Vision and Mission of the Institute

Vision of the Institute

To be a preferred technical institution from rural background to contribute towards the advancement of community, region and nation as a whole and to elevate the students into technically strong and ethically sound individuals.

Mission of the Institute

- Engage all the stake holders and utilize the infrastructure to develop technically sound employable human resources to translate our vision into a reality.
- Providing quality education in this region.
- Creating curiosity and innovative thinking among the students.

PRINCIPAL

Vision and Mission of the Department

Vision of the Department

To become a front-runner, the department of Electrical and Electronics Engineering brings out competent engineers, innovators, researchers with human and ethical values, thereby contributing value to the knowledge-based economy and society.

Mission of the Department

- To educate and train engineers who are highly skilled, innovative, and committed to ethical values.
- To encourage research and innovation, fostering a culture of curiosity and creativity among our students.
- To produce graduates who make a positive impact on the knowledge-based economy and society as a whole by using their knowledge and values to solve real-world problems.

HOD

Program Educational Objectives (PEOs)

PEO1: To Excel in professional career and/or higher education by acquiring knowledge in mathematics and Basic Sciences, Basic Electrical Sciences, Power Systems, Power Electronics and Electrical Drives

PEO2: To identify the problems in society and design electrical systems appropriate to its solutions using soft controllers that are technically sound, economically feasible and socially acceptable.

PEO3: To Exhibit professionalism, ethical attitude, communication skills, team work in their profession and adapt to current trends in technology by engaging in continuous professional development.

Program Specific Outcomes (PSOs)

PSO1: Able to utilize the knowledge of high voltage engineering in collaboration with power systems in innovative, dynamic and challenging environment, for the research based team work.

PSO2: Able to explore the scientific theories, ideas, methodologies and the new cutting edge technologies in renewable energy engineering, and use this erudition in their professional development and gain sufficient competence to solve the current and future energy problems universally.

PSO3: Able to provide socially acceptable technical solutions to complex electrical engineering problems with the application of modern and appropriate techniques for sustainable development.

Program Outcomes (POs)

Engineering Graduates will be able to:

PO1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
PO2	**Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
PO3	**Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
PO4	**Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
PO5	**Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations
PO6	**The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice
PO7	**Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
PO8	**Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
PO9	**Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
PO10	**Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
PO11	**Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one"s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments
PO12	**Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

Course Outcomes (Cos) with BT Level Mapping

SUB: Full Internship & Project work CODE: C409

S. No	Course Outcome (CO)	Bloom's Taxonomy Level
1	Demonstrate practical application of theoretical knowledge in a professional work environment, showcasing proficiency in executing tasks related to electrical engineering practices.	Apply (K3)
2	Exhibit effective problem-solving skills by identifying challenges, analyzing root causes, and proposing innovative solutions within the scope of assigned internship or project tasks.	Analyse (K4)
3	Develop interpersonal and communication skills through interactions with colleagues, clients, and stakeholders, fostering teamwork, collaboration, and effective information exchange.	Understand (K2)
4	Reflect on the learning experience gained during the internship or project work, critically evaluating personal growth, professional development, and the application of ethical principles in engineering practice.	Analyse (K4)

"CONTROL AND MANAGEMENT OF RAILWAY SYSTEM CONNECTED TO MICROGRID STATIONS"

A project report submitted in partial fulfilment of requirements for the award of degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

By

BUGUDI MOHAN KUMAR	**(20G31A0207)**
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Under the Esteemed Guidance of

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(Affiliated to J.N.T.U., ANANTAPURAMU, Accredited by NAAC 'B++ Grade)

2023-2024

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2023-2024

BONAFIDE CERTIFICATE

This is to certify that the project report entitled "**CONTROL AND MANAGEMENT OF RAILWAY SYSTEM CONNECTED TO MICROGRID STATIONS**" is being submitted by **BUGUDI MOHAN KUMAR (20G31A0207), MALIREDDY LAKSHMAN (20G31A0215), SEELAM RAJASEKHAR (20G31A0221), BOYA JOLANNA GARI RAMAKRISHNA (20G31A0205), M FAREED AKRAM (21G35A0215)** in partial fulfilment for the award of the degree of Bachelor of Technology in **ELECTRICAL AND ELECTRONICS ENGINEERING** to the Jawaharlal Nehru Technology University Anantapuramu, as a record of bonafide work carried out by them under my guidance and supervision. The result embodied in this project report have not been submitted to any other university or Institute for the award of any degree or Diploma.

INTERNAL GUIDE **HEAD OF THE DEPARTMENT**

Submitted for the university examination held on________________________

INTERNAL EXAMINER **EXTERNAL EXAMINER**

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All endeavours over a long period can be successfully only with advice and support of many well-wishers. We take this opportunity to express our gratitude and appreciation to all of them.

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ABSTRACT

This project suggests a techno-economic process for the energy storage by using SCs in the train, with the aim to reduce the energy consumptions. The proposed design of railway station uses PV and wind sources, and batteries for energy storage system (ESS). For the train, SCs are implemented to the ESS where they are alimented breaking phases and from stations by a pantograph installed in an air power line in each stop. SCs are distinguished by high characteristics power and a wide number of charge/discharge cycles, they provide low particular energy and a fast-charging time. An energy management approach is suggested to control the DC bus by voltage and the buck-boost converter by current. The Sizing of PI controller used for the stabilization of the DC bus of train and station is given. The whole system is modelled in MATLAB-Simulink. Simulations for the train and station show the suitability of the suggested powertrain and control strategy.

Keywords: Energy management, railway system control, energy storage system, Supercapacitors

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INTRODUCTION

CHAPTER-I

INTRODUCTION

1.1 INTRODUCTION

In the last few decades, generally there are growing in energy using and pollutions. The growing number of citizens traveling between cities has implied the continuous development of mass transit systems as buses, taxies, and trains. However, the use of railway transportation systems other conventional means of transport is widely recognized due to the Carrying capacity of a large number of people. The development of rail transportation allows people to travel quickly. Thereby, growing environmental like climate change and CO2 emissions change issues dictate the requisite for ameliorate the performance energy regulation of railway systems. For these raisons, the electrified railway traffic has become a principal development management of current public transportation networks.

The production of clean energy from renewable sources have become the hot topics of social development. However, railway system integrates different renewable energy sources, like photovoltaics (PV) and wind turbines. To ensure a continuous power supply and to respond to the charge power of train from station to the train, an energy storage system (ESS) is necessary. In order to manage the overload variation in railway power supply structure in the time of heights commuting hours, a wide number of ESS technologies are implemented in the railway system as a constructive means to improve load needs. The on-board storage augmented the weight and space of a vehicle that encourage the underground storage.

SCs represent an appear energy storage devices characterized with a high-power density, a long span life and a wide temperature range, has become the best appropriate storage element match with the functioning characteristics of train system. By comparing SCs to different energy storage devices like batteries and flywheels, SCs present fast charging and discharging time because of the high-power density, and important potential of energy recovery. In general, ESS with SC is considered like energy buffer accelerating mode of train and recycles the excess of power during the braking mode, realizing a good balance of charge and discharge. SCs are considered a best solution in systems which characterized with different fluctuations. SCs are also used in interruptible power systems to stabilized the power and bus voltage. The energy storage in railway system presents a challenge for researches.

Energy management system (EMS) is currently a big challenge in large-scale complex energy distribution networks like railway structure. Most of EMS researches in railway structure interest on ameliorating the railway system technologically. EMS on the system level with an integrated strategy into the railway structure often is ignored The optimal control theory for railway vehicle is presented in many articles. EMS is implemented to control and connect different devices in railway system, energy storage devices, sources and train.

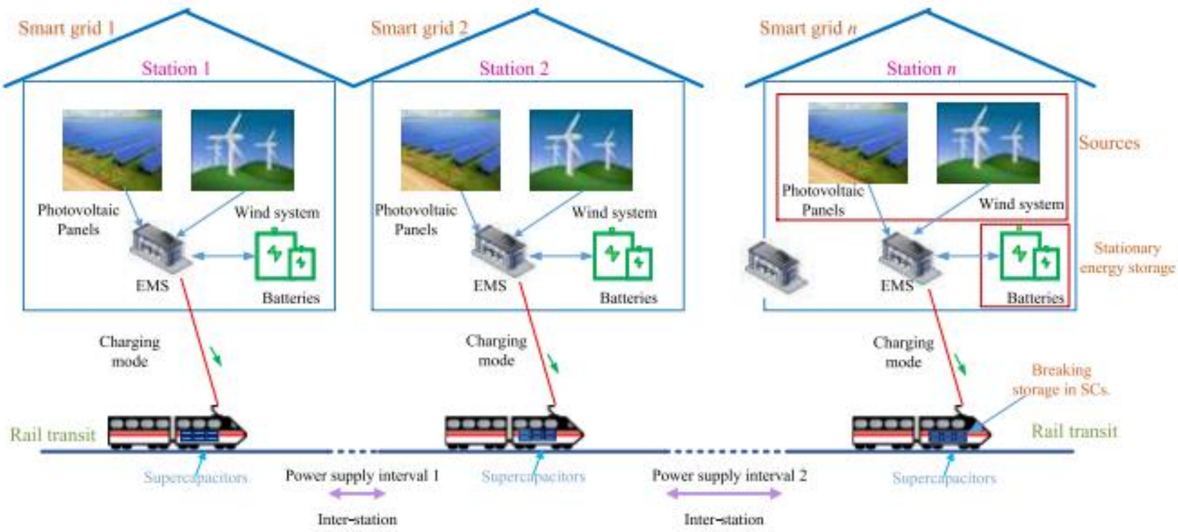


Fig 1.1: Train network traction characteristic.

The railway system has been studied successfully in many articles by researches such as: Jiang presents a fast inspection method for high-speed railway infrastructure monitoring; Feng gives the electric railway smart microgrid system with integration of multiple energy systems and power-quality improvement. Khayyam gives railway system energy management optimization demonstrated at offline and online case studies, Zhang presents the method using a prediction approach, He shown the energy harvesting approach for railway wagon monitoring sensor with high reliability and simple structure, Sun presents the hybrid method for life prediction of railway, Novak presents the hierarchical model predictive control for coordinated electric railway traction system energy management, Sengor gives the energy management of a smart railway station considering regenerative braking and stochastic behaviour of ESS and PV Generation.

The proposed system, is composed of two parts: the first one concern the stations, the second one is addressed to the control of trains. The stations are composed PV and wind fields where the energy storage is insured by batteries. The trains are composed by SCs and engine. SCs are used because of their high power. The innovative contributions given in this article are as follows:

- A design of train implementing SCs for energy storage alimented from stations and breaking phases.
- A new EMS is suggested to control the DC bus by voltage and the buck-boost converter by current.
- Sizing of PI controller used for the stabilization of the DC bus of train and station. A design of railway station using PV and wind sources, and batteries for energy storage.

1.2 LITERATURE REVIEW

G. Cui, L. Luo, C. Liang, S. Hu, Y. Li, Y. Cao, B. Xie, J. Xu, Z. Zhang, Y. Liu, and T. Wang, In order to increase the utilization rate of the regenerative braking energy (RBE), reduce the operation cost, and improve the power quality of traction power supply system (TPSS) in high-speed railway, a supercapacitor (SC)-based energy storage system (SCESS) integrated railway static power conditioner (RPC) is presented in this article. In this scheme, the SC is connected onto the dc link of the RPC via a bidirectional dc-dc converter. A hierarchical control strategy, with an energy management layer and a converter control layer, is presented. Four operation modes and transition conditions of SCESS-RPC are elaborated in detail in the energy management layer. To obtain rapid and stable control performance, in the converter control layer, a passivity-based control (PBC)-based nonlinear controller is designed for the RPC, and an optimal control strategy based on the linear quadratic regulator with integral action (LQRI) is adopted for the bidirectional dc-dc converter. By means of simulations and experiments, the feasibility of the proposed topology and control strategy are verified.

F. Ciccarelli, A. Del Pizzo, and D. Iannuzzi, The authors propose a control strategy based on the maximum kinetic energy recovery throughout braking operations of the running vehicles. The stored energy comes back to the vehicles during the accelerations. The strategy stays on the knowledge of the state of charge of LiC device and the actual vehicle speeds. In particular, the control algorithm evaluates, in real time, the actual value of LiC voltage and current references on the basis of the vehicles inertial forces and acceleration estimations, taking into account the power losses of the system. Experimental tests made on electromechanical simulator, equipped with a 136-V, 30.5-F LiC module, fully confirm the validity of the suggested control. Finally, experimental characterization of LiC module has been achieved.

V. A. Kleftakis and N. D. Hatziargyriou, The methods proposed for maximizing the recovered energy are presented together with their theoretical analysis. A novel optimization strategy, based on the linearization of the dc power flow equations, is analytically explained, while a successive approximation method is used. The proposed control strategy is evaluated through simulations on a modified version of the Thessaloniki metro railway network (Greece). Simulation results show that the system performance is significantly improved when reversible substations or energy storage are in operation.

T. Ratniyomchai, S. Hillmansen, and P. Tricoli, his study presents the recent application of energy storage devices in electrified railways, especially batteries, flywheels, electric double layer capacitors and hybrid energy storage devices. The storage and reuse of regenerative braking energy is managed by energy storage devices depending on the purpose of each system. The advantages resulting from the use of energy storage devices are presented by observing the results of both verification tests and practical applications in passenger services. Several real installations of energy storage for railways are shown and compared by using the Ragone plot. The effect of the use of energy storage devices on electrified railways of the future is discussed. Finally, a discussion on the recent applications and developments of energy storage devices is presented in this study. The effective use of energy storage devices is characterised on the basis of the specific applications and current trends of the research undertaken by public bodies and manufacturers.

H. Yang, W. Shen, Q. Yu, J. Liu, Y. Jiang, E. Ackom, and Z. Y. Dong lectric trains typically travel across the railway networks in an inter-provincial, inter-city and intra-city manner. The electric train generally serves as a load/source in tractive/brake mode, through which power networks and railway networks are closely coupled and mutually influenced. Based on the operational mode of rail trains and the characteristics of their load power, this project proposes a coordinated optimal decision-making method of demand response for controllable load of rail trains and energy storage systems. First, a coordinated approach of dynamically adjusting the load of the controllable rail train in considering the driving comfort and energy storage battery is designed. Secondly, under the time conditions that satisfy the train's operational diagram, the functional relationship between the train speed and the load power is presented. Based on this, in considering the constraints of the train's arrival time, driving speed, motor power, and driving comfort, the capacity of energy storage batteries and other constraints, an optimization model for demand response in managing the traction power supply system under a two-part price and time-of-use (TOU) price is proposed.

CHAPTER-II

RENEWABLE ENERGY SYSTEM

CHAPTER II

RENEWABLE ENERGY SYSTEM

2.1 SOLAR POWER

Fig 2.1: A solar photovoltaic system array on a rooftop

Fig 2.2: The first three concentrated solar power (CSP) units in the foreground, with the PS10 and PS20 solar power towers in the background

This is a horizontal surface mount solar panels, whereas solar panels are normally propped up at an angle and receive more energy per unit area, especially at high latitudes. Potential of solar energy. The small black dots show land area required to replace the world primary energy supply with solar power.

Solar power is the conversion of energy from sunlight into electricity, either directly using photovoltaics (PV), or indirectly using concentrated solar power. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic cells convert light into an electric current using the photovoltaic effect.

The International Energy Agency projected in 2014 that under its "high renewables" scenario, by 2050, solar photovoltaics and concentrated solar power would contribute about 16 and 11 percent, respectively, of the worldwide electricity consumption, and solar would be the world's largest source of electricity. Most solar installations would be in China and India.

Photovoltaics were initially solely used as a source of electricity for small and medium-sized applications, from the calculator powered by a single solar cell to remote homes powered by an off-grid rooftop PV system. As the cost of solar electricity has fallen, the number of grid-connected solar PV systems has grown into the millions and utility-scale solar power stations with hundreds of megawatts are being built. Solar PV is rapidly becoming an inexpensive, low-carbon technology to harness renewable energy from the Sun. The current largest photovoltaic power station in the world is the 850 MW Longyangxia Dam Solar Park, in Qinghai, China.

Commercial concentrated solar power plants were first developed in the 1980s. The 392 MW Ivanpah installation is the largest concentrating solar power plant in the world, located in the Mojave Desert of California

2.2 MAINSTREAM TECHNOLOGIES

Many industrialized nations have installed significant solar power capacity into their grids to supplement or provide an alternative to conventional energy sources while an increasing number of less developed nations have turned to solar to reduce dependence on expensive imported fuels *(see solar power by country)*. Long distance transmission allows remote renewable energy resources to displace fossil fuel consumption. Solar power plants use one of two technologies:

Photovoltaic (PV) systems use solar panels, either on rooftops or in ground-mounted solar farms, converting sunlight directly into electric power.

Concentrated solar power (CSP, also known as "concentrated solar thermal") plants use solar thermal energy to make steam, that is thereafter converted into electricity by a turbine.

2.3 PHOTOVOLTAICS

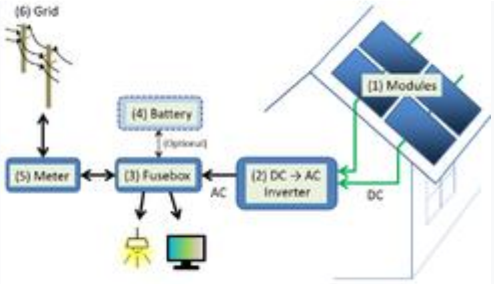


Fig2.3: Schematics of a grid-connected residential PV power system

A solar cell, or photovoltaic cell (PV), is a device that converts light into electric current using the photovoltaic effect. The first solar cell was constructed by Charles Fritts in the 1880s. The German industrialist Ernst Werner von Siemens was among those who recognized the importance of this discovery. In 1931, the German engineer Bruno Lange developed a photo cell using silver selenide in place of copper oxide, although the prototype selenium cells converted less than 1% of incident light into electricity. Following the work of Russell Ohl in the 1940s, researchers Gerald Pearson, Calvin Fuller and Daryl Chapin created the silicon solar cell in 1954. These early solar cells cost 286 USD/watt and reached efficiencies of 4.5–6%.

2.3.1 CONVENTIONAL PV SYSTEMS

The array of a photovoltaic power system, or PV system, produces direct current (DC) power which fluctuates with the sunlight's intensity. For practical use this usually requires conversion to certain desired voltages or alternating current (AC), through the use of inverters. Multiple solar cells are connected inside modules. Modules are wired together to form arrays, then tied to an inverter, which produces power at the desired voltage, and for AC, the desired frequency/phase.

Many residential PV systems are connected to the grid wherever available, especially in developed countries with large markets. In these grid-connected PV systems, use of energy storage is optional. In certain applications such as satellites, lighthouses, or in developing countries, batteries or additional power generators are often added as back-ups. Such stand-alone power systems permit operations at night and at other times of limited sunlight.

2.3.2 CONCENTRATED SOLAR POWER

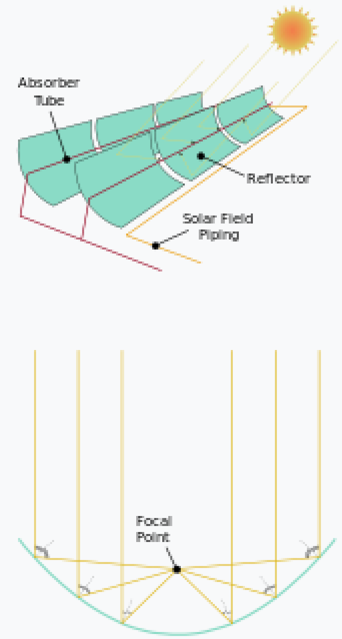


Fig 2.4: A parabolic collector concentrates sunlight onto a tube in its focal point.

Concentrated solar power (CSP), also called "concentrated solar thermal", uses lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Contrary to photovoltaics – which converts light directly into electricity – CSP uses the heat of the sun's radiation to generate electricity from conventional steam-driven turbines.

A wide range of concentrating technologies exists: among the best known are the parabolic trough, the compact linear Fresnel reflector, the Stirling dish and the solar power tower. Various techniques are used to track the sun and focus light. In all of these systems a working fluid is heated by the concentrated sunlight, and is then used for power generation or energy storage. Thermal storage efficiently allows up to 24-hour electricity generation.

A parabolic trough consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line. The receiver is a tube positioned right above the middle of the parabolic mirror and is filled with a working fluid. The reflector is made to follow the sun during daylight hours by tracking along a single axis. Parabolic trough systems provide the best land-use factor of any solar technology. The SEGS plants in California and Acciona's Nevada Solar One near Boulder City, Nevada are representatives of this technology.

Compact Linear Fresnel Reflectors are CSP-plants which use many thin mirror strips instead of parabolic mirrors to concentrate sunlight onto two tubes with working fluid. This has the advantage that flat mirrors can be used which are much cheaper than parabolic mirrors, and that more reflectors can be placed in the same amount of space, allowing more of the available sunlight to be used. Concentrating linear fresnel reflectors can be used in either large or more compact plants.

The Stirling solar dish combines a parabolic concentrating dish with a Stirling engine which normally drives an electric generator. The advantages of Stirling solar over photovoltaic cells are higher efficiency of converting sunlight into electricity and longer lifetime. Parabolic dish systems give the highest efficiency among CSP technologies. The 50 kW Big Dish in Canberra, Australia is an example of this technology.

A solar power tower uses an array of tracking reflectors (heliostats) to concentrate light on a central receiver atop a tower. Power towers are more cost effective, offer higher efficiency and better energy storage capability among CSP technologies. The PS10 Solar Power Plant and PS20 solar power plant are examples of this technology.

2.3.3 HYBRID SYSTEMS

A hybrid system combines (C)PV and CSP with one another or with other forms of generation such as diesel, wind and biogas. The combined form of generation may enable the system to modulate power output as a function of demand or at least reduce the fluctuating nature of solar power and the consumption of non-renewable fuel. Hybrid systems are most often found on islands.

2.3.4 CPV/CSP SYSTEM

A novel solar CPV/CSP hybrid system has been proposed, combining concentrator photovoltaics with the non-PV technology of concentrated solar power, or also known as concentrated solar thermal.

2.3.5 ISCC SYSTEM

The Hassi R'Mel power station in Algeria, is an example of combining CSP with a gas turbine, where a 25-megawatt CSP-parabolic trough array supplements a much larger 130 MW combined cycle gas turbine plant. Another example is the Yazd power station in Iran.

2.3.6 PVT SYSTEM

Hybrid PV/T), also known as photovoltaic thermal hybrid solar collectors convert solar radiation into thermal and electrical energy. Such a system combines a solar (PV) module with a solar thermal collector in an complementary way.

2.3.7 CPVT SYSTEM

A concentrated photovoltaic thermal hybrid (CPVT) system is similar to a PVT system. It uses concentrated photovoltaics (CPV) instead of conventional PV technology, and combines it with a solar thermal collector.

2.3.8 PV DIESEL SYSTEM

It combines a photovoltaic system with a diesel generator. Combinations with other renewable are possible and include wind turbines.

2.3.9 PV-THERMOELECTRIC SYSTEM

Thermoelectric, or "Thermovoltaic" devices convert a temperature difference between dissimilar materials into an electric current. Solar cells use only the high frequency part of the radiation, while the low frequency heat energy is wasted. Several patents about the use of thermoelectric devices in tandem with solar cells have been filed. The idea is to increase the efficiency of the combined solar/thermoelectric system to convert the solar radiation into useful electricity.

2.3.10 EARLY DAYS

The early development of solar technologies starting in the 1860s was driven by an expectation that coal would soon become scarce. Charles Fritts installed the world's first rooftop photovoltaic solar array, using 1%-efficient selenium cells, on a New York City roof in 1884. However, development of solar technologies stagnated in the early 20th century in the face of the increasing availability, economy, and utility of coal and petroleum. In 1974 it was estimated that only six private homes in all of North America were entirely heated or cooled by functional solar power systems. The 1973 oil embargo and 1979 energy crisis caused a reorganization of energy policies around the world and brought renewed attention to developing solar technologies. Deployment strategies focused on incentive programs such as the Federal Photovoltaic Utilization Program in the US and the Sunshine Program in Japan. Other efforts included the formation of research facilities in the United States (SERI, now NREL), Japan (NEDO), and Germany (Fraunhofer–ISE). Between 1970 and 1983 installations of photovoltaic systems grew rapidly, but falling oil prices in the early 1980s moderated the growth of photovoltaics from 1984 to 1996.

2.3.11 MID-1990S TO EARLY 2010S

In the mid-1990s, development of both, residential and commercial rooftop solar as well as utility-scale photovoltaic power stations, began to accelerate again due to supply issues with oil and natural gas, global warming concerns, and the improving economic position of PV relative to other energy technologies. In the early 2000s, the adoption of feed-in tariffs—a policy mechanism, that gives renewables priority on the grid and defines a fixed price for the generated electricity—lead to a high level of investment security and to a soaring number of PV deployments in Europe.

