Different Energy Vector Integration and their Storage

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A Project Report

on

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by

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Under the Supervision of Professor Vishal Kumar

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<u>CANDIDATE'S DECLARATION</u>

I hereby declare that the work carried out in this project report entitled **"Different Energy Vector Integration and their Storage"** is being submitted in partial fulfilment of the requirements for the award of the degree of "Master of Technology" in "Systems and control" submitted to the Department of Electrical Engineering, Indian Institute of Technology, Roorkee, under the supervision of **Professor Vishal Kumar,** Department of Electrical Engineering, IIT Roorkee.

I have not submitted the record embodied in this project report for the award of any other degree or diploma.

Date: 25th November 2023

Place: IIT Roorkee **SAQUIB TAJ**

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ABSTRACT

Over the course of the past few decades, there has been a steady rise in the utilization of renewable energy resources. India harnesses about 72 GW of solar power and is the 4th largest harnesser of wind power with 42.6 GW energy production.

The increasing demand for clean and sustainable energy sources has driven the exploration of hybrid renewable energy systems. This study focuses on the optimal integration of solar and wind energy, employing Maximum Power Point Tracking (MPPT) techniques to enhance energy capture efficiency. Additionally, excess energy is efficiently stored in batteries for later use in the time of energy scarce, addressing the intermittent nature of renewable sources.

The proposed system utilizes MPPT algorithms tailored to the characteristics of both solar and wind energy generation, ensuring the extraction of maximum power from these variable sources. The integration of solar and wind resources offers a complementary nature, mitigating the challenges associated with intermittency and variability inherent in individual sources.

To address the temporal misalignment between energy production and consumption, surplus energy is stored in batteries. This storage system not only facilitates stability by providing power during low generation periods but also enhances the overall reliability and resilience of the renewable energy system. Thus, the selection of an appropriate energy storage technology becomes very crucial. This study considers DC Battery Energy Storage System (BESS) to optimize the overall system performance.

The research incorporates simulation studies to assess the effectiveness of the proposed system under diverse environmental conditions. The findings of this study contribute to the development of sustainable energy solutions by demonstrating the feasibility and benefits of synergistic solar and wind energy integration with MPPT and energy storage. The optimized system design aims to enhance the reliability and effectiveness of renewable energy systems, paving the way for increased adoption of clean energy technologies in the transition towards a more sustainable and resilient energy future.

LIST OF FIGURES

CONTENTS

CHAPTER-1
SOLAR ENERGY

1.1. Introduction to PV Cell

The Sun is source of abundant energy - solar radiation, also known as electromagnetic radiation, is emitted by the sun. While every location on the Earth receives some sunlight over a year, the amount of solar radiation that reaches any spot on the Earth's surface varies. Solar technologies capture this radiation and turn it into useful forms of energy. The system which performs conversion of sunlight into electricity using semiconducting materials that exhibit the photovoltaic effect is known as photovoltaic system.

The photovoltaic cell is the most fundamental component of a solar system. Panels and modules are made up of cells grouped together. Large photovoltaic arrays can be created by grouping panels together. A solar panel (with numerous cells connected in series and/or parallel) or a set of panels is commonly referred to as an array.

The electricity available at the photovoltaic array's terminals can be used to power light loads like lighting and DC motors. For some applications, electronic converters are required to process the electricity generated by the photovoltaic device. These converters can be used to adjust voltage and current at the load, control power flow in grid-connected systems, and most importantly, track the device's maximum power point.

Photovoltaic arrays have a nonlinear I-V characteristic with a number of parameters that must be tuned based on experimental results from real-world devices. The solar array mathematical model may be used in the study of converter dynamic analysis, maximum power point tracking (MPPT) algorithms, and most importantly, in the simulation of the photovoltaic system and its components using circuit simulators.

1.2. Working

A solar cell more conventionally is a PN junction, which works on the principle of Photovoltaic effect. In Photovoltaic effect, when light is incident on a PN junction (N type semiconductor region facing sunlight), incident photons those which have energy equivalent to that of energy gap of semiconductor material, are absorbed producing electrons and holes as charge carriers (Fig 1.1)

These electrons and holes are separated due to inbuilt potential. This developed voltage is measured (Fig 1.2). This DC voltage can be converted into AC voltage to run different household appliances or to be used in various industries.

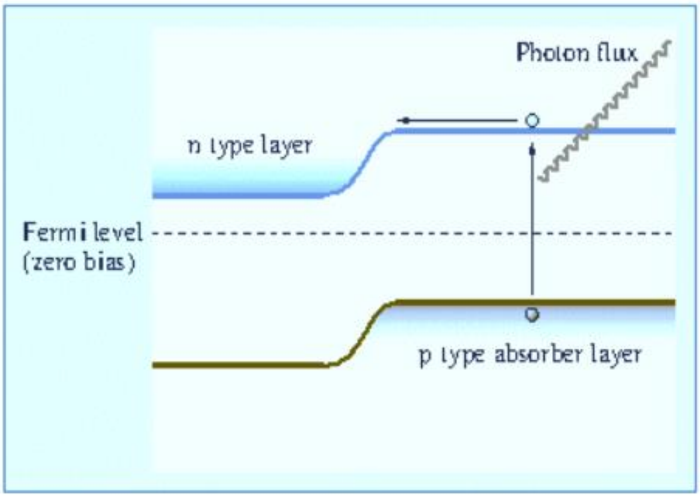

Fig 1.1 A PN junction showing absorption of incident photon, generation of electron and hole and diffusion of electron towards junction

