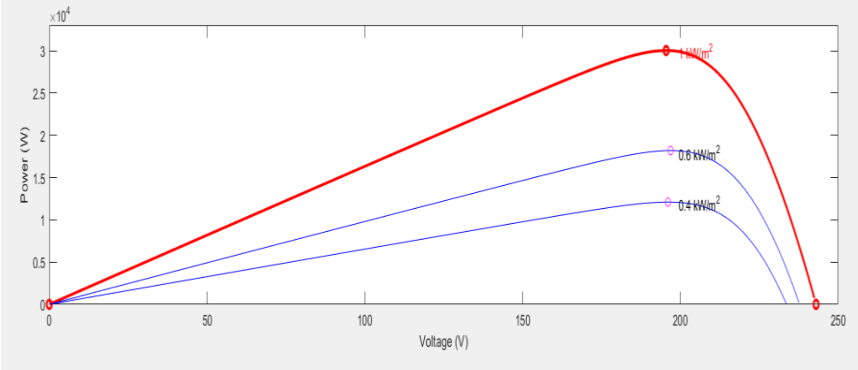

Fig. 18 P-V characteristic of the solar array at 1000 W/m^2, 600 W/m^2, 400 W/m^2

The various characteristics curve for the solar system at varying irradiation levels provided to the solar system is being studied and that gives an idea of measure in that the power produced by a photovoltaic array is affected by changing of irradiance

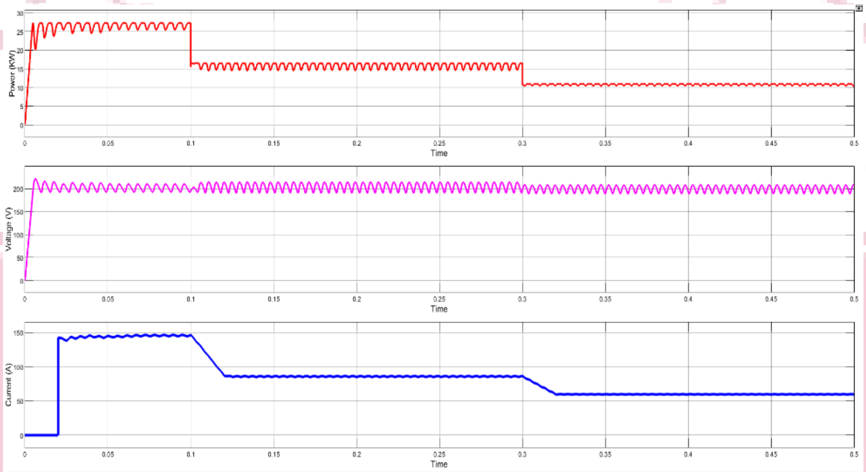

Fig. 19 Output from the solar array with variable irradiations feeding in the charging station (a) Power Output in KW (b) Voltage (c) Current Output

The figure shows that there are changes in the output current and therefore changes in the output solar power in the system feeding charging station. The power output is reduced from 25KW to 15KW when the irradiation levels are reduced to 600W/m^2 and it is further reduced to 400W/m^2 which brings down the voltage levels to 10KW.

5.1 Proposed controller assessment with the Wind energy system integration to charging station architecture in system 2

During simulation the charging station architecture is also equipped with wind energy system in combination with solar energy system. Both of these are renewable based energy systems whose outputs are variable depending upon the input provided to them. 11 kilowatt wind energy system is connected in hybridization with solar energy of 25 kilowatt. The analysis of the systems is done in two parts

- when both the energy systems are producing power and their maximum efficiency
- when the input to these energy systems are reduced and they are producing power half their efficiency

During analysis the EV files is increased from 1 to 2 which means that it will require 10 kilowatt power at the charging point. The DC loads are kept same to 5 kilowatt as well as ac loads are kept at 10 kilowatt as done in previous analysis

In this case the Solar and wind energy systems are driven at their maximum efficiency as input provided to them are according to the rated values. For solar the input radiation is kept thousand and for wind the speed is kept at its base speed of 15m/s. The systems produced output power of 25 kilowatt from solar and 11 kilowatt from wind respectively.

Total load connected to the systems are 25 kilowatt. Therefore this is an ambient situation for charging the energy storage systems namely battery and flywheel as well as charging the ev piles connected at the charging points

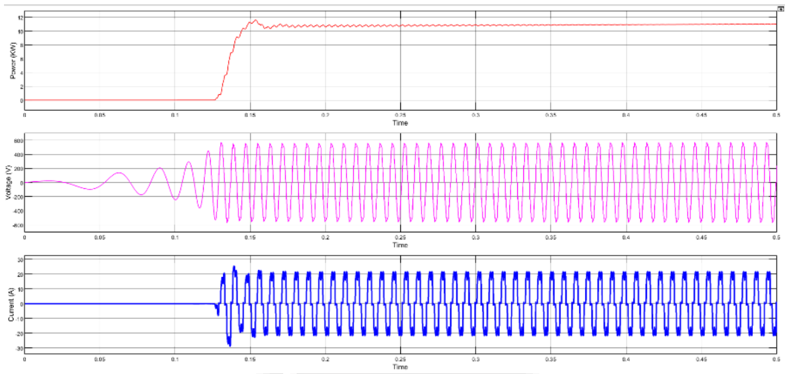

Fig. 20 Output wind energy system parameters for the charging station architecture (a) Power Output in KW (b) Voltage (c) Current Output

The output produced from the wind energy system when the input is maintained at its peak value is 11KW and is shown in figure. The associated voltage and current waveforms from the system are also depicted.

5.1.1 Storage Battery Response in hybrid CS architecture in system 2.

The battery system is used as energy storage and energy supply unit vis a bidirectional DC-DC converter. The controller coordinated with the proposed Optimized power flow genetic algorithm (OPGA) controller for regulating the power flow as well as maintaining the DC link voltage to its stable form.

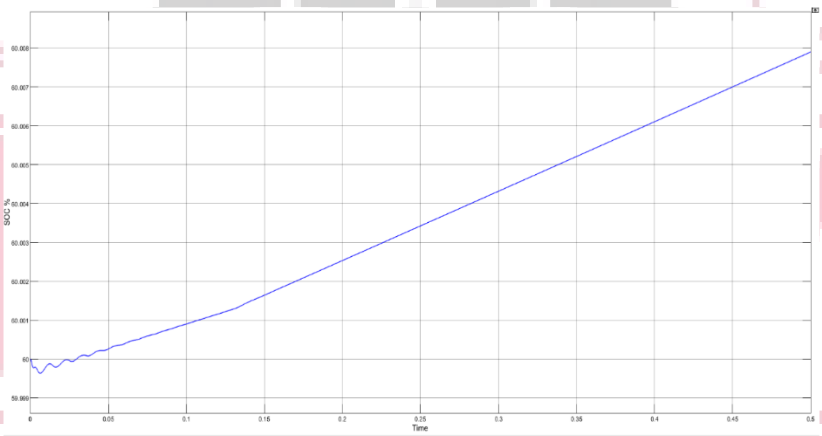

Fig. 21 SOC% of the storage battery in system 2 in hybrid charging station

State of charge percentage of the battery used for storing the excessive power in the line is presented in figure. It is seen that as there is excessive power available in the line the battery is getting charged and hence soc percentage is increasing from its initial 60% value.