2.3.12 CURRENT STATUS

For several years, worldwide growth of solar PV was driven by European deployment, but has since shifted to Asia, especially China and Japan, and to a growing number of countries and regions all over the world, including, but not limited to, Australia, Canada, Chile, India, Israel, Mexico, South Africa, South Korea, Thailand, and the United States.

Worldwide growth of photovoltaics has averaged 40% per year since 2000 and total installed capacity reached 139 GW at the end of 2013 with Germany having the most cumulative installations (35.7 GW) and Italy having the highest percentage of electricity generated by solar PV (7.0%).The largest manufacturers are located in China.

Concentrated solar power (CSP) also started to grow rapidly, increasing its capacity nearly tenfold from 2004 to 2013, albeit from a lower level and involving fewer countries than solar PV. As of the end of 2013, worldwide cumulative CSP-capacity reached 3,425 MW.

2.3.13 FORECASTS

In 2010, the International Energy Agency predicted that global solar PV capacity could reach 3,000 GW or 11% of projected global electricity generation by 2050—enough to generate 4,500 TWh of electricity. Four years later, in 2014, the agency projected that, under its "high renewables" scenario, solar power could supply 27% of global electricity generation by 2050 (16% from PV and 11% from CSP). In 2015, analysts predicted that one million homes in the U.S. will have solar power by the end of 2016.

2.3.14 ENERGY PAYBACK

The energy payback time (EPBT) of a power generating system is the time required to generate as much energy as is consumed during production and lifetime operation of the system. Due to improving production technologies the payback time has been decreasing constantly since the introduction of PV systems in the energy market. In 2000 the energy payback time of PV systems was estimated as 8 to 11 years and in 2006 this was estimated to be 1.5 to 3.5 years for crystalline silicon silicon PV systems and 1–1.5 years for thin film technologies (S. Europe). These figures fell to 0.75–3.5 years in 2013, with an average of about 2 years for crystalline silicon PV and CIS systems.

Another economic measure, closely related to the energy payback time, is the energy returned on energy invested (EROEI) or energy return on investment (EROI), which is the ratio of electricity generated divided by the energy required to build *and maintain* the equipment. (This is not the same as the economic return on investment (ROI), which varies according to local energy prices, subsidies available and metering techniques.) With expected lifetimes of 30 years, the EROEI of PV systems are in the range of 10 to 30, thus generating enough energy over their lifetimes to reproduce themselves many times (6-31 reproductions) depending on what type of material, balance of system (BOS), and the geographic location of the system.

2.3.15 OTHER ISSUES

One issue that has often raised concerns is the use of cadmium (Cd), a toxic heavy metal that has the tendency to accumulate in ecological food chains. It is used as semiconductor component in CdTe solar cells and as buffer layer for certain CIGS cells in the form of CdS. The amount of cadmium used in thin-film PV modules is relatively small (5–10 g/m²) and with proper recycling and emission control techniques in place the cadmium emissions from module production can be almost zero. Current PV technologies lead to cadmium emissions of 0.3–0.9 microgram/kWh over the whole life-cycle. Most of these emissions actually arise through the use of coal power for the manufacturing of the modules, and coal and lignite combustion leads to much higher emissions of cadmium. Life-cycle cadmium emissions from coal are 3.1 microgram/kWh, lignite 6.2, and natural gas 0.2 microgram/kWh.

In a life-cycle analysis it has been noted, that if electricity produced by photovoltaic panels were used to manufacture the modules instead of electricity from burning coal, cadmium emissions from coal power usage in the manufacturing process could be entirely eliminated.

In the case of crystalline silicon modules, the solder material, that joins together the copper strings of the cells, contains about 36 percent of lead (Pb). Moreover, the paste used for screen printing front and back contacts contains traces of Pb and sometimes Cd as well. It is estimated that about 1,000 metric tonnes of Pb have been used for 100 gigawatts of c-Si solar modules. However, there is no fundamental need for lead in the solder alloy.

Some media sources have reported that concentrated solar power plants have injured or killed large numbers of birds due to intense heat from the concentrated sunrays. This adverse effect does not apply to PV solar power plants, and some of the claims may have been overstated or exaggerated.

A 2014-published life-cycle analysis of land use for various sources of electricity concluded that the large-scale implementation of solar and wind potentially reduces pollution-related environmental impacts. The study found that the land-use footprint, given in square meter-years per megawatt-hour (m^2a/MWh), was lowest for wind, natural gas and rooftop PV, with 0.26, 0.49 and 0.59, respectively, and followed by utility-scale solar PV with 7.9. For CSP, the footprint was 9 and 14, using parabolic troughs and solar towers, respectively. The largest footprint had coal-fired power plants with 18 m^2a/MWh.

2.4 EMERGING TECHNOLOGIES

2.4.1 CONCENTRATOR PHOTOVOLTAICS

Fig 2.5: CPV modules on dual axis solar trackers

Concentrator photovoltaics (CPV) systems employ sunlight concentrated onto photovoltaic surfaces for the purpose of electrical power production. Contrary to conventional photovoltaic systems, it uses lenses and curved mirrors to focus sunlight onto small, but highly efficient, multi-junction solar cells. Solar concentrators of all varieties may be used, and these are often mounted on a solar tracker in order to keep the focal point upon the cell as the sun moves across the sky. Luminescent solar concentrators (when combined with a PV-solar cell) can also be regarded as a CPV system. Concentrated photovoltaics are useful as they can improve efficiency of PV-solar panels drastically.

In addition, most solar panels on spacecraft are also made of high efficient multi-junction photovoltaic cells to derive electricity from sunlight when operating in the inner Solar System.

2.4.2 FLOATOVOLTAICS

Floatovoltaics are an emerging form of PV systems that float on the surface of irrigation canals, water reservoirs, quarry lakes, and tailing ponds. Several systems exist in France, India, Japan, Korea, the United Kingdom and the United States. These systems reduce the need of valuable land area, save drinking water that would otherwise be lost through evaporation, and show a higher efficiency of solar energy conversion, as the panels are kept at a cooler temperature than they would be on land. Although not floating, other dual-use facilities with solar power include fisheries.

2.4.3 GRID INTEGRATION

Fig 2.6: Grid integration

Construction of the Salt Tanks which provide efficient thermal energy storage so that output can be provided after the sun goes down, and output can be scheduled to meet demand requirements. The 280 MW Solana Generating Station is designed to provide six hours of energy storage. This allows the plant to generate about 38 percent of its rated capacity over the course of a year.

Fig 2.7: Thermal energy storage. The Andasol CSP plant uses tanks of molten salt to store solar energy.

Fig 2.8: Pumped-storage hydroelectricity (PSH). This also includes a solar array.

Since solar energy is not available at night, storing its energy is an important issue in order to have continuous energy availability. Both wind power and solar power are variable renewable energy, meaning that all available output must be taken when it is available, and either stored for *when it can be used later*, or transported over transmission lines to *where it can be used now*. Concentrated solar power plants may use thermal energy storage to store the solar energy, such as in high-temperature molten salts. These salts are an effective storage medium because they are low-cost, have a high specific heat capacity, and can deliver heat at temperatures compatible with conventional power systems. This method of energy storage is used, for example, by the Solar Two power station, allowing it to store 1.44 TJ in its 68 m^3 storage tank, enough to provide full output for close to 39 hours, with an efficiency of about 99%.

Rechargeable batteries have been traditionally used to store excess electricity in stand-alone PV systems. With grid-connected photovoltaic power system, excess electricity can be sent to the electrical grid. Net metering and feed-in tariff programs give these systems a credit for the electricity they produce. This credit offsets electricity provided from the grid when the system cannot meet demand, effectively trading with the grid instead of storing excess electricity. Credits are normally rolled over from month to month and any remaining surplus settled annually. When wind and solar are a small fraction of the grid power, other generation techniques can adjust their output appropriately, but as these forms of variable power grow, additional balance on the grid is needed. As prices are rapidly declining, PV systems increasingly use rechargeable batteries to store a surplus to be later used at night. Batteries used for grid-storage stabilize the electrical grid by levelling out peak loads usually for several minutes, and in rare cases for hours. In the future, less expensive batteries could play an important role on the electrical grid, as they can charge during periods when generation exceeds demand and feed their stored energy into the grid when demand is higher than generation.

Although not permitted under the US National Electric Code, it is technically possible to have a “plug and play” PV microinverter. A recent review article found that careful system design would enable such systems to meet all technical, though not all safety requirements. There are several companies selling plug and play solar systems available on the web, but there is a concern that if people install their own it will reduce the enormous labour advantage solar has over fossil fuels.

Common battery technologies used in today's home PV systems include, the valve regulated lead-acid battery– a modified version of the conventional lead–acid battery, nickel–cadmium and lithium-ion batteries. Lead-acid batteries are currently the predominant technology used in small-scale, residential PV systems, due to their high reliability, low self-discharge and investment and maintenance costs, despite shorter lifetime and lower energy density. However, lithium-ion batteries have the potential to replace lead-acid batteries in the near future, as they are being intensively developed and lower prices are expected due to economies of scale provided by large production facilities such as the Gigafactory 1. In addition, the Li-ion batteries of plug-in electric cars may serve as a future storage devices in a vehicle-to-grid system. Since most vehicles are parked an average of 95 percent of the time, their batteries could be used to let electricity flow from the car to the power lines and back. Other rechargeable batteries used for distributed PV systems include, sodium–sulfur and vanadium redox batteries, two prominent types of a molten salt and a flow battery, respectively.

Conventional hydroelectricity works very well in conjunction with variable electricity sources such as solar and wind, the water can be held back and allowed to flow as required. Where a suitable river is not available, pumped-storage hydroelectricity stores energy in the form of water pumped when surplus electricity is available, from a lower elevation reservoir to a higher elevation one. The energy is recovered when demand is high by releasing the water through a hydroelectric power generator. However, this cycle can lose 20% of the energy to round trip inefficiencies.

The combination of wind and solar PV has the advantage that the two sources complement each other because the peak operating times for each system occur at different times of the day and year. The power generation of such solar hybrid power systems is therefore more constant and fluctuates less than each of the two component subsystems. Solar power is seasonal, particularly in northern/southern climates, away from the equator, suggesting a need for long term seasonal storage in a medium such as hydrogen or pumped hydroelectric. The Institute for Solar Energy Supply Technology of the University of Kassel pilot-tested a combined power plant linking solar, wind, biogas and hydro storage to provide load-following power from renewable sources.

Research is also undertaken in this field of artificial photosynthesis. It involves the use of nanotechnology to store solar electromagnetic energy in chemical bonds, by splitting water to produce hydrogen fuel or then combining with carbon dioxide to make biopolymers such as methanol. Many large national and regional research projects on artificial photosynthesis are now trying to develop techniques integrating improved light capture, quantum coherence methods of electron transfer and cheap catalytic materials that operate under a variety of atmospheric conditions. Senior researchers in the field have made the public policy case for a Global Project on Artificial Photosynthesis to address critical energy security and environmental sustainability issues

2.5 WIND ENERGY

2.5.1 WIND ENERGY AND WIND POWER

Wind is a form of **solar energy.** Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern **wind turbines**, can be used to generate **electricity.**

2.5.2 HOW WIND POWER IS GENERATED

The terms "**wind energy**" or "**wind power"** describe the process by which the wind is used to generate **mechanical power or electricity**. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

2.5.3 WIND TURBINES

Wind turbines, like aircraft propeller blades, turn in the moving air and power an **electric generator** that supplies an electric current. Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.

2.5.4 WIND TURBINE TYPES

Modern wind turbines fall into two basic groups; the **horizontal-axis** variety, like the traditional farm windmills used for pumping water, and the **vertical-axis** design, like the eggbeater-style Darrieus model, named after its French inventor. Most large modern wind turbines are horizontal-axis turbines.

2.5.5 TURBINE COMPONENTS

Horizontal turbine components include:

- **blade or rotor,** which converts the energy in the wind to rotational shaft energy;
- a **drive train**, usually including a gearbox and a generator;
- a **tower** that supports the rotor and drive train; and
- Other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.

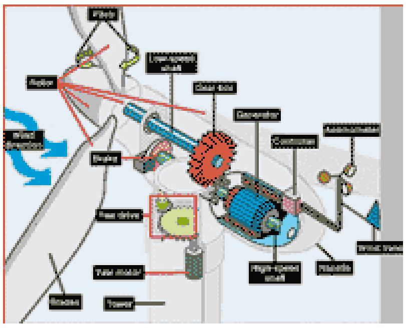


Fig 2.6: Grid integration

2.5.6 TURBINE CONFIGURATIONS

Wind turbines are often grouped together into a single wind power plant, also known as a **wind farm,** and generate bulk electrical power. Electricity from these turbines is fed into a utility grid and distributed to customers, just as with conventional power plants.

2.5.7 WIND TURBINE SIZE AND POWER RATINGS

Wind turbines are available in a variety of sizes, and therefore power ratings. The largest machine has blades that span more than the length of a football field, stands 20 building stories high, and produces enough electricity to power 1,400 homes. A small home-sized wind machine has rotors between 8 and 25 feet in diameter and stands upwards of 30 feet and can supply the power needs of an all-electric home or small business.

Utility-scale turbines range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications dishes, or water pumping.

2.5.8 WIND ENERGY RESOURCES IN THE UNITED STATES

Wind energy is very abundant in many parts of the United States. Wind resources are characterized by **wind-power density classes**, ranging from class 1 (the lowest) to class 7 (the highest). Good wind resources (e.g., class 3 and above, which have an average annual wind speed of at least 13 miles per hour) are found in many locations (see United States Wind Energy Resource Map). Wind speed is a critical feature of wind resources, because the energy in wind is proportional to the **cube** of the wind speed. In other words, a stronger wind means a lot more power.

2.5.9 A RENEWABLE NON-POLLUTING RESOURCE

Wind energy is a **free, renewable resource**, so no matter how much is used today, there will still be the same supply in the future. Wind energy is also a source of **clean, non-polluting, electricity.** Unlike conventional power plants, wind plants emit no air pollutants or greenhouse gases. According to the U.S. Department of Energy, in 1990, California's wind power plants offset the emission of more than 2.5 billion pounds of carbon dioxide, and 15 million pounds of other pollutants that would have otherwise been produced. It would take a forest of 90 million to 175 million trees to provide the same air quality.

2.5.10 COST ISSUES

Even though the cost of wind power has decreased dramatically in the past 10 years, the technology requires a **higher initial investment** than fossil-fueled generators. Roughly 80% of the cost is the machinery, with the balance being site preparation and installation. If wind generating systems are compared with fossil-fueled systems on a "life-cycle" cost basis (counting fuel and operating expenses for the life of the generator), however, wind costs are much more competitive with other generating technologies because there is no fuel to purchase and minimal operating expenses.

2.5.11 ENVIRONMENTAL CONCERNS

Although wind power plants have relatively little impact on the environment compared to fossil fuel power plants, there is some concern over the **noise** produced by the rotor blades, **aesthetic (visual) impacts**, and birds and bats having been killed (**avian/bat mortality**) by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.

2.5.12 SUPPLY AND TRANSPORT ISSUES

The major challenge to using wind as a source of power is that it **is intermittent** and does not always blow when electricity is needed. Wind cannot be stored (although wind-generated electricity can be stored, if batteries are used), and not all winds can be harnessed to meet the timing of electricity demands. Further, good wind sites are often located in **remote locations** far from areas of electric power demand (such as cities). Finally, wind resource development may compete with other uses for the land, and those **alternative uses** may be more highly valued than electricity generation. However, wind turbines can be located on land that is also used for grazing or even farming.

2.6 FOR MORE INFORMATION

Much additional information on wind energy science and technology and wind energy development issues is available through the Web. Visit the Wind Energy Links page to access sites with more information. In particular, the DOE Wind Energy Technologies page has good information on wind energy basics, and is the source for much of the information presented here. The American Wind Energy Association web site has an excellent FAQ page with information about wind technology, and the Danish Wind Industry Association web site has extensive information about wind energy and technology, including a 28-minute video introducing wind technology.

Air flow through wind turbines or sails can produce significant mechanical power. Windmills are used for their mechanical power, wind pumps for water pumping, and sails to propel ships, but the most frequent current use is to turn a generator for electrical power. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, and uses little land. The net effects on the environment are far less problematic than those of non-renewable power sources.

Fig 2.10: Wind Turbines

Wind farms consist of many individual wind turbines which are connected to the electric power transmission network. Onshore wind is an inexpensive source of electricity, competitive with or in many places cheaper than coal or gas plants. Offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance costs are considerably higher. Small onshore wind farms can feed some energy into the grid or provide electricity to isolated off-grid locations.

Wind power is very consistent from year to year but has significant variation over shorter time scales. It is therefore used in conjunction with other electric power sources to give a reliable supply. As the proportion of wind power in a region increases, a need to upgrade the grid and a lowered ability to supplant conventional production can occur. Power management techniques such as having excess capacity, geographically distributed turbines, dispatch able backing sources, sufficient hydroelectric power, exporting and importing power to neighbouring areas, using vehicle-to-grid strategies or reducing demand when wind production is low, can in many cases overcome these problems. In addition, weather forecasting permits the electricity network to be readied for the predictable variations in production that occur.

As of 2015, Denmark generates 40% of its electricity from wind, and at least 83 other countries around the world are using wind power to supply their electricity grids. Wind power capacity has expanded to 369,553 MW by December 2014, and total wind energy production is growing rapidly and has reached around 4% of worldwide electricity usage.

2.6.1 HISTORY

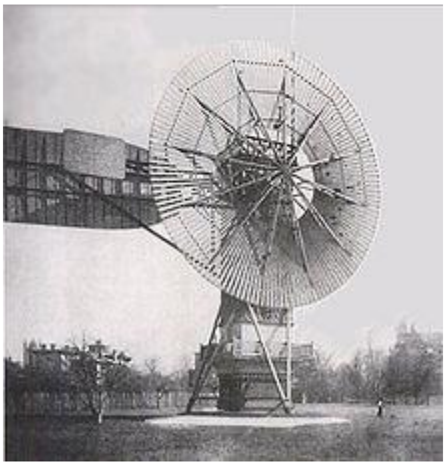


Fig 2.11: Charles Brush's windmill of 1888, used for generating electricity.

Wind power has been used as long as humans have put sails into the wind. For more than two millennia wind-powered machines have ground grain and pumped water. Wind power was widely available and not confined to the banks of fast-flowing streams, or later, requiring sources of fuel. Wind-powered pumps drained the polders of the Netherlands, and in arid regions such as the American mid-west or the Australian outback, wind pumps provided water for livestock and steam engines.

With the development of electric power, wind power found new applications in lighting buildings remote from centrally-generated power. Throughout the 20th century parallel paths developed small wind stations suitable for farms or residences, and larger utility-scale wind generators that could be connected to electricity grids for remote use of power. Today wind powered generators operate in every size range between tiny stations for battery charging at isolated residences, up to near-giga watt sized offshore wind farms that provide electricity to national electrical networks.

A wind farm is a group of wind turbines in the same location used for production of electricity. A large wind farm may consist of several hundred individual wind turbines distributed over an extended area, but the land between the turbines may be used for agricultural or other purposes. For example, Gansu Wind Farm, the largest wind farm in the world, has several thousand turbines. A wind farm may also be located offshore.

Almost all large wind turbines have the same design a horizontal axis wind turbine having an upwind rotor with three blades, attached to a nacelle on top of a tall tubular tower.

In a wind farm, individual turbines are interconnected with a medium voltage (often 34.5 kV), power collection system and communications network. At a substation, this medium-voltage electric current is increased in voltage with a transformer for connection to the high voltage electric power transmission system.

2.6.2 GENERATOR CHARACTERISTICS AND STABILITY

Induction generators, which were often used for wind power projects in the 1980s and 1990s, require reactive power for excitation so substations used in wind-power collection systems include substantial capacitor banks for power factor correction. Different types of wind turbine generators behave differently during transmission grid disturbances, so extensive modelling of the dynamic electromechanical characteristics of a new wind farm is required by transmission system operators to ensure predictable stable behaviour during system faults. In particular, induction generators cannot support the system voltage during faults, unlike steam or hydro turbine-driven synchronous generators.

Today these generators aren't used any more in modern turbines. Instead today most turbines use variable speed generators combined with partial- or full-scale power converter between the turbine generator and the collector system, which generally have more desirable properties for grid interconnection and have Low voltage ride through-capabilities. Modern concepts use either doubly fed machines with partial-scale converters or squirrel-cage induction generators or synchronous generators (both permanently and electrically excited) with full scale converters.

Transmission systems operators will supply a wind farm developer with a grid code to specify the requirements for interconnection to the transmission grid. This will include power factor, constancy of frequency and dynamic behaviour of the wind farm turbines during a system fault.

2.6.3 OFFSHORE WIND POWER

The world's second full-scale floating wind turbine (and first to be installed without the use of heavy-lift vessels), Wind Float, operating at rated capacity (2 MW) approximately 5 km offshore of Póvoa de Varzim, Portugal

Main articles: Offshore wind power and List of offshore wind farms.

Fig 2.12: Offshore Wind Power

Offshore wind power refers to the construction of wind farms in large bodies of water to generate electricity. These installations can utilize the more frequent and powerful winds that are available in these locations and have less aesthetic impact on the landscape than land-based projects. However, the construction and the maintenance costs are considerably higher.

Siemens and Vestas are the leading turbine suppliers for offshore wind power. DONG Energy, Vattenfall and E.ON are the leading offshore operators. As of October 2010, 3.16 GW of offshore wind power capacity was operational, mainly in Northern Europe. According to BTM Consult, more than 16 GW of additional capacity will be installed before the end of 2014 and the UK and Germany will become the two leading markets. Offshore wind power capacity is expected to reach a total of 75 GW worldwide by 2020, with significant contributions from China and the US.

2.6.4 COLLECTION AND TRANSMISSION NETWORK

In a wind farm, individual turbines are interconnected with a medium voltage (usually 34.5 kV) power collection system and communications network. At a substation, this medium-voltage electric current is increased in voltage with a transformer for connection to the high voltage electric power transmission system.

A transmission line is required to bring the generated power to (often remote) markets. For an off-shore plant this may require a submarine cable. Construction of a new high-voltage line may be too costly for the wind resource alone, but wind sites may take advantage of lines installed for conventionally fuelled generation.

One of the biggest current challenges to wind power grid integration in the United States is the necessity of developing new transmission lines to carry power from wind farms, usually in remote lowly populated states in the middle of the country due to availability of wind, to high load locations, usually on the coasts where population density is higher. The current transmission lines in remote locations were not designed for the transport of large amounts of energy. As transmission lines become longer the losses associated with power transmission increase, as modes of losses at lower lengths are exacerbated and new modes of losses are no longer negligible as the length is increased, making it harder to transport large loads over large distances. However, resistance from state and local governments makes it difficult to construct new transmission lines. Multi state power transmission projects are discouraged by states with cheap electricity rates for fear that exporting their cheap power will lead to increased rates. A 2005 energy law gave the Energy Department authority to approve transmission projects states refused to act on, but after an attempt to use this authority, the Senate declared the department was being overly aggressive in doing so. Another problem is that wind companies find out after the fact that the transmission capacity of a new farm is below the generation capacity, largely because federal utility rules to encourage renewable energy installation allow feeder lines to meet only minimum standards. These are important issues that need to be solved, as when the transmission capacity does not meet the generation capacity, wind farms are forced to produce below their full potential or stop running all together, in a process known as curtailment. While this leads to potential renewable generation left untapped, it prevents possible grid overload or risk to reliable service.

2.6.5 GROWTH TRENDS

In 2010, more than half of all new wind power was added outside of the traditional markets in Europe and North America. This was largely from new construction in China, which accounted for nearly half the new wind installations (16.5 GW). Global Wind Energy Council (GWEC) figures show that 2007 recorded an increase of installed capacity of

20 GW, taking the total installed wind energy capacity to 94 GW, up from 74 GW in 2006. Despite constraints facing supply chains for wind turbines, the annual market for wind continued to increase at an estimated rate of 37%, following 32% growth in 2006. In terms of economic value, the wind energy sector has become one of the important players in the energy markets, with the total value of new generating equipment installed in 2007 reaching €25 billion, or US$36 billion.

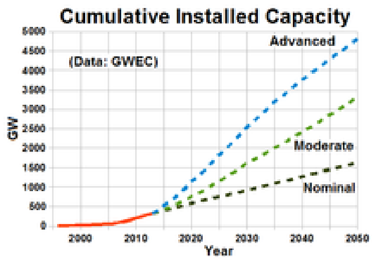


Fig 2.13: Worldwide installed wind power capacity forecast (Source: Global Wind Energy Council)

Although the wind power industry was affected by the global financial crisis in 2009 and 2010, a BTM Consult five-year forecast up to 2013 projects substantial growth. Over the past five years the average growth in new installations has been 27.6% each year. In the forecast to 2013 the expected average annual growth rate is 15.7%. More than 200 GW of new wind power capacity could come on line before the end of 2014. Wind power market penetration is expected to reach 3.35% by 2013 and 8% by 2018.