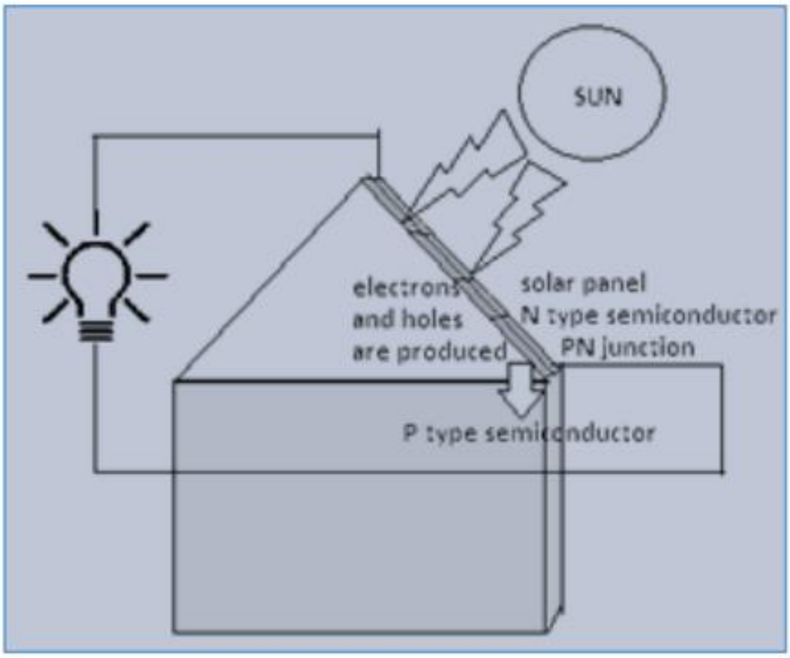

Fig 1.2 Photovoltaic Effect

CHAPTER-2

WIND ENERGY

2.1. Introduction

Wind Turbines convert the aerodynamic energy of wind into mechanical energy which are then transformed into electrical energy according to the requirements via generator and needed power converter topologies. Wind energy or Wind Energy Conversion System (WECS) structures have a huge scale farm, from a basic design to highly developed wind farms which can be operated with appropriate configurations under constant and variable wind speed conditions. Thanks to MPPT algorithms and controllers, Variable Speed WECSs (VS-WECS) are capable of generating electrical power under all wind speed ranges by controlling shaft speed based on wind speed.

Various types of generators such as Squirrel Cage Induction Generator (SCIG), Doubly-Fed Induction Generator (DFIG), Wound Rotor Induction Generator (WRIG) and Permanent Magnet Synchronous Generator (PMSG) are frequently preferred in VS-WECS structures. In the small and medium scale WECS, PMSGs are commonly used due to many advantages such as gearless operation, efficiency, energy density, small-size, lightweight, reliability and low maintenance costs. Therefore, we have also used PMSG based VS-WECS in this study.

While different power conversion topologies can be used in the WECS, but usually in the small scale WECS structures, an uncontrolled rectifier and DC-DC converter topology are preferred. Fig 2.1 shows the block diagram of designed WECS for this study and PMSG is attached to mechanical output of wind turbine in WECS.

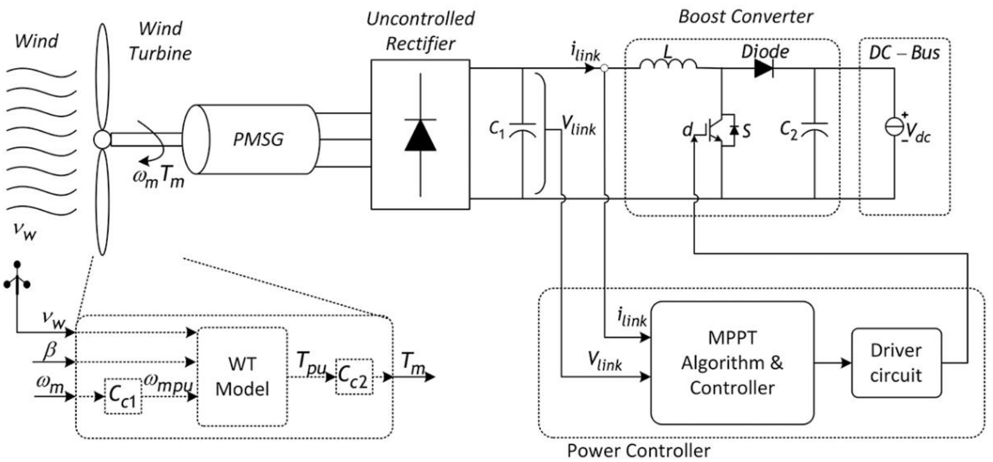

Fig 2.1 WECS Configuration

2.2. Working

The wind turbines receive input power from the rotational force of the wind acting on its blades. According to the aerodynamic structure of the wind turbines, mechanical power that can be captured from existing wind can be calculated by using:

$$P_m = \frac{1}{2}\rho A C_p(\lambda, \beta) {v_w}^3$$

With this definition, it is seen that the energy transferred to the rotor depends on the air density ρ (kg/m^3), swept area by turbine blades A (m^2), power coefficient $C_P\ (\lambda, \beta)$ and wind speed v_w (m/s). While mentioned power coefficient C_P is often referred to power factor, λ and β indicate tip speed ratio and blade angle, respectively. Moreover, C_P is commonly in the range of 0.2–0.5 for wind turbines. Considering the fixed blade angle wind turbine, $\beta = 0$, and C_P varies only depending on λ. On the other hand, λ, which is the relation between wind speed and linear speed in blade, can be defined as:

$$\lambda = \frac{\omega_m R}{v_w}$$

where, R and ω_m represent blade radius and rotational speed, respectively. The torque generated can be calculated as:

Torque = Power/Angular speed

$$T = P/\omega_m$$

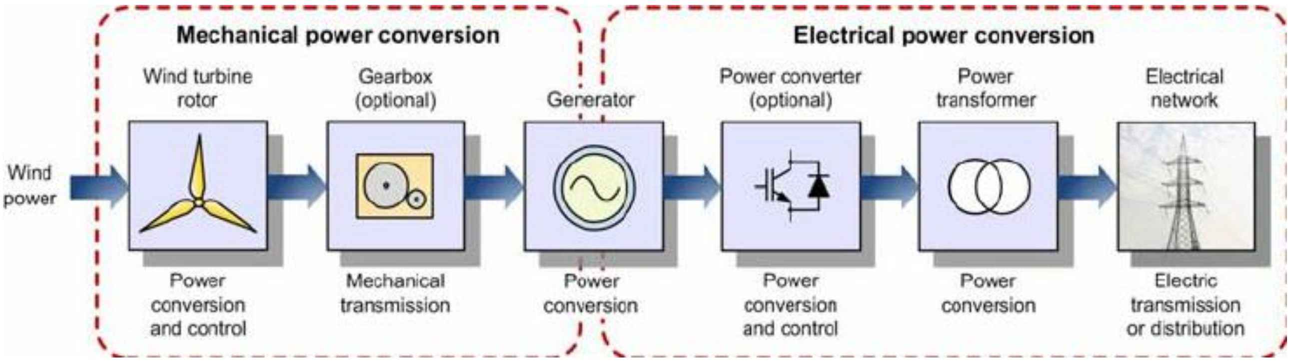

Fig 2.2 Power Flow Diagram

CHAPTER-3
CONCEPT OF MPPT

3.1. Introduction

Maximum power point tracking (MPPT) is a methodology for maximizing energy extraction from variable power sources due to changes in conditions. Photovoltaic solar systems are the most popular application, although it can also be utilized with wind turbines, optical power transmission, thermophotovoltaics, and fuel cells.

The efficiency of power transfer from the module depends on various parameters and conditions. As these conditions vary, the load characteristic that gives the highest power transfer changes. The system is optimized when the load characteristic changes due to various different variables to keep power transfer at highest efficiency. The maximum power point is the name given to this ideal load feature and the process of adjusting the load characteristic as conditions change is known as MPPT.

In the PV module or the wind energy module, there is a single operating point at any given end of time such that maximum power can be drawn while operating at that point. So, there is a need to locate or track this point and ensure that the module operates at that point or hover near to it.

3.2. MPPT for energy module

Consider an energy module connected to a variable load R_0. The terminal voltage and current of the module are V_T and I_T respectively. The net equivalent resistance of the circuit seen from the output terminal of the module is given by R_T. The I-V characteristics and P-V characteristics of the module with the varying load is as shown in Fig. 3.2.

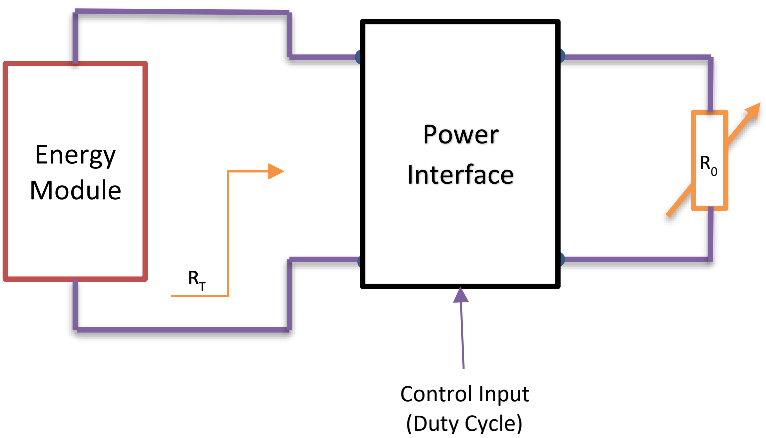

Fig 3.1 PV array connected to a variable load

As the load of the external circuit changes, the operating point changes. The maximum power can be obtained only at a single point. The voltage and current corresponding to the peak power point are V_M and I_M respectively. As the operating point shifts on either side of peak power point due to change in the load resistance, the power delivered by the module is less than the maximum power that can be delivered.

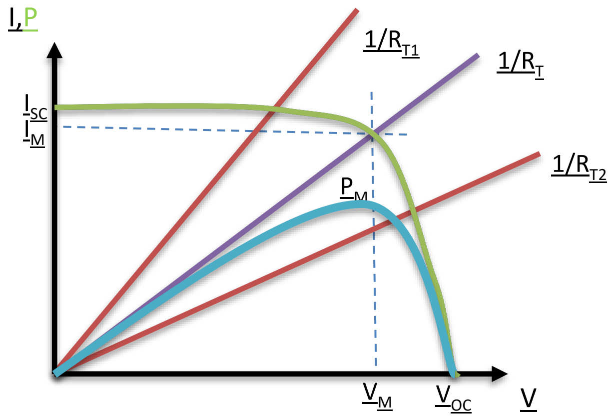

Fig 3.2 Load line analysis of PV array characteristics

In order to stabilize the operating point at peak power point irrespective of changes of load in the external circuit, a power interfacing circuit and a controller are required. This is done by maintaining the terminal resistance (R_T) constant irrespective of the value of the load resistance (R_0).

Here a power interfacing circuit is the DC-DC converter because we are taking a DC load into consideration, but it will be an inverter in case of AC load. It is connected in between the module and the load. Thus, by changing the duty cycle of the power interfacing circuit, the terminal resistance of the module is maintained constant. The terminal resistance of the module is basically a function of load resistance R_0 and duty ratio of the power interfacing circuit.

The MPPT controller senses the current and voltage of the module and compares them with the feedback variable values and generates an error signal which is fed to PI controller. PI controller, then generates the control signal which is fed to PWM generator which appropriately generates the duty cycle for the power interfacing circuit. As the duty cycle changes, the terminal resistance also changes as it is a function of external resistance and duty cycle.