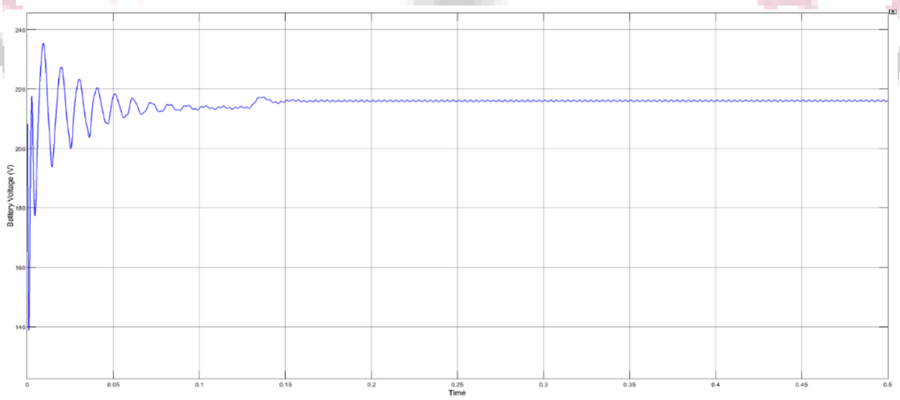

Fig. 22 voltage of the storage battery in system 2 in hybrid charging station

Initial voltage of the Storage battery when it is only 60% charged is shown in figure and as the disturbances present in the DC link of the system are being simplified by the proposed controlled by driven by proposed Optimized power flow genetic algorithm (OPGA) systems.

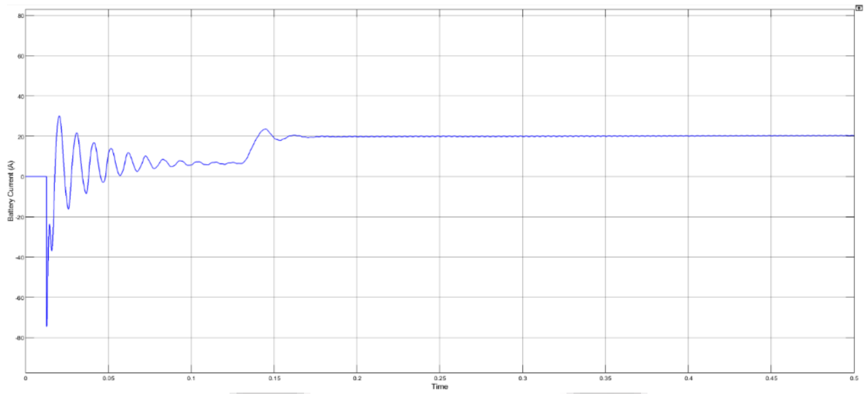

Fig. 23 Current available in the storage battery in system 2 in hybrid charging station

The charging current of the battery storage system is shown in figure. The charging current is found to be approximately 20 amperes due to availability of more input power from the hybrid energy storage system and it increases the charge of the battery from its initial SOC% at bigger slope.

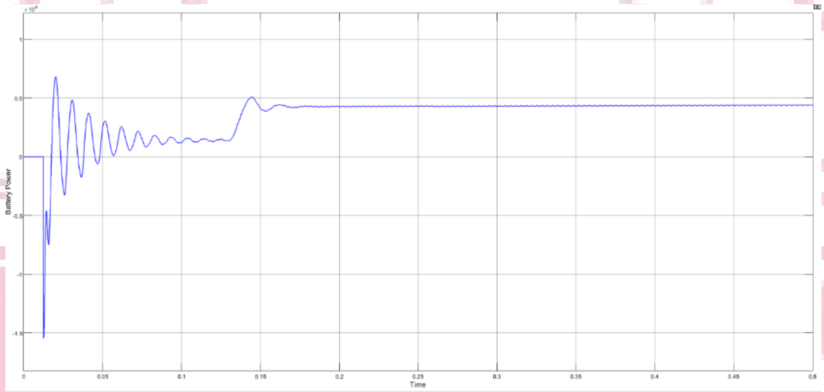

Fig. 24 Power of the storage battery in system 2 in hybrid charging station

The power available in battery storage system is shown in figure which is the product of available battery voltage and the current charging the battery to store the power in system 2 having proposed controller controlling the power flow of the wind energy systems as well.

5.1.2 Response of Storage System as Flywheel in hybrid CS architecture in system 2.

The flywheel energy storage systems are now able to store power available from the both solar as well as wind energy systems.

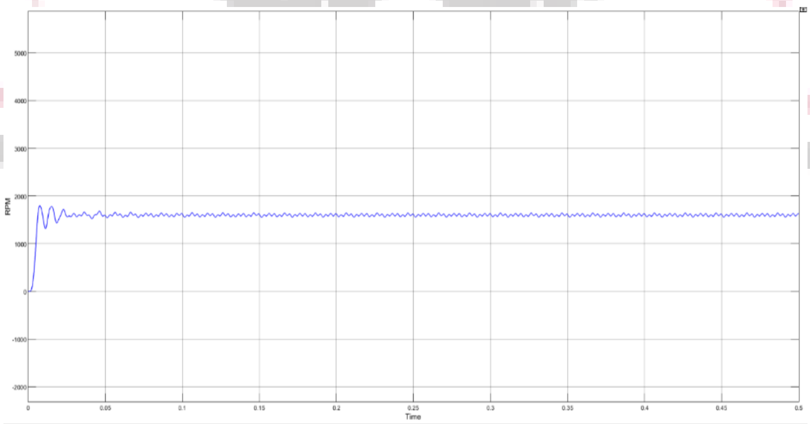

Fig. 25 Speed of the PMSM based Flywheel energy storage in hybrid CS in system 2

The flywheel system is rotating at its maximum possible speed produce rated power in thre hybrid solar wind energy based charging station where the excess power is used to drive the PMSM in the system 2.

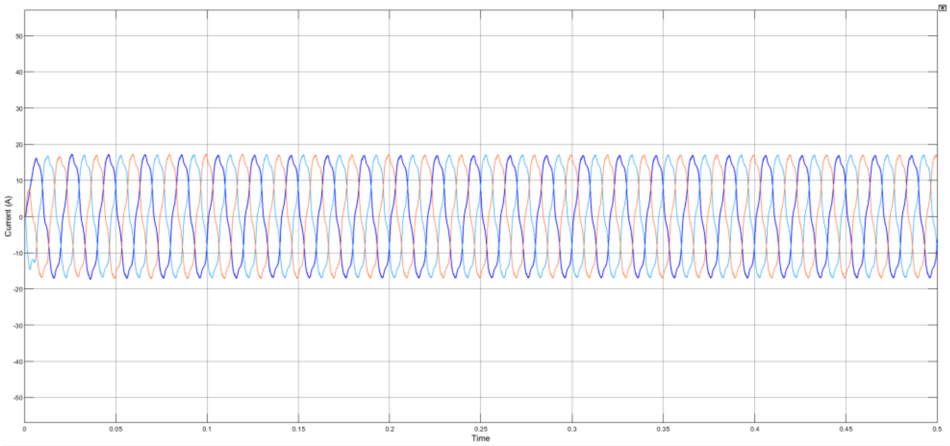

Fig. 26 Stator current of the PMSM based Flywheel energy storage in hybrid CS in system 2

During the rotation the PMSM based machine is drawing a stator charging current of 18 amperes in hybrid solar wind energy-based CS as shown in figure. The three colours depict the current in all the three phases that drives the machine.

