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DESIGNING AND MODELLING OF PHOTO-VOLTAIC CELL

Project Stage-I
Report submitted
in
Partial fulfillment of requirement
***for the award of* degree of**

Bachelor of Engineering
in
Electrical Engineering

Submitted by

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CERTIFICATE

This is to certify that the dissertation titled "**DESIGNING AND MODELING OF PHOTO-VOLTAIC**", which is being submitted herewith for the award of the, **'Bachlor of Engineering'** in **Electrical Engineering** of Anjuman-I-Islam's Kalsekar Technical Campus, New Panvel (M.S., India). This is the result of the original research work and contribution by following students under my supervision and guidance. The work embodied in this dissertation has not formed earlier for the basis of award of any degree or compatible certificate or similar title of this for any other diploma/examining body or university to the best of knowledge and belief.

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DECLARATION

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ACKNOWLEDGEMENT

It is indeed a matter of great pleasure and privilege to be able to present this project on

DESIGNING AND MOELLING OF PHOTO-VOLTAIC CELL The completion of the project work which is partial fulfillment of Degree academic works is a milestone in student's life and its execution is inevitable in the hands of guide. I am highly indebted to the project guide Prof. SYED KALEEM for their invaluable guidance and appreciation for giving form and substances to this report. It is due to their enduring efforts, patience and enthusiasm which has given a sense of direction and purposefulness to this seminar report and ultimately made it success.

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ABSTRACT

Our aim is to innovate and integrate renewable energy sources as a new source of energy. We thoughtfully chose the Solar energy as a source to be worked upon. We have hence made use of photo-voltaic cell, modelled and designed it in Matlab Simulation. We have integrated Auto-tuning of PID Controller and Boost Converters. Also we have used Battery Storage Energy system (BESS) to store excess energy and give it back to the load I needed.

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ABBREVATIONS:

PV- Photovoltaic

$BESS$- Battery Energy Storage system

I_{PV}–Photocurrent,

I_0–diode’s Reverse saturation current,

V–Voltage across the diode,

a– Ideality factor

V_T –Thermal voltage

R_S– Series resistance

R_P–Shunt resistance

K_I – cell’s short circuit current temperature coefficient

G – solar irradiation in W/m2

G_{STC} – nominal solar irradiation in W/m2

$I_{PV_{STC}}$ – Light generated current under STC.

I_{0_STC}– Nominal saturation current

E_g – Energy band gap of semiconductor

T_{STC}–temperature at standard test condition

q – Charge of electrons

I_{SC_STC} – short circuit current at standard test condition

V_{OC_STC}– short circuit voltage at standard test condition

K_V– Temperature coefficient of open circuit voltage,

$\mathrm{N_S}$– Number of series cells

$\mathrm{N_P}$– Number of parallel cells

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Chapter 1

INTRODUCTION

1.1 MOTIVATION

Increasing industrialization, rising population and the ever growing need for higher comfort levels have resulted in a consistent rise in the demand for electric energy. To meet this demand, the number of power generating stations has risen at a brisk pace, causing an enormous stress on the conventional fuel reservoirs, which are rapidly shrinking. The escalating fuel costs coupled with growing concern about their harmful effects on the environment have further compounded the problems, forcing the mankind to think of friendlier, safer and cheaper energy alternatives such as solar photovoltaic (PV), wind energy , tidal energy and so on. However, most of the energy are getting from non-renewable energy sources, which include the fossils—oil, natural gas, and coal. These are called fossil fuels because these were formed over millions and millions of years by the action of heat from the earth's core and pressure from rock and soil on the remains or fossils of dead plants and animals. Another non-renewable energy source is uranium, whose atoms can be split through a process called nuclear fission to create heat and electricity. All type of these energy sources are used to generate the electricity. Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat etc. These resources are known renewable energy sources and can be naturally replenished. Therefore, for all practical purposes, these resources can be considered to be inexhaustible, unlike dwindling conventional fossil fuels. The global energy crunch has provided a renewed impetus to the growth and development of clean and renewable energy sources. Apart from the rapidly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution associated with their combustion. Contrastingly, renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts.

There are various types of renewable energy sources which are given below :-

- **Wind Power**

  Wind turbines can be used to harness the energy available in airflows. Current day turbines range from around 600 kW to 5 MW of rated power. Since the power output is a function of the cube of the wind speed, it increases rapidly with an increase in available wind velocity. Recent advancements have led to aerofoil wind turbines, which are more efficient due to a better aerodynamic structure.

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- **Solar Power**

The tapping of solar energy owes its origins to the British astronomer John Herschel who famously used a solar thermal collector box to cook food during an expedition to Africa. Solar energy can be utilized in two major ways. Firstly, the captured heat can be used as solar thermal energy, with applications in space heating. Another alternative is the conversion of incident solar radiation to electrical energy, which is the most usable form of energy. This can be achieved with the help of solar photovoltaic cells or with concentrating solar power plants.

- **Small Hydropower**

Hydropower installations up to 10MW are considered as small hydropower and counted as renewable energy sources . These involve converting the potential energy of water stored in dams into usable electrical energy through the use of water turbines. Run-of-the-river hydroelectricity aims to utilize the kinetic energy of water without the need of building reservoirs or dams.

- **Biomass**

Plants capture the energy of the sun through the process of photosynthesis. On combustion, these plants release the trapped energy. This way, biomass works as a natural battery to store the sun's energy and yield it on requirement.

- **Geothermal**

Geothermal energy is the thermal energy which is generated and stored within the layers of the Earth. The gradient thus developed gives rise to a continuous conduction of heat from the core to the surface of the Earth. This gradient can be utilized to heat water to produce superheated steam and use it to run steam turbines to generate electricity. The main disadvantage of geothermal energy is that it is usually limited to regions near tectonic plate boundaries, though recent advancements have led to the propagation of this technology.

So, the renewable energy sources are much cleaner and produce energy without the emission of harmful gases such as carbon dioxide, nitrous oxide and sulphur hexafluoride, etc Out of these, the solar PV has emerged as a strong contender due to many of its advantages. A major advantage is that solar PV can directly convert the sun light into electricity and no extra mechanical or rotating assemble is needed. Further, the fuel cost is completely eliminated. The PV market has seen an annual growth rate of nearly 25% in recent years, which assures a reasonable cost of electricity generated by solar PV. Many countries are currently busy setting up large electric power generations units based on solar PV. For example, our India has set a target of up to 100 GW capacities by the end of 2022 by tapping solar energy. This is more than thirteen times of the country's total current installed capacity from solar generators. It is, therefore, clears that in the near future, the power system in India, and elsewhere would require a sustainable infrastructure for generation and utilization of solar PV based electric energy. Not only solar PV but other renewable sources like wind, biomass, tidal show great promise for the future of energy generation.

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1.2 Application of Solar Energy

Solar application is divided into two types depending on the insolation from sun converted into energy. The energy from the sun is heat and light.

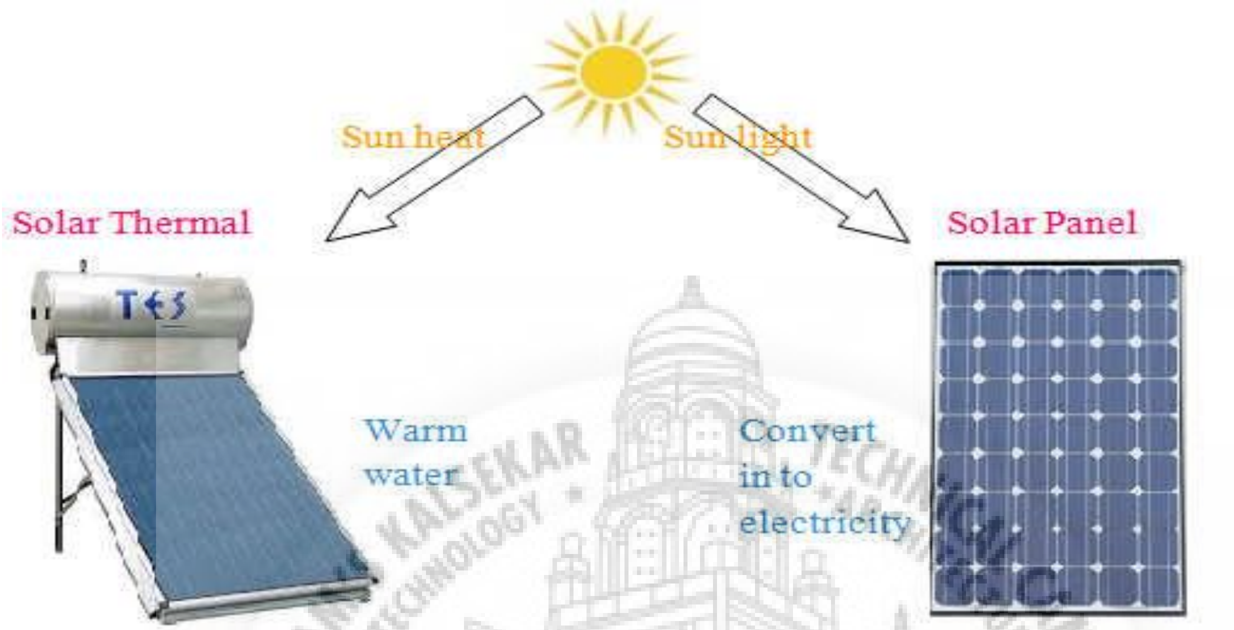

Fig 1.1 Types of Solar Energy

- The solar power system observes the heat and uses this to warm up the water is called solar thermal.
- Light is converted into electricity by using solar cells is called solar PV system.

Generally, solar energy is directly associated with photovoltaic and not with solar thermal power generation. In contrast to photovoltaic's plants, solar thermal power plants are not base on the photo effect, but generate electricity from the heat produced by sunlight. Due to their modality, photovoltaic operation covers a wide range from less than one Watt to several megawatts and solar thermal power plants are small units in the kilowatt range. On the other hand, Global solar irradiance consists of direct and diffuse irradiance. When skies are overcast, only diffuse irradiance is available. While solar thermal power plants can only use direct irradiance for power generation, photovoltaic systems can convert the diffuse irradiance as well. It means that they can produce some electricity even with cloud-covered skies. From economical point of view, market introduction of photovoltaic systems is much more aggressive than that of solar thermal power plants; cost reduction can be faster for photovoltaic systems. But even if there is a 50% cost reduction in photovoltaic systems and no cost reduction at all in solar thermal power plants. Thus it is concluded that solar PV power plant is better than solar thermal power plant

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1.3 Advantages & Disadvantages of Renewable Energy Sources

1.3.1 Advantages of Renewable Energy Sources

1. Renewable Energy Sources has infinity of sustainability and we will never run out of it unlike conventional sources like coal, oil and gas.
2. It is clean energy means they do not produce any byproducts which are hazardous to any living life or possess threat to the environmental systems.
3. They produce economically cheap energy considering they produce energy depending upon things which economically doesn't cost any penny like sunlight or wind. The only cost is there maintenance.
4. Personalize energy production is possible with renewable sources. One can install solar panels on their rooftop but will never be able to install a hydro plant.

1.3.2 Disadvantage of Renewable Energy Sources

1. Reliability of supply is major drawback as many environmental factors like rain, wind, solar, cloudy weather, dust can affect the energy generation. Hence complete reliability on renewable is avoided.
2. Energy production is large amount is not always possible. This means that either we need to set up more such facilities to match the growing demand or to find a suitable location which have ample availability of resources.
3. Initial capital cost for such projects are high. It takes years for consumer to get back its investment and start producing profit. But a vast research work is ongoing to reduce the cost and make system technologically efficient.

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1.4 Different Configuration of PV System

Photovoltaic power systems are classified based on the functional, operational requirements and component configurations. The PV systems are classified as standalone PV systems and grid connected PV systems. Photovoltaic systems can be operated either in DC or AC output power mode depending on the system or load to which it is connected.

1.4.1 Stand alone PV system

Standalone PV system is not connected to the main electricity grid and it consists of PV modules, load, with or without batteries for energy storage and charge controller to control the battery charging and discharging. This system may be combined with the diesel generator and wind power generator and it can be operated with both DC and/or AC loads. When the PV modules are directly connected to the DC load, it is referred as direct coupled standalone PV system which is shown in Figure 1.2. It has no energy storage device and it needs maximum power point tracking controller to obtain the maximum power from the PV modules.

Fig 1.2 Direct coupled standalone PV system

PV systems are used for residential applications, to supply power to off-grid residences and remote communities, and it may be combined with other renewable energy sources and diesel generators. PV and other on-site generation technologies are often less costly than grid extension when the distribution load is far away from the main grid. In developing countries, 1.4 billion peoples are inadequate to access power supply in villages.

1.4.2 Grid-connected PV System

Grid-connected PV system is shown in Figure 1.14 and it can be operated in parallel with the main electricity grid. The important components of the grid connected system are PV array, system monitor, inverter, utility breaker and utility meter. The function of inverter is to convert the PV module’s DC output into AC voltage and it provides the regulated voltage to the main electricity grid. The power from the PV system to the utility grid is automatically stopped when the main grid is not energized. When the PV generated power is greater than the on-site load demand, the PV system supplies power to both on-site loads and to the main grid. During the night or cloudy days, the required power by the on-site loads is received from the main grid since the PV system’s output power is lesser than the connected electrical loads. The PV system does not need energy storage device when it is interconnected with the main grid. For safety

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measures, the grid connected PV system is not allowed to operate and fed the power to the main grid when the main grid is down for service or repair.