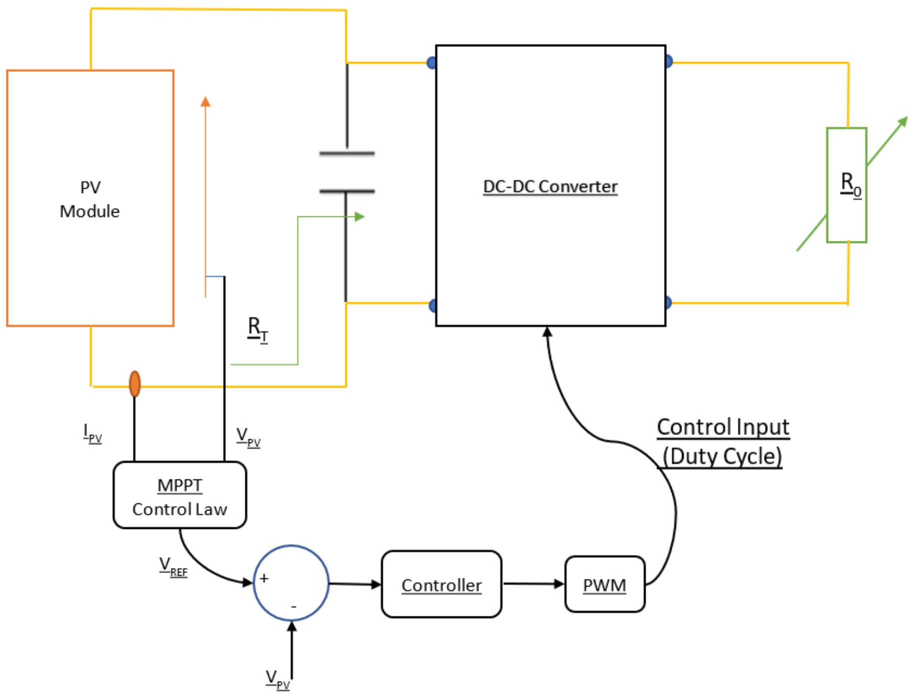

Fig 3.3 Interfacing of PV with load using DC-DC converter and MPPT controller

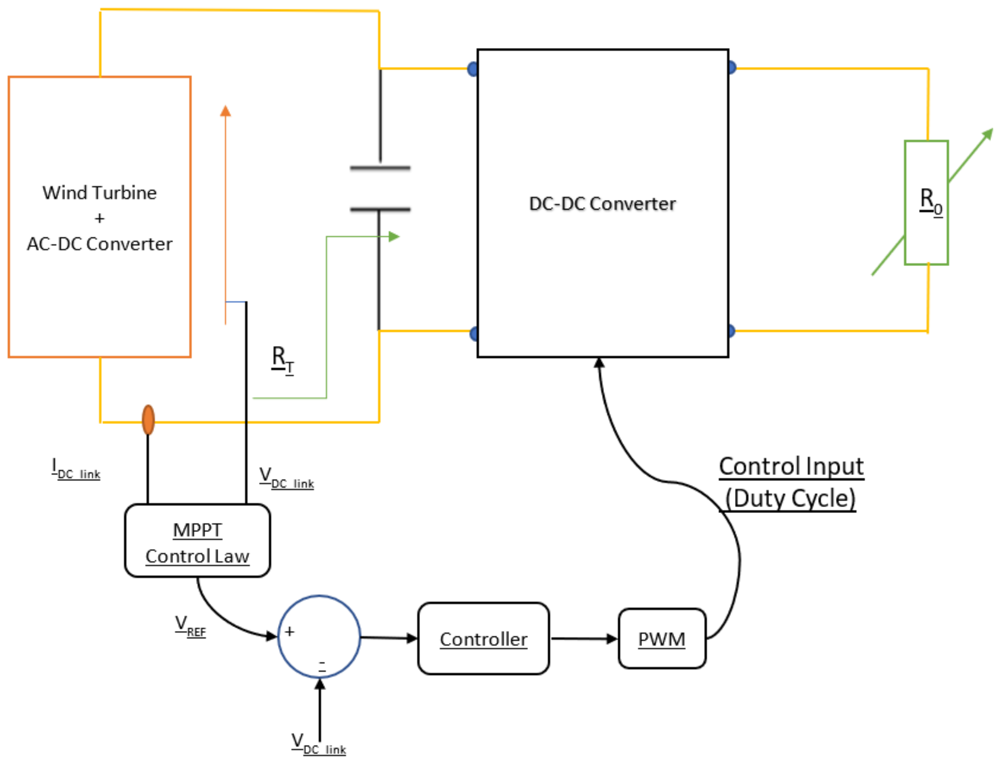

Fig 3.4 Interfacing of Wind Turbine after converting AC to DC through rectifier with the load using DC-DC converter and MPPT controller

3.3. MPPT Algorithm

There are various types of MPPT techniques used to run the modules on maximum power. The efficiency of a particular technique depends on its tracking ability in instantaneously changing weather conditions.

Here we are using Boost converter to obtain the Maximum Power Point by using - Direct Duty Cycle Perturb & Observe MPPT Technique.

It is the relationship between change in power with respect to change in voltage. It follows the principle that when the change in power is equal to the previous power, the wind turbine is operating at the Maximum Power Point voltage, therefore, the control variable will keep perturbing in the same direction until the power decreased. In Simulink, the algorithm is implemented by reading the voltage and current at the DC-Link. Thereafter, the power is calculated. Then a unit delay is added to the voltage and the calculated power, and the result is subtracted from the initial reading of voltage and power to get dV and dP. The control variable of the P&O algorithm is the Duty cycle (D). The algorithm aims to extract maximum power in WECS by varying the duty cycle in step-size until the optimal operating point is reached.