In 2013 wind power constituted 13% of installed power generation capacity in the EU and generated 7.8% of power used.

CHAPTER-III

BATTERY

CHAPTER III

BATTERY

In this tutorial, we will learn about one of the important components in Electrical and Electronic Systems: A Battery. We will see some basic information about a battery, take a look at different types of Batteries and also a guide on what Battery Type is suitable for your application.

3.1 BATTERY INTRODUCTION

Whether you are an Electrical Engineer or not, you might have come across at least a couple of different types of batteries in your life. Some of the common places where you use batteries are a wall clocks, alarms or smoke detectors, which uses small disposable batteries or cars, trucks or motor cycles, which uses relatively large rechargeable batteries.

Batteries have become a very important source of energy in the last decade or so. Even before that, they were an integral part of our lives in powering several portable devices like transistor radios, Walkman, handheld games, cameras etc.

But with the development in advanced smart phones, tablets, laptops, solar energy and electric vehicles, the research into powerful batteries that can last longer and can deliver the necessary energy has been at its peak.

As a matter of fact, the 2019 Nobel Prize in Chemistry has been awarded to three scientists John B. Goodenough, M. Stanley Whittingham and Akira Yoshino for the development of lithium-ion batteries.

3.1.1 WHAT IS A BATTERY?

A Battery is a chemical device that stores electrical energy in the form of chemicals and by means of electrochemical reaction, it converts the stored chemical energy into direct current (DC) electric energy. Alessandro Volta, an Italian Physicist, invented the first battery in 1800.

The electrochemical reaction in a battery involves transfer of electrons from one material to another (called electrodes) through an electric current.

3.1.2 CELL AND BATTERY

Even though the term battery is often used, the basic electrochemical unit responsible for the actual storage of energy is called a Cell. A Cell, as just mentioned, is the fundamental electrochemical unit that is the source of electrical energy produced by conversion of chemical energy.

In its basic form, a cell typically contains three main components: two electrodes and electrolyte and also consists of terminals, separator and a container. Speaking of electrodes, there are two types of electrodes called the Anode and the Cathode.

The Anode is the negative electrode (also called the Fuel Electrode or the Reducing Electrode). It loses electrons to the external circuit and in the electrochemical reaction, it gets oxidized.

Cathode on the other hand, is the positive electrode (also called the Oxidizing Electrode). It accepts electrons from the eternal circuit and in the electrochemical reaction, it gets reduced. Hence, the energy conversion in a battery is due to electrochemical oxidation-reduction reaction.

The third important component of a cell is the electrolyte. An electrolyte acts as medium for transfer of charge in the form of ions between the two electrodes. Hence, the electrolyte is sometime referred to as Ionic Conductor. An important point to be noted here that the electrolyte is not electrically conductive but just have ionic conductivity.

A battery often consists of one or more “cells” that are electrically connected in either a series or parallel configuration to provide the necessary voltage and current levels.

3.2 DIFFERENT TYPES OF BATTERIES

Basically, all the electrochemical cells and batteries are classified into two types:

i. Primary (non-rechargeable)
ii. Secondary (rechargeable)

Even though there are several other classifications within these two types of batteries, these two are the basic types. Simply speaking, Primary Batteries are non-rechargeable batteries i.e., they cannot be recharged electrically while the Secondary Batteries are rechargeable batteries i.e., they can be recharged electrically.

Battery Type	Characteristics	Applications
Zinc – Carbon	Common, low cost, variety of sizes	Radios, toys, instruments
Magnesium (Mg/MnO2)	High capacity, long shelf life	Military and aircraft Radios
Mercury (Zn/HgO)	Very high capacity, long shelf life	Medical (hearing aids, pacemakers), photography
Alkaline (Zn/Alkaline/MnO2)	Very popular, moderate cost, high performance	Most popular primary batteries
Silver/Zinc (Zn/Ag2O)	Highest capacity, costly, flat discharge	Hearing aids, photography, pagers
Lithium/Soluble Cathode	High energy density, good performance, wide temp range	Wide range of applications with capacity between 1 – 10,000 Ah
Lithium/Solid Cathode	High energy density, low temp performance, long shelf life	Replacement for button and cylindrical cells

Lithium/Solid Electrolyte	Low power, extremely long shelf life	Memory circuits, medical electronics

Table2.1 Different Types of Batteries

3.2.1 PRIMARY BATTERY

A Primary Battery is one of the simple and convenient sources of power for several portable electronic and electrical devices like lights, cameras, watches, toys, radios etc. As they cannot be recharged electrically, they are of "use it and when discharged, discard it" type.

Usually, primary batteries are inexpensive, light weight, small and very convenient to use with relatively no or less maintenance. Majority of the primary batteries that are used in domestic applications are single cell type and usually come in cylindrical configuration (although, it is very easy to produce them in different shapes and sizes).

3.2.2 COMMON PRIMARY BATTERY TYPES

Up until the 1970's, Zinc anode-based batteries were the predominant primary battery types. During the 1940's, the World War II and after the war, Zinc – Carbon based batteries and they have an average capacity of 50 Wh / kg.

Most significant development in the battery technology took place during the 1970 – 1990 period. It is during this time, the famous Zinc / Alkaline Manganese Dioxide batteries were developed and they slowly replaced the older Zinc – Carbon types as the main primary battery.

Fig 3.1: Primary Battery

Zinc – Mercuric Oxide and Cadmium – Mercuric Oxide batteries were also used during this period but due to the environmental concerns with respect to the usage of Mercury, these battery types slowly phased out.

It is during this period, where the development of batteries with Lithium as active anode material has been started and is considered a major accomplishment due to the high specific energy and longer shelf life of Lithium batteries over traditional Zinc batteries.

Lithium batteries are manufactured as button and coin cell for a specific range of applications (like watches, memory backup, etc.) while larger cylindrical type batteries are also available.

The following table shows different types of primary batteries along with their characteristics and applications.

3.2.3 SECONDARY BATTERIES

A Secondary Battery is also called as Rechargeable Battery as they can be electrically recharged after discharge. The chemical status of the electrochemical cells can be "recharged" to their original status by passing a current through the cells in the opposite direction of their discharge.

Basically, secondary batteries can be used in two ways:

In the first category of applications, the secondary batteries are essentially used as energy storage devices where they are electrically connected to a main energy source and also charged by it and also supplying energy when required. Examples of such applications are Hybrid Electric Vehicles (HEV), Uninterrupted Power Supplies (UPS), etc.

The second category of applications of secondary batteries are those applications where the battery is used and discharged as a primary battery. Once it is completely discharged (or almost completely discharged), instead of discarding it, the battery is recharged with an appropriate charging mechanism. Examples of such applications are all the modern portable electronics like mobiles, laptops, electric vehicles, etc.

Energy Density of secondary batterie are relatively lower than that of primary batteries but have other good characteristics like high power density, flat discharge curves, high discharge rate, low temperature performance.

3.2.4 COMMON SECONDARY BATTERY TYPES

Two of the oldest batteries are in fact secondary batteries called the Lead – Acid Batteries, which were developed in late 1850's and Nickel – Cadmium Batteries, which were developed in early 1900's. Until recent times, there are only two types of secondary batteries.

The first and the most commonly used rechargeable batteries are called Lead – Acid Batteries. They are based on the Lead – Lead Dioxide (Pb – PbO2) electrochemical couple. The electrolyte used in these types of batteries is the very common Sulfuric Acid.

The second type of the rechargeable batteries are called Nickel – Cadmium Batteries. They are based on Nickel Oxyhydroxide (Nickel Oxide) as the positive electrode and Cadmium metal based negative electrode. Coming to the electrolyte, an alkaline solution of Potassium Hydroxide is used.

In the recent decades, two new types of rechargeable batteries have emerged. They are the Nickel – Metal Hydride Battery and the Lithium – Ion Battery. Of these two, the lithium – ion battery came out to be a game changer and became commercially superior with its high specific energy and energy density figures (150 Wh / kg and 400 Wh / L).

There are some other types of Secondary Batteries but the four major types are:

i. Lead – Acid Batteries
ii. Nickel – Cadmium Batteries
iii. Nickel – Metal Hydride Batteries
iv. Lithium – Ion Batteries
v. Let us now briefly see about these battery types individually.

3.2.5 LEAD – ACID BATTERIES

The lead-acid batteries are by far the most popular and most used rechargeable batteries. They have been a successful product for more than a century. Lead-acid batteries are available in several different configurations like small sealed cells with capacity of 1 Ah to large cells with capacity of 12,000 Ah.

One of the major applications od lead-acid batteries are in the automotive industry as they are primarily used as SLI Batteries (Starting, Lighting and Ignition).

Other applications of lead-acid batteries include energy storage, emergency power, electric vehicles (even hybrid vehicles), communication systems, emergency lighting systems, etc.

The wide range of applications of lead-acid batteries are a result of its wide voltage ranges, different shapes and sizes, low cost and relatively easy maintenance. When compared to other secondary battery technologies, lead-acid batteries are the least expensive option for any application and provide very good performance.

Electrical efficiency of lead-acid batteries is between 75 to 80%. This efficiency value them suitable for energy storage (Uninterrupted Power Supplies – UPS) and electric vehicles.

3.2.6 NICKEL – CADMIUM BATTERIES

The Nickel – Cadmium Batteries or simply Ni-Cd Batteries are one of the oldest battery types available today along with the lead-acid batteries. They have a very long life and are very reliable and sturdy.

Fig 3.2: Nickel-Cadmium Batteries

One of the main advantages of Ni-Cd Batteries is that they can be subjected to high discharge rates and they can be operated over a wide range of temperatures. Also, the shelf life of Ni-Cd batteries is very long. The cost of these batteries is higher that lead-acid batteries on per Watt-hour basic but it is less that other type of alkaline batteries.

As mentioned earlier, the Ni-Cd batteries use Nickel Oxyhydroxide (NiOOH) as Cathode and Cadmium metal (Cd) as anode. Typical consumer grade batteries come with an on-line voltage of 1.2V. In industrial applications, Ni-Cd are just second to lead-acid batteries due to their low temperature performances, flat discharge voltage, long life, low maintenance and excellent reliability.

Unfortunately, there is one major characteristic of Ni-Cd batteries called the "memory effect", which is their only disadvantage. When Ni-Cd cells are discharged partially and then recharged, they lose their capacity progressively i.e., cycle-by-cycle. "Conditioning" is the process where the lost capacity of the batteries can be restored.

In this process, the cells are completely discharged to zero volts and then fully recharged.

3.2.7 NICKEL – METAL HYDRIDE BATTERIES

These are relatively new type of batteries are an extended version of Nickel – Hydrogen Electrode Batteries, which were exclusively used in aerospace applications (satellites). The positive electrode is the Nickel Oxyhydroxide (NiOOH) while the negative electrode of the cell is a metal alloy, where hydrogen is stored reversibly.

Fig 3.3: Nickel-Meta Hydride Batteries

During charge, the metal alloy absorbs the hydrogen to form metal hydride and while discharge, the metal hydride loses hydrogen.

One main advantage of Nickel-metal hydride batteries over Ni-Cd batterie its higher specific energy and energy density. Sealed Nickel-metal hydride batteries are available commercially as small cylindrical cells and are used in portable electronics.

3.2.8 LITHIUM – ION BATTERIES

The emergence of lithium-ion batteries in the last couple of decades has been quite phenomenal. More than 50% of the consumer market has adopted the use of lithium-ion batteries. Particularly, laptops, mobile phones, cameras, etc. are the largest applications of lithium-ion batteries.

Fig 3.4: Lithium-ion Batteries

Lithium-ion batteries have significantly high energy density, high specific energy and longer cycle life. Other main advantages of lithium-ion batteries are slow self-discharge rate and wide range of operating temperatures.

3.3 BATTERY APPLICATIONS

In the last few decades, the usage of small sealed batteries in consumer applications has been exponential. Primary or rechargeable batteries in small form factor are being used in a huge number of appliances. Some of them are mentioned below.

Portable Electronic Devices: Watches, Cameras, Mobile Phones, Laptops, Camcorders, Calculators, testing equipment (Multimeters).

Entertainment: Radios, MP3 players, CD Players, all infrared remote controls, toys, games, keyboards.

Household: Clocks, Alarms, Smoke Detectors, Flash lights, UPS, Emergency lights, tooth brushes, hair trimmers and shavers, Blood Pressure Monitors, Hearing Aids, pacemakers, portable power tools (drills, screw driver).

3.4 HOW TO CHOOSE A BATTERY?

Selecting a battery for your application can be dialled down to just two characteristics: Performance and Cost. But if we dig a little bit deeper, then the following are determining factors in choosing the right battery for your application.

- Primary or Secondary
- Energy or Power
- Shelf Life
- Energy Efficiency and Recharge Rate
- Battery Life
- Battery Temperature

3.5 CONCLUSION

This was a brief introduction to Battery, Different Types of Batteries, Primary and Secondary Batteries, Rechargeable and Non-Rechargeable Batteries and also few common applications of each type of battery.

3.6 SUPER CAPACITOR (SC)

An ultra-capacitor is a type of super capacitor. The electrode and electrolyte characteristics, rather than a dielectric material, are responsible for charge separation. An electric potential is formed in the system when an electric current is delivered, much like a typical capacitor. However, this potential occurs between the substrate's surface and the ions in the electrolyte solution. In the middle, the solvent acts as a dielectric medium. The Helmholtz layer is a thin dielectric layer that is only one or two molecules thick. We can see from the calculations that this increases capacitance and the amount of energy that can be stored. Supercapacitors can also attain high power densities by keeping the low ESR characteristic of regular capacitors. The schematic of a charged supercapacitor is given in Figure 3.4.

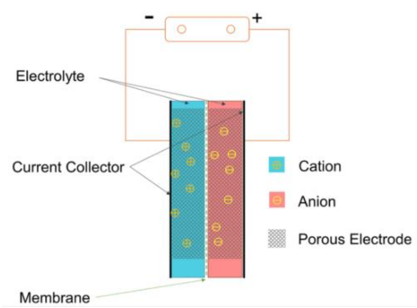


Fig 3.5: Super capacitor

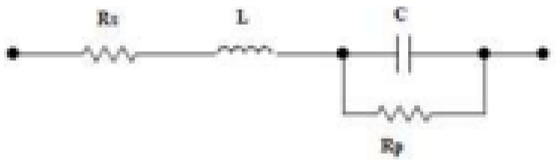
The supercapacitor has a very high-power density, exceeding 10kW/kg compared to 0.4kW/kg for batteries. Because of this feature, the supercapacitor extremely useful in applications where there is a need for fast charging and discharging like in regenerative braking of vehicles, elevators and cranes. It is also useful in applications where high power is required for short durations like electric drills, toys, and sensors. Even though the energy density of a supercapacitor is less than mid to high-end batteries and fuel cells, supercapacitor have been used in high energy applications like utility and grid storage.

3.6.1 TYPES OF SUPER CAPACITORS

- Hybrid capacitors
- Electrochemical pseudo capacitors
- Electrostatic double-layer capacitors

3.6.2 MODELLING OF THE SUPERCAPACITOR

The supercapacitor equivalent circuit design by using conventional capacitor model. The first order semantic circuit diagram of super capacitor in shown for fig 3.5.



3.6: The first order circuit model of a super capacitor

In this circuit explained some elements of super capacitor in above diagram, it is

C= capacitance

R_s= series resistance

R_p= parallel resistance

L= inductance

Charging and discharging time also series resistance called by equivalent series resistance and parallel resistance called by leakage current resistance and it is energy loss taken from capacitance discharge. Parallel resistance high value in compare to series resistance. So parallel resistance neglected for high power applications.

The fig 3.5 shown for the basic circuit diagram supercapacitor, and this model based on double layer capacitor technology. The model design by two activated porous carbon-based electrodes ant in this model occupied by palace in two thousand square-meters per gram. In this model porous model connected for transmission system have more resistance and capacitance, in fig 3.6 shows for the equivalent circuit of porous model connected transmission line system. In this model voltage value depends on the destitution side capacitance.

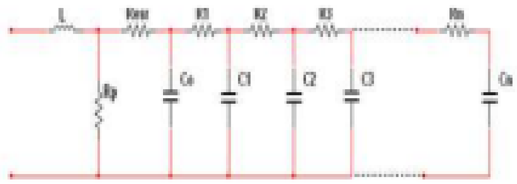


Fig 3.7: Exact equivalent circuit of the SC

In this diagram 3.7 shown for the equivalent circuit supercapacitor model. In this model negated for slow branch RC values in the diagram of 3.6. In classical model of upper capacitor model shown in fig 3.7 it is used for calculated for capacitor performance in the all charge and discharge application. In this model used analysis this working of supercapacitor.

The voltage of the supercapacitor is collected by capacitance supercapacitor cell, the content and variable capacitance value based the voltage of cell measured.

Hence, the equivalent capacitance of supercapacitor is;

$$C_{cell} = C_o + kV_c \qquad 10$$

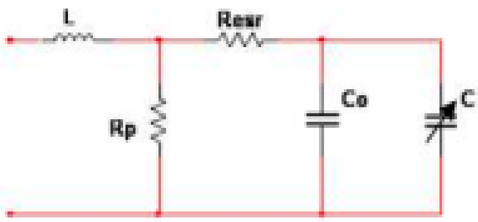


Fig3.8: Simplified equivalent circuit of the super capacitor

Resr = equivalent series

Rp = equivalent parallel

Rp > Resr

L = inductor

The supercapacitor overall model for series connection of 18 supercapacitor cell, each one cell 2.7 in operating voltage, finally overall voltage is 48.6V. The parallel resistance negated in this system any explain for below exuviations.

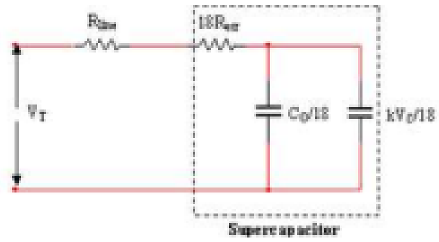


Fig 3.9: BMOD0140-E048 SC comparable circuit derived from a MAXWELL 48V series

Series Total capacitance is:

$$C_{total} = \frac{1}{\frac{1}{C_{cell1}}+\frac{1}{C_{cell2}}+\frac{1}{C_{cell3}}\cdots\frac{1}{C_{cell18}}} \qquad 11$$

$$C_{total} = \frac{1}{18}C_{cell} = \frac{1}{18}(C_o + kV_c) \qquad 12$$

total equivalent series resistance is:

$$R_{ESR} = 18(R_{esr})$$

Appling for Kirchhoff's low in fig 3.8

Supercapacitor charging equation is:

$$(R_{line} + R_{ESR})i + \frac{1}{C_{total}}\int idt = V_T \qquad 13$$

Using differential method of terms of charger(q);

$$(R_{line} + R_{ESR})\frac{dq}{dt} + \frac{1}{C_{total}}q = V_T \qquad 14$$

In q=CV

voltage of the supercapacitor (V_c):

$$(R_{line} + R_{esr})(C_o + 2kV_c)\frac{dv_c(t)}{dt} + V_c(t) = V_T \qquad 15$$

Or

$$\frac{dv_c}{dt} = \frac{V_T - V_c}{(R_{line}+R_{esr})(C_o+2kV_c)} \qquad 16$$

internal resistance;

$$R_{ESR}i(t) + \frac{1}{C_{total}}\int i(t)dt = V_T \qquad 17$$

At the instant of switching, t=0;

$$R_{ESR}i(t) - \frac{1}{C_{total}}\int i(t)dt = V_0 \qquad 18$$

Multiply by C_{total} and take derivatives

$$C_{total}R_{ESR}i(t)\frac{di(t)}{dt} - i(t) = 0 \qquad 19$$

$V_r(t)$=Ri(t) and both side Appling for R_{ESR}

$$R_{ESR}C_{total}\frac{dv_r(t)}{dt} - v_r(t) = 0 \qquad 20$$

And the solution of above equation is,

$$v_r(t) = ke^{\frac{1}{R_{ESR}C_{total}}} \qquad 21$$

Hence, the voltage across the terminal of the supercapacitor is,

$$v_t(t) = v_r(t) + v_c(t) \qquad 22$$

And for discharging a supercapacitor, the equation is;

$$\frac{dv_c}{dt} = \frac{-(v_c)}{(R_{line}+R_{esr})(C_o+2kV_c)} \qquad 23$$

Supercapacitor in discharging terminal voltage

$$v_t(t) = v_r(t) + v_c(t) \qquad 24$$

3.6.3 ADVANTAGES OF SUPER CAPACITORS

- Backup and peak power provide
- Battery life time increased
- Small size
- Less weight
- Low cost
- Working for low and high temperature

3.6.4 DISADVANTAGE OF SUPER CAPACITOR

- Self-discharge rate is high
- Low voltage
- Energy density is low

3.6.5APPLICATION OF SUPER CAPACITOR

- Digital camera
- Electric vehicle
- Regenerative braking system
- Low power devices
- Electrical and electronic devices

CHAPTER-IV

BOOST CONVERTER

CHAPTER IV

BOOST CONVERTER

4.1 BOOST CONVERTER INTRODUCTION

A DC-to-DC converter is an electronic circuit or electromechanical device that converts a source of direct current (DC) from one voltage level to another. It is a type of electric power converter. Power levels range from very low (small batteries) to very high (high-voltage power transmission).

- A dc chopper converts fixed dc input voltage to a controllable dc output voltage.
- The chopper circuits require forced, or load commutation to turn-off the SCR.
- For low power circuits we can use Power BJTs. Choppers are used in dc drives, battery driven vehicles etc.

The terms DC–DC converters and choppers are one and same. In the texts usually these terms are interchanged.

The Choppers can be operated in either a continuous or discontinuous current conduction mode.

They can be built with and without electrical isolation.

Chopper - Definition:

A chopper is a static device that converts fixed dc input voltage to a variable dc output voltage directly.

- A chopper is considered as DC equivalent of an AC transformer since it behaves in an identical manner.
- The choppers are more efficient as they involve in one stage conversion.
- The choppers are used in trolley cars, marine hoists, forklift trucks and mine hauler.
- The future electric automobiles are likely to use choppers for their speed control and braking.
- The chopper systems offer smooth control, high-efficiency, fast response and regeneration.
- The chopper is the dc equivalent to an ac transformer having continuously variable turns ratio. Like a transformer, a chopper can be used to step down or step up the fixed dc input voltage.

Principle of Operation:

A chopper is a high-speed on/off semiconductor switch. It connects source to load and disconnects the load from source at high-speed.

- In other words, the principle of chopper is application of fixed dc voltage intermittently to the load.
- This is achieved by continuously triggering ON and triggering OFF the power switch (SCR) at rapid speed.
- The duration for which the SCR remains in ON and OFF states are called ON time and OFF time respectively.
- By varying the ON time and OFF time of the SCR, the average voltage across the load can be varied.

4.2 APPLICATIONS OF CHOPPERS

- They are used for DC motor control (battery-supplied vehicles), solar energy conversion and wind energy conversion.
- Choppers are used in electric cars, airplanes and spaceships, where onboard-regulated DC power supplies are required.
- In general, Chopper circuits are used as power supplies in computers, commercial electronics, and electronic instruments.

4.3 BOOST CONVERTER:

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

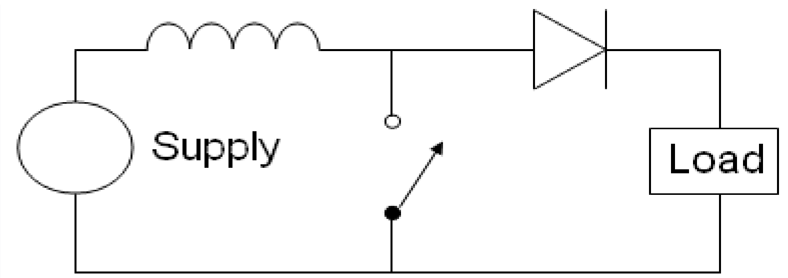


Fig 4.1: The basic schematic of a boost converter.

The switch is typically a MOSFET, IGBT, or BJT. Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since power (p=vi) must be conserved, the output current is lower than the source current.

4.4 APPLICATIONS

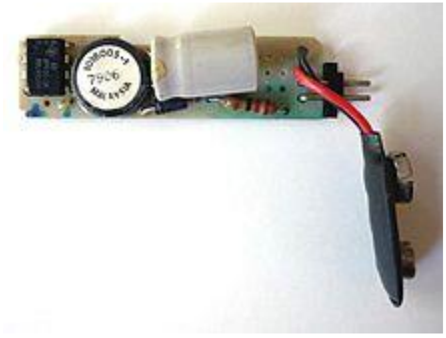


Fig 4.2: Boost converter from a TI calculator, generating 9 V from 2.4 V provided by two AA rechargeable cells.