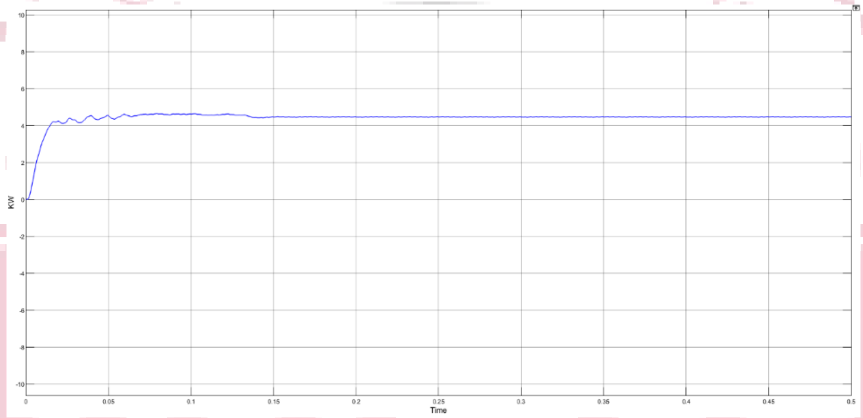

Fig. 27 Power output of the PMSM based Flywheel energy storage in hybrid CS in system 2

During this case the excessive power is being stored in the Flywheel energy storage system and hence the power is positive and is measured to be approximately of 4.9 KW.

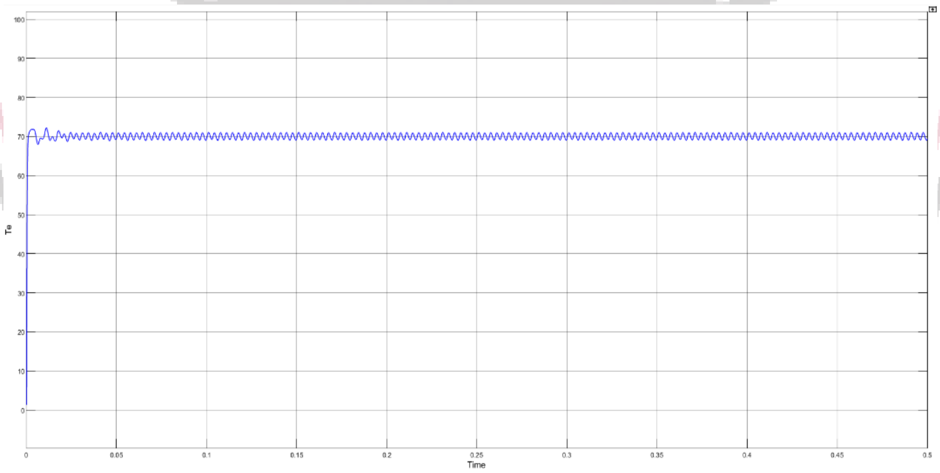

Fig. 28 Torque of the PMSM machine working as Flywheel energy storage in hybrid CS in system 2

The rotational torque generated in the system with management with proposed Optimized power flow genetic algorithm (OPGA) controller in system 2 is shown in figure. The nature of torque generated in the machine is stable due to better power flow control which effects the nature of output power and machine rotation speed.

5.1.3 Feeding bus of the EV points at the plug in stations (EV1 + EV2 in connection/ 10KW)

The loads of the Charging station which are modelled as battery used in EV are increased to 10KW. This means that there are two batteries of same rating connected to the charging station point. AS the input resource to the charging station is increased the loads connected to the system can also be increased

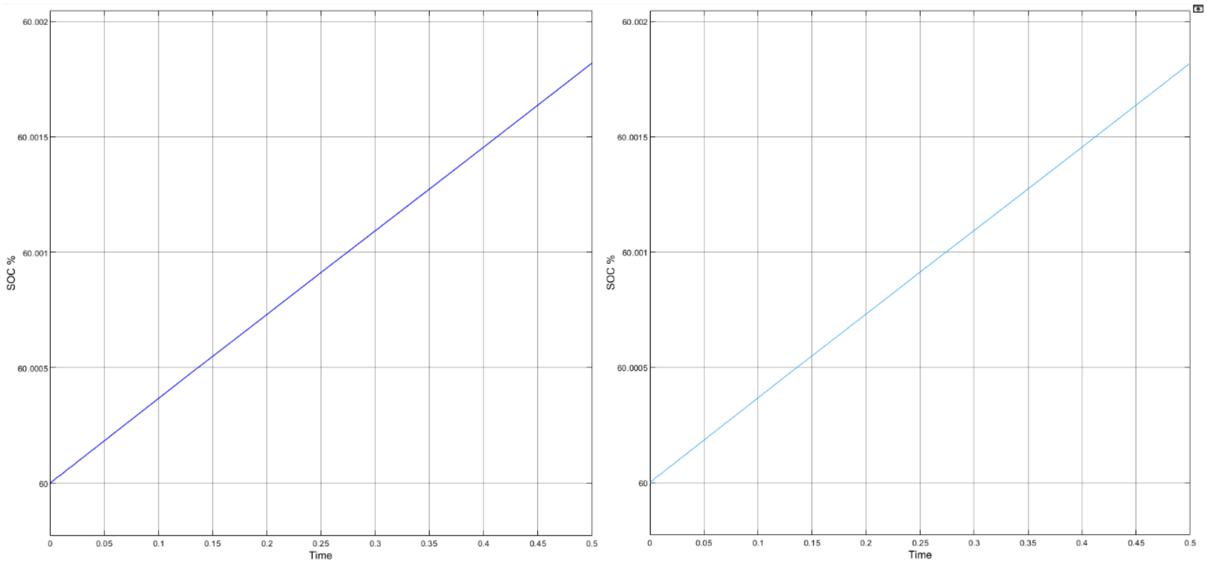

Fig. 29 SOC% of the EV piles connected to hybrid CS in system 2

The state of charge of the batteries present in the electric vehicle increases when they are connected to the charging point of the charging station powered by both solar and wind energy system.