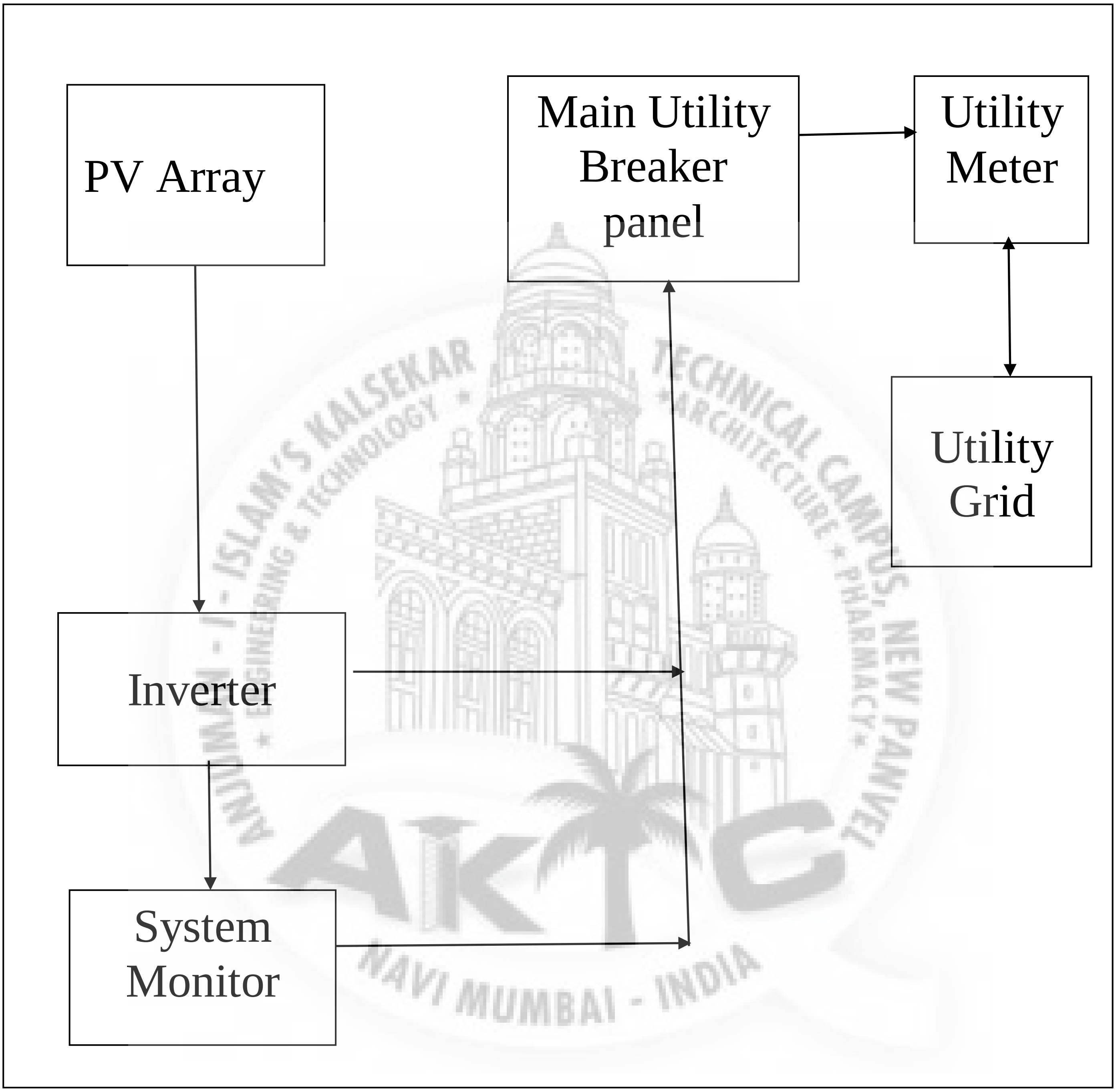

Fig. 1.3 Grid connected PV system

1.4.3 Hybrid PV System

The PV system is combined with the other power sources such as diesel generator and/or wind turbines and it is referred as a hybrid PV system. In order to enhance the performance of hybrid PV system, more sophisticated controls are required than the standalone PV system. Hybrid PV system is required to supply power to the remote areas and it consists of PV system, diesel generator and energy storage devices such as flywheel or super capacitor or battery.

The PV system reduces the running time of diesel generator and increase the lifetime of the generator. As a result, the diesel consumption is reduced. In PV/diesel systems, the diesel generator should start when energy storage device reach the certain discharge level and stopped again when energy storage device reach a sufficient state of charge. If the energy storage devices are charged more than sufficient charge, then it will reduce the life of the energy storage devices. Hence, the hybrid PV systems need an automatic system for starting and stopping of the diesel generator and controlling its output. The configuration of hybrid PV system is shown in Figure 1Hybrid PV system is installed in remote location where main electricity grid connection does not exist and its application includes remote telecommunications sites, remote homes and villages, water pumping and boating. It may be located nearer to the distributed loads that lead to reduce
the purchase and delivery of fuel to the site.

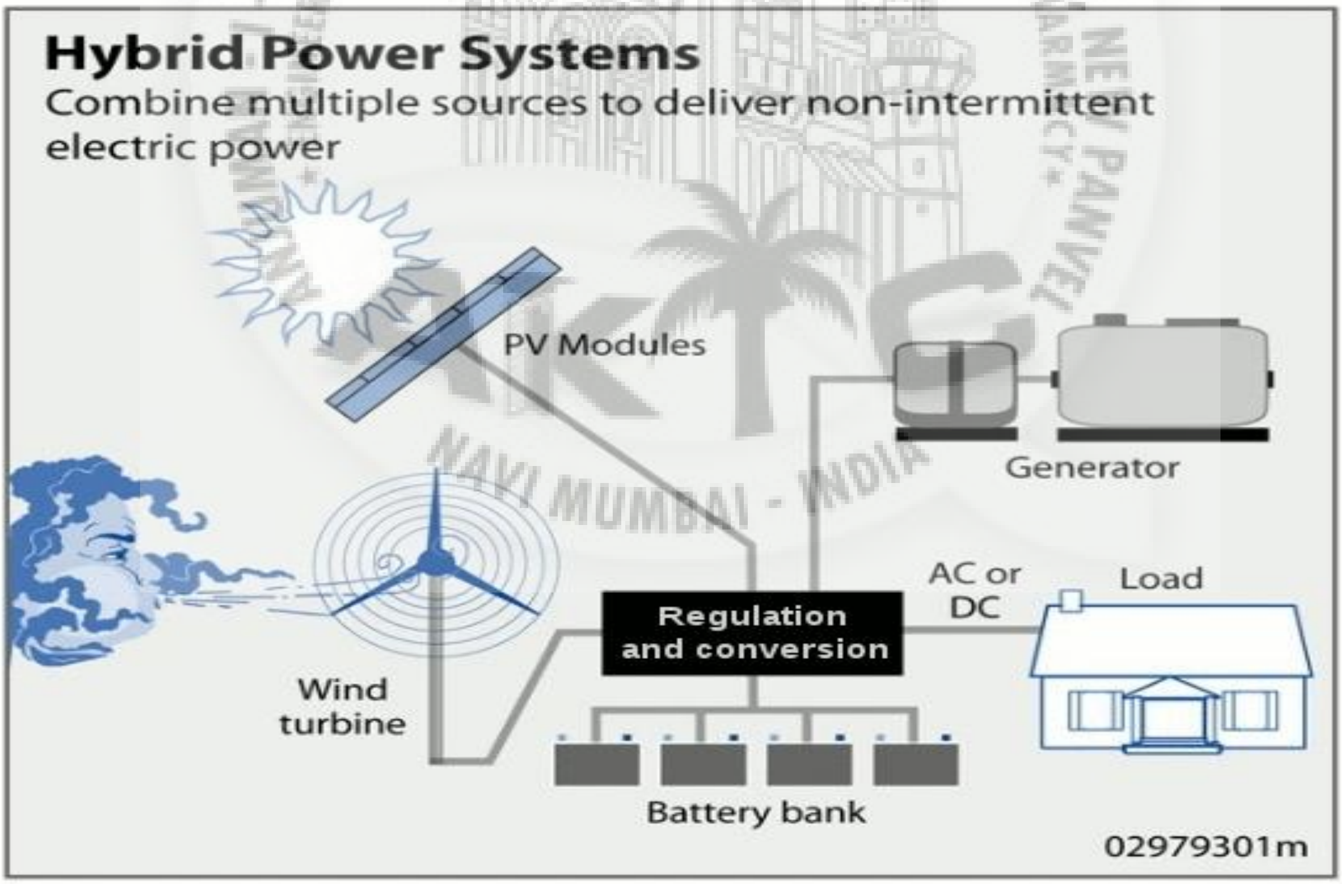

Fig 1.4 Hybrid PV System in Reality

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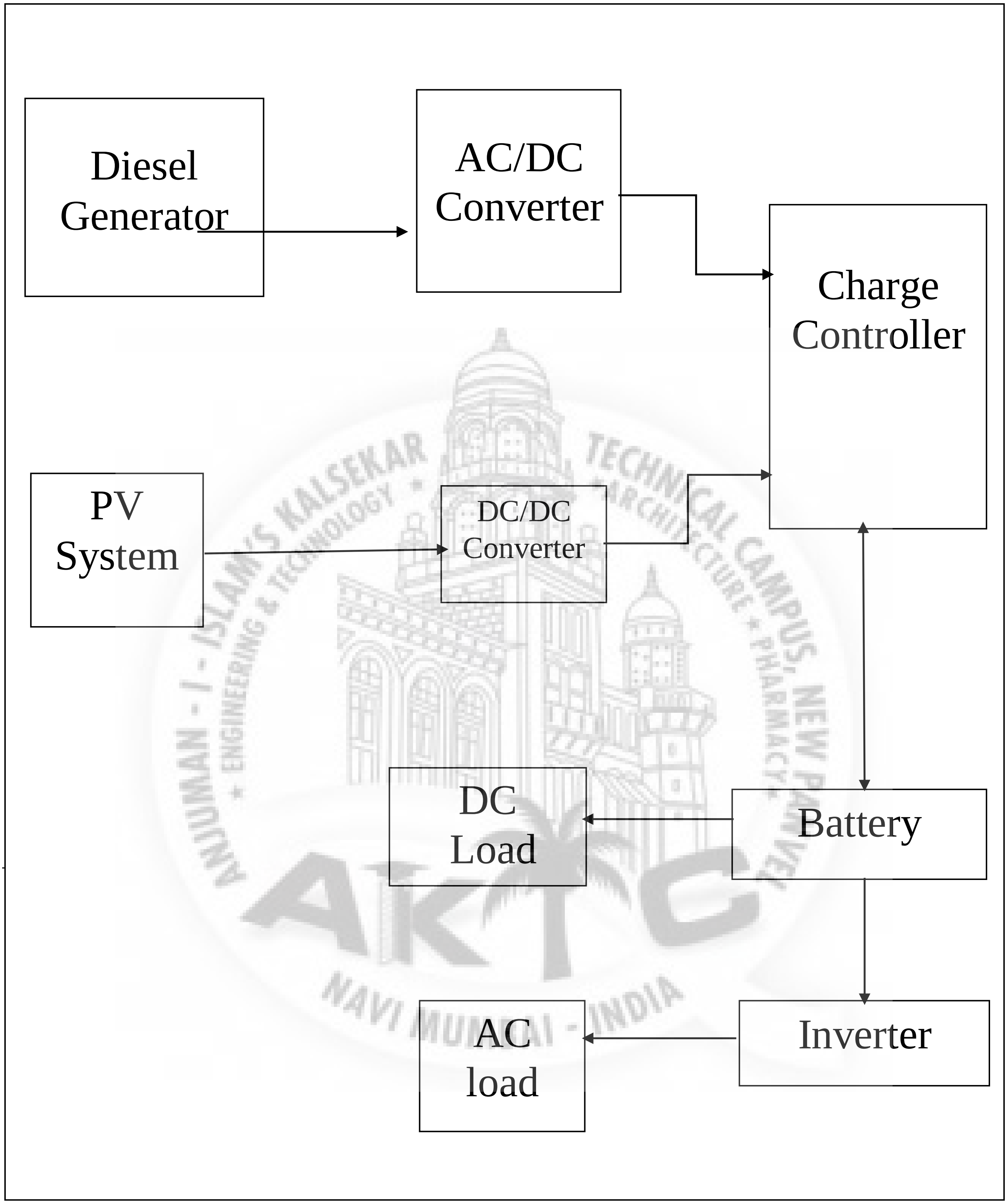

Fig 1.5 Hybrid PV System

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1.5 Photovoltaic Cell (PV)

Photovoltaic is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. Photovoltaic cell is nothing but a reverse biased diode made up of this material. When we connect load across diode, these free electrons are captured, an electric current result that can be used as electricity. and practical implementations are also done. Some authors propose standalone PV system [7] with maximum power point operation without grid connection, while some authors like [5] with grid connection. Fuzzy logic approach is analyzed by [8] with standalone system with DSP controller. Also PV along with Ultra-capacitor (UC) and Battery for Electrical Vehicle application is explained in [9], a DC motor application for irrigation purposes proposed in [10].