Battery power systems often stack cells in series to achieve higher voltage. However, sufficient stacking of cells is not possible in many high voltage applications due to lack of space. Boost converters can increase the voltage and reduce the number of cells. Two battery-powered applications that use boost converters are used in hybrid electric vehicles (HEV) and lighting systems.

The NHW20 model Toyota Prius HEV uses a 500 V motor. Without a boost converter, the Prius would need nearly 417 cells to power the motor. However, a Prius actually uses only 168 cells and boosts the battery voltage from 202 V to 500 V. Boost converters also power devices at smaller scale applications, such as portable lighting systems. A white LED typically requires 3.3 V to emit light, and a boost converter can step up the voltage from a single 1.5 V alkaline cell to power the lamp.

An unregulated boost converter is used as the voltage increase mechanism in the circuit known as the 'Joule thief'. This circuit topology is used with low power battery applications, and is aimed at the ability of a boost converter to 'steal' the remaining energy in a battery. This energy would otherwise be wasted since the low voltage of a nearly depleted battery makes it unusable for a normal load. This energy would otherwise remain untapped because many applications do not allow enough current to flow through a load when voltage decreases. This voltage decrease occurs as batteries become depleted, and is a characteristic of the ubiquitous alkaline battery. Since the equation for power is (p=v^2r), and R tends to be stable, power available to the load goes down significantly as voltage decreases.

4.5 MPPT

Maximum power point tracking (MPPT or sometimes just PPT) is a technique used commonly with wind turbines and photovoltaic (PV) solar systems to maximize power extraction under all conditions.

Although solar power is mainly covered, the principle applies generally to sources with variable power: for example, optical power transmission and thermophotovoltaics.

PV solar systems exist in many different configurations with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads. Regardless of the ultimate destination of the solar power, though, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency. This load characteristic is called the maximum power point and MPPT is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analysed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

Solar inverters convert the DC power to AC power and may incorporate MPPT: such inverters sample the output power (I-V curve) from the solar modules and apply the proper resistance (load) so as to obtain maximum power.

The power at the MPP (P_{mpp}) is the product of the MPP voltage (V_{mpp}) and MPP current (I_{mpp}).

4.5.1 I-V CURVE

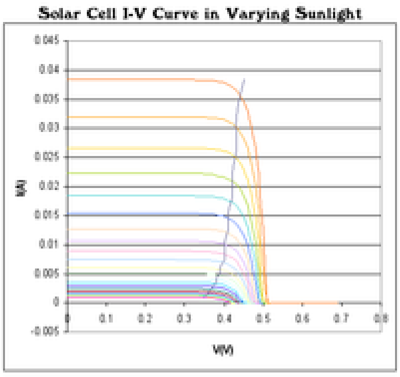


Fig 4.3: Photovoltaic solar cell I-V curves where a line intersects the knee of the curves where the maximum power transfer point is located.

Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, abbreviated *FF*, is a parameter which characterizes the non-linear electrical behaviour of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of Open Circuit Voltage V_{oc} and Short-Circuit Current I_{sc}. In tabulated data it is often used to estimate the maximum power that a cell can provide with an optimal load under given conditions, $P=FF*V_{oc}*I_{sc}$. For most purposes, FF, V_{oc}, and I_{sc} are enough information to give a useful approximate model of the electrical behaviour of a photovoltaic cell under typical conditions.

For any given set of operational conditions, cells have a single operating point where the values of the current (*I*) and Voltage (*V*) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to *V* / I as specified by Ohm's Law. The power P is given by $P=V*I$. A photovoltaic cell, for the majority of its useful curve, acts as a constant current source. However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized where the derivative (graphically, the slope) dI/dV of the I-V curve is equal and opposite the I/V ratio (where $dP/dV=0$). This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve.

A load with resistance $R=V/I$ equal to the reciprocal of this value draws the maximum power from the device. This is sometimes called the 'characteristic resistance' of the cell. This is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be. Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

4.6.2 MPPT IMPLEMENTATION

When a load is directly connected to the solar panel, the operating point of the panel will rarely be at peak power. The impedance seen by the panel derives the operating point of the solar panel. Thus, by varying the impedance seen by the panel, the operating point can be moved towards peak power point. Since panels are DC devices, DC-DC converters must be utilized to transform the impedance of one circuit (source) to the other circuit (load). Changing the duty ratio of the DC-DC converter results in an impedance change as seen by the panel. At a particular impedance (or duty ratio) the operating point will be at the peak power transfer point. The I-V curve of the panel can vary considerably with variation in atmospheric conditions such as radiance and temperature. Therefore, it is not feasible to fix the duty ratio with such dynamically changing operating conditions.

MPPT implementations utilize algorithms that frequently sample panel voltages and currents, then adjust the duty ratio as needed. Microcontrollers are employed to implement the algorithms. Modern implementations often utilize larger computers for analytics and load forecasting.

4.5.3 CLASSIFICATION

Controllers can follow several strategies to optimize the power output of an array. Maximum power point trackers may implement different algorithms and switch between them based on the operating conditions of the array.

4.5.4 PERTURB AND OBSERVE

In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and is most common, although this method can result in oscillations of power output. It is referred to as a *hill climbing* method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

4.5.5 INCREMENTAL CONDUCTANCE

In the incremental conductance method, the controller measures incremental changes in PV array current and voltage to predict the effect of a voltage change. This method requires more computation in the controller, but can track changing conditions more rapidly than the perturb and observe method (P&O). Like the P&O algorithm, it can produce oscillations in power output. This method utilizes the incremental conductance (dI/dV) of the photovoltaic array to compute the sign of the change in power with respect to voltage (dP/dV).

The incremental conductance method computes the maximum power point by comparison of the incremental conductance (I_Δ / V_Δ) to the array conductance (I / V). When these two are the same (I / V = I_Δ / V_Δ), the output voltage is the MPP voltage. The controller maintains this voltage until the irradiation changes and the process is repeated.

The incremental conductance method is based on the observation that at the maximum power point dP/dV = 0, and that P = IV. The current from the array can be expressed is a function of the voltage: P = I(V)V. Therefore dP/dV = VdI/dV + I(V). Setting this equal to zero yields: dI/dV = -I(V)/V. Therefore, the maximum power point is achieved when the incremental conductance is equal to the negative of the instantaneous conductance.

4.5.6 CURRENT SWEEP

The current sweep method uses a sweep waveform for the PV array current such that the I-V characteristic of the PV array is obtained and updated at fixed time intervals. The maximum power point voltage can then be computed from the characteristic curve at the same intervals.

4.5.7 CONSTANT VOLTAGE

The term "constant voltage" in MPP tracking is used to describe different techniques by different authors, one in which the output voltage is regulated to a constant value under all conditions and one in which the output voltage is regulated based on a constant ratio to the measured open circuit voltage (V_{OC}). The latter technique is referred to in contrast as the "open voltage" method by some authors. If the output voltage is held constant, there is no attempt to track the maximum power point, so it is not a maximum power point tracking technique in a strict sense, though it does have some advantages in cases when the MPP tracking tends to fail, and thus it is sometimes used to supplement an MPPT method in those cases.

In the "constant voltage" MPPT method (also known as the "open voltage method"), the power delivered to the load is momentarily interrupted and the open-circuit voltage with zero current is measured. The controller then resumes operation with the voltage controlled at a fixed ratio, such as 0.76, of the open-circuit voltage V_{OC}. This is usually a value which has been determined to be the maximum power point, either empirically or based on modelling, for expected operating conditions. The operating point of the PV array is thus kept near the MPP by regulating the array voltage and matching it to the fixed reference voltage $V_{ref}=kV_{OC}$. The value of V_{ref} may be also chosen to give optimal performance relative to other factors as well as the MPP, but the central idea in this technique is that V_{ref} is determined as a ratio to V_{OC}.

One of the inherent approximations to the "constant voltage" ratio method is that the ratio of the MPP voltage to V_{OC} is only approximately constant, so it leaves room for further possible optimization.

4.5.8 COMPARISON OF METHODS

Both perturb and observe, and incremental conductance, are examples of "hill climbing" methods that can find the local maximum of the power curve for the operating condition of the PV array, and so provide a true maximum power point.

The perturb and observe method requires oscillating power output around the maximum power point even under steady state irradiance.

The incremental conductance method has the advantage over the perturb and observe (P&O) method that it can determine the maximum power point without oscillating around this value. It can perform maximum power point tracking under rapidly varying irradiation conditions with higher accuracy than the perturb and observe method. However, the incremental conductance method can produce oscillations (unintentionally) and can perform erratically under rapidly changing atmospheric conditions. The sampling frequency is decreased due to the higher complexity of the algorithm compared to the P&O method.

In the constant voltage ratio (or "open voltage") method, the current from the photovoltaic array must be set to zero momentarily to measure the open circuit voltage and then afterwards set to a predetermined percentage of the measured voltage, usually around 76%. Energy may be wasted during the time the current is set to zero. The approximation of 76% as the MPP/V_{OC} ratio is not necessarily accurate though. Although simple and low-cost to implement, the interruptions reduce array efficiency and do not ensure finding the actual maximum power point. However, efficiencies of some systems may reach above 95%.

4.5.9 MPPT PLACEMENT

Traditional solar inverters perform MPPT for the entire PV array (module association) as a whole. In such systems the same current, dictated by the inverter, flows through all modules in the string (series). Because different modules have different I-V curves and different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some modules will be performing below their MPP, resulting in lower efficiency.

Some companies (see power optimizer) are now placing maximum power point tracker into individual modules, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch.

Data suggests having one inverter with one MPPT for a project that has east and west-facing modules presents no disadvantages when compared to having two inverters or one inverter with more than one MPPT.

4.6 OPERATION WITH BATTERIES

At night, an off-grid PV system may use batteries to supply loads. Although the fully charged battery pack voltage may be close to the PV panel's maximum power point voltage, this is unlikely to be true at sunrise when the battery has been partially discharged. Charging may begin at a voltage considerably below the PV panel maximum power point voltage, and an MPPT can resolve this mismatch.

When the batteries in an off-grid system are fully charged and PV production exceeds local loads, an MPPT can no longer operate the panel at its maximum power point as the excess power has no load to absorb it. The MPPT must then shift the PV panel operating point away from the peak power point until production exactly matches demand. (An alternative approach commonly used in spacecraft is to divert surplus PV power into a resistive load, allowing the panel to operate continuously at its peak power point.)

In a grid connected photovoltaic system, all delivered power from solar modules will be sent to the grid. Therefore, the MPPT in a grid connected PV system will always attempt to operate the PV modules at its maximum power point.

CHAPTER-V

CONVERTER

CHAPTER V

CONVERTER

5.1 CONVERTER

The term "Converters" is used to refer a system which transforms one form of electrical energy into another form of electrical energy. For example, AC into DC or DC into AC. Here conversion of ac into dc is called as "rectification" and conversion of dc into ac is known as "inversion".

The power conversion systems can be classified according to the type of the input and output power

i. AC to DC (rectifier)
ii. DC to AC (inverter)
iii. DC to DC (DC-to-DC converter)
iv. AC to AC (AC-to-AC converter)
v. DC to AC converters (inverter)

DC to AC converters produces an AC output waveform from a DC source. Applications include adjustable speed drives (ASD), uninterruptible power supplies (UPS), Flexible AC transmission systems (FACTS), voltage compensators, and photovoltaic inverters. Topologies for these converters can be separated into two distinct categories: voltage source inverters and current source inverters. Voltage source inverters (VSIs) are named so because the independently controlled output is a voltage waveform. Similarly, current source inverters (CSIs) are distinct in that the controlled AC output is a current waveform.

DC to AC power conversion is the result of power switching devices, which are commonly fully controllable semiconductor power switches. The output waveforms are therefore made up of discrete values, producing fast transitions rather than smooth ones. For some applications, even a rough approximation of the sinusoidal waveform of AC power is adequate. Where a near sinusoidal waveform is required, the switching devices are operated much faster than the desired output frequency, and the time they spend in either state is controlled so the averaged output is nearly sinusoidal. Common modulation techniques include the carrier-based technique, or Pulse-width modulation, space-vector technique, and the selective-harmonic technique.

Voltage source inverters have practical uses in both single-phase and three-phase applications. Single-phase VSIs utilize half-bridge and full-bridge configurations, and are widely used for power supplies, single-phase UPSs, and elaborate high-power topologies when used in multicell configurations. Three-phase VSIs are used in applications that require sinusoidal voltage waveforms, such as ASDs, UPSs, and some types of FACTS devices such as the STATCOM. They are also used in applications where arbitrary voltages are required as in the case of active power filters and voltage compensators.

Current source inverters are used to produce an AC output current from a DC current supply. This type of inverter is practical for three-phase applications in which high-quality voltage waveforms are required.

A relatively new class of inverters, called multilevel inverters, has gained widespread interest. Normal operation of CSIs and VSIs can be classified as two-level inverters, due to the fact that power switches connect to either the positive or to the negative DC bus. If more than two voltage levels were available to the inverter output terminals, the AC output could better approximate a sine wave. It is for this reason that multilevel inverters, although more complex and costly, offer higher performance.

Each inverter type differs in the DC links used, and in whether or not they require freewheeling diodes. Either can be made to operate in square-wave or pulse-width modulation (PWM) mode, depending on its intended usage. Square-wave mode offers simplicity, while PWM can be implemented several different ways and produces higher quality waveforms.

5.2 CONSTANT-VOLTAGE SOURCE.

The desired quality of the current output waveform determines which modulation technique needs to be selected for a given application. The output of a VSI is composed of discrete values. In order to obtain a smooth current waveform, the loads need to be inductive at the select harmonic frequencies. Without some sort of inductive filtering between the source and load, a capacitive load will cause the load to receive a choppy current waveform, with large and frequent current spikes.

There are three main types of VSIs:

1. Single-phase half-bridge inverter
2. Single-phase full-bridge inverter
3. Three-phase voltage source inverter

5.3 SINGLE-PHASE HALF-BRIDGE INVERTER

The single-phase voltage source half-bridge inverters are meant for lower voltage applications and are commonly used in power supplies. Figure 1 shows the circuit schematic of this inverter.

Low-order current harmonics get injected back to the source voltage by the operation of the inverter. This means that two large capacitors are needed for filtering purposes in this design. As Figure 1 illustrates, only one switch can be on at time in each leg of the inverter. If both switches in a leg were on at the same time, the DC source will be shorted out.

Inverters can use several modulation techniques to control their switching schemes. The carrier-based PWM technique compares the AC output waveform, vc, to a carrier voltage signal, v∆. When vc is greater than v∆, S+ is on, and when vc is less than v∆, S- is on. When the AC output is at frequency fc with its amplitude at vc, and the triangular carrier signal is at frequency f∆ with its amplitude at v∆, the PWM becomes a special sinusoidal case of the carrier based PWM. This case is dubbed sinusoidal pulse-width modulation (SPWM).For this, the modulation index, or amplitude-modulation ratio, is defined as ma = vc/v∆ .

The normalized carrier frequency, or frequency-modulation ratio, is calculated using the equation mf = f∆/fc.

If the over-modulation region, ma, exceeds one, a higher fundamental AC output voltage will be observed, but at the cost of saturation. For SPWM, the harmonics of the output waveform are at well-defined frequencies and amplitudes. This simplifies the design of the filtering components needed for the low-order current harmonic injection from the operation of the inverter. The maximum output amplitude in this mode of operation is half of the source voltage. If the maximum output amplitude, ma, exceeds 3.24, the output waveform of the inverter becomes a square wave.

As was true for PWM, both switches in a leg for square wave modulation cannot be turned on at the same time, as this would cause a short across the voltage source. The switching scheme requires that both S+ and S- be on for a half cycle of the AC output period. The fundamental AC output amplitude is equal to vo1 = vaN = 2vi/π .

Its harmonics have an amplitude of voh = vo1/h.

Therefore, the AC output voltage is not controlled by the inverter, but rather by the magnitude of the DC input voltage of the inverter.

Using selective harmonic elimination (SHE) as a modulation technique allows the switching of the inverter to selectively eliminate intrinsic harmonics. The fundamental component of the AC output voltage can also be adjusted within a desirable range. Since the AC output voltage obtained from this modulation technique has odd half and odd quarter wave symmetry, even harmonics do not exist. Any undesirable odd (N-1) intrinsic harmonics from the output waveform can be eliminated.

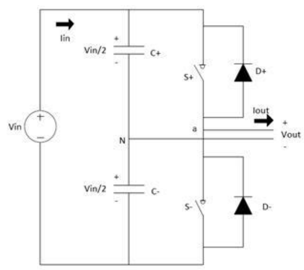


Fig 5.1: Single-Phase Half-Bridge Voltage Source Inverter

5.4 SINGLE-PHASE FULL-BRIDGE INVERTER

The full-bridge inverter is similar to the half bridge-inverter, but it has an additional leg to connect the neutral point to the load. Figure 2 shows the circuit schematic of the single-phase voltage source full-bridge inverter.

To avoid shorting out the voltage source, S1+ and S1- cannot be on at the same time, and S2+ and S2- also cannot be on at the same time. Any modulating technique used for the full-bridge configuration should have either the top or the bottom switch of each leg on at any given time. Due to the extra leg, the maximum amplitude of the output waveform is Vi, and is twice as large as the maximum achievable output amplitude for the half-bridge configuration.

States 1 and 2 from Table 2 are used to generate the AC output voltage with bipolar SPWM. The AC output voltage can take on only two values, either Vi or –Vi. To generate these same states using a half-bridge configuration, a carrier based technique can be used. S+ being on for the half-bridge corresponds to S1+ and S2- being on for the full-bridge. Similarly, S- being on for the half-bridge corresponds to S1- and S2+ being on for the full bridge. The output voltage for this modulation technique is more or less sinusoidal, with a fundamental component that has an amplitude in the linear region of less than or equal to one vo1 =vab1= vi • ma.

Unlike the bipolar PWM technique, the unipolar approach uses states 1, 2, 3 and 4 from Table 2 to generate its AC output voltage. Therefore, the AC output voltage can take on the values Vi, 0 or –Vi. To generate these states, two sinusoidal modulating signals, Vc and –Vc, are needed, as seen in Figure 2.

Vc is used to generate VaN, while –Vc is used to generate VbN. The following relationship is called unipolar carrier-based SPWM vo1 =2 • vaN1= vi • ma.

The phase voltages VaN and VbN are identical, but 180 degrees out of phase with each other. The output voltage is equal to the difference of the two phase voltages, and do not contain any even harmonics. Therefore, if mf is taken, even the AC output voltage harmonics will appear at normalized odd frequencies, fh. These frequencies are centered on double the value of the normalized carrier frequency. This particular feature allows for smaller filtering components when trying to obtain a higher quality output waveform.

As was the case for the half-bridge SHE, the AC output voltage contains no even harmonics due to its odd half and odd quarter wave symmetry.

5.5 THREE-PHASE VOLTAGE SOURCE INVERTER

Single-phase VSIs are used primarily for low power range applications, while three-phase VSIs cover both medium and high power range applications, Figure 5 shows the circuit schematic for a three-phase VSI.

Switches in any of the three legs of the inverter cannot be switched off simultaneously due to this resulting in the voltages being dependent on the respective line current's polarity. States 7 and 8 produce zero AC line voltages, which result in AC line currents freewheeling through either the upper or the lower components. However, the line voltages for states 1 through 6 produce an AC line voltage consisting of the discrete values of Vi, 0 or –Vi.

For three-phase SPWM, three modulating signals that are 120 degrees out of phase with one another are used in order to produce out of phase load voltages. In order to preserve the PWM features with a single carrier signal, the normalized carrier frequency, mf, needs to be a multiple of three. This keeps the magnitude of the phase voltages identical, but out of phase with each other by 120 degrees. The maximum achievable phase voltage amplitude in the linear region, ma less than or equal to one, is $vphase = vi / 2$. The maximum achievable line voltage amplitude is $Vab1 = vab \cdot \sqrt{3} / 2$

The only way to control the load voltage is by changing the input DC voltage.

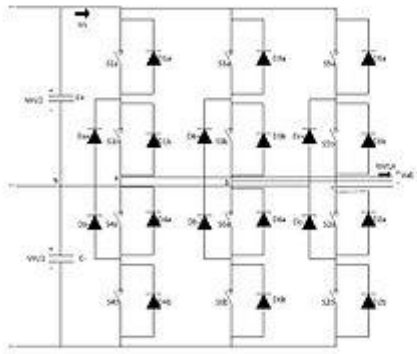


Fig 5.2: Three-Phase Voltage Source Inverter Circuit Schematic

5.6 CURRENT SOURCE INVERTER

Current source inverters convert DC current into an AC current waveform. In applications requiring sinusoidal AC waveforms, magnitude, frequency, and phase should all be controlled. CSIs have high changes in current overtime, so capacitors are commonly employed on the AC side, while inductors are commonly employed on the DC side. Due to the absence of freewheeling diodes, the power circuit is reduced in size and weight, and tends to be more reliable than VSIs. Although single-phase topologies are possible, three-phase CSIs are more practical.

In its most generalized form, a three-phase CSI employs the same conduction sequence as a six-pulse rectifier. At any time, only one common-cathode switch and one common-anode switch are on.

As a result, line currents take discrete values of –ii, 0 and ii. States are chosen such that a desired waveform is output and only valid states are used. This selection is based on modulating techniques, which include carrier-based PWM, selective harmonic elimination, and space-vector techniques.

Carrier-based techniques used for VSIs can also be implemented for CSIs, resulting in CSI line currents that behave in the same way as VSI line voltages. The digital circuit utilized for modulating signals contains a switching pulse generator, a shorting pulse generator, a shorting pulse distributor, and a switching and shorting pulse combiner. A gating signal is produced based on a carrier current and three modulating signals.

A shorting pulse is added to this signal when no top switches and no bottom switches are gated, causing the RMS currents to be equal in all legs. The same methods are utilized for each phase, however, switching variables are 120 degrees out of phase relative to one another, and the current pulses are shifted by a half-cycle with respect to output currents. If a triangular carrier is used with sinusoidal modulating signals, the CSI is said to be utilizing synchronized-pulse-width-modulation (SPWM). If full over-modulation is used in conjunction with SPWM the inverter is said to be in square-wave operation.

The second CSI modulation category, SHE is also similar to its VSI counterpart. Utilizing the gating signals developed for a VSI and a set of synchronizing sinusoidal current signals, results in symmetrically distributed shorting pulses and, therefore, symmetrical gating patterns. This allows any arbitrary number of harmonics to be eliminated. It also allows control of the fundamental line current through the proper selection of primary switching angles. Optimal switching patterns must have quarter-wave and half-wave symmetry, as well as symmetry about 30 degrees and 150 degrees. Switching patterns are never allowed between 60 degrees and 120 degrees. The current ripple can be further reduced with the use of larger output capacitors, or by increasing the number of switching pulses.

The third category, space-vector-based modulation, generates PWM load line currents that equal load line currents, on average. Valid switching states and time selections are made digitally based on space vector transformation. Modulating signals are represented as a complex vector using a transformation equation. For balanced three-phase sinusoidal signals, this vector becomes a fixed module, which rotates at a frequency, ω. These space vectors are then used to approximate the modulating signal. If the signal is between arbitrary vectors, the vectors are combined with the zero vectors I7, I8, or I9. The following equations are used to ensure that the generated currents and the current vectors are on average equivalent.

5.7 MULTILEVEL INVERTERS

A relatively new class called multilevel inverters has gained widespread interest. Normal operation of CSIs and VSIs can be classified as two-level inverters because the power switches connect to either the positive or the negative DC bus. If more than two voltage levels were available to the inverter output terminals, the AC output could better approximate a sine wave. For this reason, multilevel inverters, although more complex and costly, offer higher performance. A three-level neutral-clamped inverter is shown in Figure 10.

Control methods for a three-level inverter only allow two switches of the four switches in each leg to simultaneously change conduction states. This allows smooth commutation and avoids shoot through by only selecting valid states. It may also be noted that since the DC bus voltage is shared by at least two power valves, their voltage ratings can be less than a two-level counterpart.

Carrier-based and space-vector modulation techniques are used for multilevel topologies. The methods for these techniques follow those of classic inverters, but with added complexity. Space-vector modulation offers a greater number of fixed voltage vectors to be used in approximating the modulation signal, and therefore allows more effective space vector PWM strategies to be accomplished at the cost of more elaborate algorithms. Due to added complexity and number of semiconductor devices, multilevel inverters are currently more suitable for high-power high-voltage applications. This technology reduces the harmonics hence improves overall efficiency of the scheme.