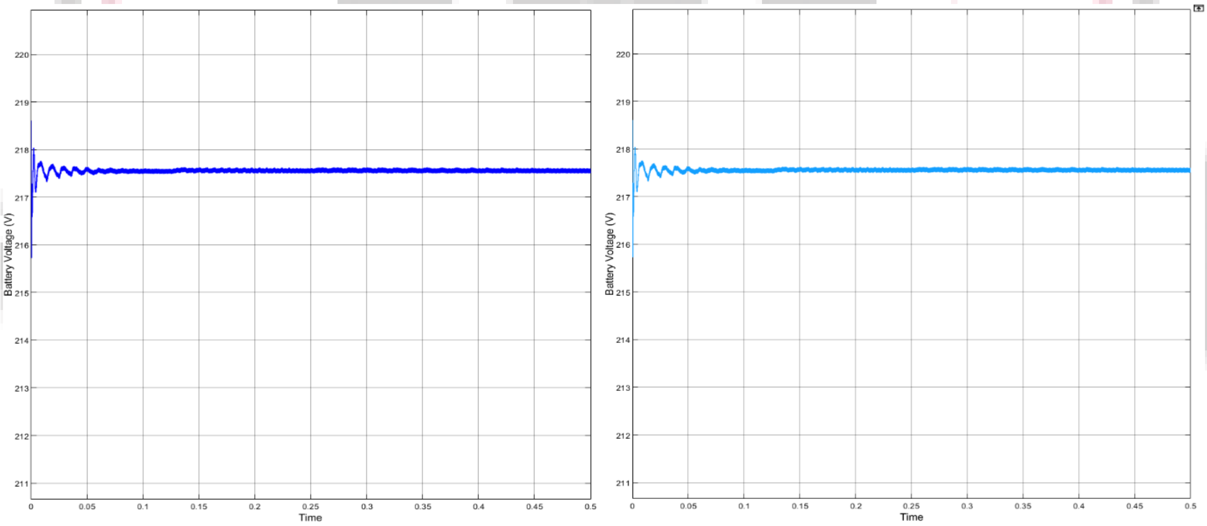

Fig. 30 Voltage of the battery in the EV piles connected to hybrid CS in system 2

The voltage of the EV system is shown in figure at their initial 60% charge which is approximately 216V. Two batteries are connected to the hybrid charging station and are provided with stable input voltage with proposed Optimized power flow genetic algorithm (OPGA) for power flow control

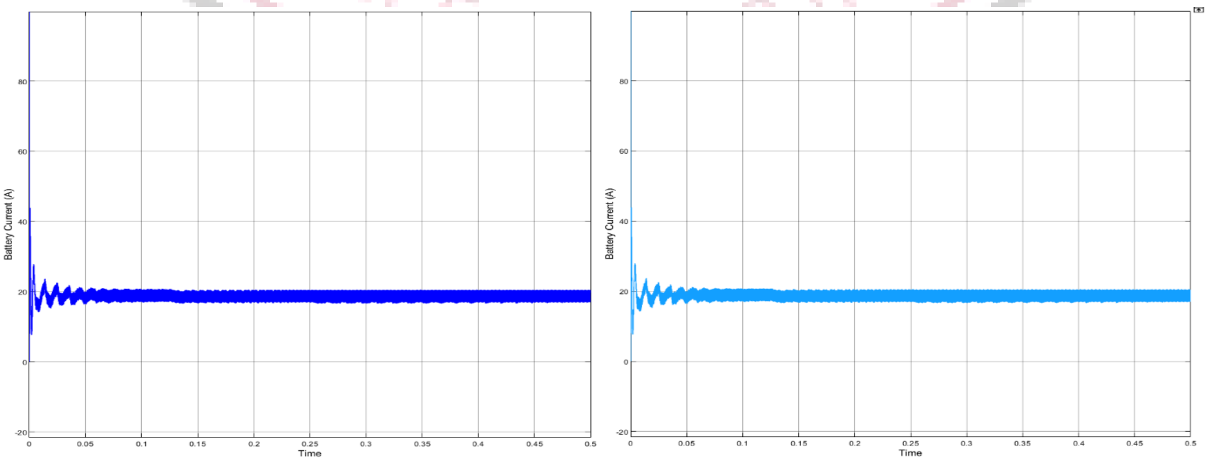

Fig. 31 Current of the battery in the EV piles connected to hybrid CS in system 2

The charging currents delivered to the two batteries present as EV to the hybrid CS with proposed Optimized power flow genetic algorithm (OPGA) for power flow control is shown in figure. The current is approximately 18A that charges these batteries.

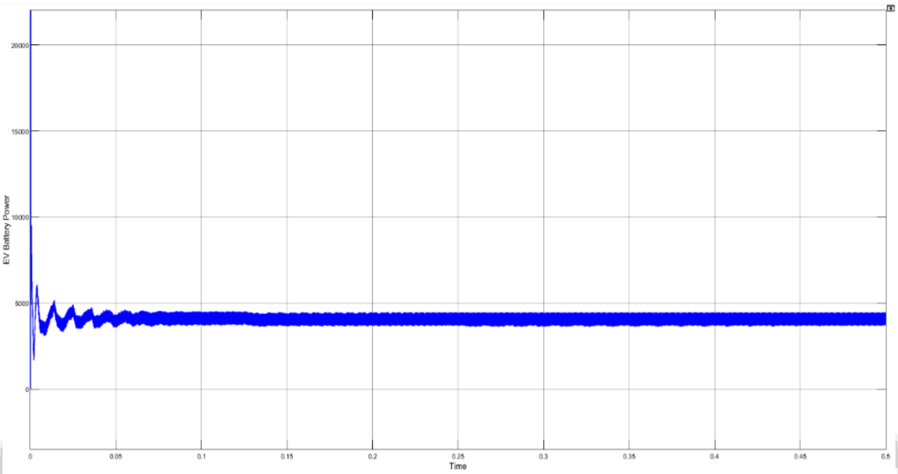

Fig. 32 Power of the battery in the EV1 connected to hybrid CS in system 2

The power of the first EV battery is shown in figure is provided with stable charging power in the hybrid charging station when controlled with proposed Optimized power flow genetic algorithm (OPGA) for power flow control

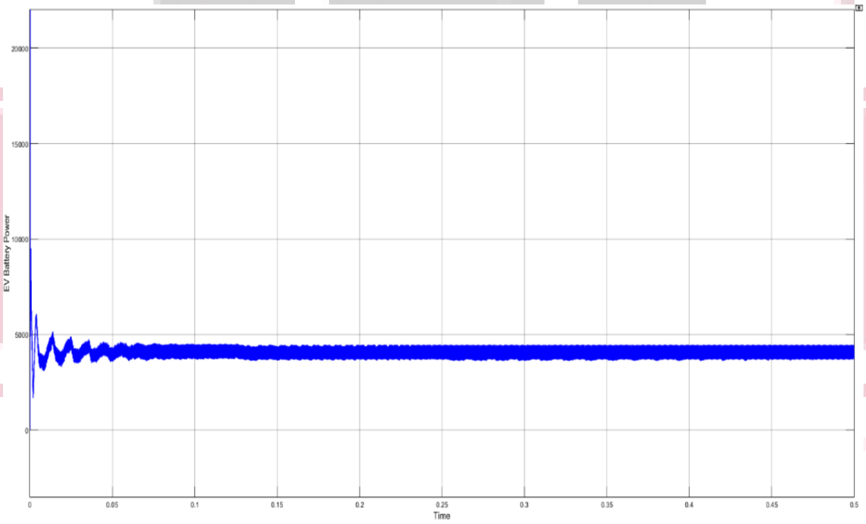

Fig. 33 Power of the battery in the EV2 connected to hybrid CS in system 2

The power of the second EV battery connected simultaneously with the first one is shown in figure is also provided with stable charging power in the hybrid charging station when controlled with proposed Optimized power flow genetic algorithm (OPGA) for power flow control