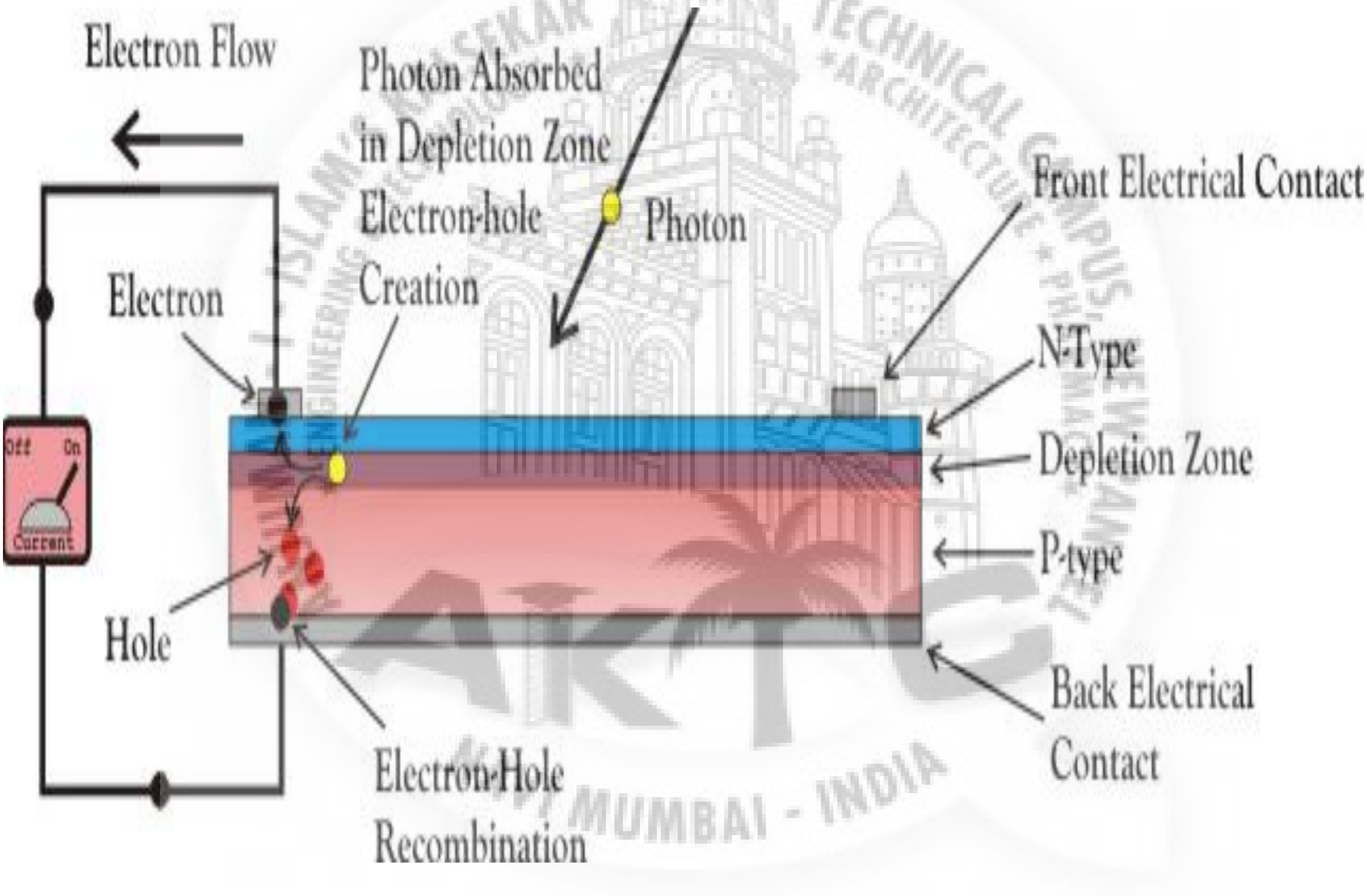

Fig. 1.6 PV Cell at Semiconductor level

The primary problem with solar photovoltaics system is that the system is intermittent and only available in daytime. Thus, for uninterrupted reliable supply of power we can't completely rely on solar hence we need a secondary active source of power.

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1.5.1 Advantages of PV System

- Solar power is free and abundant.
- Solar energy provides clean and green energy.
- PV module is environmentally friendly and reduces the emission of greenhouse gases.
- PV modules have no moving parts and hence less maintenance cost is involved.
- Onetime investment
- Reduces the import of fossil fuels and their usage
- Reduces global warming and makes reclamation of degraded land is possible.
- The operating life of crystalline PV modules is 25 to 30 years and hence return on investment is possible.

1.5.2 Disadvantages of PV system

- Initial cost of the PV systems is very high.
- Conversion efficiency is very low compared to other renewable energy systems.
- Efficiency of the crystalline silicon PV cell is high but its manufacturing cost is high.
- Efficiency of amorphous silicon thin-film PV cell is half of the efficiency of crystalline PV cell but it is less expensive to produce.
- PV plants require large area for installation.
- PV module's intermittency and unpredictable power reduces the reliability.

1.5.3 Applications of PV System

- Cathodic protection System (used to control the corrosion of a metal by making it the cathode of the electrochemical cell).
- Solar powered water pumping.
- Electric fences (for protection of farms from wild animals).
- Remote area lighting System
- Water treatment system (Improving water quality, reducing energy loss, increasing crop yields).

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1.6 NEED FOR BOOST CONVERTERS IN RENEWABLE ENERGY SECTOR

The PV cell is considered as one of the major renewable energy source which produces DC output. Similarly, FC is used in energy generation as a backup source which produces DC output. Battery plays an important role in the storage of an electric power in terms of DC. By considering the above renewable energy sources with DC, it is necessary to analyze about the DC-DC converters.

In the power electronics field, purpose of interleaving method can be traced back to extremely early days, particularly in high power applications. In high power applications, the voltage and current stress on the power devices may rise beyond its withstanding capability. Coupling many power devices in parallel or series could be one result to meet the above problem. However, voltage division and current distribution are still the concerns. Instead of power devices paralleling, power converters paralleling is another solution which could be more helpful. Moreover, with the power converter architecture paralleling, interleaving technique comes logically. Advantages like harmonic deletion, improved efficiency, superior thermal performance, and high power density can be gained. In previous days, for high power applications, in order to gather certain system necessity, interleaving multi-port converter could be a better solution particularly in view of the existing power devices with constricted performance at that instant.

There are numeral applications that necessitate changing the produced DC power into a regulated AC output, and vice versa, depending on the applications. A power electronic converter interface has to bridge over the variation between input energy and load. From the system-level point of view, power converter interface circuit must be able to do voltage boosting, DC-AC conversion and its regulation, so as to accurately rate the power system. From the energy storage device point of view, one more problem is how to boost the efficient consumption, with respect to run-time and climate changes of uneven cells.

Interleaving method is also examined in the early days for the small power aircraft, satellite applications, and launched as unconventional Switched Mode Power Supply (SMPS) power stage design. In such cases, one main concern is the input side and output side filters due to the maximum accessible power storage to size ratio problem in that time. Interleaving converters can considerably decrease the amount of switching pulsed current go through the output side filter capacitor (Jung et al 2010; Wang & Li 2011). By properly selecting the duty cycle, the input ripple content in current may be decreased to zero. Moreover, interleaving raises the ripple frequency to be N times the switching frequency. Interleaving method can successfully shrink

the capacitor filter dimension and weight. One more concern of this method is covering. Because of thermal management problems, non-interleaved converter power loss goes beyond the classic dissipation capacity. Interleaving method can split the power transmit into many modules, lighter

and lesser parts can be accumulating on the printed circuit card. The third advantage of the converter lies in the redesign to higher power levels are necessary than originally operating arrange at the time of start of the

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design. With the interleaving construction, enlarged power output may be supplied by adding further similar sections. The interleaved converter is planned and developed which can demonstrate the advantages on modularity, filter design and packaging.

Converters in power electronics are required to interface many renewable power sources with the load along with storage element in standalone or grid-connected housing, commercial and vehicle applications. Newly, multi-port DC-DC converters have fascinated concentration for many applications since they utilize one-stage high frequency AC-link conversion as compared to many conversion stages in conventional DC-link systems. Two high frequency AC-link method, series resonant and current-fed three port DC-DC converters already exist. In this a renewable source such as FC or PV is connected to one port, energy storage elements such as batteries in another port and the load is used as a third port. Batteries are only utilized as storage elements.

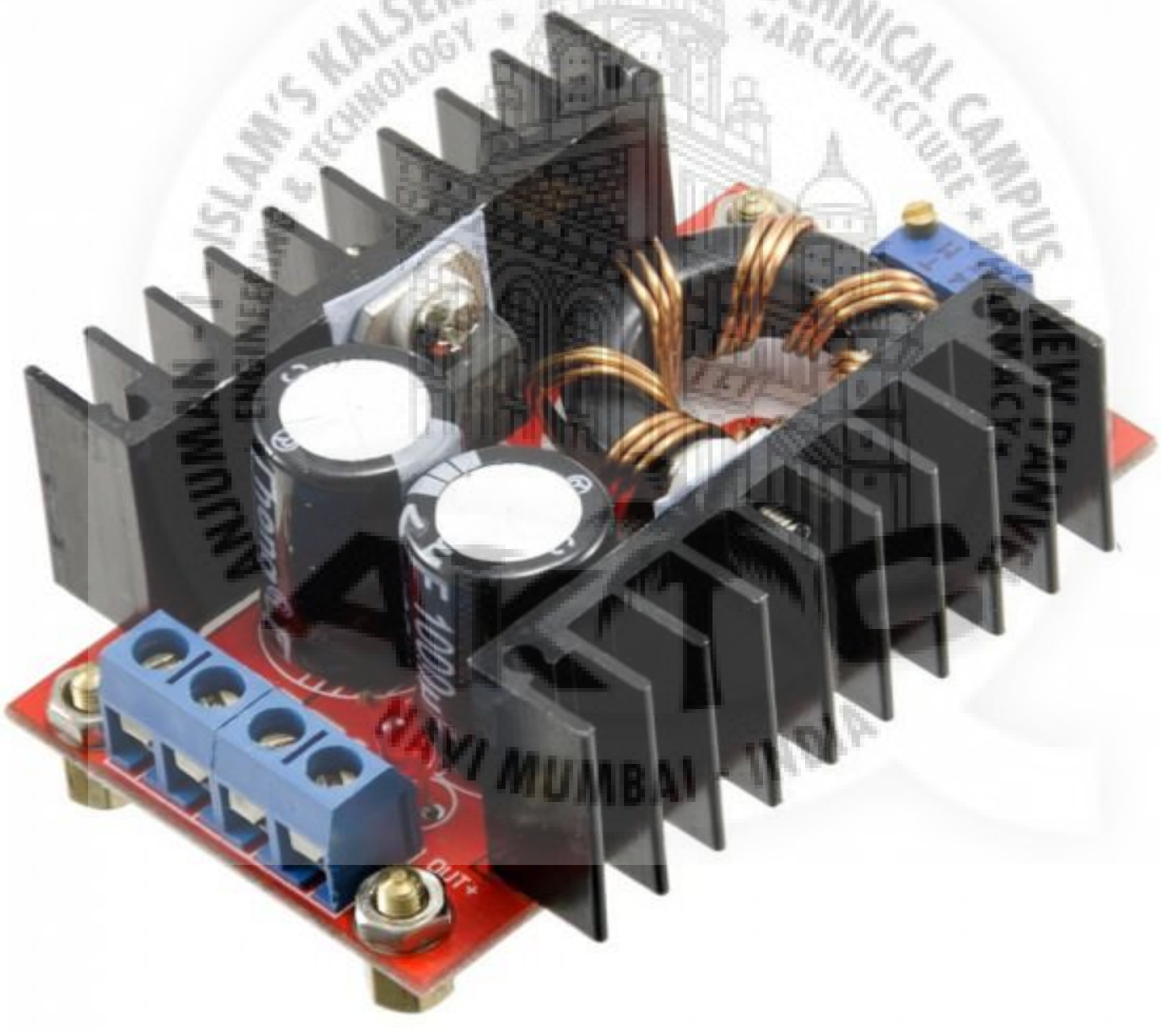

Fig. 1.7 BOOST CONVERTER in reality

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1.7 Literature Survey

India has become the top country in the world to make a law of minister called Minister of New and Renewable energy for non-conventional energy resources. Being the tropical country India has high solar isolation so the best renewable green energy source is solar energy. Our country is the 5th largest producer. From research it is noted that, by March 2017, the demand of electricity will be increased from 900 billion kilowatt-hours to 1400 billion kilowatt-hours. Consequently it is in verge of energy lack with a huge gap of demand and supply. To fulfill the required demand, solar energy is needed. It is the1only entirelyavailable1renewable2alternative4energy2source with the1fundamental1capability2to5satisfy the energy6needs of our country. Based on PV installed capacity, India has become fourth After Japan, Germany and U.S. A major drive has also been initiated by the Government to trade Indian PV products, systems, technologies and services. From [1], it is clear that, the performance of the photovoltaic panel is affected by the environmental condition like Temperature & Solar Irradiation. In addition to these factors it also shows how the shadow affects it. Under shaded condition, PV characteristics get more complicated and difficult to analyze. Hence to make it easily understandable, different methods are adopted so far by the researchers. By those techniques I-V & P-V2curves are recovered from partial shading condition. In [2], importance of solar energy, PV module and its uses in different field are illustrated. Its working procedures, equivalent model with all sets of equations are also

discussed. Different factors affecting the characteristics of PV module are manifested. In [5] & [3], PV module simulated considering the variation in Temperature and Solar irradiation. Behavior of the characteristics is all together listed. In [4], need of MPPT controller circuit is discussed. Basically MPPT controller circuit helps in tracking the maximum possible output power, so that further operation can be easily carried out without any interruption, as initially the curve of PV module is nonlinear. Different methods of MPPT also described in this paper. In [6], approach for battery charge controller for stand-alone PV system is manifested. Various charge algorithms are discussed along with their terminology. Brief introduction on battery charge performance characteristics are all considered. The studies in [3] and [8] show that when the PV array is under partially shaded conditions, the array characteristics become more complex with multiple MPPs. Partial shaded condition is defined as the circumstance where one or more of the PV modules in the array received less amount of solar9irradiance. In [9], [11], [14], it has been clear that the battery provides the dc link constant voltage to the load and also it prevents high voltage stress problem. From PV panel current and voltage are extracted through current and voltage sensor respectively and given to battery for maintaining constant dc link voltage.