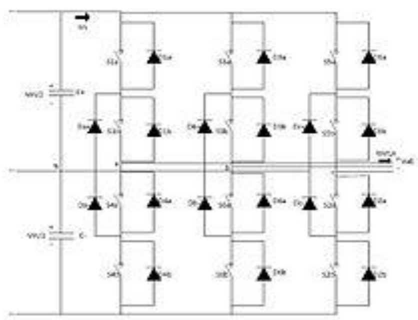


Fig 5.3: Three-Level Neutral-Clamped Inverter

CHAPTER-VI

SIMULATION THEORY

CHAPTER VI

SIMULATION THEORY

6.1 SIMULATION THEORY

MATLAB (Matrix Laboratory) is a numerical registering condition and fourth-age programming language. Created by Math Works, MATLAB permits grid controls, plotting of capacities and information, usage of calculations, formation of UIs and interfacing with projects written in different dialects, including C, C++, Java, and Fortran. In spite of the fact that MATLAB is proposed principally for numerical figuring, a discretionary tool compartment utilizes the MPAD representative motor, enabling access to emblematic registering abilities. An extra bundle, Simulink, includes graphical multi-space recreation and Model-Based Design for dynamic and installed frameworks. In 2004, MATLAB had around one million clients crosswise over industry and the scholarly community. MATLAB clients originate from different foundations of designing, science, and financial matters. MATLAB is generally utilized in scholarly and inquire about establishments just as modern ventures.

6.2 MATLAB HISTORY

Cleve Moler, the director of the software engineering division at the University of New Mexico, began creating MATLAB in the late 1970s. He planned it to give his understudy's entrance to LINPACK and EISPACK without them learning FORTRAN. It before long spread to different colleges and found a solid group of onlookers inside the connected science network. Jack Little, a specialist, was presented to it amid a visit Moler made to Stanford University in 1983. Perceiving its business potential, he joined with Moler and Steve Bangert. They changed MATLAB in C and established Math Works in 1984 to proceed with its improvement. These reworked libraries were known as JACKPAC. In 2000, MATLAB was revamped to utilize a more current arrangement of libraries for lattice control, LAPACK.

MATLAB was first received by analysts and professionals in control building, Little's strength, however rapidly spread to numerous different areas. It is currently likewise utilized in instruction, specifically the educating of direct variable based math and numerical investigation, and is well known among researchers associated with picture preparing.

6.3 SIMULINK

SIMULINK, created by Math Works, is a business device for displaying, reproducing and examining multi-space dynamic frameworks. Its essential interface is a graphical square outlining device and an adaptable arrangement of square libraries. It offers tight combination with whatever is left of the MATLAB condition and can either drive MATLAB or be scripted from it. SIMULINK is generally utilized in charge hypothesis and advanced flag preparing for multi-space reproduction and Model-Based Design.

SIMULINK is a square graph condition for multi-space reenactment and Model-Based Design. It bolsters framework level structure, reproduction, programmed code age, and ceaseless test and check of installed frameworks. SIMULINK gives a graphical supervisor, adaptable square libraries, and solvers for displaying and mimicking dynamic frameworks. It is coordinated with MATLAB, empowering you to consolidate MATLAB calculations into models and fare reenactment results to MATLAB for further investigation.

6.3.1 BUILDING THE MODEL

SIMULINK gives a lot of predefined obstructs that you can consolidate to make a point-by-point square chart of your framework. Devices for various levelled demonstrating, information the board, and subsystem customization empower you to speak to even the most perplexing framework succinctly and precisely.

6.3.2 SELECTING BLOCKS

The SIMULINK Library Browser contains a library of squares generally used to display a framework. As appeared in Fig 1.1 these include:

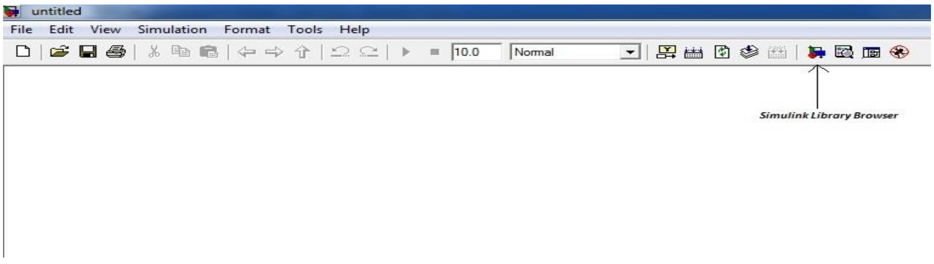


Fig 6.1: Building a new model

•Continuous and discrete elements squares, for example, Integration and Unit Delay

•Algorithmic squares, for example, Sum, Product, and Lookup Table

•Structural squares, for example, Mux, Switch, and Bus Selector

We can manufacture modified capacities by utilizing these squares or by fusing transcribed MATLAB, C, FORTRAN, or Ada code into the model. The custom squares can be put away in claim libraries inside the SIMULINK Library Browser.

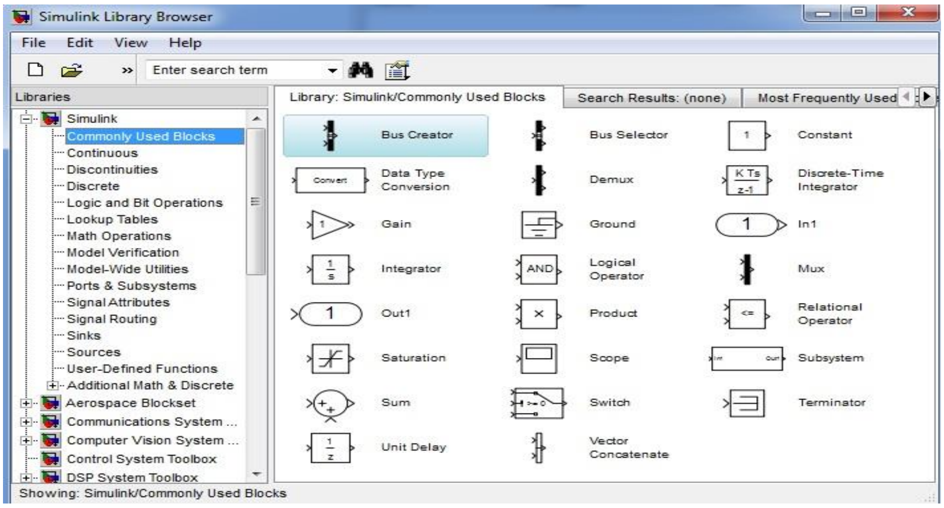


Fig 6.2: Commonly used blocks

6.3.3 NAVIGATING THROUGH THE MODEL HIERARCHY

The Explorer bar and Model Browser in SIMULINK explores the model. The Explorer bar shows the dimension of chain of importance that we are right now survey and gives us a chance to can climb and down the progressive system. The Model Browser gives a total various leveled tree perspective on your model, and like the Explorer bar, can be utilized to travel through the dimensions of progression.

6.3.4 MANAGING SIGNALS AND PARAMETERS

SIMULINK models contain the two signs and parameters. Signs are time-changing information spoken to by the lines associating squares. Parameters are coefficients that characterize framework elements and conduct. SIMULINK decides the accompanying sign and parameter qualities as appeared in fig.

• Data type—single, twofold, marked, or unsigned 8-, 16-or 32-bit numbers; Boolean; identification; or fixed point

•Dimensions—scalar, vector, grid, N-D, or variable-sized clusters

•Complexity—genuine or complex qualities

•Minimum and most extreme range, starting quality, and building units

On the off chance that we decide not to indicate information qualities, SIMULINK decides them consequently through spread calculations, and behaviours consistency checking to guarantee information honesty. These flag and parameter properties can be indicated either inside the model or in a different information lexicon. We would then be able to utilize the Model Explorer to compose, see, alter, and include information without exploring through the whole model as appeared in fig.

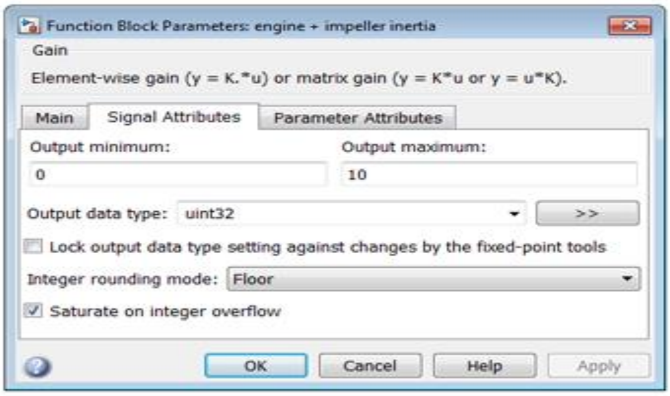


Fig 6.3: Signal Attributes tab

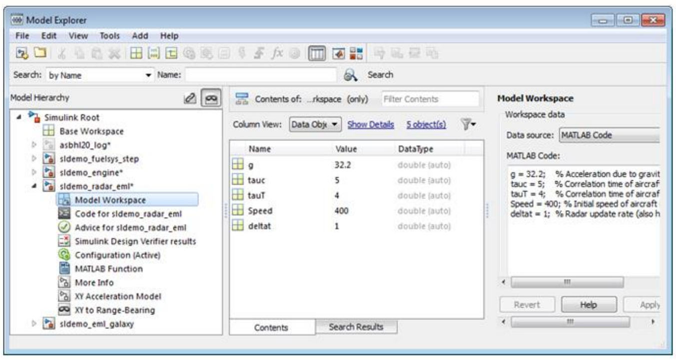


Fig 6.4: Model Explorer Window

6.3.5 SIMULATING THE MODEL

We can recreate the dynamic conduct of the framework and view the outcomes as the reproduction runs. To guarantee reenactment speed and exactness, SIMULINK gives fixed-advance and variable-advance ODE solvers, a graphical debugger, and a model profiler.

6.3.6 CHOOSING A SOLVER

Solvers as appeared in Fig.1.5 are numerical combination calculations that register the framework elements after some time utilizing data contained in the model. SIMULINK gives solvers to help the recreation of an expansive scope of frameworks, including nonstop time (simple), discrete-time (computerized), mixture (blended flag), and multi rate frameworks of any size.

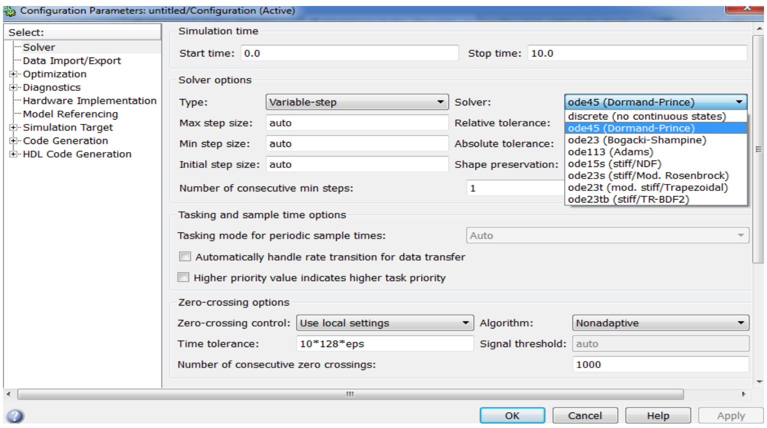


Fig 6.5: Configuration Parameters dialog box showing the Solver pane

These solvers can reproduce solid frameworks and frameworks with discontinuities. We can determine reenactment choices, including the sort and properties of the solver, recreation begin and stop times, and whether to load or spare reproduction information. We can likewise set advancement and indicative data. Diverse mixes of alternatives can be spared with the model.

6.3.7ANALYZING SIMULATION RESULTS

In the wake of running a reproduction, we can break down the reenactment results in MATLAB and SIMULINK. It incorporates troubleshooting devices to comprehend the reproduction conduct.

6.3.8 VIEWING SIMULATION RESULTS

We can envision the reenactment conduct by survey signals with the showcases and degrees gave in SIMULINK. We can likewise see reproduction information inside the Simulation Data Inspector, where we can look at numerous signs from various reenactment runs. Extension is the square in SIMLINK by which we can gauge and view the voltage, flow, and power in electrical space. Fig.1.6 demonstrates the yield of a staggered converter through extension. On the other hand, we can fabricate custom HMI shows utilizing MATLAB, or log signs to the MATLAB workspace to see and dissect the information utilizing MATLAB calculations and perception instruments.

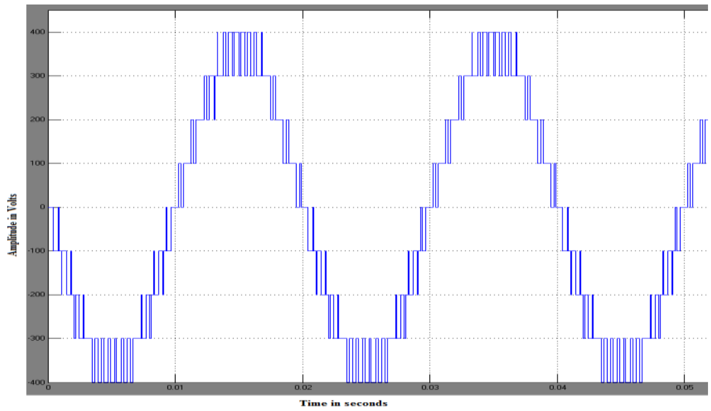


Fig 6.6: Multi-step waveform

6.3.9 DEBUGGING THE SIMULATION

SIMULINK underpins troubleshooting with the Simulation Stepper, which gives we a chance to venture forward and backward through your recreation seeing information on degrees or examining how and when the framework changes states. With the SIMULINK debugger we can venture through a recreation one technique at any given moment and look at the aftereffects of executing that strategy. As the model recreates, you can show data on square states, square sources of info and yields, and square technique execution inside the SIMULINK Editor.

6.4 SIM POWER SYSTEMS

SIM Power Systems™ gives segment libraries and examination instruments for demonstrating and recreating electrical power frameworks. The libraries incorporate models of electrical power segments, including three-stage machines, electric drives, and segments for applications, for example, adaptable AC transmission frameworks (FACTS) and sustainable power source frameworks. Symphonious examination, estimation of complete consonant contortion (THD), load stream, and other key electrical power framework investigations are mechanized. SIM Power Systems was created by Hydro-Québeco Montreal. SIM Power Systems models as appeared in Fig 1.6 can be utilized to create control frameworks and test framework level execution. We can parameterize the models utilizing MATLAB® factors and articulations, and configuration control frameworks for the electrical power framework in SIMULINK.

We can include mechanical, water driven, pneumatic, and different segments to the model utilizing SIM scape and test them all in a solitary reproduction condition. To send models to other reenactment conditions, incorporating equipment on the up and up (HIL) frameworks, SIM Power Systems underpins C-code age.

The libraries contain models of run of the mill control gear, for example, transformers, lines, machines, and power hardware. These models are demonstrated ones originating from reading material, and their legitimacy depends on the experience of the Power Systems Testing and Simulation Laboratory of Hydro-Québec, a huge North American utility situated in Canada. The abilities of SIM Power Systems for displaying an ordinary electrical framework are delineated in show records. What's more, for clients who need to revive their insight into power framework hypothesis, there are likewise self-learning contextual investigations.

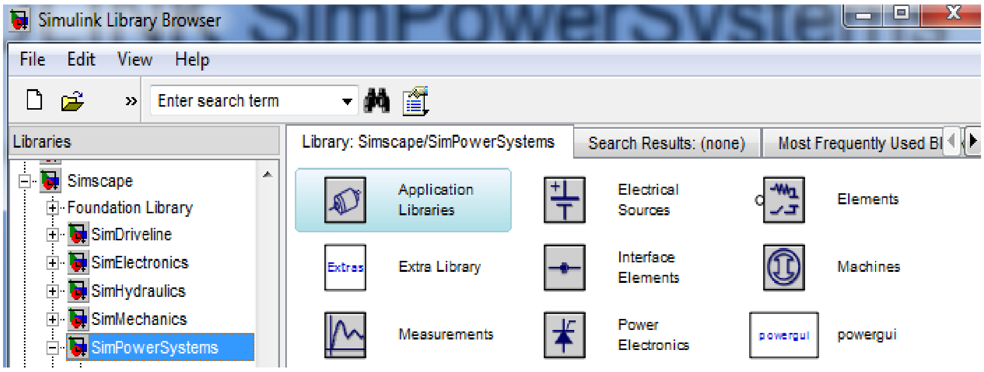


Fig 6.7: SIM Power System plane

6.4 MODELLING ELECTRICAL POWER SYSTEMS

With SIM Power Systems, we fabricate a model of a framework similarly as we would amass a physical framework. The parts in the model are associated by physical associations that speak to perfect conduction ways. This methodology depicts the physical structure of the framework as opposed to determining and actualizing the conditions for the framework. From the model, which intently looks like a schematic, SIM Power Systems naturally builds the differential logarithmic conditions (DAEs) that describe the conduct of the framework. These conditions are coordinated with whatever remains of the SIMULINK demonstrate.

We can utilize the sensor hinders in SIM Power Systems to gauge current and voltage in your capacity system, and after that pass these signs into standard SIMULINK squares. Source squares empower SIMULINK signs to dole out qualities to the electrical factors flow and voltage. Sensor and source squares associate a control calculation created in SIMULINK to a SIM Power Systems arrange.

6.5 MODELING CUSTOM COMPONENTS

SIM Power Systems empowers to display custom parts by utilizing the key components incorporated into its libraries and by joining these components with SIMULINK squares.

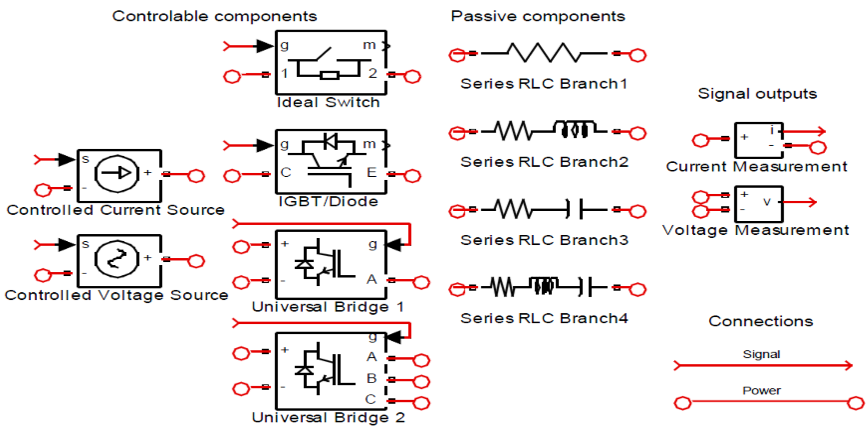


Fig 6.8: SIM power system Libraries

Electrical components: Linear and saturable transformers; arrestors and breakers; and transmission line models.

Electrical elements: Models of synchronous, perpetual magnet synchronous, and DC machines; excitation frameworks; and models of pressure driven and steam turbine-senator frameworks.

Electric machinery: Diodes, disentangled and complex Thyristors, GTOs, switches, IGBT models, and all-inclusive scaffolds that permit choice of standard extension topologies

Power electronics: Diodes, simplified and complex Thyristors, GTOs, switches, IGBT models, and universal bridges that allow selection of standard bridge topologies

Control and measurement: Voltage, current, and impedance estimations; RMS estimations; dynamic and receptive power computations; clocks, multi meters, and Fourier investigation; HVDC control; all out symphonious mutilation; abc-to-dq0 and dq0-to-abc changes **Electrical sources**: To execute sinusoidal flow source, sinusoidal voltage source, conventional battery demonstrate, Controlled AC Current and Voltage sources, DC Voltage Source. To execute three-stage voltage source with programmable time variety of abundancy, stage, recurrence, and music, and to actualize three-stage source with inside R-L impedance. The whole square sets are appeared in Fig 5.8.

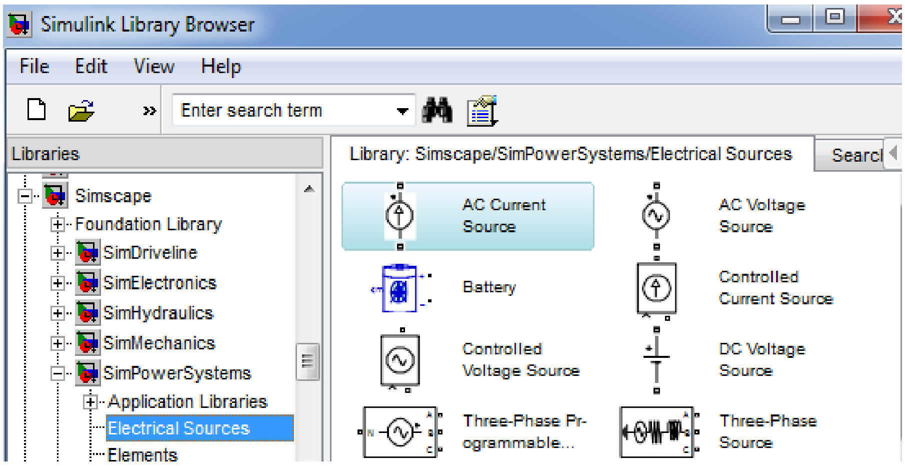


Fig 6.9: Block sets of electrical sources used in SIM Power Systems

Three-phase components: RLC loads and branches; breakers and issues; pi-segment lines; voltage sources; transformers; synchronous and non-concurrent generators; and engines, analysers, and estimations

Electric Drives and Other Application Libraries: SIM Power Systems gives the accompanying particular application libraries:

Flexible AC Transmission Systems (FACTS): Phase models of adaptable AC transmission frameworks

Distributed Resources: Phase models of wind turbines

Electric Drives: Editable models of electric drives that incorporate point by point depictions of the engine, converter, and controller for each drive. The Electric Drives library incorporates changeless magnet, synchronous, and no concurrent (acceptance) engines. The converters and controllers execute the most well-known methodologies for controlling the speed and torque for these engines, for example, direct-torque control and field-arranged control. SIM Power Systems bolsters the improvement of mind boggling, independent power frameworks, for example, those in cars, flying machine, fabricating plants, and power utility applications

You can consolidate SIM Power Systems with other Math Works physical demonstrating items to display complex communications in multi-area physical frameworks. The square libraries and reenactment strategies in SIM Power Systems were created by Hydro-Québec of Montreal.

Along these lines clients can quickly give SIM Power Systems something to do. The libraries that containing models of common power gear, for example, transformers, lines, machines, and power gadgets are utilized to build an electrical circuit and the totally planned circuit of the equivalent in SIMULINK window.

.

6.6 CONNECTING TO HARDWARE

We can associate the SIMULINK model to equipment for quick prototyping, equipment on the up and up (HIL) reproduction, and arrangement on an inserted framework.

6.6.1 RUNNING SIMULATIONS ON HARDWARE

SIMULINK gives worked in help to prototyping, testing, and running models on ease target equipment, including Arduino®, LEGO® MINDSTORMS® NXT, Panda Board, and Beagle Board. We can plan calculations in SIMULINK for control frameworks, apply autonomy, sound preparing, and PC vision applications and see them perform progressively.

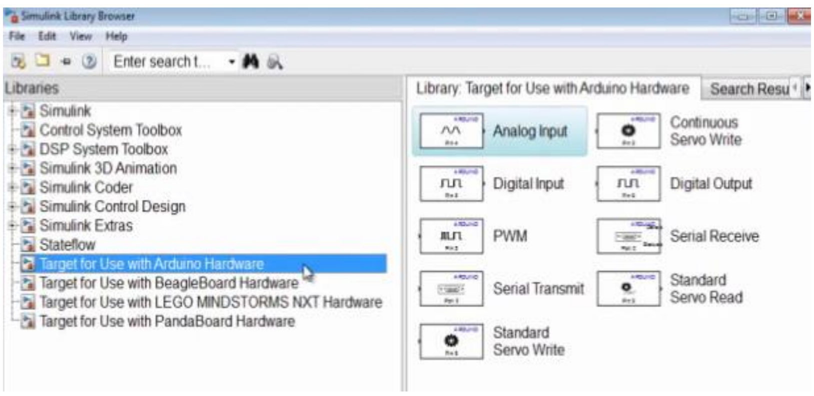


Fig 6.10: Hardware Interface to Simulink

SIMULINK gives worked in help to prototyping, testing, and running models on minimal effort target equipment, including Arduino®, LEGO® MINDSTORMS® NXT, and Beagle Board as appeared in Fig.5.11.

Fig 6.11: Low-cost target hardware

With Real-Time Windows Target™, we can run SIMULINK models continuously on Microsoft® Windows® PCs and interface with a scope of I/O loads up to make and control an ongoing framework as appeared in Fig.5.11. To run the model continuously on an objective PC, we can utilize XPC Target™ for HIL recreation, quick control prototyping, and other constant testing applications. See XPC Target Turnkey for accessible target PC equipment. SIMULINK models can be arranged and made prepared for code age. By utilizing SIMULINK with extra code age items, you can produce C and C++, HDL, or PLC code straightforwardly from your model.