5.2 Analysis with Reduced Efficiency Operating Conditions

Here in this case the solar and wind energy systems are reduced from their maximum efficiency to produce less power outputs. The solar energy system is provided with irradiation levels of 600 watt per metre square at 0.2 seconds which results in reduction of the power output from the Solar to 15 KW. The wind energy system is also provided with reduced input wind speed that results in reduction of output power available from the wind system. The power from the wind system available after 0.2 seconds is 5 kilowatt.

The electric vehicle loads are still intact to 10 kilowatt. The other types of loads are drawing a total power of 15 kilowatt. The DC load derives a power of 5KW and the loads on the AC line are also drawing a power of 10 kilowatt. Therefore the hybrid Renewable energy system has a total load of 25 kilowatt and the power produced in combination with solar and wind is 20 kilowatt. The remaining power required is delivered by energy storage systems, BESS and FESS where the power is drawn equally from both of them

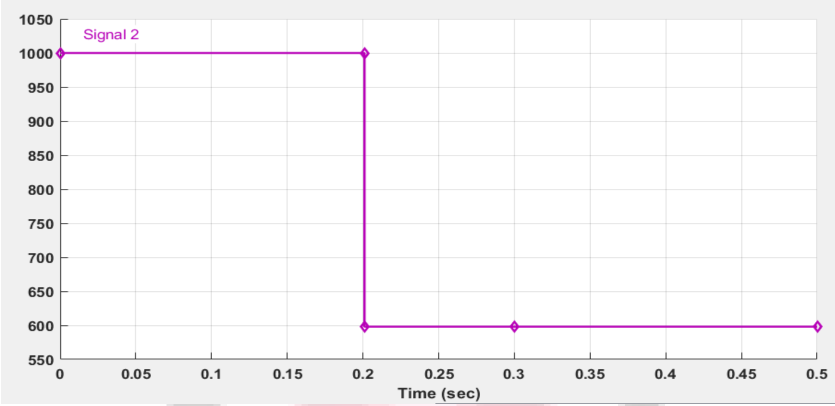

Fig. 34 Variation in the irradiation level provided to the solar system

The irradiation input provided to the Solar Energy in hybrid charging station is shown in figure. It can be observed that at 0.2 seconds the irradiation level is reduced from 1000 W/m^2 to 600 W/m^2

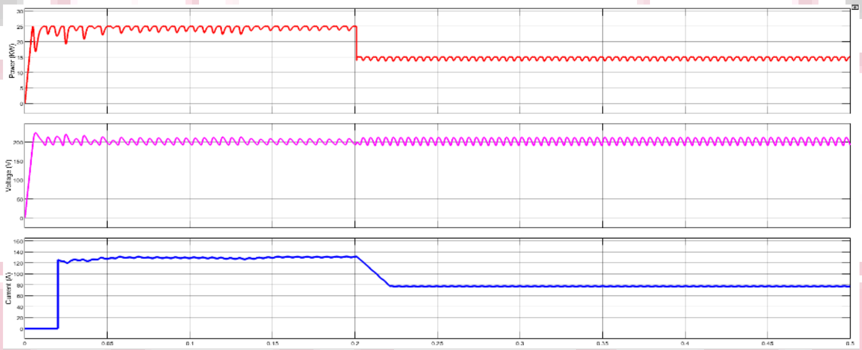

Fig. 35 Power outputs from the solar system at variable inputs in hybrid CS (a) Power Output in KW (b) Voltage (c) Current Output

The figure shows changes in the power output in the solar system due to changes in the irradiation level. The power is reduced from 25 kilowatt to 15 kilowatt at 0.2 seconds when the radiation level is reduced as an input to the solar energy module.

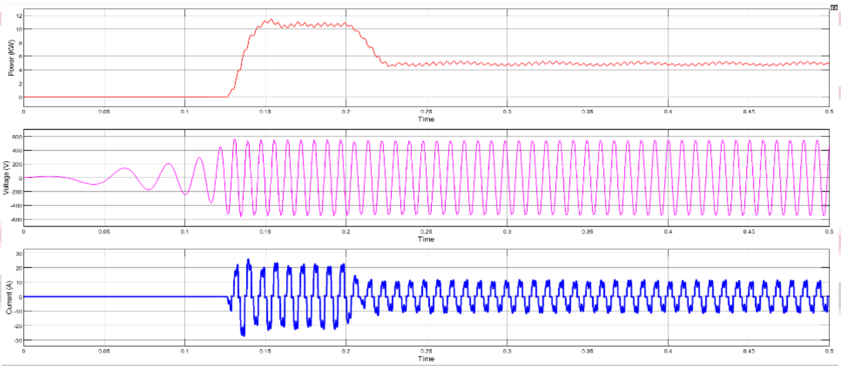

Fig. 36 Power outputs from the solar system at variable inputs in hybrid CS (a) Power Output in KW (b) Voltage (c) Current Output

The figure shows changes in the power output in the wind system due to changes in the speed level. The power is reduced from 11 kilowatt to 5 kilowatt at 0.2 seconds when the there is changes in the input parameters to the generator

5.2.1 Storage Battery Response in hybrid CS architecture in system 2 with variable inputs.

The battery system is used as energy storage and energy supply unit via a bidirectional DC-DC converter when it is targeted to produce an approximate power of 2.5KW at 0.2 seconds to meet the load demands of the hybrid CS architecture.

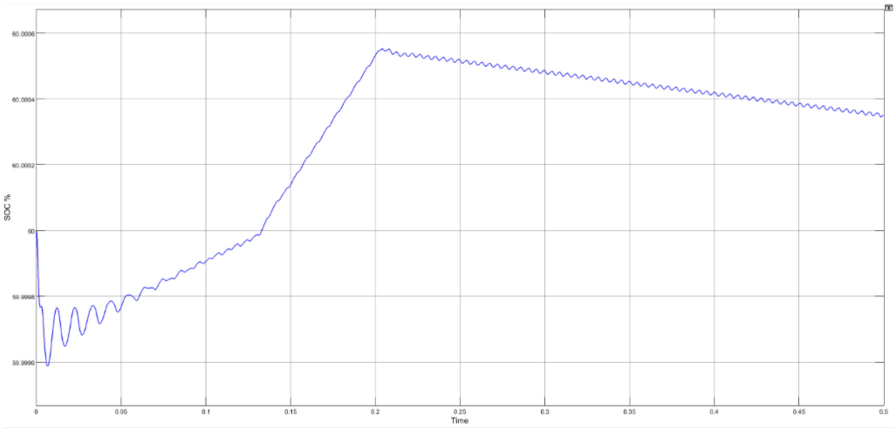

Fig. 37 SOC% of the storage battery in system 2 in hybrid charging station with variable inputs