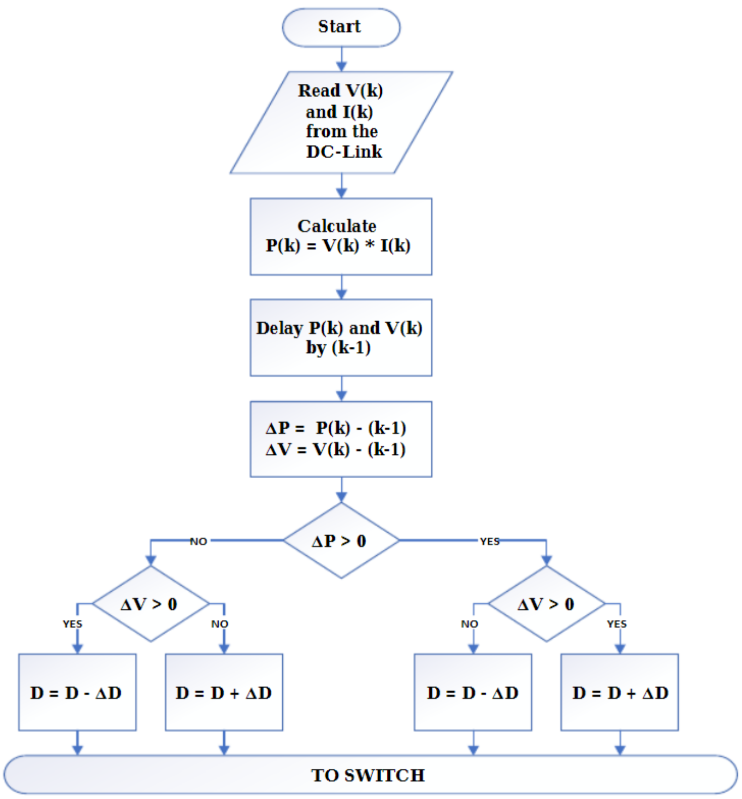

Fig 3.5 Direct Duty Cycle Perturb & Observe MPPT Technique

CHAPTER-4

ENERGY STORAGE SYSTEM

4.1. Introduction

Energy storage is a critical component in the evolution of our energy systems, offering a solution to the intermittent nature of renewable energy sources and providing a means to enhance reliability and stability. The primary purpose of energy storage is to capture the excess energy when it is in abundance and release it when the demand is high, ensuring a consistent and reliable power supply.

There are various forms of energy storage technologies, each with their unique characteristics and applications. It can be mechanical like flywheel, electrochemical like fuel cell and battery, electrical like supercapacitor, thermal, or hybrid. Here we are using DC battery as the energy storage which is connected with bi-directional converter to the load.

Batteries, such as lithium-ion batteries, are widely used for their high energy density, efficiency, and versatility. Other technologies include pumped hydro storage, compressed air energy storage, and thermal energy storage, each suited for different scales and applications.

One key advantage of energy storage is its ability to mitigate the variability of renewable sources like solar and wind. During periods of high energy production, the excess energy is stored for later use, reducing waste, and optimizing resource utilization. For the purpose, a controller is placed to give the control signal by measuring the load voltage and comparing it with the reference voltage (50 volts in the simulation). This feature is crucial for the transition to a more sustainable energy landscape, where the reliance on fossil fuels diminishes, and cleaner alternatives become more prevalent.

4.2. Use of Bi-directional Converter

A bi-directional DC-DC converter is a specialized electronic device that can efficiently manage the bidirectional flow of electrical power between two direct current (DC) sources. This converter is capable of both stepping up (boosting) and stepping down (bucking) the voltage levels as needed. This dual functionality makes it an essential component in applications where energy needs to flow bidirectionally, such as in battery energy storage systems and electric vehicles. The bi-directional DC-DC converter ensures optimal energy transfer, allowing for the effective integration of renewable energy sources and efficient energy management in various electrical systems. Its flexibility and ability to control power flow bidirectionally contribute to the overall efficiency and reliability of modern energy infrastructure.

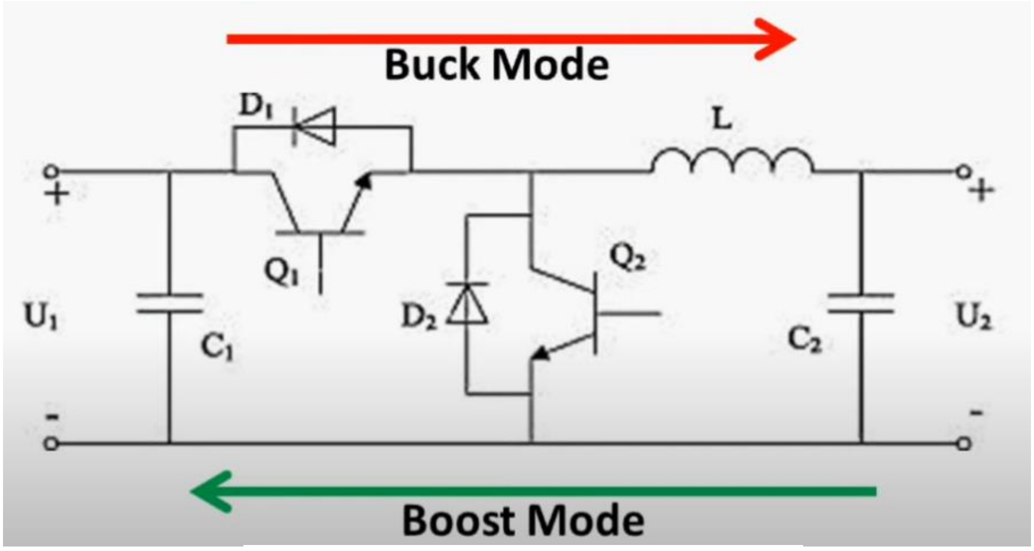

Fig 4.1 Bi-directional DC-DC Converter

When Q1 is switched ON and Q2 is switched OFF → Buck Mode operation and thus can be used for charging the battery.

When Q2 is switched ON and Q1 is switched OFF → Boost Mode operation and thus can be used for supplying the load.