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Chapter 2

Topology and Design of Power Stages

2.1 System Description

This chapter discuses topology for the system is described and which DC-DC converter operates in which mode. The system operation algorithm and mathematical modeling of PV presented.

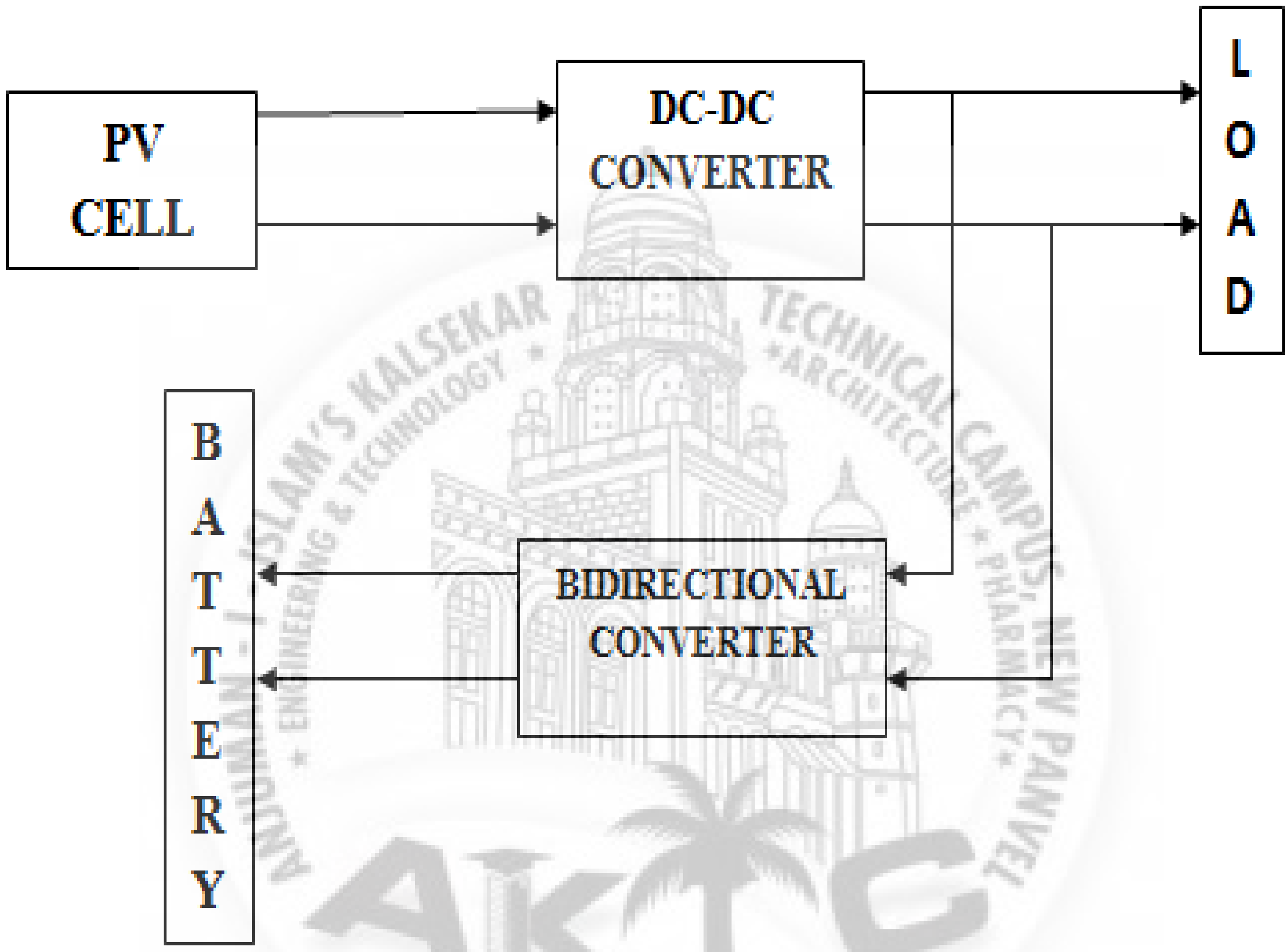

Fig. 2.1 Block-Diagram of our PV connected and Controlled system

Fig. 2.1 shows the basic block diagram of the proposed system. The PV cell acts as the main energy source, while the Battery source is used as an auxiliary energy system. The arrangement consists of a PV cell connected to a DC link through a unidirectional DC-DC converter, which operates in current controlled mode. A bidirectional DC- DC converter is operated in a voltage controlled mode to interface the Battery source to the DC link. For transferring energy from each source to the DC link, a step-up mode is used, while to charge the Battery source, a bidirectional DC-DC converter is operated in a step-down (Buck) mode.

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2.2 PV interface Design

2.2.1 PV Mathematical Modeling:

A solar cell is basically a PN junction diode operated in reverse biased condition. The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device. The Fig. 2.1 manifests the equivalent circuit of PV cell. Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The electromagnetic radiation of solar energy breaks covalent bond and produce free electrons which produce photovoltaic current (Ipv) when external voltage (Vpv) is applied. Different modeling techniques have been presented in the literature but here we consider single diode model for simulation of the PV panel [25] as shown ing (2.3).

$$I = I_{PV} - I_0\left[exp\left\{\frac{V + IR_S}{aV_t}\right\} - 1\right] - \left[\frac{V + IR_S}{R_P}\right]$$

Where

I_{PV}–Photocurrent,

I_0–diode's Reverse saturation current,

V–Voltage across the diode,

a– Ideality factor

V_T –Thermal voltage

R_S– Series resistance

R_P–Shunt resistance

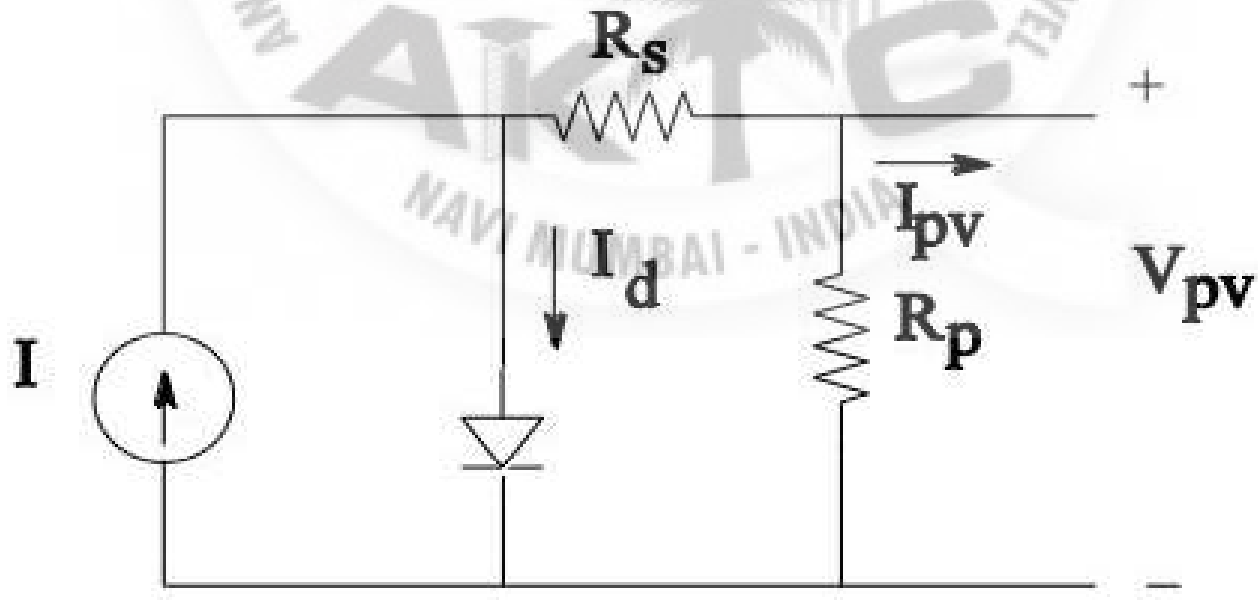

Fig. 2.2 Equivalent Circuit of PV Cell

PV cell photocurrent, which depends on the radiation and temperature, can be given as,

$$I_{PV} = (I_{PV_{STC}} + K_I \Delta T)\frac{G}{G_{STC}}$$

Where

K_I – cell's short circuit current temperature coefficient

G – solar irradiation in W/m2

G_{STC} – nominal solar irradiation in W/m2

$I_{PV_{STC}}$ – Light generated current under STC.

The reverse saturation current varies as a cubic function of temperature, which is expressed as,

$$I_0 = I_{0\_STC}\left(\frac{T_{STC}}{T}\right)^3 \exp\left[\frac{qE_g}{aK}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right]$$

Where

I_{0_STC}– Nominal saturation current

E_g – Energy band gap of semiconductor

T_{STC}–temperature at standard test condition

q – Charge of electrons

The reverse saturation current can be further improved as a function of temperature as follows,

$$I_0 = \frac{(I_{SC\_STC} + K_I \Delta T)}{\exp\left[\frac{V_{OC\_STC} + K_V \Delta T}{aV_T}\right] - 1}$$

I_{SC_STC} – short circuit current at standard test condition

V_{OC_STC}– short circuit voltage at standard test condition

K_V– Temperature coefficient of open circuit voltage,

Many authors proposed more developed models for better accuracy and for different purposes. In some of the models, the effect of the recombination of carriers is represented by an extra diode [2]. Some authors also used three diode models which included influences of some other effects that are not considered in previous models. But due to simplicity we use single diode model for our work. Efficiency of a PV cell does not depend on the variation in the shunt resistance Rp of the cell but efficiency of a PV cell depends on the variation in series resistance Rs. As Rp of the cell is inversely proportional to the shunt leakage current to ground so it can be assumed to be very large value for a very small leakage current to ground. As the total

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power generated by a single PV cell is very low, we used a combination of PV cells to fulfill the desired requirement [5]. This grid of PV cells is knows as PV array. The equations of the PV array can be represented as,

$$I = I_{PV}N_P - I_0 N_P[\exp\left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{aV_T N_S}\right) - 1] - \left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{R_P\left(\frac{N_S}{N_P}\right)}\right)$$

N_S– Number of series cells

N_P– Number of parallel cells

A small change in series resistance can affect more on the efficiency of a PV cells but variation in shunt resistance does not affect the parameter. For very small leakage current to |ground, shunt resistance assumed to be infinity and can be treated as open. After considering shunt resistance infinity, the mathematical equation of the model can be expressed as.

$$I = I_{PV}N_P - I_0 N_P[\exp\left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{aV_T N_S}\right) - 1]$$

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2.3 BESS interface:

BESS is connected to the DC link through DC-DC bidirectional converter as shown in figure 2.4

The main objective of converter is to maintain DC link voltage level to the reference provided by the user. When the power generation of the Solar is greater than that of load demand then battery is charged and if the load demand is greater than that of overall energy generation it delivers that difference of power to the load.