State of charge percentage of the battery used for storing the excessive power in the line is presented in figure. It is seen that as when there is excessive power available in the line the battery is getting charged and when the power reduces the battery state of charge starts reducing to supply power to the loads and maintain DC link voltage

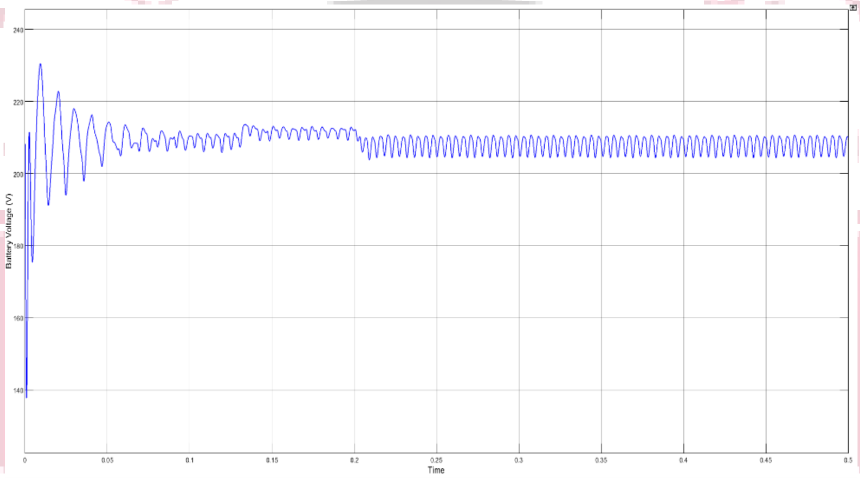

Fig. 38 Voltage of the storage battery in system 2 in hybrid charging station with variable inputs

Initial voltage of the Storage battery when it is only 60% charged is shown in figure and the varying inputs of the CS are used to rise the battery voltage by improving the SOC%.

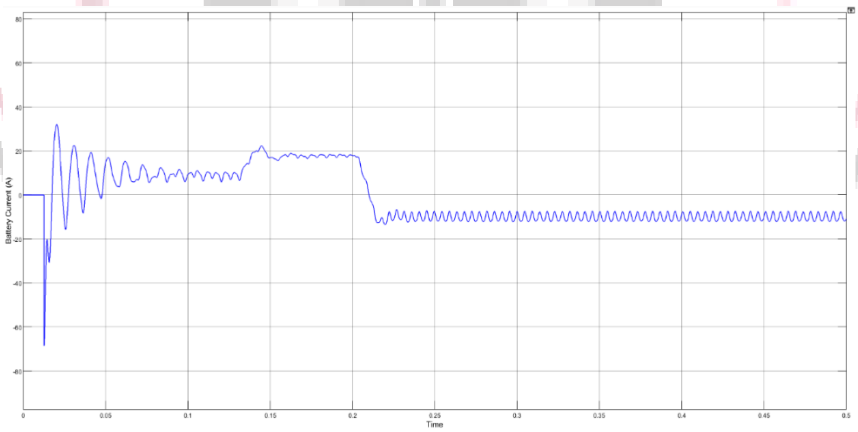

Fig. 39 Current available in the storage battery in system 2 in hybrid charging station with variable inputs

The charging current of the battery storage system is shown in figure. The charging current is found to be approximately 20 amperes due to availability of more input power initially then at 0.2 seconds when the available power reduces it is negative as power is being drawn from the battery.

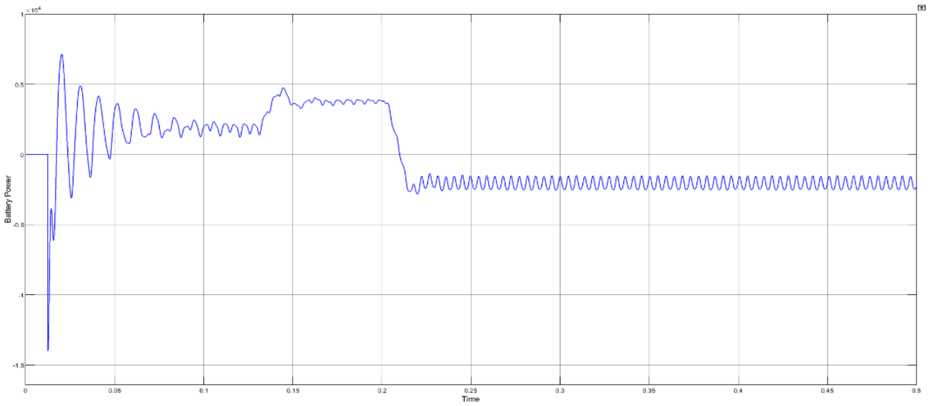

Fig. 40 Power of the storage battery in system 2 in hybrid charging station with variable inputs

The power available in battery storage system is shown in figure which is positive when the battery is getting charged and then becomes negative to approximately 2.5KW which is the power drawn from battery storage system.

5.2.2 Response of Storage System as Flywheel in hybrid CS architecture in system 2 with variable inputs.

The flywheel energy storage systems are now able to store power available from the both solar as well as wind energy systems but as the load is increased and power is reduced at 0.2 second the flywheel energy storage system also supplies power.

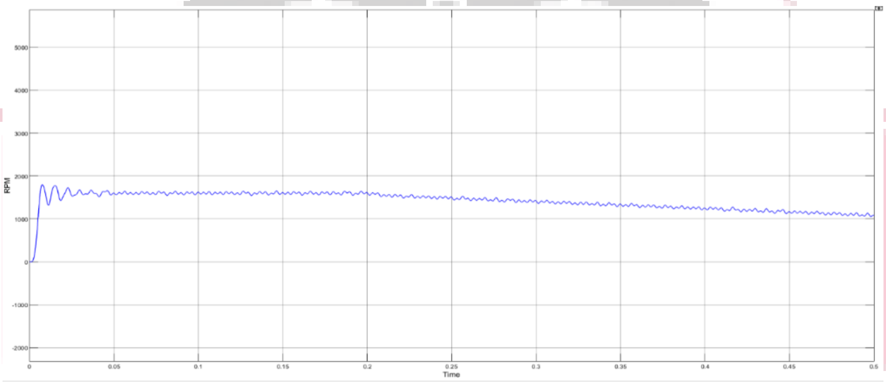

Fig. 41 Speed of the PMSM based Flywheel energy storage in hybrid CS in system 2 with variable inputs

The flywheel system is rotating at its maximum possible speed when it is getting charged from hybrid solar wind energy based charging station but at 0.2 seconds the speed gradually reduces as the flywheel energy system supplies power to the system.