6.7 APPLICATIONS

Various Math Works and outsider equipment and programming items are accessible for use with SIMULINK. For instance, State stream expands SIMULINK with a structure domain for creating state machines and stream graphs. Combined with SIMULINK Coder, another item from Math Works, SIMULINK can naturally create C source code for continuous usage of frameworks. As the productivity and adaptability of the code improves, this is winding up more broadly embraced for generation frameworks, notwithstanding being a prevalent instrument for implanted framework configuration work due to its adaptability and limit with regards to fast emphasis. Installed Coder makes code sufficiently proficient for use in implanted frameworks.

XPC Target together with X86-based constant frameworks gives a domain to reproduce and test SIMULINK and State stream models continuously on the physical framework. Installed Coder likewise bolsters explicit implanted targets, including Infineon C166, Motorola68HC12, Motorola MPC 555, TI C2000,

TI C6000, RenesasV850 and Renesas with HDL Coder, additionally from Math Works, SIMULINK and State stream can naturally create synthesizable VHDL and Very log.

SIMULINK Verification and Validation empowers methodical confirmation and approval of models through demonstrating style checking, necessities detectability and model inclusion investigation. SIMULINK Design Verifier utilizes formal techniques to recognize structure mistakes like whole number flood, division by zero and dead rationale, and creates experiment situations for model checking inside the SIMULINK condition.

The orderly testing instrument TPT offers one approach to perform formal test-check and approval procedure to invigorate SIMULINK models yet in addition amid the advancement stage where the designer produces contributions to test the framework. By the substitution of the Constant and Signal generator squares of SIMULINK the incitement moves toward becoming reproducible. SIM Events includes a library of graphical structure hinders for demonstrating lining frameworks to the SIMULINK condition. It additionally includes an occasion-based recreation motor to the time sensitive reenactment motor in SIMULINK

CHAPTER-VII

SIMULATION RESULT

CHAPTER VII

SIMULATION RESULTS

7.1 SIMULATION RESULTS:

7.2 AT STATION 1 WITH TRAIN-1 CONFIGURATION

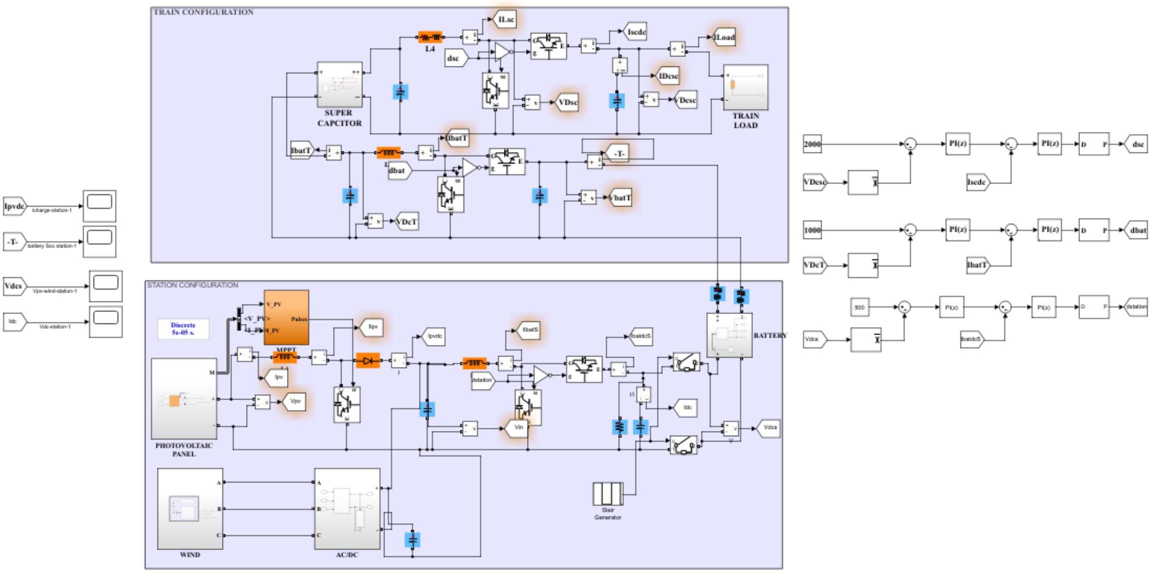
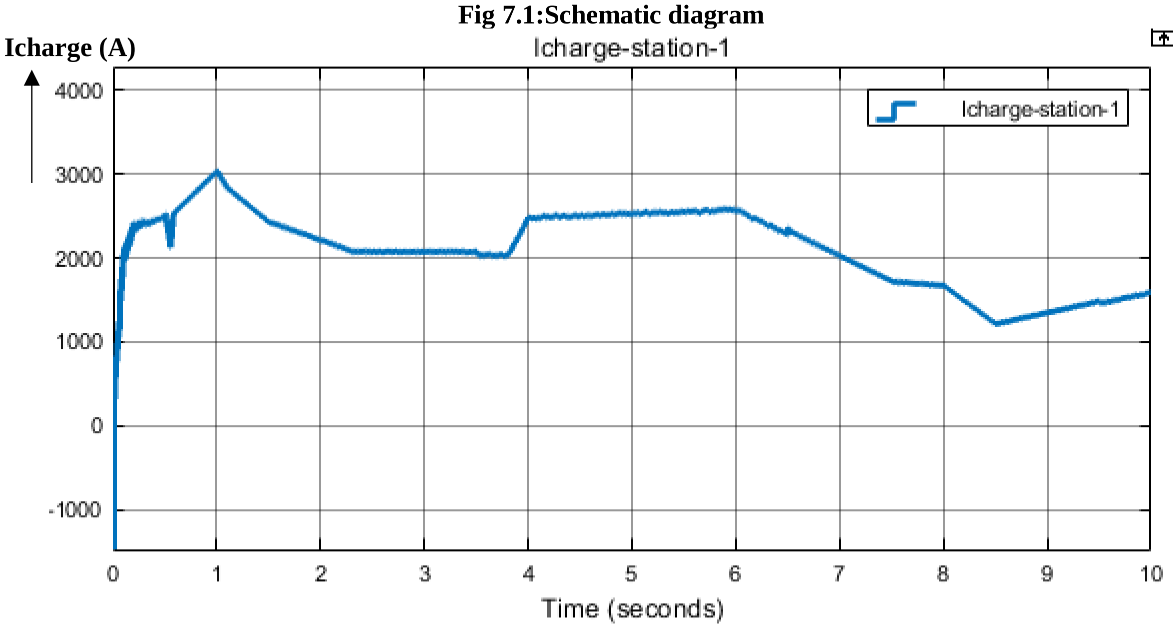
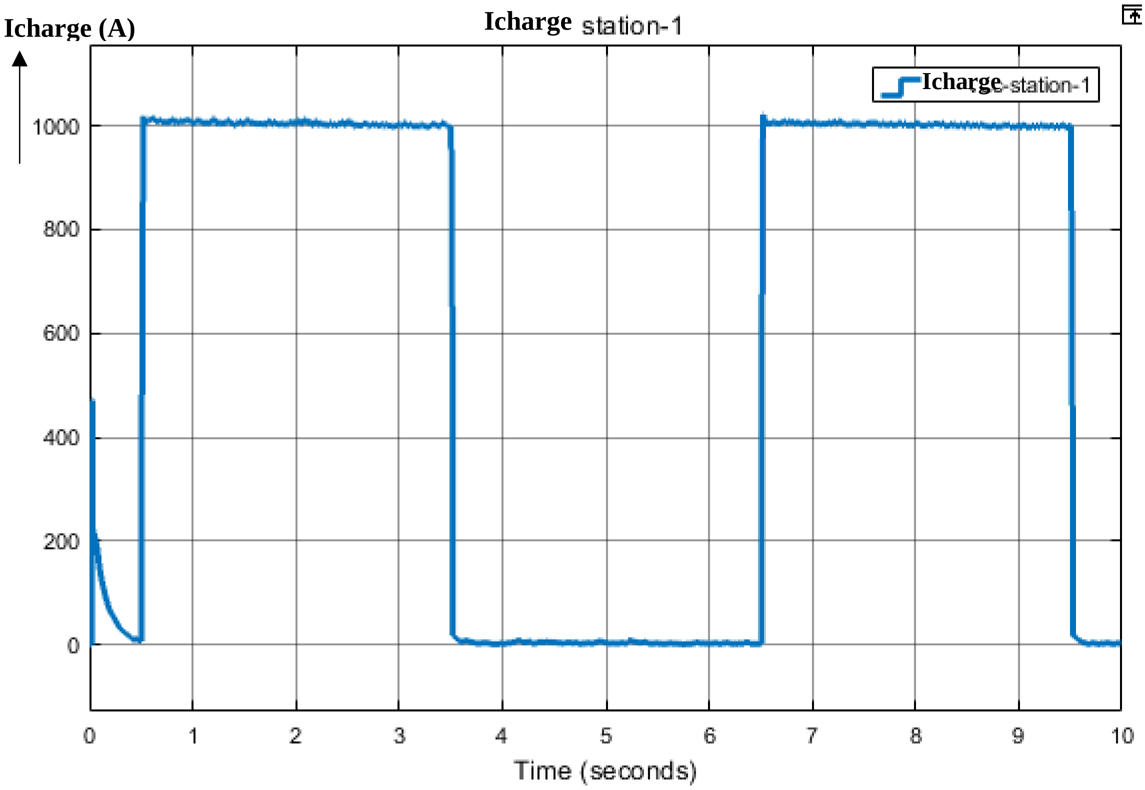


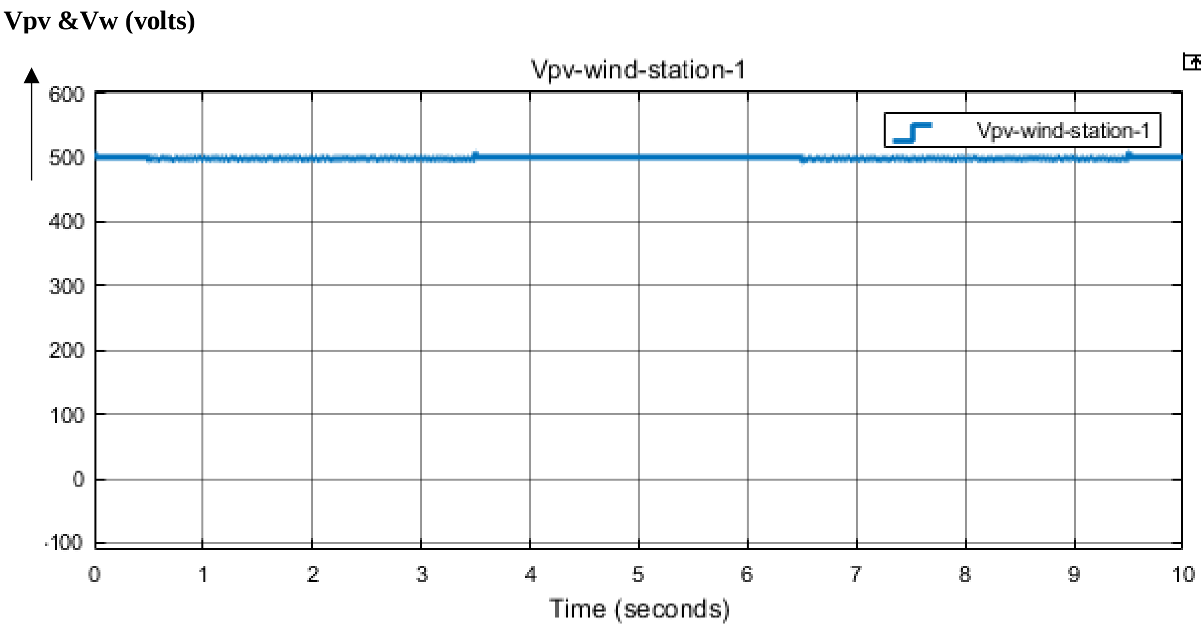
Fig 7.1:Schematic diagram



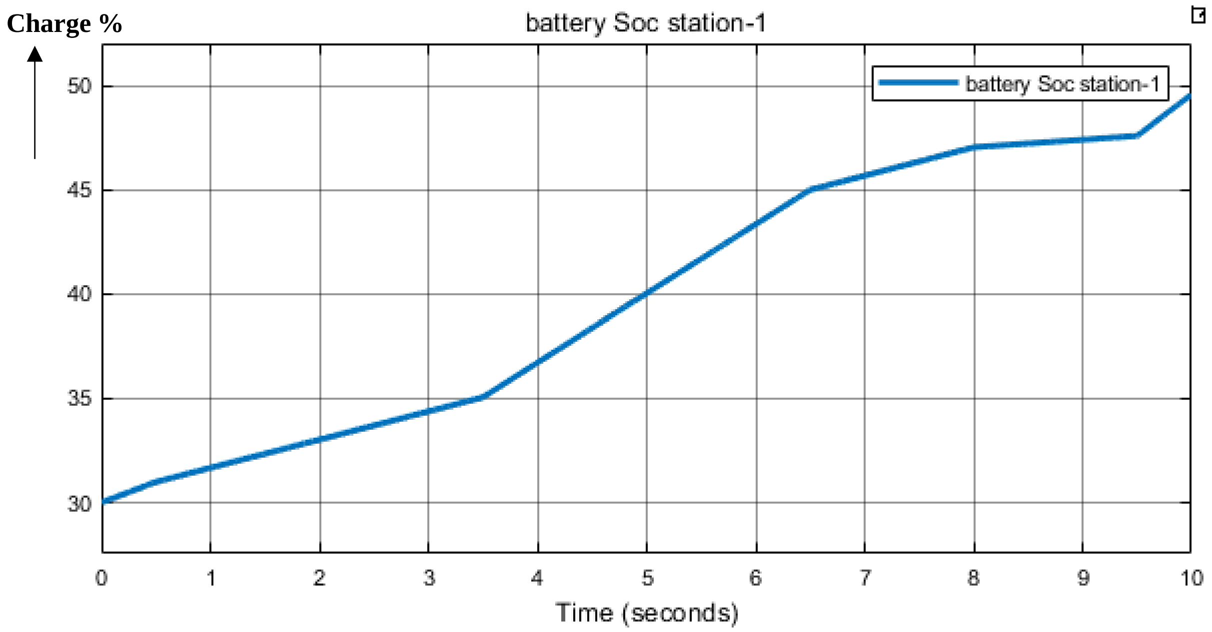
Simulation test of station 1. (a) PV and wind current of station 1. 1



Simulation test of station 1. (b) Charge current from station 1.



Simulation test of station 1. (c) DC bus voltage of station 1.



D Simulation test of station 1. (d) SoC of batteries of station 1

Fig 7.2:Simulation test of station 1. (a) PV and wind current of station 1. (b) Charge current from station 1. (c) DC bus voltage of station 1. (d) SoC of batteries of station 1

7.3 AT STATION 1 AND STATION-2 WITH TRAIN-1 CONFIGURATION

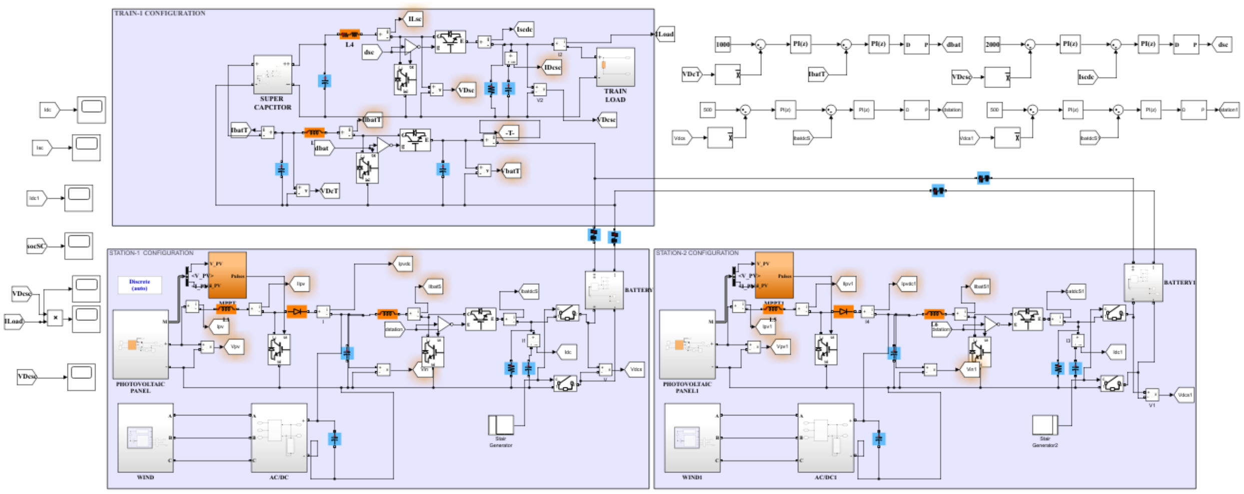
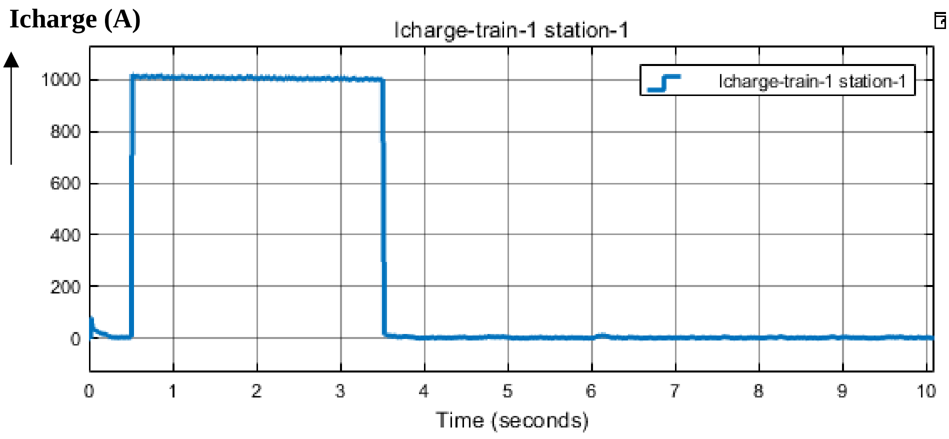
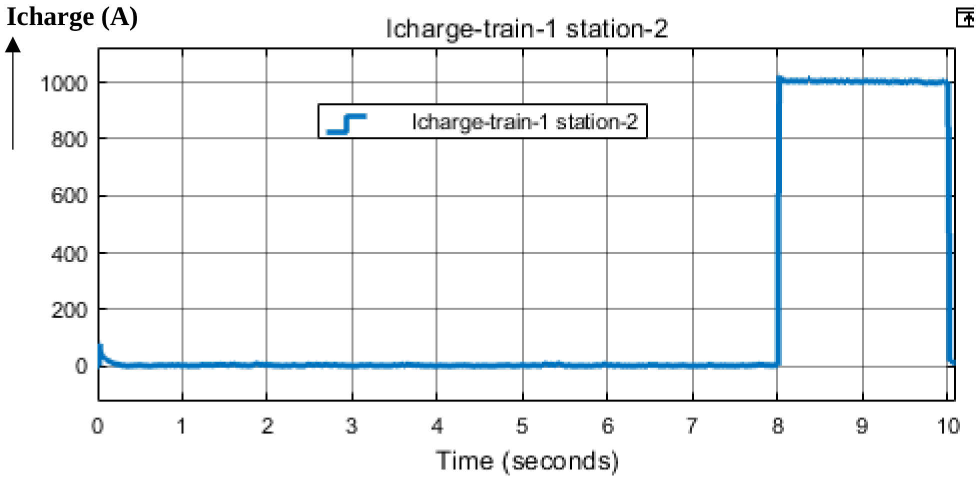


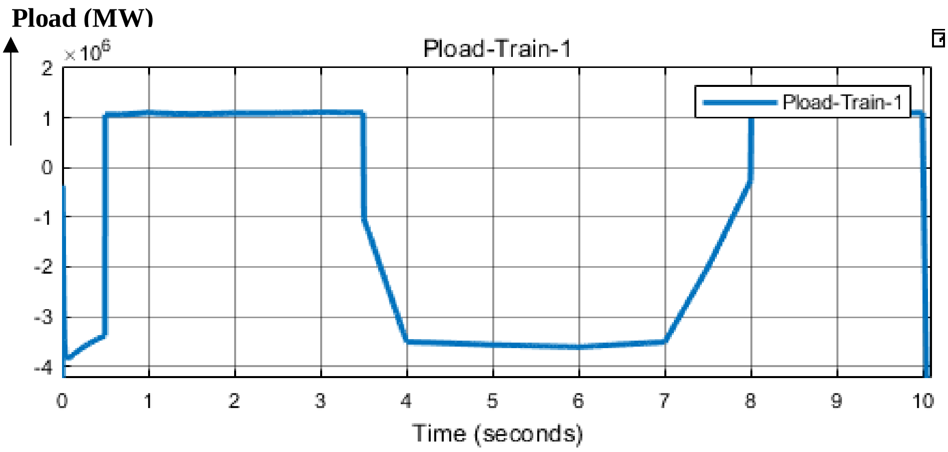
Fig 7.3:Schematic diagram



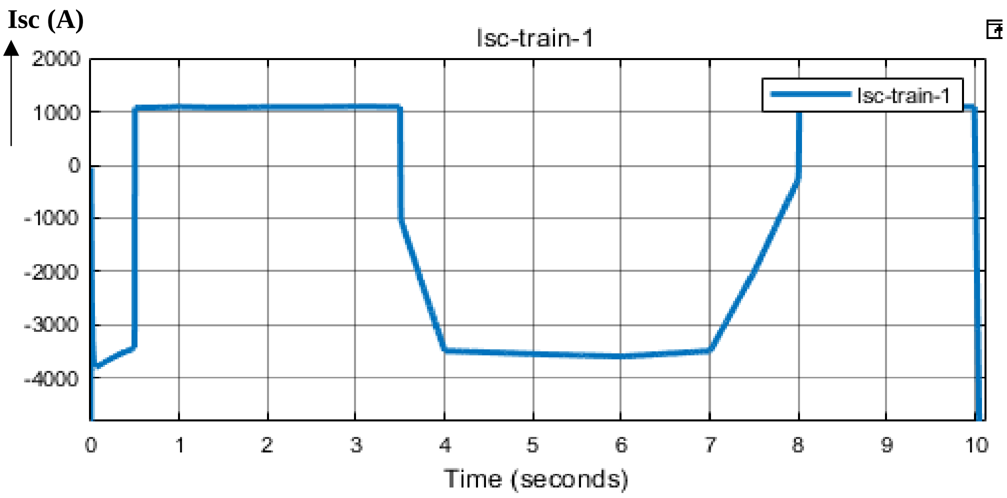
Simulation test of train 1. (a) Charge current of train 1 from station 1.



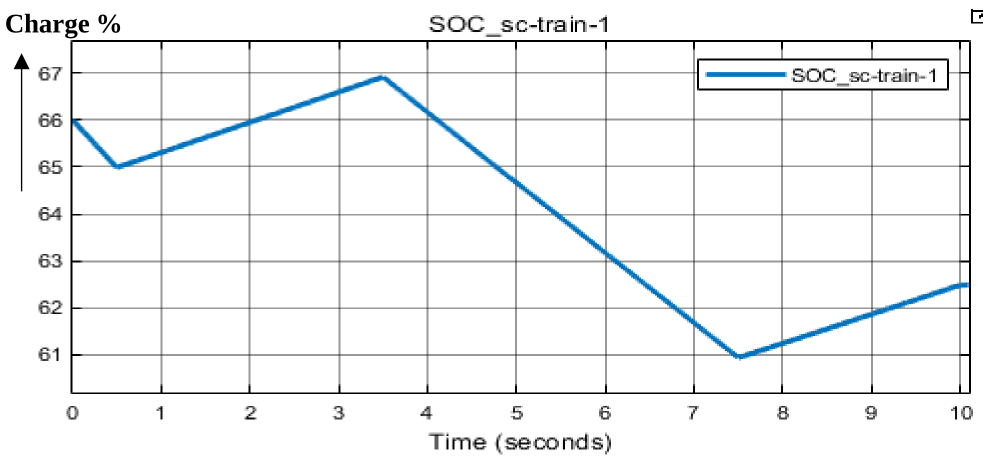
Simulation test of train 1. (b) Charge current of train 1 from station 2.