CHAPTER-5

SIMULATION

5.1. Block Diagram & Simulink Model

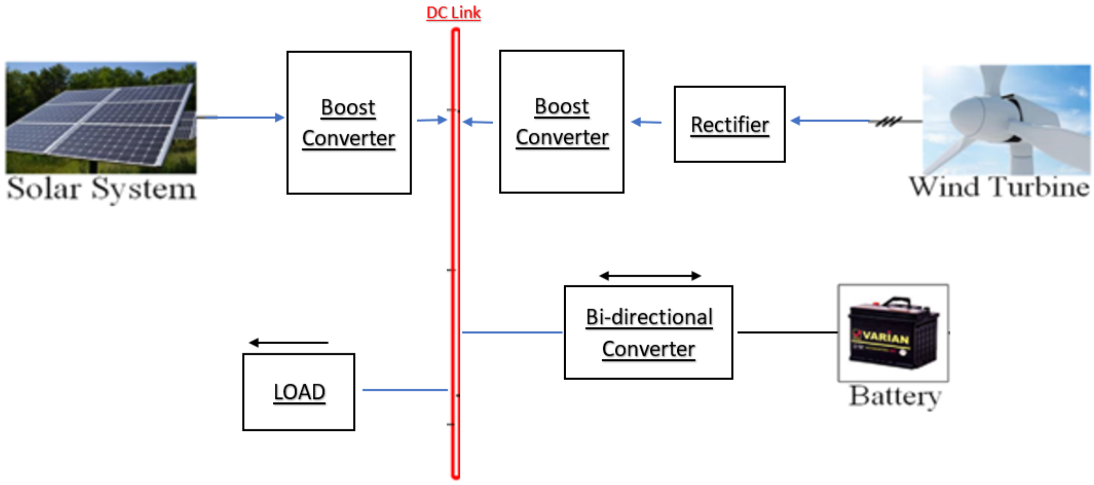

Fig 5.1 Block Diagram

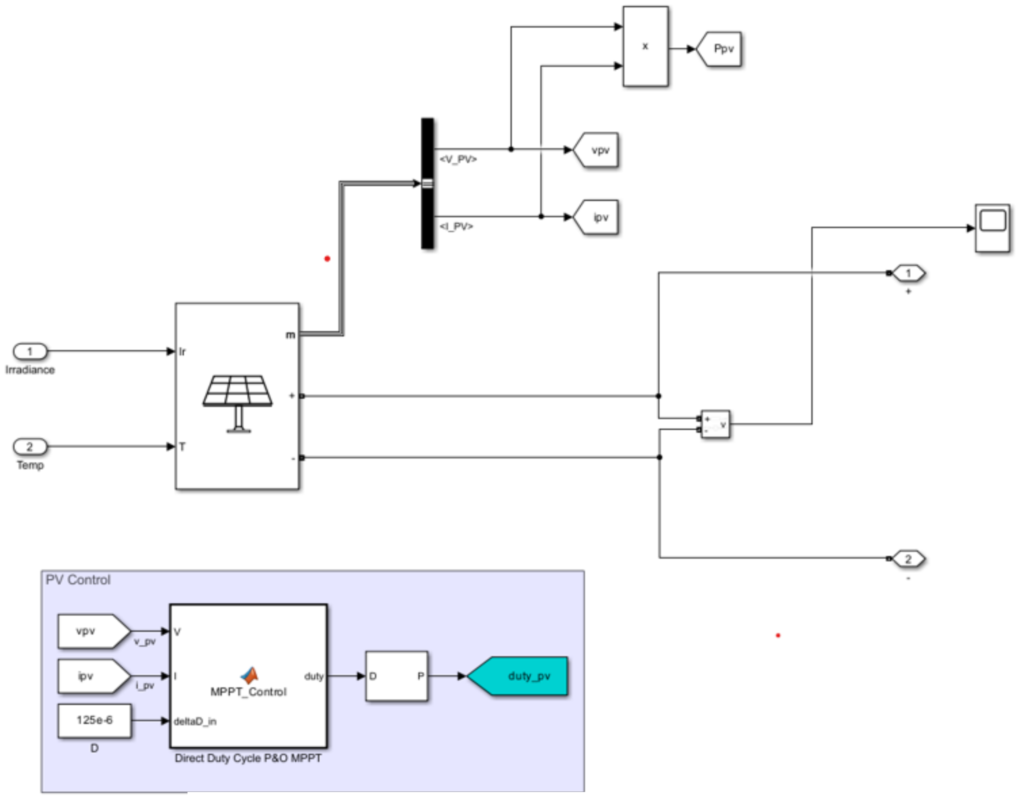

Fig 5.2 PV Model

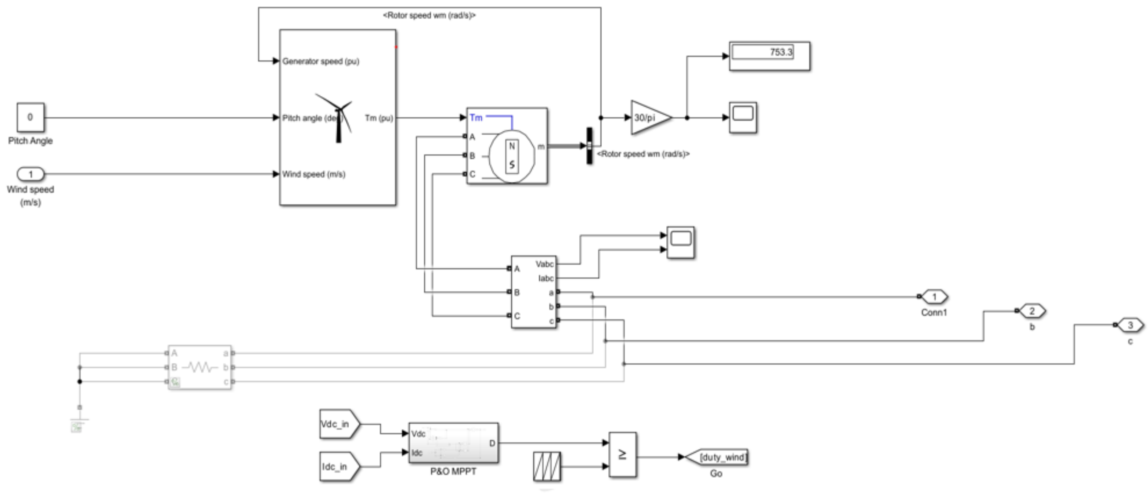

Fig 5.3 Wind Energy Model