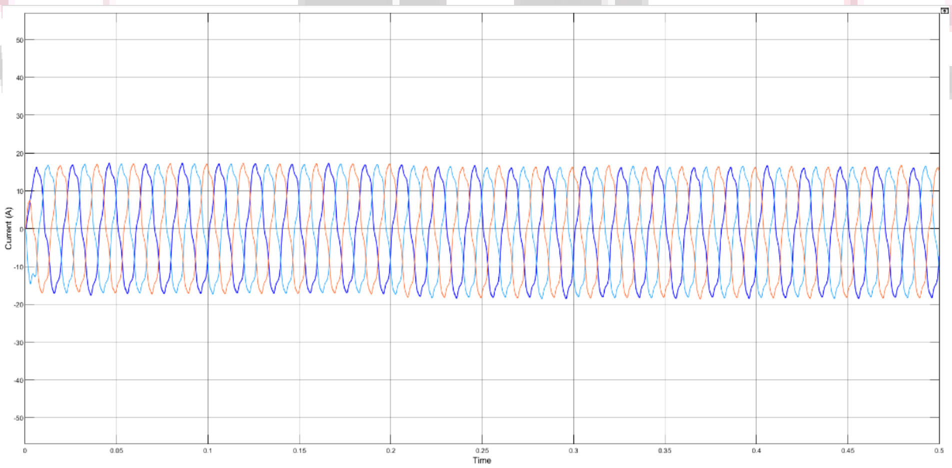

Fig. 42 Stator current of the PMSM based Flywheel energy storage in hybrid CS in system 2 with variable inputs

During the rotation the PMSM based machine is drawing a stator charging current of 18 amperes in hybrid solar wind energy-based CS as shown in figure. And it varies as the requirement of the power is changed in the system 2

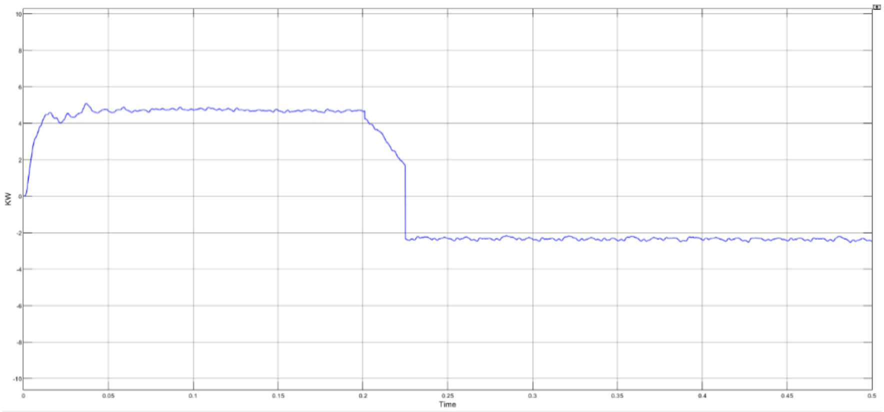

Fig. 43 Power output of the PMSM based Flywheel energy storage in hybrid CS in system 2 with variable inputs

During this case the excessive power is being stored in the Flywheel energy storage system and hence the power is positive upto 0.2 seconds and after that the power is delivered which is negative and is approximately 2.5 KW.

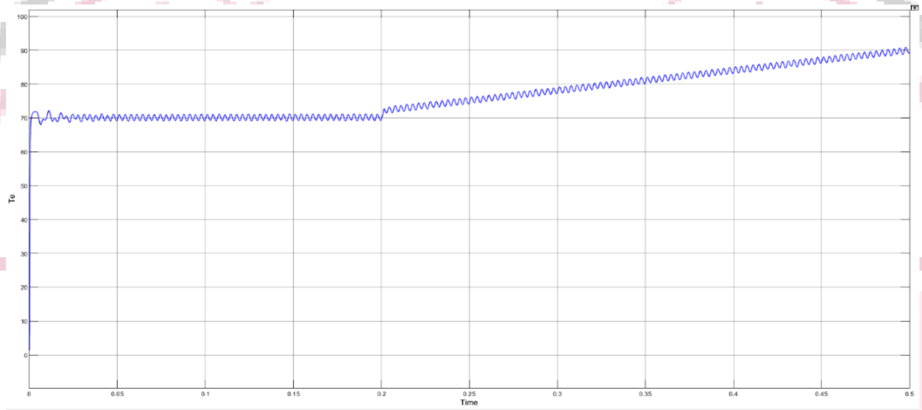

Fig. 44 Torque of the PMSM machine working as Flywheel in hybrid CS in system 2 with variable inputs

The rotational torque generated in the system with management with proposed Optimized power flow genetic algorithm (OPGA) in the system is shown in figure. The nature of torque generated in the machine is stable and increases at 0.2 seconds because it varies inversely with the speed of PMSM.

5.2.3 Feeding bus of the EV points at the plug in stations (EV1 + EV2 in connection/ 10KW)

The loads of the Charging station which are modelled as battery used in EV are increased to 10KW. This means that there are two batteries of same rating connected to the charging station point. AS the input resource to the charging station is increased the loads connected to the system can also be increased but when the input resources are reduced the power flow control derives its remaining power from the storage systems.

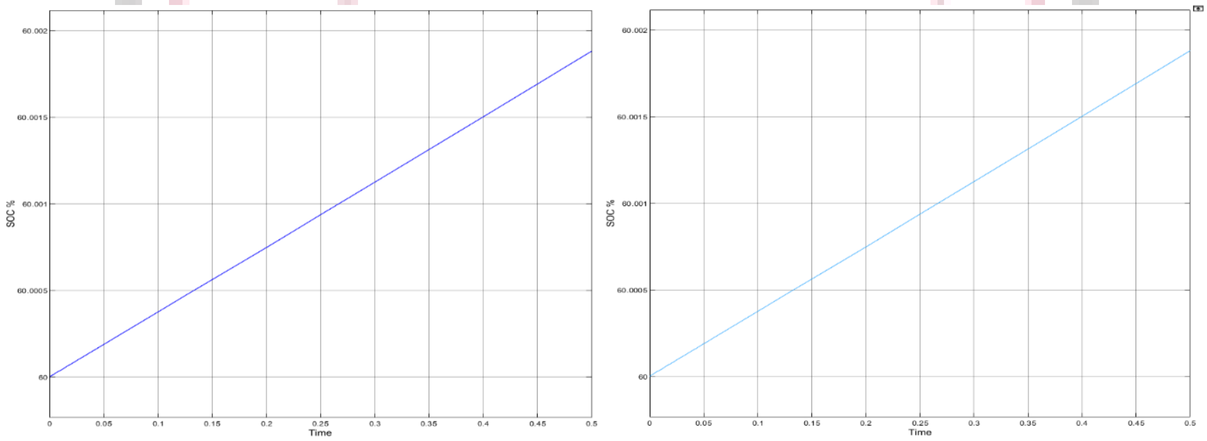

Fig. 45 SOC% of the EV piles connected to hybrid CS in system 2 with variable inputs

The state of charge of the batteries present in the electric vehicle increases when they are connected to the charging point of the charging station powered by both solar and wind energy system.