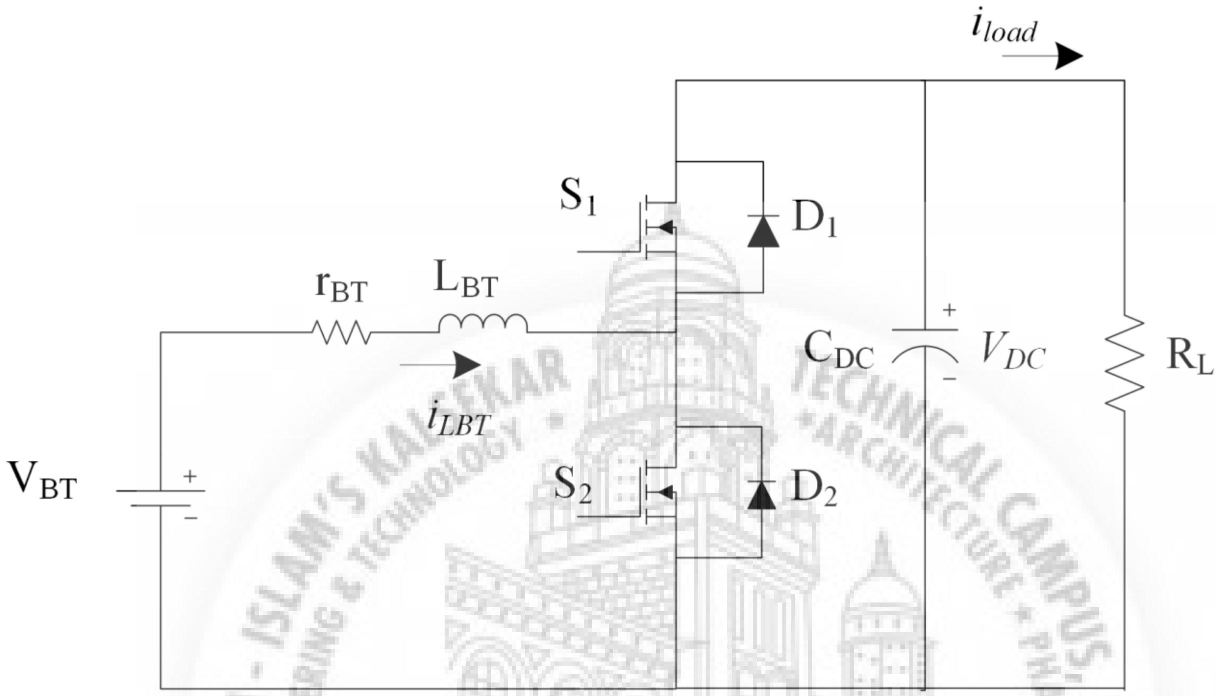

Fig. 2.3 Bi-directional Converter

Various techniques are discussed in literature regarding the control of bidirectional control. Many propose a different control of charging and discharging condition separately but that is very cumbersome task and system reliability at boundary condition is not guaranteed. A approach similar to unified controller defined in [30] is proposed which perform under both charging and discharging conditions.

Also in order to enhance battery life deep discharging is avoided by monitoring the State of Charge (SOC) of battery. Battery is allowed to deep discharge up to min level of SOC min and to avoid overcharging is charged up to max level of SOC max.

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2.4 System Algorithm

Depending upon various load conditions system is operated in different modes. The working of overall system is illustrated.

2.4.1 Case 1: When $P_{pv} > P_{Load}$

Under this condition our PV generation is more than that of load demand hence we do not take any power from Battery and operate on it minimum generation value. As battery can be charged in this case we operate PV in current control mode and Battery in charging mode.

2.4.2 Case 2: When $P_{pv} < P_{Load}$

This condition describes the scenario when even PV is not able to full load demand hence we generate that surplus power requirement from the BESS. This is only possible if battery have enough charge stored in it.

2.4.3 Case 2: When $(P_{pv}+P_{Bat}) < P_{Load}$

This is the worst case scenario in the system. Both PV and BESS are working at full capacity but still not able to full load demand. So there is no source that can provide power. At such level system is shut down and alarmed to the user.

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2.5 EFFECT OF VARIATION OF SOLAR IRRADIATION

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values. The solar irradiation as a result of the environmental changes keeps on fluctuating, but control mechanisms are available that can track this change and can alter the working of the solar cell to meet the required load demands. Higher is the solar irradiation, higher would be the solar input to the solar cell and hence power magnitude would increase for the same voltage value. With increase in the solar irradiation the open circuit voltage increases. This is due to the fact that, when more sunlight incidents on to the solar cell, the electrons are supplied with higher excitation energy, thereby increasing the electron mobility and thus more power is generated.

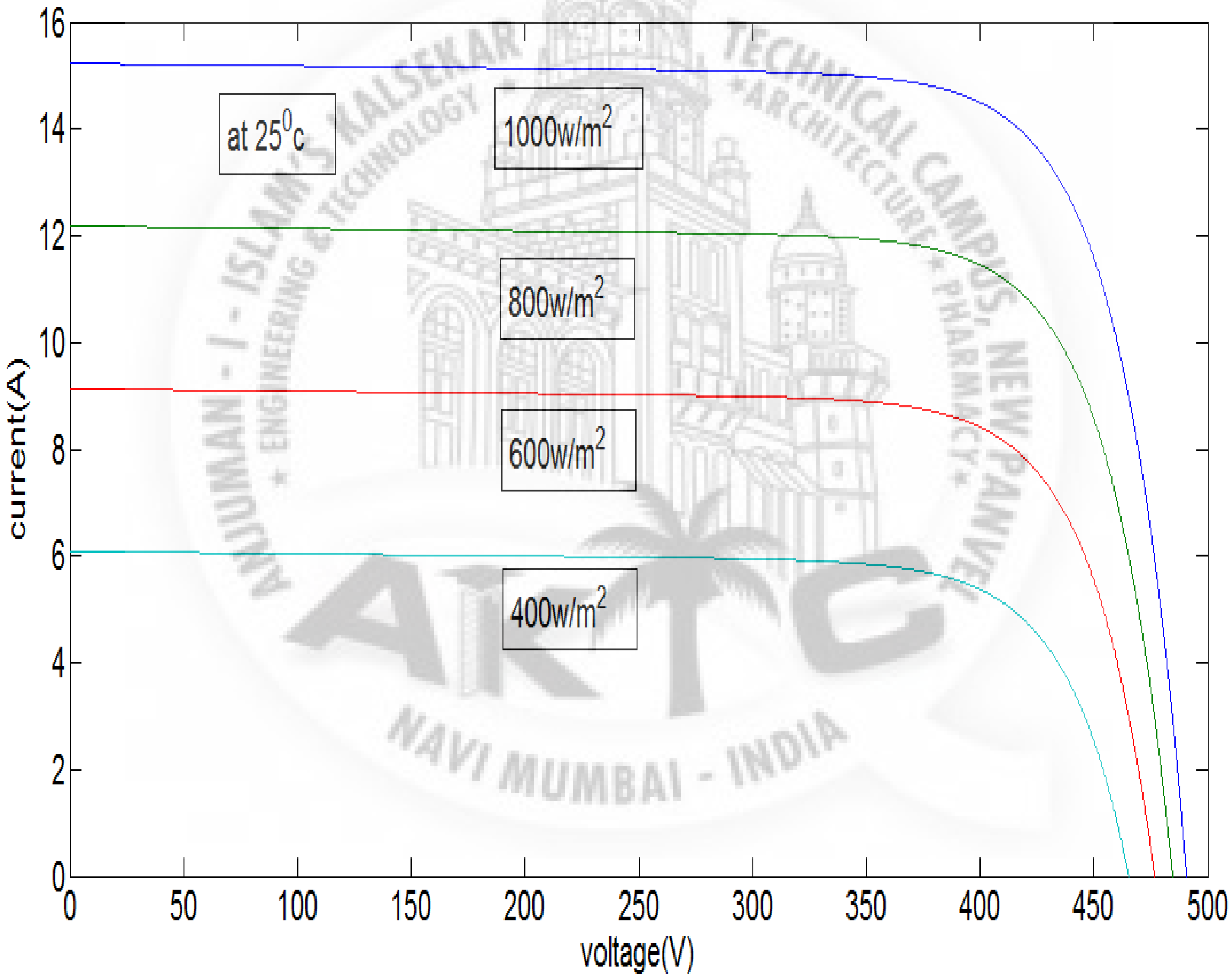

Figure 2.4: Variation of I-V curve with solar irradiation

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2.6 EFFECT OF VARIATION OF SOLAR TEMPERATURE

On the contrary the temperature increase around the solar cell has a negative impact on the power generation capability. Increase in temperature is accompanied by a decrease in the open circuit voltage value. Increase in temperature causes increase in the band gap of the material and thus more energy is required to cross this barrier. Thus the efficiency of the solar cell is reduced.