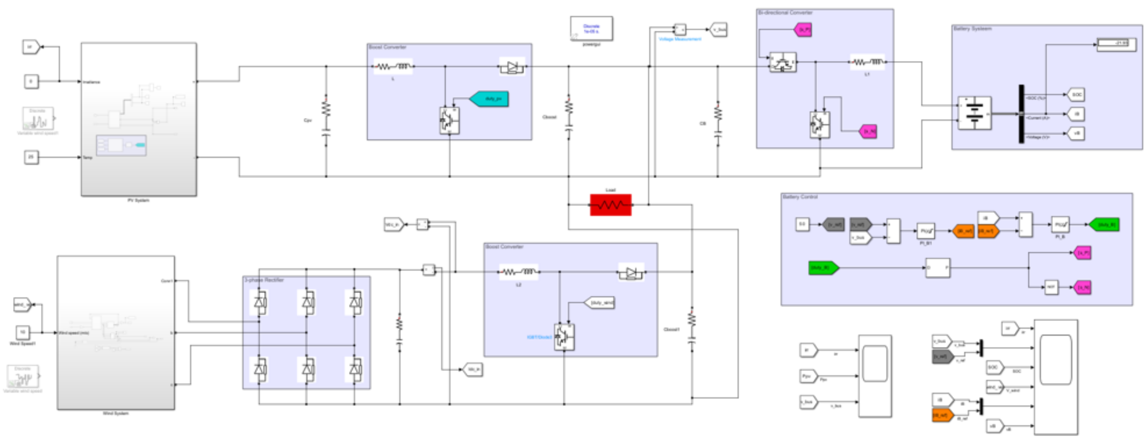

Fig 5.4 Integrated Model

5.2. Simulation Results

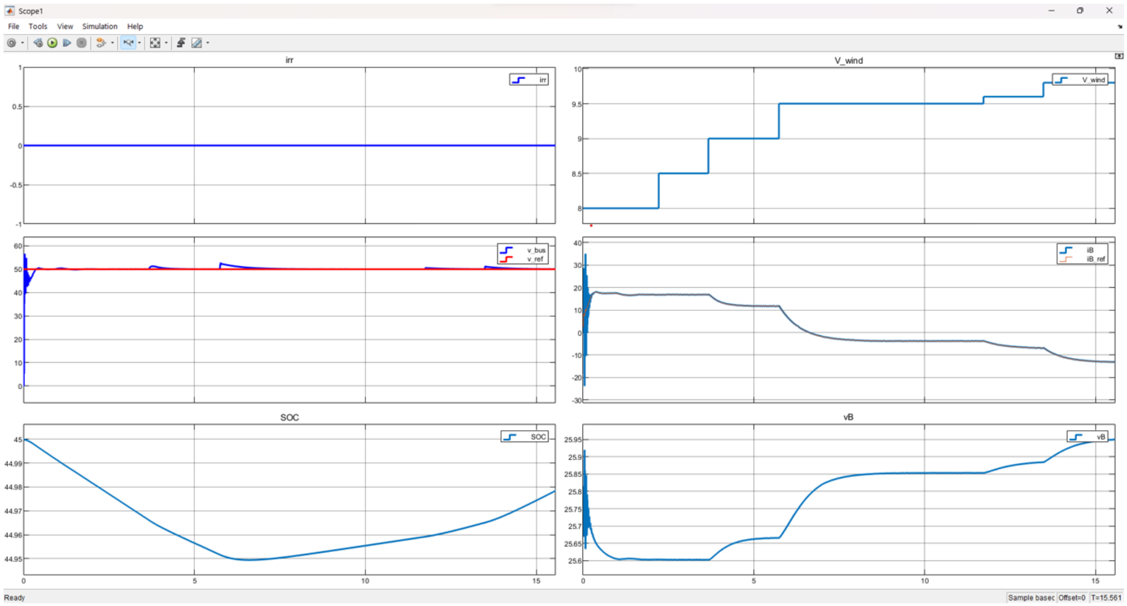

Fig 5.5 Considering only Wind Energy (irradiance = 0)

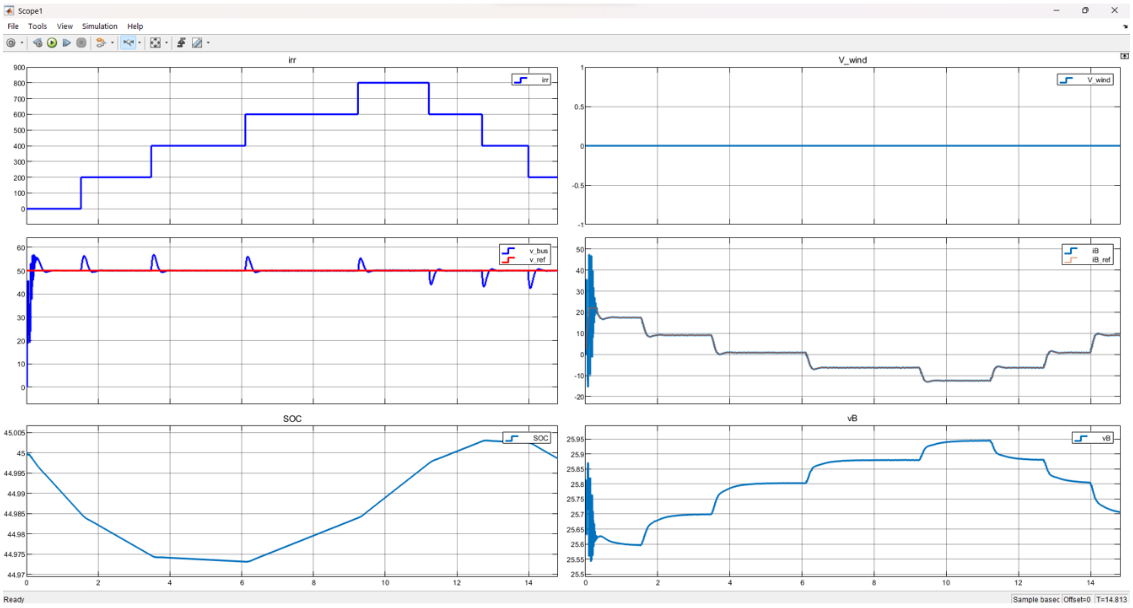

Fig 5.6 Considering only Solar Energy (wind velocity = 0)