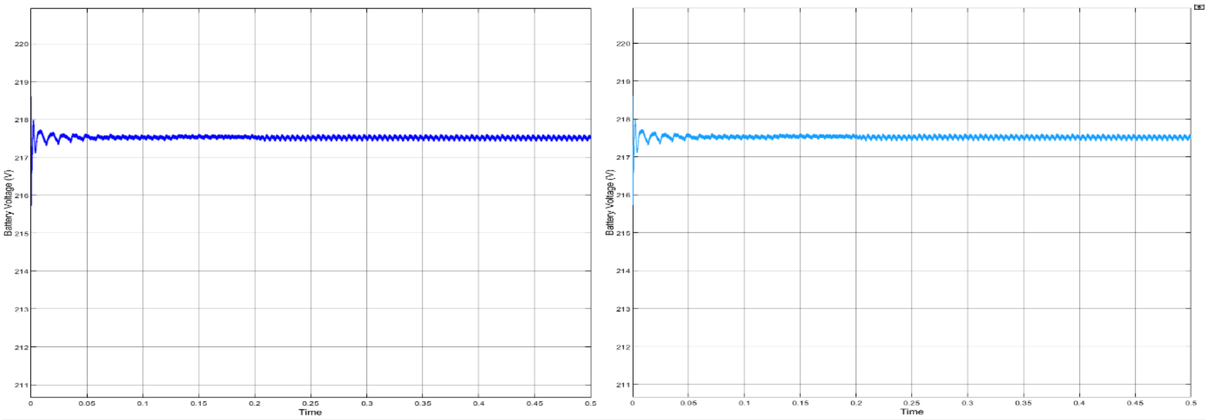

Fig. 46 Voltage of the battery in the EV piles connected to hybrid CS in system 2 with variable inputs

The voltage of the EV system is shown in figure at their initial 60% charge which is approximately 216V. Two batteries are connected to the hybrid charging station and are provided with stable input voltage even when the inputs from the renewable energy resources is reduced and power flow is controlled with proposed Optimized power flow genetic algorithm (OPGA)

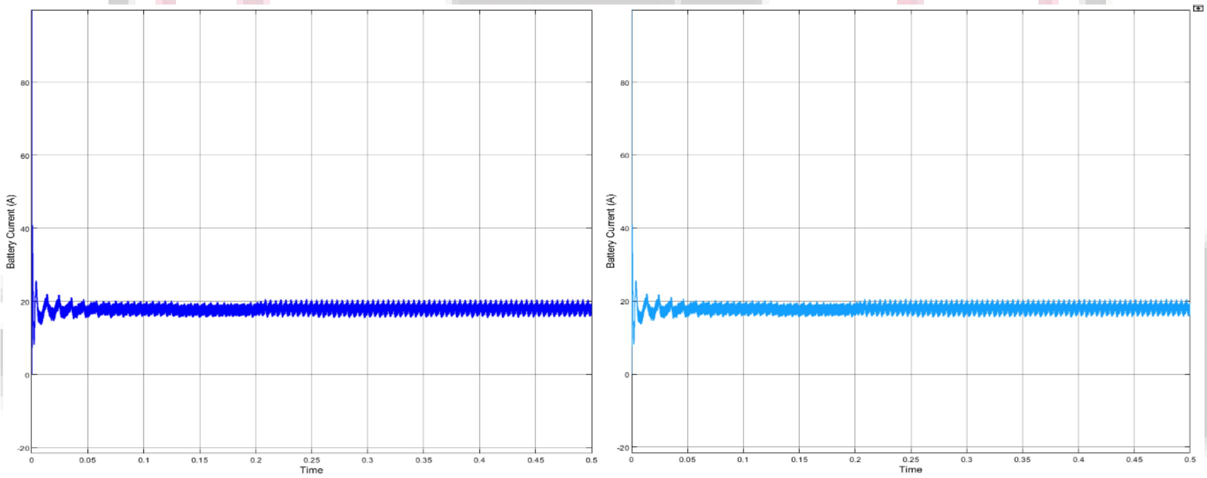

Fig. 47 Current of the battery in the EV piles connected to hybrid CS in system 2 with variable inputs

The charging currents delivered to the two batteries present as EV to the hybrid CS with proposed Optimized power flow genetic algorithm (OPGA) for power flow control is shown in figure. The current is approximately 18A that charges these batteries when the variable inputs are received from the energy resources.

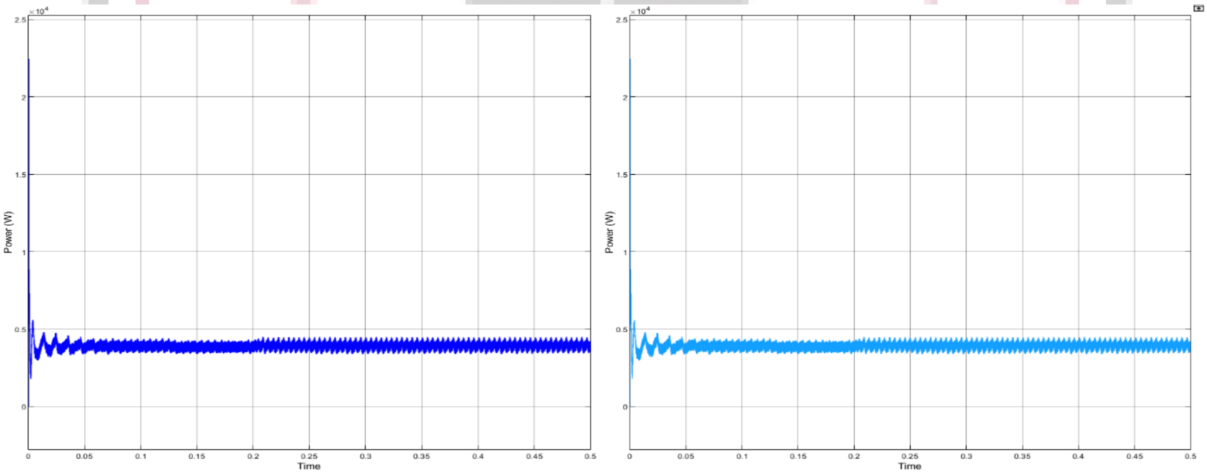

Fig. 48 Power of the battery in the EV1 and EV 2 connected to hybrid CS in system 2 with variable inputs

The power of the first EV battery is shown in figure is provided with stable charging power in the hybrid charging station when controlled with proposed Optimized power flow genetic algorithm (OPGA) for power flow control.

V. CONCLUSION

This research underscores the significance of integrating renewable energy sources and advanced energy storage technologies into electric vehicle charging infrastructure to address environmental concerns and enhance energy efficiency. By designing hybrid solar-wind charging stations w ith flywheel energy storage and employing optimized power flow genetic algorithms, the study demonstrates effective power management and grid integration capabilities. The findings emphasize the feasibility and benefits of renewable energy-integrated electric vehicle charging infrastructure in mitigating greenhouse gas emissions, reducing reliance on fossil fuels, and fostering sustainable transportation solutions.

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