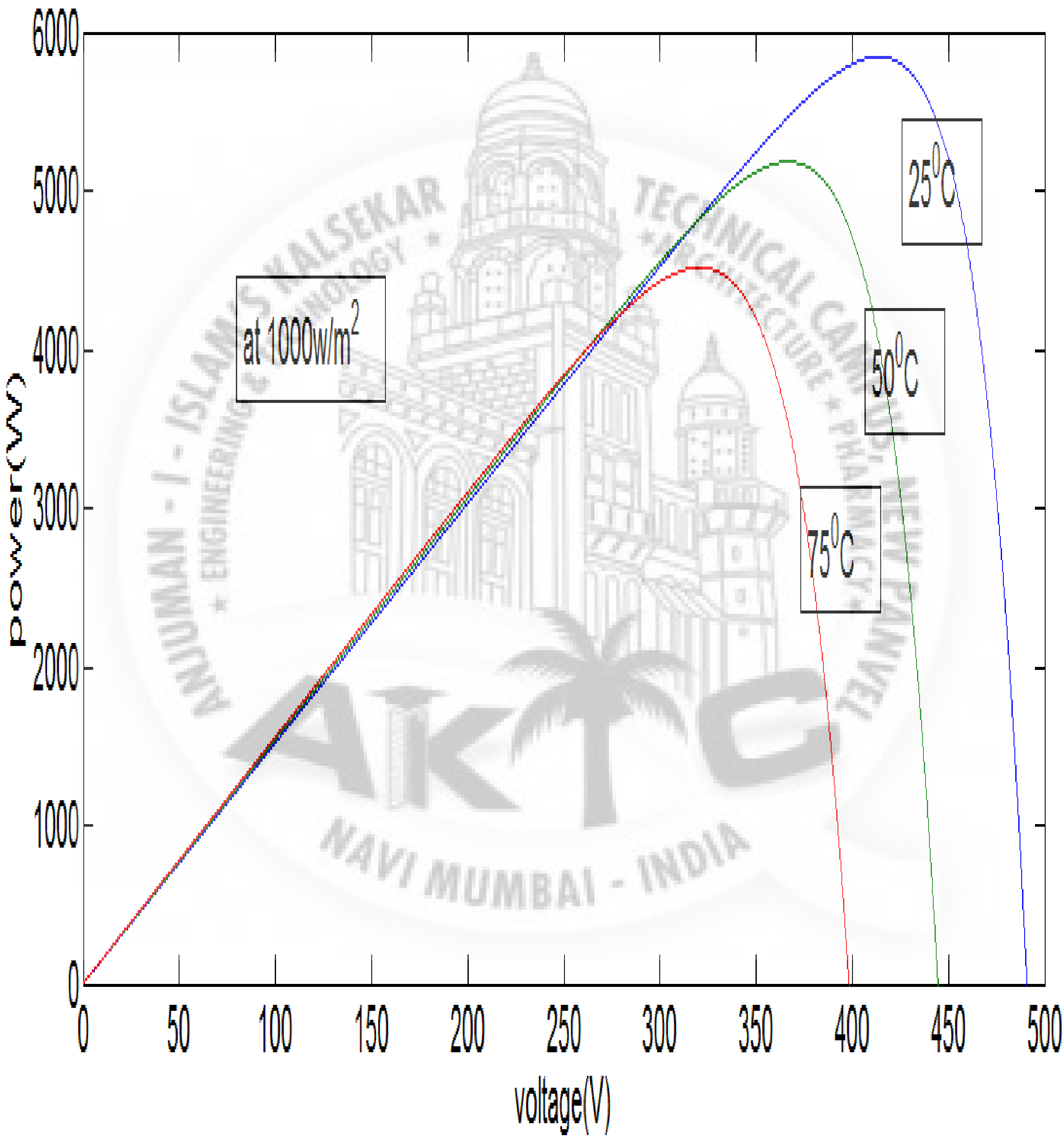

Fig. 2.5 Variation of P-V curve with temperature

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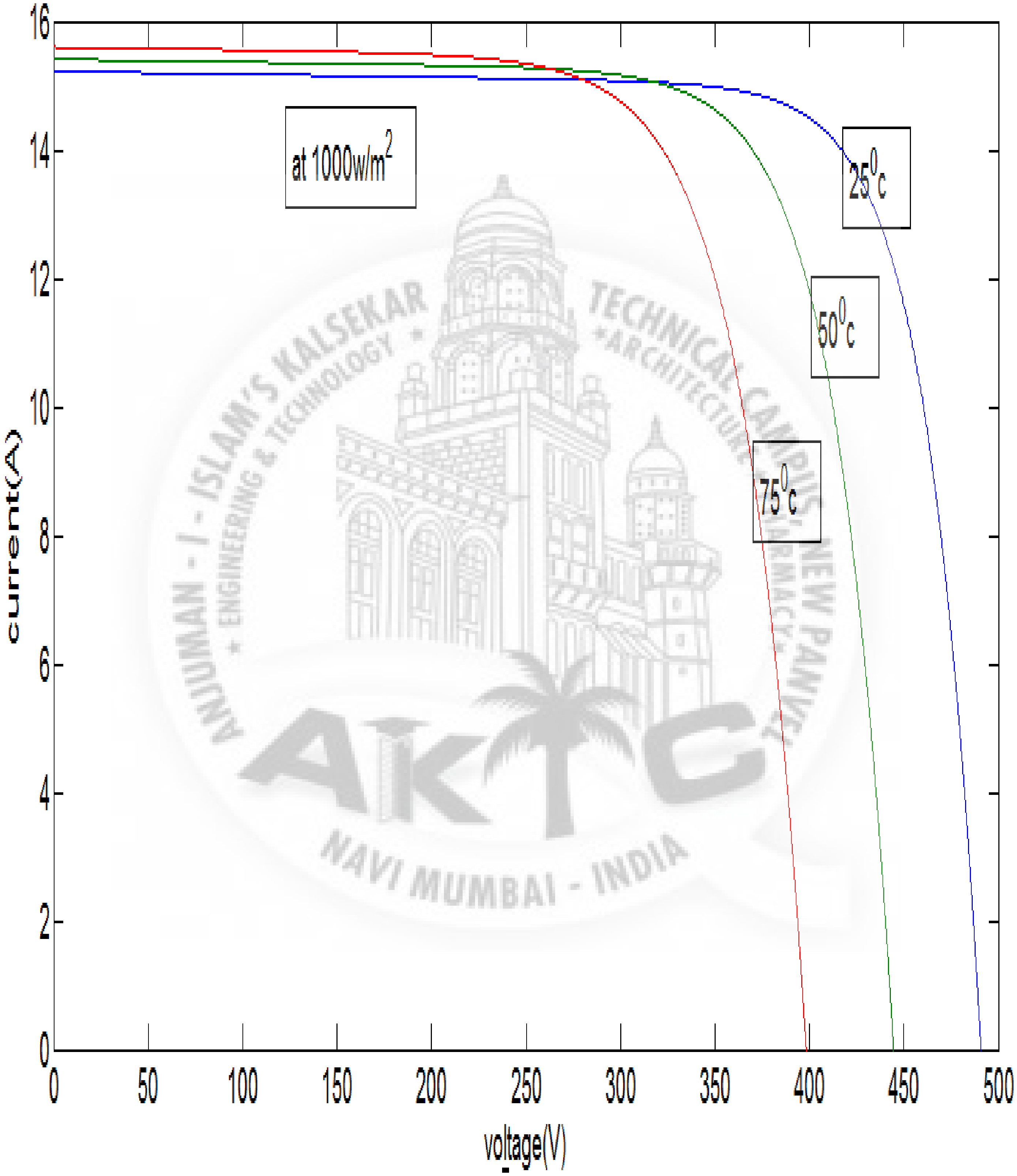

Fig. 2.6 Variation of I-V with temperature

Chapter 3

Controller Design

As explained in chapter 2 section 2.1 the different DC-DC converter operates in different control mode depending upon the system condition. The PV system modeling along with the effect of temperature and radiation on the system. Battery is operated in voltage control to stabilize the DC link. This chapter explains in detail analysis of controller design. A conventional linear control strategy is used for the controller. Our converters are switching devices consist of nonlinear component hence we need to first linearize them. An approach of small signal modeling [31] is applied to linearize the converter model. Then a standard PI control [32] or K-factor approach [33] whichever is applicable.

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3.1 BESS Bidirectional DC-DC Converter

3.1.1 Small Signal modeling

The bidirectional DC-DC converter is shown in figure (2.8) is operated in complementary manner. Means when switch S1 is ON, diode D2 is conducting and switch S2 is OFF and Diode D1 is in non-conducting state. And when switch S2 is ON, diode D1 is conducting and switch S1 is OFF and Diode D2 is in non-conducting state. The duty cycle generated by the controller is given to the switch S1 and its complementary signal is given to switch S2.

For the ON state of converter equivalent circuit is shown in figure 3.1

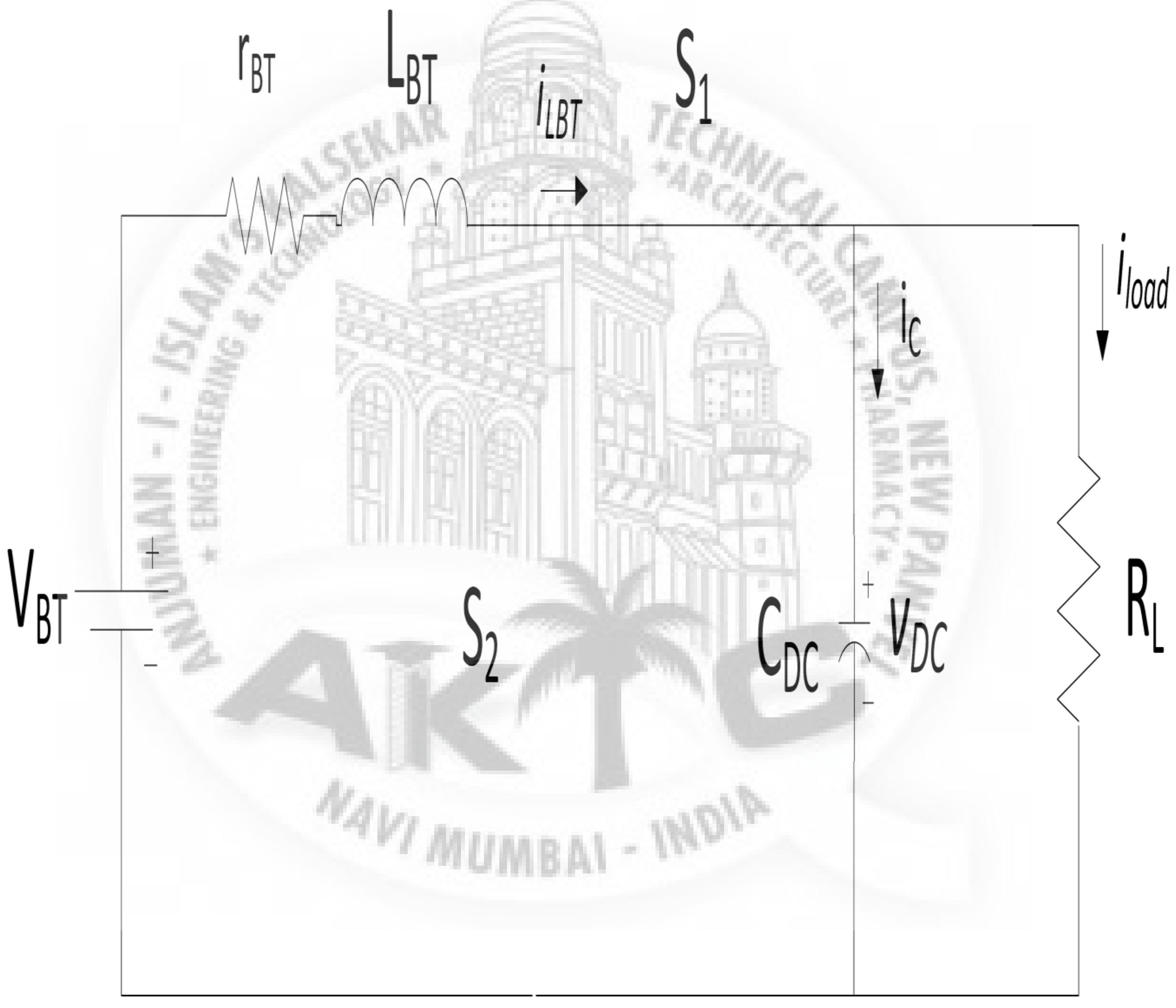

Fig.3.1 Bidirectional ON state: S1=ON S2=OFF

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$\frac{di_{LBT}}{dt} = \frac{1}{L_{BT}}(V_{BT}\text{-}V_{DC}\text{-}r_{BT}i_{LBT})$	4.1

The dynamics of above circuit can be mathematically represented in terms of differential equation with state variable taken to be inductor current (i_{LBT}) and capacitor voltage (V_{DC}) are as follows:

$$\frac{di_{LBT}}{dt} = \frac{1}{L_{BT}}(V_{BT}\text{-}V_{DC}\text{-}r_{BT}i_{LBT})$$

$$\frac{dV_{DC}}{dt} = \frac{1}{C_{DC}}(i_{LBT} - \frac{V_{dc}}{R_L})$$

For the OFF state of converter equivalent circuit is shown in figure 3.2

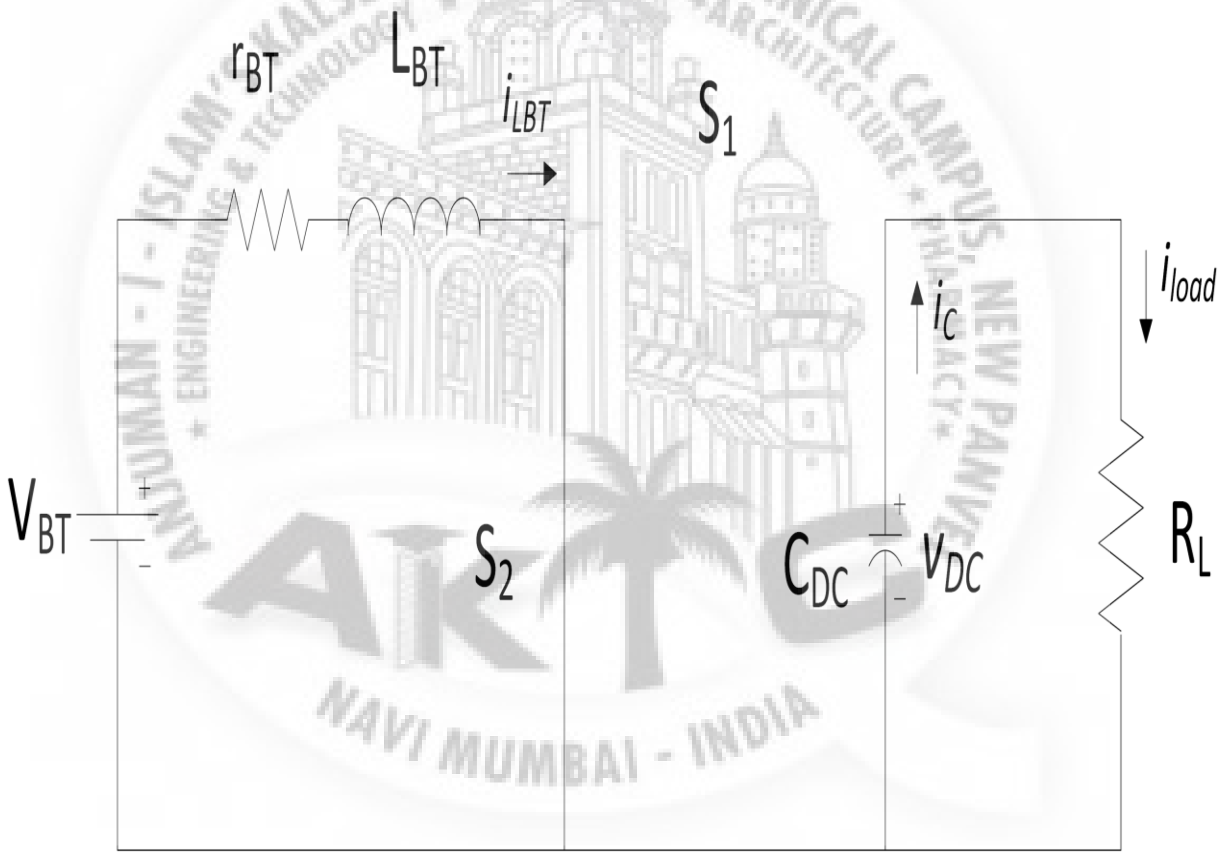

Fig. 3.2: Bidirectional OFF state: S1=OFF S2=ON

State dynamics equation with for the OFF states are as follows :

$$\frac{di_{LBT}}{dt} = \frac{1}{L_{BT}}(V_{BT} - r_{BT} i_{LBT}) \ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

$$\frac{dV_{DC}}{dt} = -\frac{V_{dc}}{R_L C_{DC}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

Average model of converter can be found as described in [31] as

(ON state equation)d + (OFF state equation)(1-d)=0;

Implies that,

$$L_{BT}\frac{di_{LBT}}{dt} = V_{BT} - dV_{DC} - r_{BT} i_{LBT} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$C_{DC}\frac{dV_{DC}}{dt} = di_{LBT} - \frac{V_{DC}}{R_L} \ldots\ldots\ldots\ldots\ldots$$

Still the system is nonlinear , in order to linearize system around its steady state (denoted by Capital letters) we perturb state variables by a small value denoted by hat (hat symbol) such that

$$i_{LBT} = I_{LBT} + \hat{\imath}_{LBT} \quad v_{DC} = V_{DC} + \hat{v}_{DC} \quad v_{BT} = V_{BT} + \hat{v}_{BT} \quad d = D + \hat{d}$$

And solve for eq (3.6) results in

$$L_{BT}\frac{d(I_{LBT} + \hat{\imath}_{LBT})}{dt} = (V_{BT} + \hat{v}_{BT}) - (D + \hat{d})(V_{DC} + \hat{v}_{DC}) - r_{BT}(I_{LBT} + \hat{\imath}_{LBT})$$

$$C_{DC}\frac{d(V_{DC} + \hat{v}_{DC})}{dt} = (D + \hat{d})(I_{LBT} + \hat{\imath}_{LBT}) - \frac{(V_{DC} + \hat{v}_{DC})}{R_L}$$

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Chapter 4

4.1 Boost Converter

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch. These in a co-ordinate manner supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change.