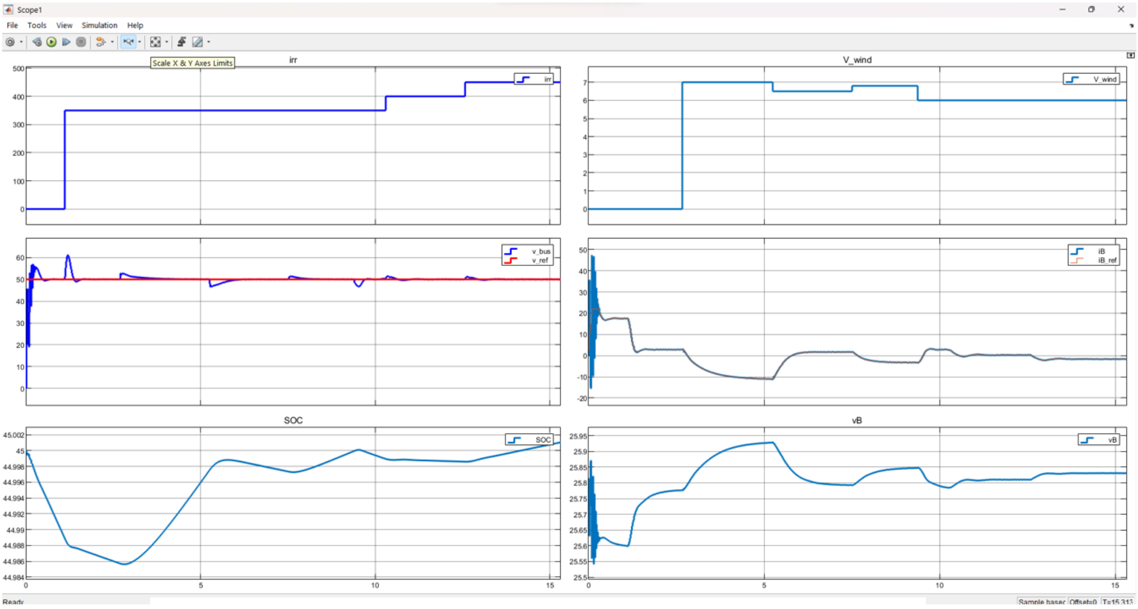

Fig 5.7 Considering both Wind and Solar Energy

CHAPTER-6

FUTURE WORKS AND CONCLUSION

6.1. Work for Next Semester

For establishing a robust energy system, we strategically connect solar panels and fuel cells to a DC-DC converter, harnessing their direct current (DC) output efficiently. Simultaneously, wind turbines are linked to an AC-DC converter, capturing the alternating current they generate in the form of direct current. These sources converge on the bus, forming a dynamic energy hub.

To ensure seamless energy utilization, a bidirectional converter links a high-capacity battery for storage. Through sophisticated optimization techniques, we seek to harmonize these inputs, fine-tuning their outputs for maximal efficiency. This holistic approach to energy integration strives to create an optimal and sustainable power system.

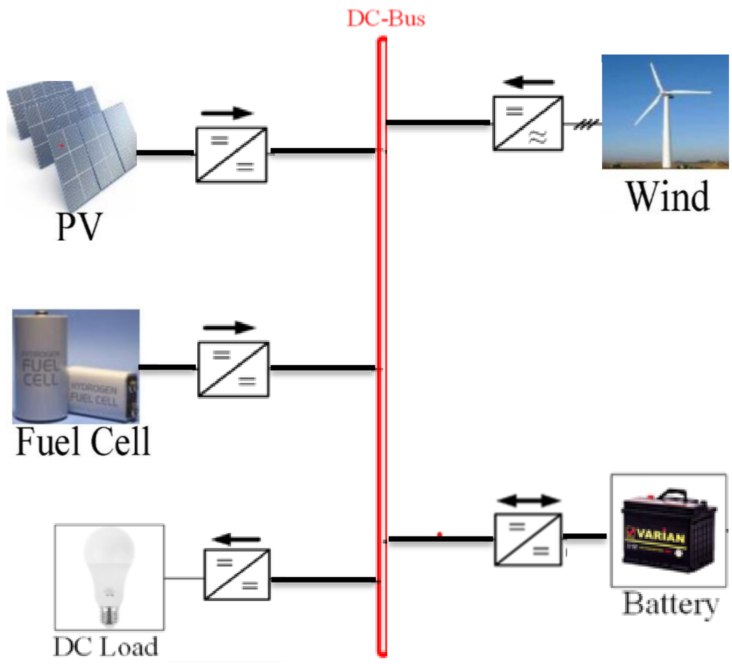

Fig 6.1 Different Energy Integration and their Storage

6.2. Conclusion

Due to depletion of fossil fuels as well as pollution caused by them, there is an urgent need to increase the proportion of power generation through renewable energy resources.

With the next phase of Paris Agreement goals also rapidly approaching, governments and organizations are now looking to increase the adoption of renewable-energy sources which can help in overcoming the problems linked with the fossil fuels, but the challenge is that there is uncertainty in the renewable energy generation due to their intermittent nature.

Therefore, one of the solutions to make them more reliable is optimal integration of the renewable energy sources along with their excess energy storage which is done in the simulation using solar and wind energy sources connected to a dc link and further interfaced with the battery through bi-directional converter.

The future scope of work may include integrating fuel cells also which will enhance the diversity of our energy sources and thereby supplying a constant voltage at the DC bus.

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