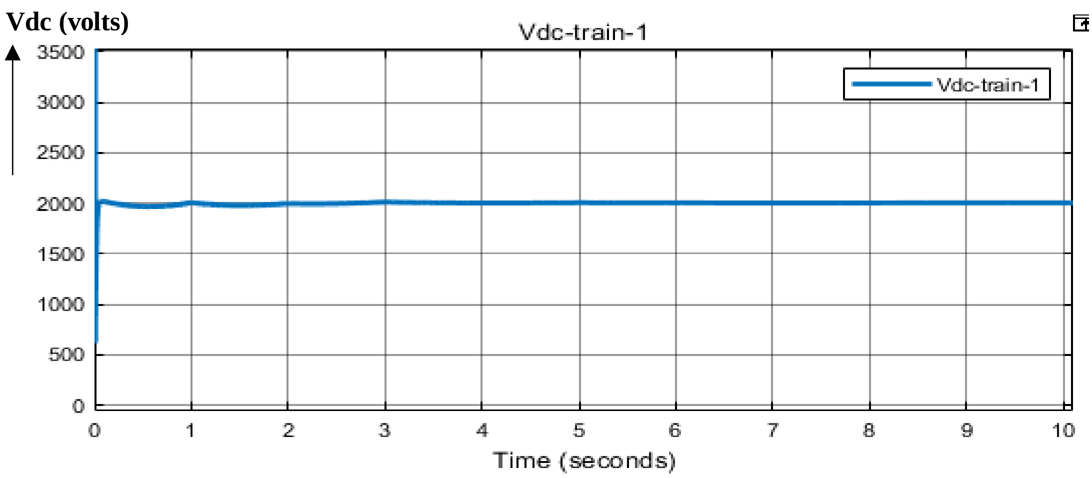
Simulation test of train 1. (c) Load power of train 1.



Simulation test of train 1. (d) SCs current of train 1.



Simulation test of train 1. (e) SoC of SCs of train 1.



Simulation test of train 1.(f) DC bus voltage of train 1.

Fig 7.4:Simulation test of train 1. (a) Charge current of train 1 from station 1. (b) Charge current of train 1 from station 2. (c) Load power of train 1. (d) SCs current of train 1. (e) SoC of SCs of train 1. (f) DC bus voltage of train 1.

7.4 AT STATION-1 WITH TRAIN-1 AND TRAIN-2 CONFIGURATION

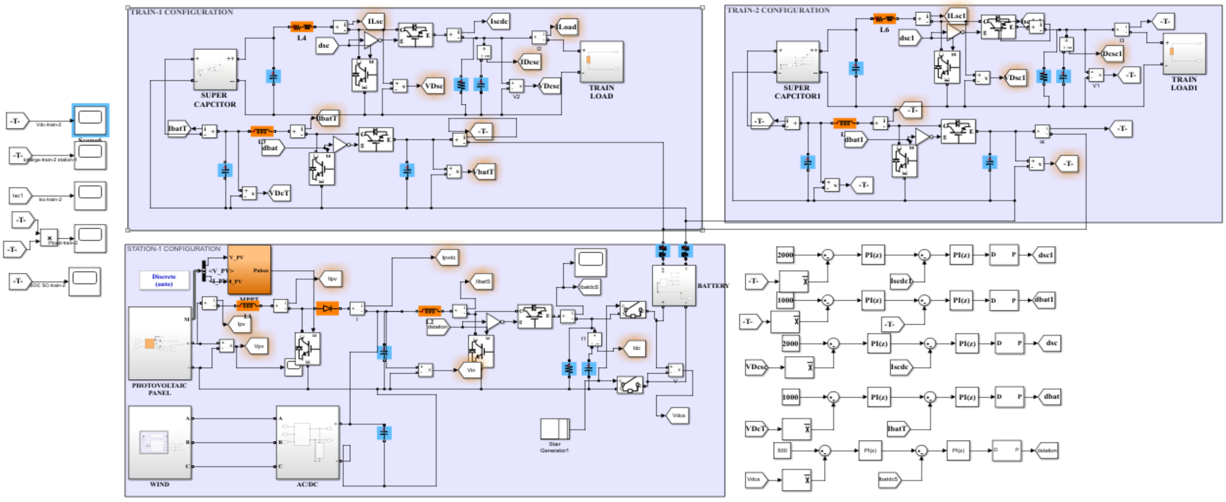
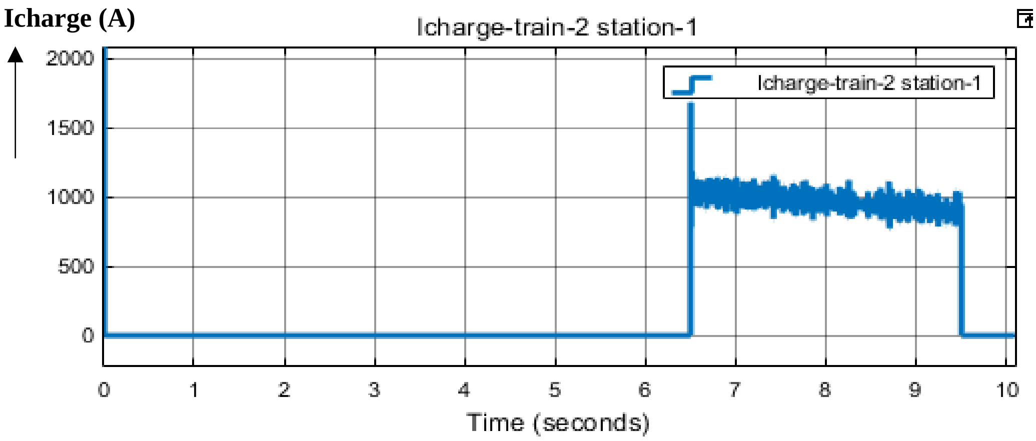
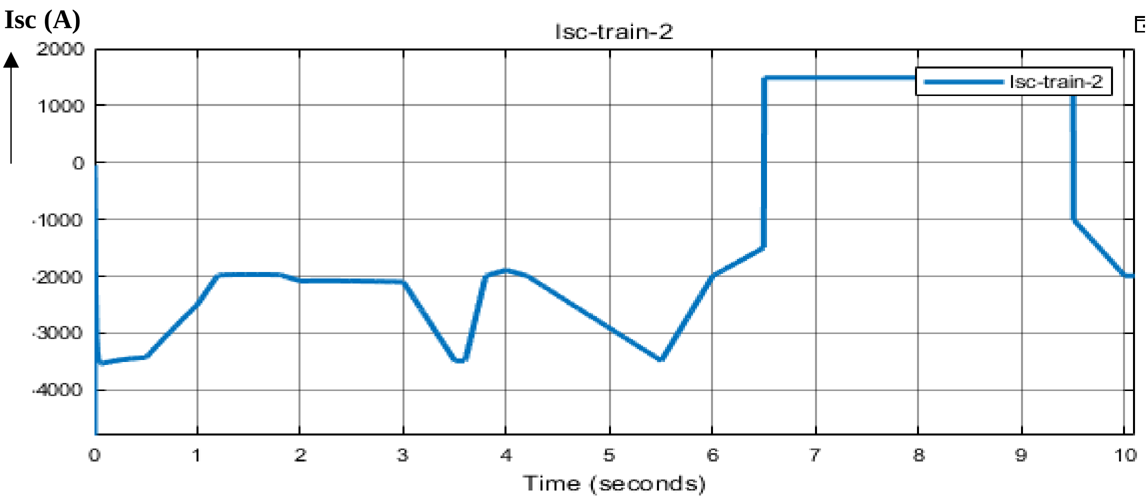


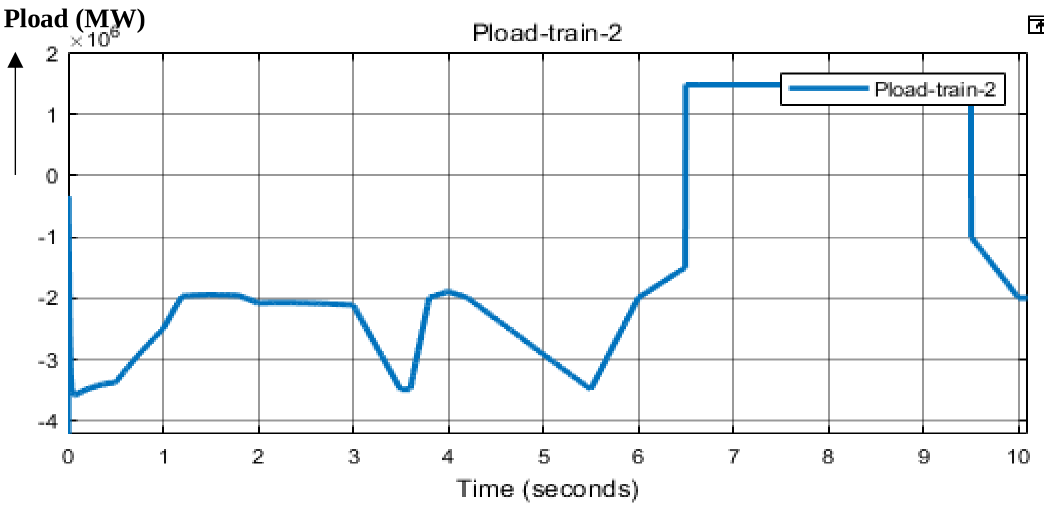
Fig 7.5:Schematic diagram



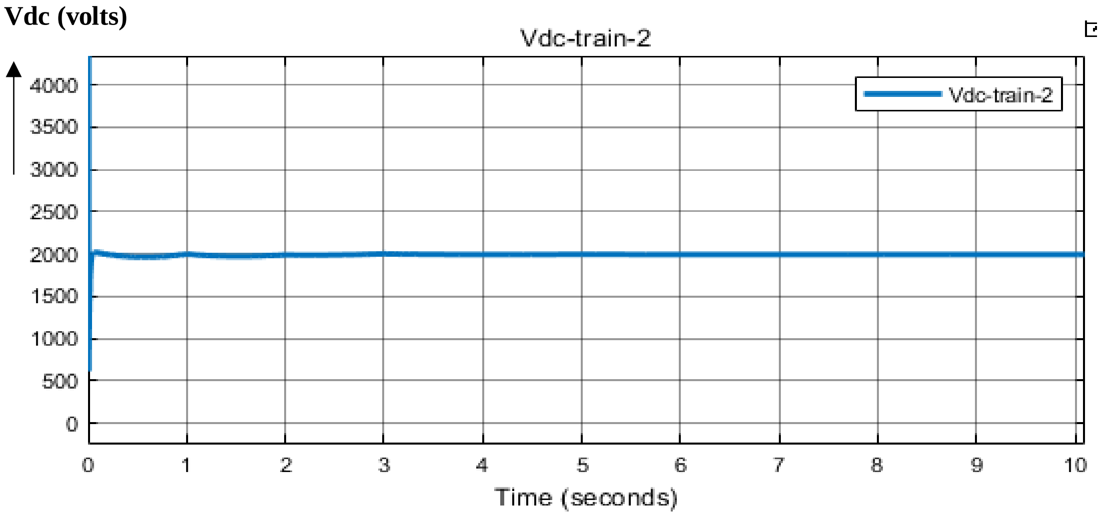
Simulation test of train 2. (a) Charge current of train 2 from station 1.



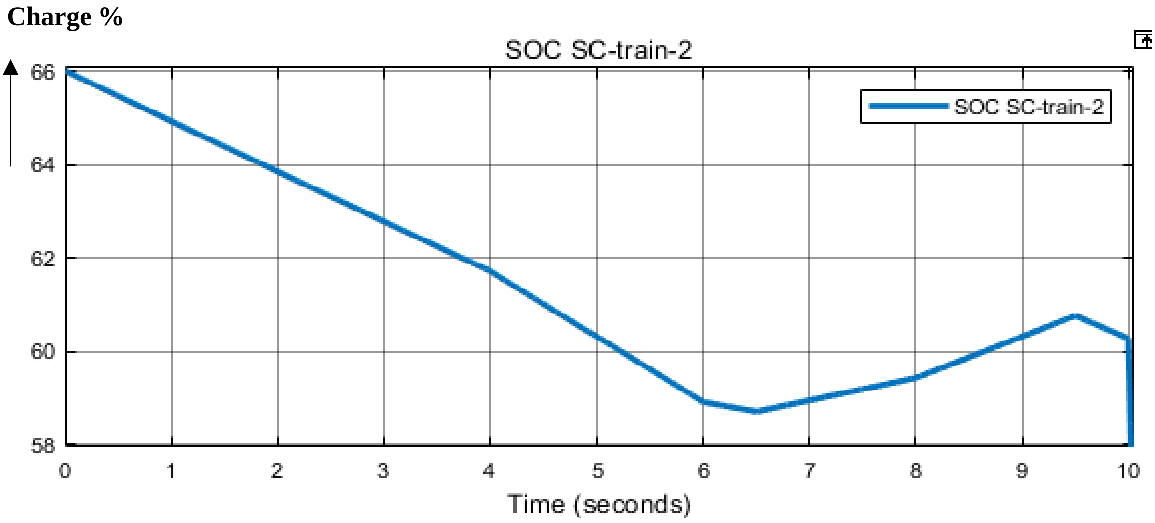
Simulation test of train 2. (b) SCs current of train 2.



Simulation test of train 2. (c) Load power of train 2.



Simulation test of train 2. (d) DC bus voltage of train 2.



Simulation test of train 2. (e) SoC of SCs of train 2

Fig 7.6:Simulation test of train 2. (a) Charge current of train 1 from station 1. (b) SCs current of train 2. (c) Load power of train 2. (d) DC bus voltage of train 2. (e) SoC of SCs of train 2

CHAPTER-VIII

CONCLUSION

CHAPTER VIII

CONCLUSION

The proposes techno-economic method for the energy storage by using SCs in the train was presented in this project. The studied system is devised on two parts: station and train. The design of railway station is presented by using PV and wind as principal sources, and batteries for ESS. The train is composed by engine and SCs. SCs are implemented to the ESS of the train, where they are alimented from the breaking phases and the stations by a pantograph installed in an air power line in each stop. SCs are used for their fast charge and discharge. An EMS is given in order to stabilize the DC bus. The calculation of parameters of the buck-boost converter are given. The Sizing of the integral and proportional gain controller used for the stabilization of the DC bus of train and station is given. A simulation test was proposed with one station and two trains. The trains recharge from the station in different times. The obtained results showed that the given EMS and system design give good results in order to stabilized the DC bus voltage and reply to the need of energy by the engine. The future work will be reserved to the application of this system with AC engine.

CHAPTER-IX

REFERENCES

CHAPTER IX

REFERENCES

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JOURNAL

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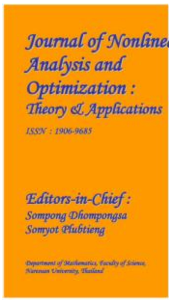
ISSN : **1906-9685**



Control and Management of Railway System Connected to Microgrid Stations

Bugudi Mohan Kumar, Malireddy Lakshman, Seelam Rajasekhar,
Boya Jolanna Gari Ramakrishna, M Fareed Akram, B. Tech Students,
Dr. K. Chithambaraiah Setty, Professor & HOD, Dept Of EEE,
St. Johns College of Engineering and Technology, Yemminganur.

ABSTRACT

The recent railway system is a huge microgrid assembling multiplex structure with distributed active loads, sources and storage devices. The active load represents the train. The sources are a microgrid based on renewable energies. The big problem of the most of electrical train is that they can't recover energy recovery during regenerative breaking phases. Another problem of the electrical train is the long charging time from the stations. This project suggests a techno-economic process for the energy storage by using SCs in the train, with the aim to reduce the energy consumptions. The proposed design of railway station uses PV and wind sources, and batteries for energy storage system (ESS). For the train, SCs are implemented to the ESS where they are alimented breaking phases and from stations by a pantograph installed in an air power line in each stop. SCs are distinguished by high characteristics power and a wide number of charge/discharge cycles, they provide low particular energy and a fast-charging time. An energy management approach is suggested to control the DC bus by voltage and the buck-boost converter by current. The Sizing of PI controller used for the stabilization of the DC bus of train and station is given. The whole system is modelled in MATLAB-Simulink. Simulations for the train and station show the suitability of the suggested powertrain and control strategy.

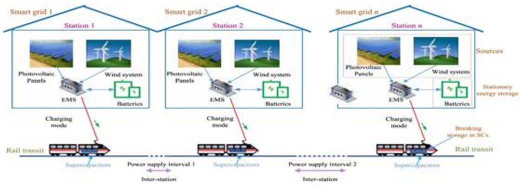
I.INTRODUCTION

A. MOTIVATION

In the last few decades, generally there are growing in energy using and pollutions [1]. The growing number of citizens traveling between cities has implied the continuous development of mass transit systems as buses, taxies, and trains [2]. However, the use of railway transportation systems other conventional means of transport is widely recognized due to the Carrying capacity of a large number of people. The development of rail transportation allows people to travel quickly. Thereby, growing environmental like climate change and CO_2 emissions change issues dictate the requisite for ameliorate the performance energy regulation of railway systems [3], [4]. For these raisons, the electric railway traffic has become a principal development management of current public transportation networks [5], [6].

The production of clean energy from renewable sources have become the hot topics of social development [7]. However, railway system integrates different renewable energy sources, like photovoltaics (PV) and wind turbines. To ensure a continuous power supply and to respond to the charge power of train from station to the train, an energy storage system (ESS) is necessary [8], [9]. In order to manage the overload variation in railway power supply structure in the time of heights commuting hours, a wide number of ESS technologies are implemented in the railway system as a constructive means to improve load needs [6], [10]. The on-board storage augmented the weight and space of a vehicle that encourage the underground storage.

SCs represent an appear energy storage devices characterized with a high-power density, a long span life and a wide temperature range, has become the best appropriate storage element match with the functioning characteristics of train system [11] [14]. By comparing SCs to different energy storage devices like batteries and flywheels, SCs present fast charging and discharging time because of the high-power density, and important potential of energy recovery [15]. In general, ESS with SC is considered like energy buffer accelerating mode of train and recycles the excess of power during the braking mode, realizing a good balance of charge and discharge [16]. SCs are considered a best solution in systems which characterized with different fluctuations. SCs are also used in interruptible power systems to stabilized the power and bus voltage. The energy storage in railway system presents a challenge for researches [17], [18].



Energy management system (EMS) is currently a big challenge in large-scale complex energy distribution networks like railway structure. Most of EMS researches in railway structure interest on ameliorating the railway system technologically. EMS on the system level with an integrated strategy into the railway structure often is ignored [19], [20]. The optimal control theory for railway vehicle is presented in many articles [21], [22].

B. LITERATURE

The railway system has been studied successfully in many articles by researches such as: Jiang presents a fast inspection method for high-speed railway infrastructure monitoring [23], Feng gives the electric railway smart microgrid system with integration of multiple energy systems and power-quality improvement[24].Khayyam gives railway system energy management optimization demonstrated at offline and online case studies [19], Zhang presents the method using a prediction approach [24], He shown the energy harvesting approach for railway wagon monitoring sensor with high reliability and simple structure [25], Sun presents the hybrid method for life prediction of railway [26], Novak presents the hierarchical model predictive control for coordinated electric railway traction system energy management [27], Sengor gives the energy management of a smart railway station considering regenerative braking and stochastic behaviour of ESS and PV Generation [28].

C. CONTRIBUTIONS

The proposed system, is composed of two parts: the first one concern the stations, the second one is addressed to the control of trains. The stations are composed PV and wind elds where the energy storage is insured by batteries. The trains are composed by SCs and engine. SCs are used because of their high power. The innovative contributions given in this article are as follows:

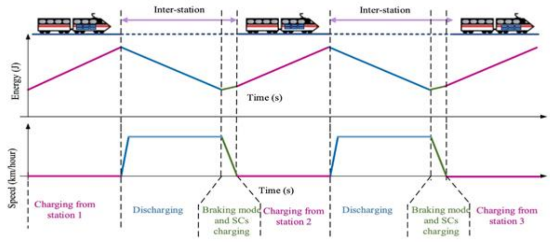
- A design of train implementing SCs for energy storage alimented from stations and breaking phases.
- A new EMS is suggested to control the DC bus by voltage and the buck-boost converter by current.
- Sizing of PI controller used for the stabilization of the DC bus of train and station. A design of railway station using PV and wind sources, and batteries for energy storage

Remainders of project are as follows: system description is depicted in Section II. The system modelling and management is designed in Section II. The simulation and validation expounded in Section IV. In Finally, Section V draws the conclusion.

II. SYSTEM DESCRIPTION

A. GLOBAL SYSTEM DESCRIPTION

The implementing of the rail transit and energy strategy is illustrated in Fig above. The railway system is constructor of two systems. The first one is stationary system which represents the different stations. Each station is composed by a main energy source which are PV panels and wind system. The energy provided from main sources is stored in batteries. The conversion of energy is insured by boost, buck-boost converters and inverter. Wind system is coupled to the DC bus by an inverter. A boost converter is used to connect PV panels to the DC bus. A buck-boost converter is implemented to couple batteries to the DC bus. The different stations have the same structure and components. The control of the DC bus is insured with an EMS based on PI control. The second one is the mobile system which represents the trains. Each train is composed by motors and supercapacitors. The transfer of energy from SCs to the motors is insured by a buck-boost converter.



B. DISTRIBUTION OF ENERGY BETWEEN DEVICES

The exchange of energy between different devices is given in Fig above. The railway system is divided in different stations. The distance between station is more than 10Km. Trains stop in each station between 5 and 15 minutes. During this trains stop, the motors train stop working and SCs charge from batteries installed in the stationary station by a buck-boost converter. The charge of SCs in the stations is insured by the pantograph connected the roof of the trains.

During of the circulation of train between stations, the SCs supply the need of energy. During the braking of the train the energy is returned to SCs. This energy which is produced by different train will be stored locally and produced later in next phases during its acceleration. However, the train in functioning as a load during tracking mode and as a source of the power during braking mode. The stations and trains are connected and mutually communicated.

The different state functioning of rail train engine resolves the form of electrical power exchange. During the traction of the engine, the alternator mode, the train is in the acceleration conditions. In this case, the electric power circle in the forward direction, that is transformed into kinetic energy from the traction system. during the traction engine, the power generation phase, the train is in braking and deceleration mode. At this moment, the electric energy circle in the inverse direction, and the kinetic energy given by the train during braking is used by the auxiliary installations of the train itself, with most of them being fed back to the SCs and used by the train in the same power supply phase.

The installation of the storage devices reduces the energy line losses, because the power circle though the line is minimized, and the smoother voltage pro les without the request of changing the infrastructure of the structure. The implementation of SCs on a vehicle however need a large space, adding at the same time extra weight that can affect significantly the dynamic specifications of the train.

The train power is 3.5MW. The energy delivered by SCs is estimated at approximately 210MJ (corresponding to 3.5MW for 60 s).

III. SYSTEM MODELLING AND ENERGY MANAGEMENT

The DC bus is controlled according to the diagram given in Fig above. The EMS is divided in two parts, the first one is the control of the stationary system and the second in the train.

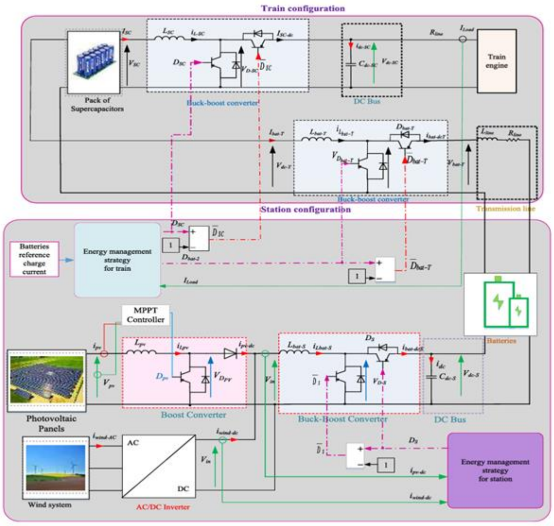
For the stationary system, the wind system produces a AC power. It is coupled to the DC bus by using an AC-DC inverter. The PV system is implemented to the same bus by using a Boost converter. An MPPT maximum power point tracking system is implemented to stabilized the PV power and voltage. A Buck-Boost converter is applied to stabilized the DC bus voltage V_{dS} and to charge the batteries. A line transmission is presented by a resistance and inductance. For the train system, a Buck-Boost converter is implemented to couple batteries to SCs. Another Buck-Boost is implemented to couple SCs train engine and to stabilize the voltage to 2KW. A capacitor is implemented in parallel to the engine and the buck-boost converter in order to filter the power fluctuation from the converters. The EMS gives the control of the converters. The mathematical modelling of PV and wind system are given in Table above. The mathematical modelling of SCs and batteries are given in Table above. The chosen SCs model two branches model. The using batteries model is CIMAT batteries.