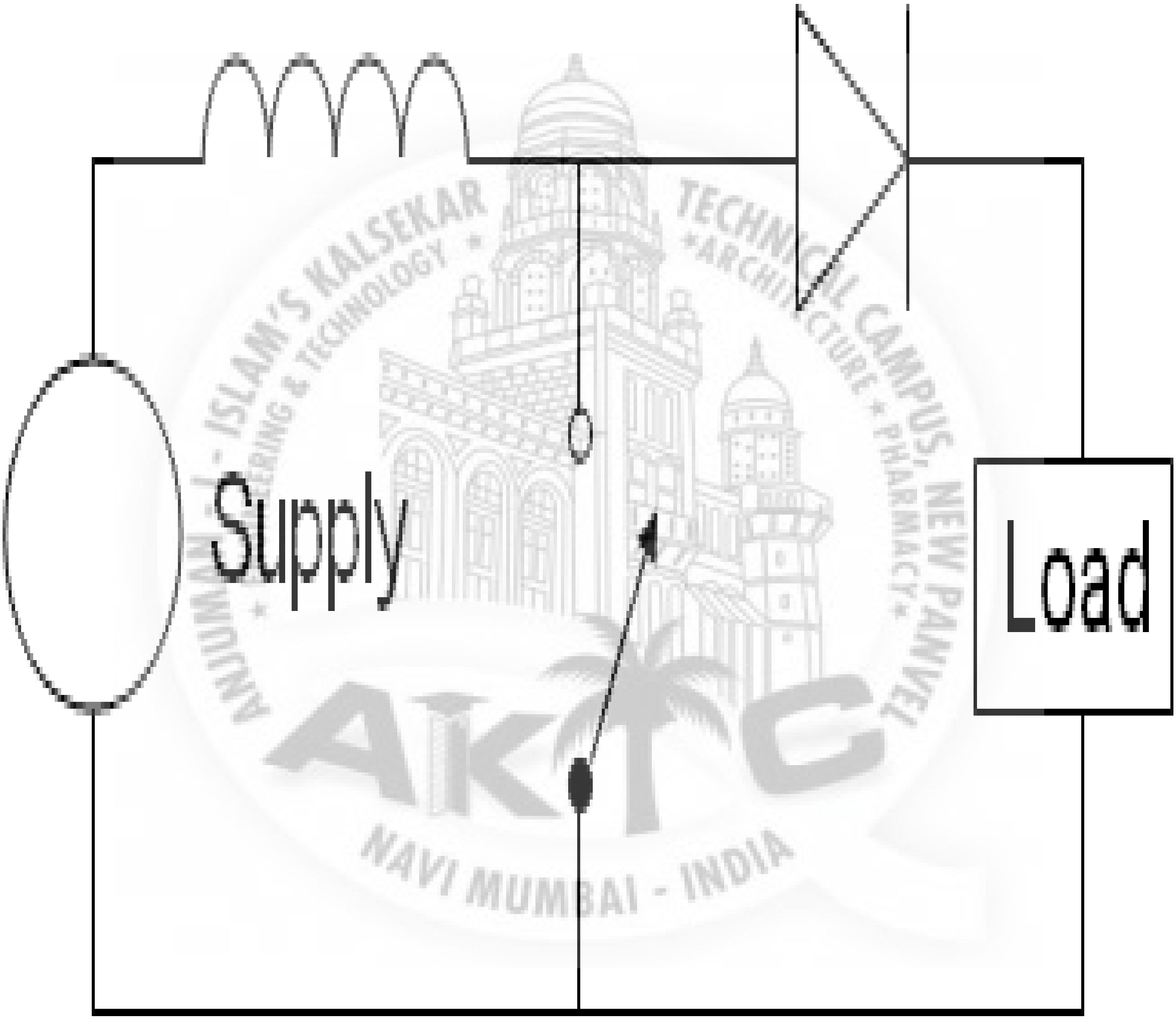

Fig.4.1 Boost Converter

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4.2 Modes of operation

There are two modes of operation of a boost converter. Those are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation.

4.2.1 Charging Mode

In this mode of operation; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor.

4.2.2 Discharging Mode

In this mode of operation; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying . The diode restricts the flow of current from the source to the load and the domain this mode of operation; the switch is open and the diode is forward biased. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation. and of the load is met by the discharging of the capacitor.

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4.3 Waveform

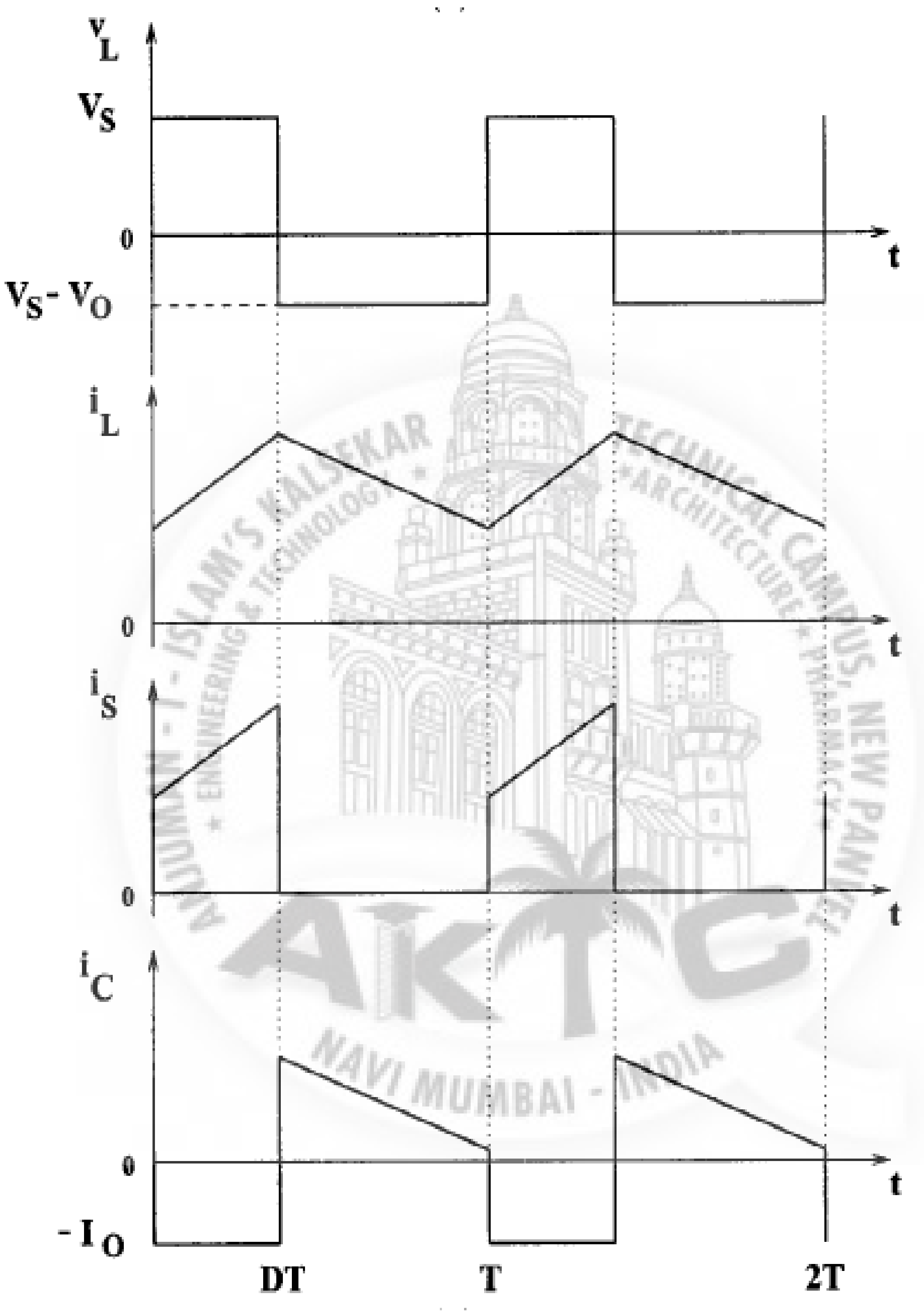

Fig4.2 Waveform of boost converter.

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Chapter 5

Simulation and Results

5.1 Simulation model of PV cell

The solar cell was modeled in the single diode format. This consists of a 0.1 ohm series resistance and an 8 ohm parallel resistance. This was modeled using the Sim Power System blocks in the MATLAB library. The Simulink model is as shown below shows that the modeling of saturation current I_0, Im and Ipv.

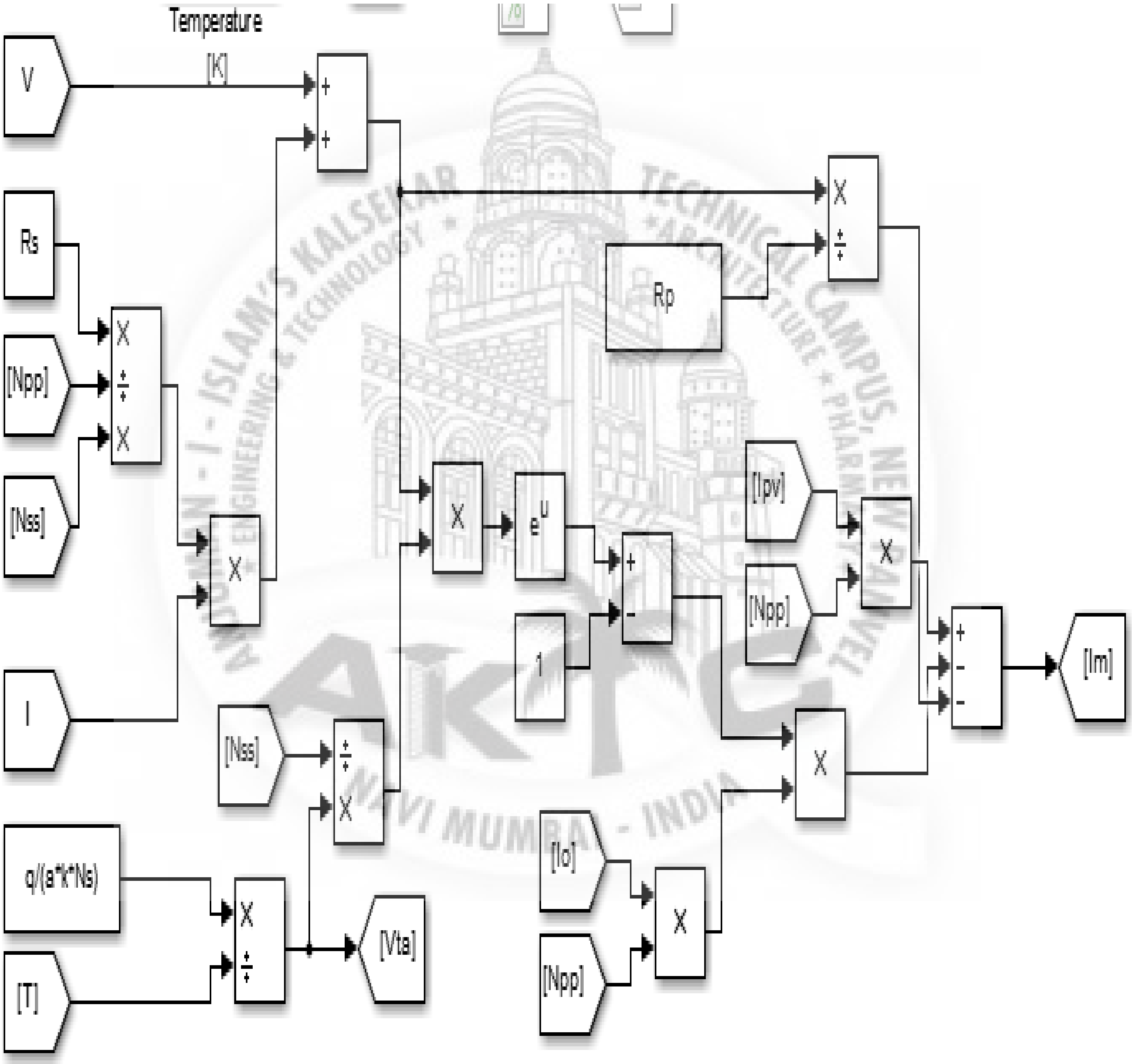

Fig. 5.1 Modeling of PV cell

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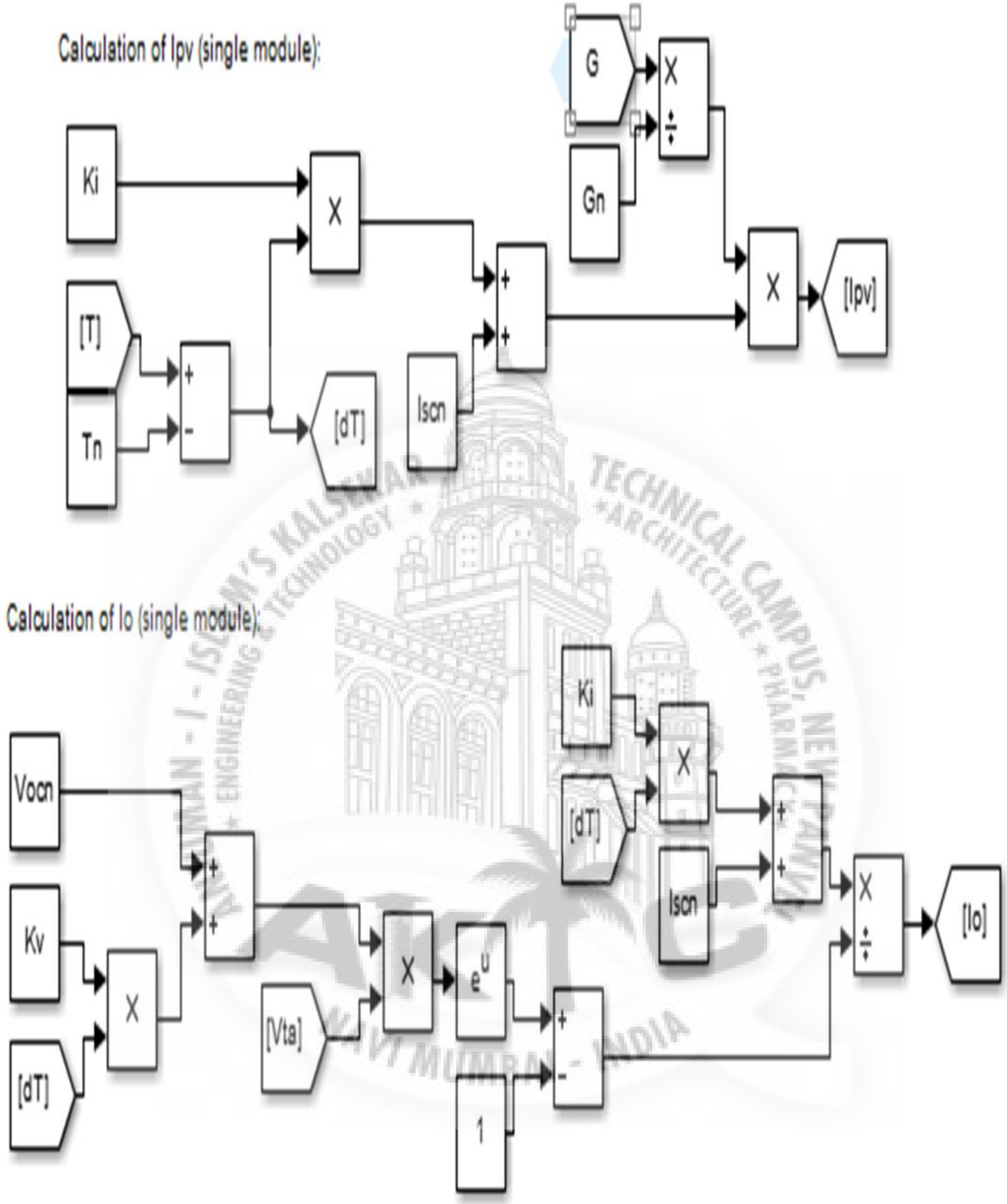

Fig. 5.2 Calculation of Ipv and Io

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5.2 INTERFACING OF THE PV ARRAY WITH BOOST CONVERTER

The PV array has been interfaced with the boost converter using a controlled voltage source as shown in the circuit diagram below.

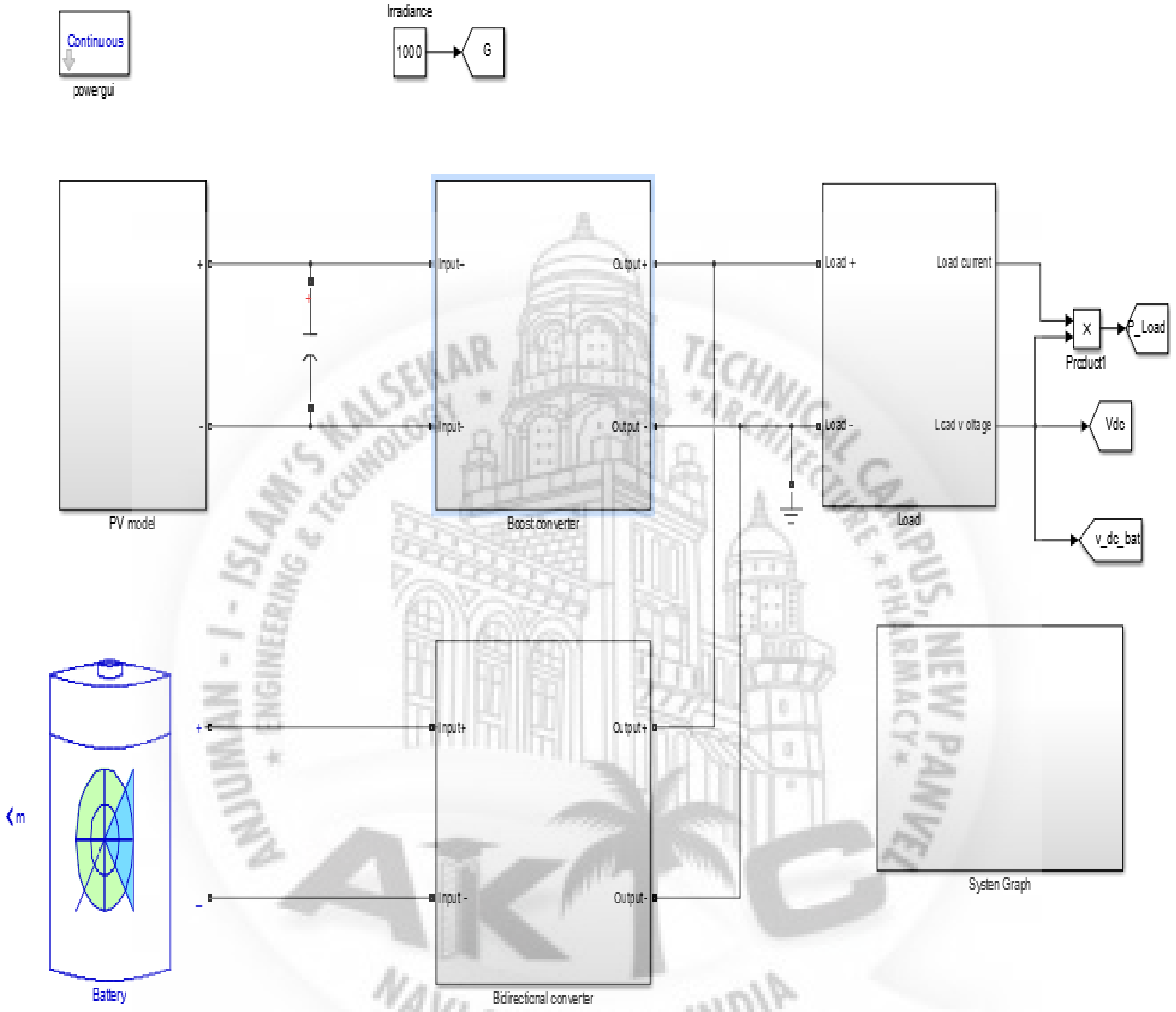

Fig. 5.3 The complete simulink circuit model showing the coupling of PV array with the boost converter

The PV array has been designed taken into consideration its dependence upon the irradiance, temperature, number of PV cells connected in series and parallel as explained earlier.

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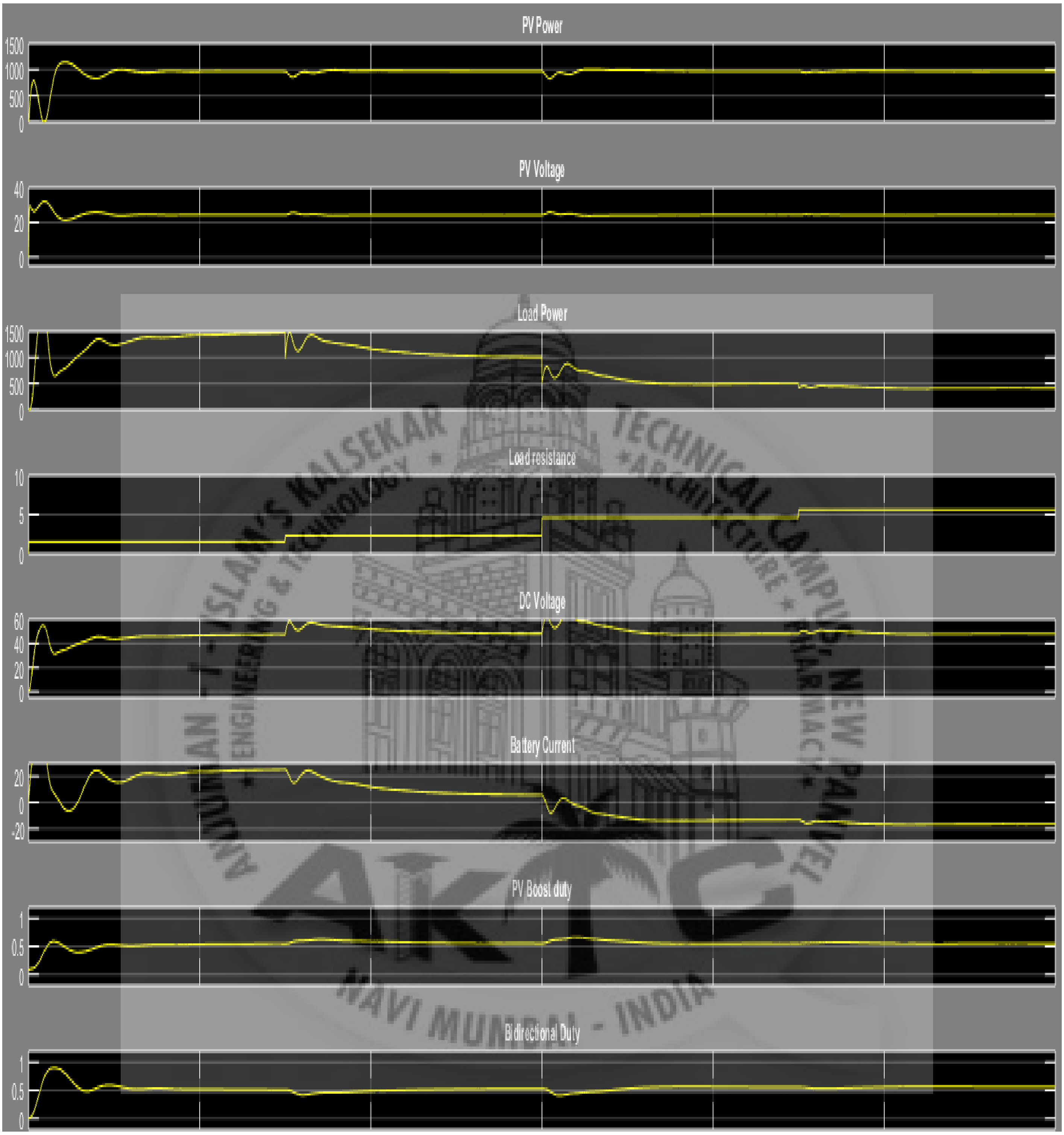

Graph. 5.1 Charging and discharging of battery

Above figure shows that the charging and discharging mode of battery due to change in load at various time. The DC voltage tries to settle down after every change in load. During charging time load consume less power so remaining power goes to the battery.

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Chapter 6

6.1 Conclusion

This thesis proposed a DC standalone microgrid environment of solar photovoltaic system. Although grid tied system are more popular the importance of standalone system have not lost its existence. These are of great importance in the rural area or places inaccessible to grid environment. The proposed standalone system is relatively compact and has stable behavior under various operating condition. The proposed control strategy have two important benefits The first one enhancing the battery life by monitoring the SOC level of battery. As the controllers designed are in linear domain the same system can be upgraded with multiple distributive generation source without change in control of previous system. The proposed PI controllers are found to be giving satisfying results for their respective task. The simulation results show the proposed control strategy is capable of maintaining DC microgrid within its prescribed limits. is use of DPC mode which reduces the requirement of dump load.

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6.2 FUTURE SCOPE

The future work aims to integrate inverter to make system AC microgrid either in grid tied or standalone environment. Also the proposed strategy without solar photovoltaic with some change in system algorithm can be applied for the electric vehicle. Also the proposed system has not talk about energy management over period of time so that optimization issue can be improved.

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