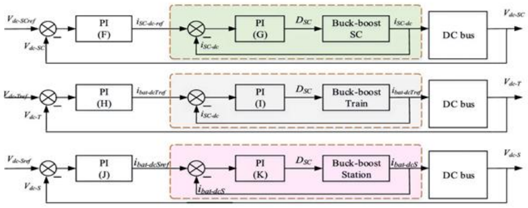
The buck-Boost converter is reversible in current. The modelling of this converter is given in Fig above [8]. In the active phase, the switch is closed, the input voltage is given by:

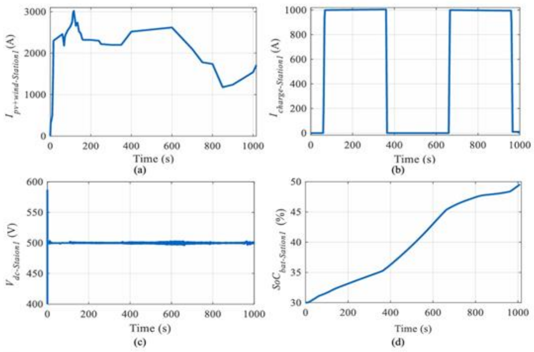
$$v_{L-SC} = V_{sc} = L_{sc}\frac{di_{L-SC}}{dt} \tag{1}$$

$$\frac{di_{L-SC}}{dt} = \frac{V_{sc}}{L_{sc}} \tag{2}$$

where LSC is the inductance, VSC is the SCs voltage, Cdc SC is the SCs buck-boost capacitor.







In the Freewheeling phase, the switch is open and the inductor current cannot fluctuate instantaneously. The input voltage is de ned by the following equations:

$$v_{L-SC} = V_{SC} - V_{dc} = L_{SC}\frac{di_{L-SC}}{dt} \quad (3)$$

$$\frac{di_{L-SC}}{dt} = \frac{V_{SC} - V_{dc}}{L_{SC}} \quad (4)$$

The main equation of the buck-boost converter is given by:

$$L_{SC}\frac{di_{L-SC}}{dt} = V_{SC} - (1 - D_{SC})V_{dc} \quad (5)$$

IV. CONTROL OF THE DC BUS VOLTAGE OF DIFFERENT SYSTEMS OF TRAIN AND STATION

The principle of the control system of SC, train and stationary system are described in Fig above. The PI controllers F(s), H(s) and J(s) calculate the reference current of the DC bus of SC system, the train system and the stationary system, $I_{sc\text{-}dc}$ ref, $i_{bat\text{-}dcT}$ ref and $i_{bat\text{-}dcS}$ ref, respectively. The PI controllers G(s), I(s) and K(s) calculate the duty cycle of SC system DSC, train system DT and the stationary system DS, respectively.

The management of the three DC bus is insured with a voltage control. The calculating of the parameters of this PI controller(F(s), H(s) and J(s)) is given by the following equations:

$$C_{dc-SC}\frac{dV_{dc-SC}}{dt} = i_{L-SC}(1 - D_{SC}) - \frac{V_{dc-SC}}{r_{L-SC}} - i_{SC-dc} \quad (6)$$

$$L_{SC}\frac{di_{L-SC}}{dt} = V_{SC} - (1 - D_{SC})V_{dc-SC} \quad (7)$$

where $\beta_{SC} = 1 - D_{SC}$. Then,

$$C_{dc-SC}\frac{dV_{dc-SC}}{dt} = i_{L-SC}\beta_{SC} - \frac{V_{dc-SC}}{r_{L-SC}} - i_{SC-dc} \quad (8)$$

$$L_{SC}\frac{di_{L-SC}}{dt} = V_{SC} - \beta_{SC}V_{dc-SC} \quad (9)$$

Thereby, the dynamic equation is expressed as:

$$C_{dc-SC}\frac{dV_{dc-SC}}{dt} = i_{L-SC}\frac{V_{SC}}{V_{dc-SC}} - \frac{V_{dc-SC}}{r_{L-SC}} - i_{SC-dc} \quad (10)$$

By supposing X V2 dc SC is replaced, the linear function is expressed by:

$$\frac{dX}{dt} = 2V_{dc-SC}\frac{dV_{dc-SC}}{dt} \quad (11)$$

where

$$\frac{dV_{dc-SC}}{dt} = \frac{1}{2V_{dc-SC}}\frac{dX}{dt} \quad (12)$$

The main equation is given:

$$C_{dc-SC}\frac{dX}{dt} = 2i_{L-SC}V_{SC} - 2\frac{X}{r_{L-SC}} - 2i_{SC-dc}V_{dc-SC} \quad (13)$$

The TF (transfer function) of between voltage and current in Laplace domain is given by:

$$FTx(s) == \frac{V_{dc-SC(s)}}{I_{SC-dc}(s)} = \frac{V_{SC}\, r_{L-SC}}{\frac{r_{L-SC}C_{dc-SC}}{2}s + 1} \quad (14)$$

The TF of the SC system is represented by

$$F(s) = K_{p-_{SC1}} + \frac{K_{i-SC1}}{s} \quad (15)$$

Where $K_{i\text{-}SC1}$ and $K_{p\text{-}SC1}$ are the integral and proportional gain used for SCs system control, respectively.

The TF of the train system is represented by

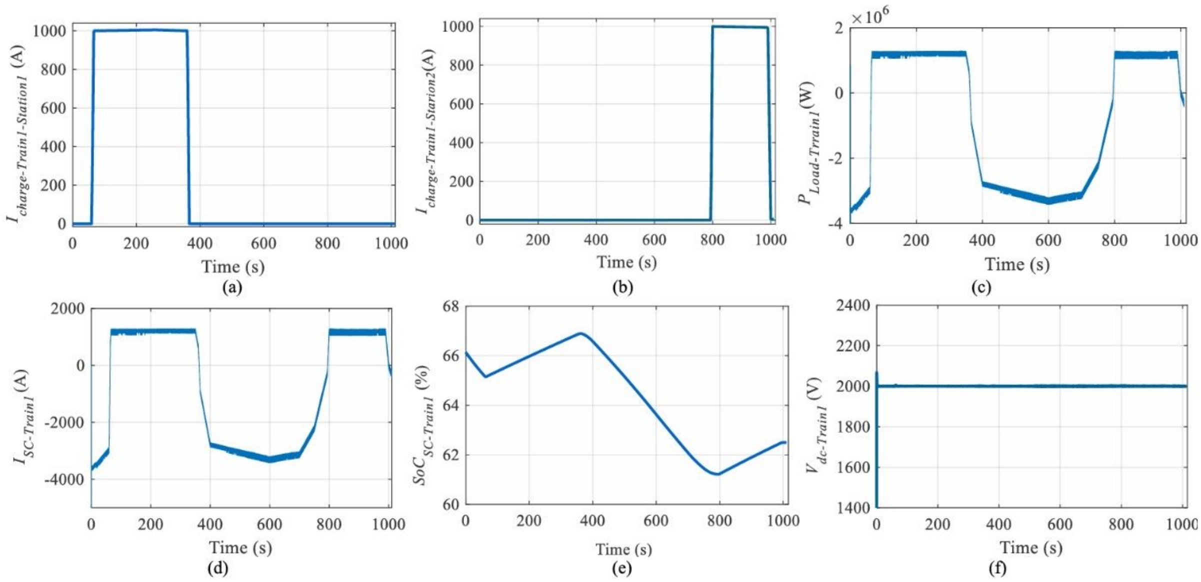
$$H(s) = K_{p-_{T1}} + \frac{K_{i-T1}}{s} \quad (16)$$

$K_{i\text{-}T1}$ and $K_{p\text{-}T1}$ are the integral and proportional used for the train system control, respectively. The transfer function of the stationary system is expressed by the following equation

$$J(s) = K_{p-_{S1}} + \frac{K_{i-S1}}{s} \quad (17)$$

$$FTBF(s)=\frac{K_{p-SC1}r_{L-SC}V_{SC}\left(s+\frac{K_{i-SC1}}{K_{p-SC1}}\right)}{\frac{r_{L-SC}C_{dc-SC}}{2}s^2+\left(K_{p-SC1}r_{L-SC}V_{SC}+1\right)s+K_{p-SC1}r_{L-SC}V_{SC}\frac{K_{i-SC1}}{K_{p-SC1}}} \tag{19}$$

$$CLTF(s)=\frac{\frac{2}{C_{dc-SC}}K_{p-SC}V_{SC}\left(s+\frac{K_{i-SC1}}{K_{p-SC1}}\right)}{s^2+\frac{2}{r_{L-SC}C_{dc-SC}}\left(K_{p-SC1}r_{L-SC}V_{SC}+1\right)s+\frac{2}{C_{dc-SC}}V_{SC}K_{i-SC1}} \tag{20}$$



Equation (14) and (15) we deduce the following expression:

$$FTBF(s)=\frac{K_{p-SC1}r_{L-SC}V_{SC}\left(s+\frac{K_{i-SC1}}{K_{p-SC1}}\right)}{K_{p-SC1}r_{L-SC}V_{SC}\left(s+\frac{K_{i-SC1}}{K_{p-SC1}}\right)+s\left(\frac{r_{L-SC}C_{dc-SC}}{2}s+1\right)} \tag{18}$$

which gives (19), as shown at the bottom of the next page. The closed-loop transfer function is the SC system is given by (20), as shown at the bottom of the next page. By identifying the denominator with that of the canonical form the SC system, we deduce

$$\begin{cases}\omega_n^2=\dfrac{2}{C_{SC}}V_{SC}K_{i_{SC1}}\\[2ex] K_{i-SC1}=\dfrac{\omega_{n-SC}^2C_{dc-SC}}{2V_{SC}}\end{cases} \tag{21}$$

Where

$$\begin{cases}2\xi_{SC}\omega_{n-SC}=\dfrac{2}{r_{L-SC}C_{dc-SC}}\left(K_{p-SC1}r_{L-SC}V_{SC}+1\right)\\[2ex] K_{p-SC1}=\dfrac{\xi_{SC}\omega_{n-SC}r_{L-SC}C_{dc-SC}-1}{r_{L-SC}V_{SC}}\end{cases} \tag{22}$$

TABLE 1. Mathematical modelling of PV and wind system.

Device	Mathematical model		Abbreviations
PV [22]	PV current I_{pv}	$I_{pv}=I_{ph}-I_d-I_r$ $I_s\left(\exp\left(\frac{q\left(V_{pv}+I_{pv}R_s\right)}{n_{s-pv}AkT_c}\right)-1\right)$ $\frac{I_{pv}R_s+V_{pv}}{R_p}$	I_{ph} : Photocurrent I_S : Cell dark saturation current $n_{s\text{-}pv}$: Number of PV cells T_C :Cell's working temperature T_n : Cell's reference temperature A : Ideal factor R_S: Series resistor R_p : Shunt resistor $I_{s,0}$: Cell's short-circuit current at a 25°C E_g : Energy of the band gap I_r: Solar irradiation I_{ph}: Light-generated current I_n : Solar irradiation at T_C temperature q: Electron charge k: Boltzmann's constant
	PV current I_{pv}	$I_{pv}=I_{ph}-I_s\left(\exp\left(\frac{q\left(V_{pv}+I_{pv}R_s\right)}{n_{s-pv}AkT_c}\right)-1\right)-\frac{I_{pv}R_s+V_{pv}}{R_p}$	
	saturation current I_s	$I_s=I_{s,0}\left(\frac{T_n}{T}\right)^3\exp\left[\frac{qE_g}{Ak}\left(\frac{1}{T_n}-\frac{1}{T}\right)\right]$	
	Photocurrent I_{ph}	$I_{ph}=\left(I_{ph,n}+K_I\Delta_T\right)\frac{G}{G_n}$ $\Delta_T=T-T_n$	
Wind	power turbine P_m	$P_m=\frac{1}{2}C_p(\lambda,\beta)\rho\frac{A}{2}V_{wind}^3$	β : blade pitch angle C_p : performance coefficient λ : tip speed ratio of the rotor blade A : turbine swept area λi is a coefficient that is given by the following equation ρ : density of air.
	$C_p(\lambda;\beta)$	$C_p=\frac{1}{2}\left(\frac{116}{4}-0.4\beta-0.5\right)e^{-\left(\frac{21}{\lambda}\right)}$	
	λi coefficient	$\frac{1}{\lambda_i}=\frac{116}{\lambda+0.08\beta}-\frac{0.035}{\beta^3+1}$	
	wind turbine torque T_m	$T_m=\frac{1}{2}\rho\pi R^3\frac{C_p(\lambda)}{\lambda}v^2=\frac{1}{2}\rho AC_p(\lambda)v^3\frac{1}{\omega_m}$	

where n SC is the pulsation for SC system, SC is the damping coefficient for SC system.

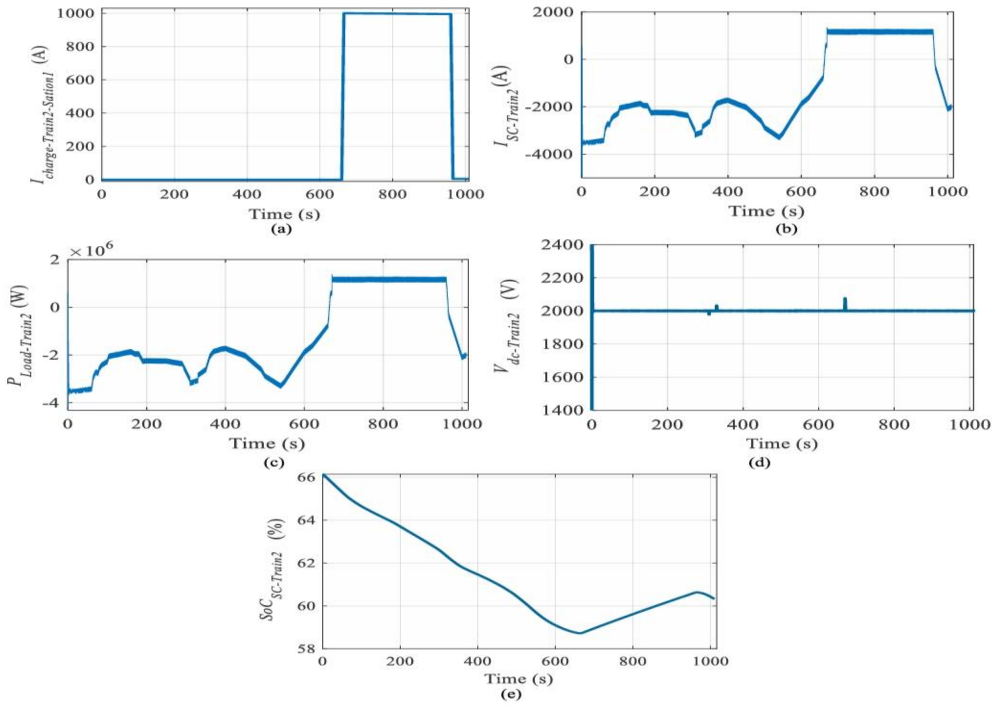
$K_{i\text{-}T1}$ and $K_{p\text{-}T1}$ are the integral and proportional used for the train system control, respectively. They are expressed by:

$$K_{i-T1}=\frac{\omega_{n-T}^2C_{dc-T}}{2V_{dc-T}} \tag{23}$$

$$K_{p-T1}=\frac{\xi_T\omega_{n-T}r_{L-T}C_{dc-T}-1}{r_{L-T}V_{dc-T}} \tag{24}$$

where n SC is the pulsation used for train system, SC is the damping coefficient used for train system.

$K_{i\text{-}S1}$ and $K_{p\text{-}S1}$ are the integral and proportional gain used for the stationary system control, respectively. They are expressed by:



$$K_{i-S1} = \frac{\omega_{n-S}^2 C_{dc-S}}{2V_{dc}} \quad (25)$$

$$K_{p-S1} = \frac{\xi_S \omega_{n-S} r_{L-S} C_{dc-S} - 1}{r_{L-S} V_{dc}} \quad (26)$$

where n SC is the pulsation used for stationary system, SC is the damping coeff cient used for stationary system. The control of the buck-boost converter is insured by a current control. The calculating of the parameters of this PI controller (G(s), I(s) andK(s)) is given by the same methodology and is represented by the following equations:

$$V_{SC} = L_{SC} i_{L-SC}(s) s + R_{Load} i_{L-SC}(s) + (1 - D_{SC}(s)) V_{dc-SC} \quad (27)$$

The DSC and ISC is expressed as follows:

$$\frac{I_{SC}(s)}{D_{SC}(s)} = \frac{\frac{V_{dc-SC}}{R_{Load}}}{1 + \frac{L_{SC}}{R_{Load}} s} \quad (28)$$

The TF of the SC system is given by the following equation:

$$G(s) = \frac{K_{i-SC2}\left(1 + \frac{K_{p-SC2}}{K_{i-SC2}} s\right)}{s} \quad (29)$$

The TF of the stationary system is expressed by the following equation:

$$I(s) = \frac{K_{i-T2}\left(1 + \frac{K_{p-T2}}{K_{i-T2}} s\right)}{s} \quad (30)$$

The TF of the stationary system is expressed by the following equation:

$$K(s) = \frac{K_{i-S2}\left(1 + \frac{K_{p-S2}}{K_{i-S2}} s\right)}{s} \quad (31)$$

In order to simplify the transfer function of the system, a pole/zero and imposing compensation are assumed: $\frac{K_{p-SC2}}{K_{i-SC2}} = \frac{L_{SC}}{R_{Load}}$. The new CLTF(s) becomes

$$CLTF(s) = \frac{1}{1 + \frac{R_{Load}}{V_{dc-SC} K_{i-SC2}} s} \quad (32)$$

where

$$\tau_{SC} = \frac{R_{Load}}{V_{dc-SC} K_{i-SC2}} \quad (33)$$

Then, K_{i-SC2} and K_{p-SC2} are the integral and proportional used for the SC system control, respectively. They are expressed by:

$$K_{i-SC2} = \frac{R_{Load}}{\tau_{SC} V_{dc-SC}} \quad (34)$$

$$K_{p-SC2} = \frac{L_{SC}}{\tau_{SC} V_{dc-SC}} \quad (35)$$

$K_{i\text{-}T2}$ and $K_{p\text{-}T2}$ used for the train system control is ex

V. SIMULATION RESULTS

For test the feasibility of the presented strategy, a model of the whole system is built by Matlab Simulink software.The proposed simulation test is presented by one station (station1) and two trains (train1 and train2). The simulation tests are proposed with the same parameters of trains and stations during1000s. The scenario of wind, solar irradiation and temperature is proposed variable.

The initial state of charge of batteries used in station1is $SoC_{bat\text{-}Station1}$ = 30%.

The initial state of charge of SCs used in train 1 is $SoC_{SC\text{-}Train1}$ = 66%.

The initial state of charge of SCs used in train 2 is $SoC_{SC\text{-}Train2}$ = 66%.

Fig.7 represents the simulation test of station1. This station is proposed by amicrogrid using PV and wind as a sources. The energy storage is insured by batteries. Fig.8 and 9 represent the simulation tests of train1 and train2, respectively. In this simulation test, train1 and train 2 charge from station1 in different duration. Train1 reach station1 at t=50s and train 2 reach station 1 at t=650s. Fig.7(a) represents the PV and wind current that is varied between 1200A and 3000A.

The charge current of station1 is illustrated in Fig.7(b). Train1 charge from station 1 between t=50s and t=350s with a constant current of $I_{charge\text{-}Station1}$ 1000A for a duration of five minutes. Train2 charge from station1 betweent t=650s and t=950s with a constant current of $I_{charge\text{-}Station1}$ = 1000A for a duration of five minutes. The DC bus voltage of station1 in given inFig above(c). It is fixed at 500V.The state of charge of batteries of station1 is given in Fig.7(d). It is represented between 30% and 50%. Train1 charge from station1 between t=50s and t=350s, and charge from station2 between t=800s and t=1000s. The charge current of SCs from station1 and 2 used for train 1 is given in Fig.8 (a and b), respectively. Power and current of SCs are shown in Fig.8 (c and d), respectively. The power and current are positive and constant in the charging mode and negative in the traction mode. The DC bus voltage of train1 is 2000V and is given in Fig.8(e). The state of charge of SCs of train 1 is given in Fig above(f). It varies between 61% and 67% that represents an augmentation during charging mode and reduction during traction mode.

Train2 charge from station1 between t=650s and t=950s. The charge current of SCs from station2 used for train2 is given in Fig above(a). The power and SCs current are represented in Fig above(b and c), respectively. The DC bus current of train 1 is 2000V and is given in Fig above(d). The stat of charge of SCs of train 1 is given in Fig above(e). It varies between 69% and 66% that represents an augmen tation during charging mode and reduction during traction mode.

The simulation results proof that the proposed energy management system and control system give good results.

VI. CONCLUSION

The proposed techno-economic method for the energy storage by using SCs in the train was presented in this project. The studied system is devised on two parts: station and train. The design of railway station is presented by using PV and wind as principal sources, and batteries for ESS. The train is composed by engine and SCs. SCs are implemented to the ESS of the train, where they are alimented from the breaking phases and the stations by a pantograph installed in an air power line in each stop. SCs are used for their fast charge and discharge. An EMS is given in order to stabilized the DC bus. The calculation of parameters of the buck-boost converter are given. The Sizing of the integral and proportional gain controller used for the stabilization of the DC bus of train and station is given. A simulation test was proposed with one station and two trains. The trains recharge from the station in different times. The obtained results showed that the given EMS and system design give good results in order to stabilized the DC bus voltage and reply to the need of energy by the engine. The future work will be reserved to the application of this system with AC engine.

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INTERNSHIP CERTIFICATES

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From College St. Johns College of Engineering and Technology

of university JNTUA, Anantapur

has Successfully Completed long-term Internship programme titled

Electric Vehicle (EEE)

Under SkillDzire for 240 Hours.Organized By **SkillDzire** in collaboration with **Andhra Pradesh State Council of Higher Education**.

Certificate ID: SDAP-07225

Issued On 17-Apr-2024

Approved By AICTE

Authorized Signature

CERTIFICATE OF INTERNSHIP

This is to Certify that Mr./Ms

Malireddy Lakshman

Enrolled in the Electrical and Electronics Engineering - 20G31A0215

From College St. Johns College of Engineering and Technology

of university JNTUA, Anantapur

has Successfully Completed long-term Internship programme titled

Electric Vehicle (EEE)

Under SkillDzire for 240 Hours.Organized By **SkillDzire** in collaboration with **Andhra Pradesh State Council of Higher Education**.

Certificate ID: SDAP-08877

Issued On 17-Apr-2024

Approved By AICTE

Authorized Signature

CERTIFICATE OF INTERNSHIP

This is to Certify that Mr./Ms

Seelam Rajasekhar

Enrolled in the Electrical and Electronics Engineering - 20G31A0221

From College St. Johns College of Engineering and Technology

of university JNTUA, Anantapur

has Successfully Completed long-term Internship programme titled

Electric Vehicle (EEE)

Under SkillDzire for 240 Hours.Organized By **SkillDzire** in collaboration with **Andhra Pradesh State Council of Higher Education**.

Certificate ID: SDAP-08227

Issued On 17-Apr-2024

Approved By AICTE

Authorized Signature

CERTIFICATE OF INTERNSHIP

This is to Certify that Mr./Ms

Boya Jolanna Gari Ramakrishna

Enrolled in the Electrical and Electronics Engineering - 20G31A0205

From College St. Johns College of Engineering and Technology

of university JNTUA, Anantapur

has Successfully Completed long-term Internship programme titled

Electric Vehicle (EEE)

Under SkillDzire for 240 Hours.Organized By **SkillDzire** in collaboration with **Andhra Pradesh State Council of Higher Education**.

Certificate ID: SDAP-09312

Issued On 17-Apr-2024

Approved By AICTE

Authorized Signature

CERTIFICATE OF INTERNSHIP

This is to Certify that Mr./Ms

M Fareed Akram

Enrolled in the Electrical and Electronics Engineering - 21G35A0215

From College St. Johns College of Engineering and Technology

of university JNTUA, Anantapur

has Successfully Completed long-term Internship programme titled

Electric Vehicle (EEE)

Under SkillDzire for 240 Hours.Organized By **SkillDzire** in collaboration with **Andhra Pradesh State Council of Higher Education**.

Certificate ID: SDAP-08004

Issued On 17-Apr-2024

Approved By AICTE

Authorized Signature

Course Outcomes Mapping with Pos and PSOs

SUB: Full Internship & Project work CODE: C409

CO-PO Mapping												
COs	POs											
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
C409.1												
C409.2												
C409.3												
C409.4												
C409												

Total CO Attainment through Direct & Indirect Assessment	
CO Attainment	

PO Attainment												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
PO Attainment												

1. Copy CO - PO matrix and CO attainment matrix from previous pages and find PO attainment.
2. PO attainment is calculated as per the following formula:
   POi * Total CO attainment Level / 3 where 'i' ranges from 1 to 12

CO-PSO Mapping

COs	PSOs		
	PSO1	PSO2	PSO3
C409.1			
C409.2			
C409.3			
C409.4			
C409			

Total CO Attainment through Direct & Indirect Assessment	
CO Attainment	

1. Slight(Low)
2. Moderate (Medium)

3. Substantial(High)

If there is no correlation put '-'

PSO Attainment			
COs	PSOs		
	PSO1	PSO2	PSO3
PSO Attainment			

1. Copy CO - PSO matrix and CO attainment matrix from previous pages and find PSO attainment.
2. PSO attainment is calculated as per the following formula:
   PSOi * Total CO attainment Level / 3 where 'i' ranges from 1 to 3