Control and Energy Management of Hybrid Wind-PV-Battery for an Isolated System

एक पृथक प्रणाली के लिए हाइब्रिड विंड-पीवी-बैटरी का नियंत्रण और ऊर्जा प्रबंधन

Kiran Kumar Nagda

Thesis

Master of Technology in Electrical Engineering

(Power Electronics)

2018

Department of Electrical Engineering

College of Technology and Engineering

Maharana Pratap University of Agriculture & Technology, Udaipur

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In Partial Fulfillment of the Requirement for the Degree of

Master of Technology in Electrical Engineering

(Power Electronics)

By

Kiran Kumar Nagda

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COLLEGE OF TECHNOLOGY AND ENGINEERING

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE &TECHNOLOGY, UDAIPUR

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Date:10-12-2018

This is to certify that this thesis entitled **"Control and Energy Management of Hybrid Wind-PV-Battery for an Isolated System"** submitted for the degree of **Master of Technology in Electrical Engineering** in the subject of **Power Electronics** embodies bonafide research work carried out by **Mr Kiran Kumar Nagda** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged.

The draft of the thesis was also approved by the advisory committee on 25-07-2018.

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This is to certify that this thesis entitled **"Control and Energy Management of Hybrid Wind-PV-Battery for an Isolated System"** submitted by **Mr Kiran Kumar Nagda** to Maharana Pratap University of Agriculture and Technology, Udaipur, in partial fulfillment of the requirements for the degree of **Master of Technology in Electrical Engineering** in the subject of **Power Electronics** after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination held on 10-12-2018 has been found satisfactory; we therefore, recommend that the thesis be approved.

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This is to certify that **Mr Kiran Kumar Nagda** student of **Master of Technology, Electrical Engineering** has made all corrections/modifications in the thesis entitled **"Control and Energy Management of Hybrid Wind-PV-Battery for an Isolated System"** which were suggested by the external examiner and the advisory committee in the oral examination held on 10-12-2018. The final copies of the thesis duly bound and corrected were submitted on 11-12-2018.

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LIST OF ABBREVIATIONS AND SYMBOLS

LIST OF ABBREVIATIONS

RE	Renewable Energy
PV	Photovoltaic
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
P&O	Perturb and Observe
PFAC	Power Frequency Alternating Current
HFAC	High Frequency Alternating Current
ESS	Energy Storage System
HRES	Hybrid Renewable Energy System
PWM	Pulse Width Modulation
BESS	Battery Energy Storage System
Ni-Cd	Nickel Cadmium
Ni-MH	Nickel Metal Hydride
Li-ion	Lithium-ion Battery
SOC	State of Charge
RES	Renewable Energy System
HPS	Hybrid Power System
HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
PMSG	Permanent Magnet Synchronous Generator
WECS	Wind Energy Conversion System
VSI	Voltage Source Inverter
R&D	Research and Development
LPSP	Loss of Power Supply Probability
ANFIS	Adaptive Neuro-Fuzzy Interface System
HOMER	Hybrid Optimization Model for Electric Renewable
HOGA	Hybrid Optimization by Genetic Algorithm

LIST OF SYMBOLS

Cp	Power Coefficient
K	Boltzmann's Constant
P	Air Density
A	Area of Rotor
V	Velocity
T	Temperature
F	Force
m_0	Mass
W	Work
E_K	Kinetic Energy
A	Acceleration
λ_0	Tip-speed ratio
R	Radius
B	Pitch angle
R_a	Armature resistance
T_e	Electromagnetic torque
L_d, L_q	Generator inductance of d-q axis
I_L	Photo generated current
I_D	Diode current
R_{sh}, L_{sh}	Shunt resistance and Inductor
Φ	Phase
I_{SH}	Shunt Current
I_0	Reserve saturation current
I_{SC}	Short-circuit current
I_{Sat}	Saturation current
N	Diode ideality factor
Q	Elementary charge
G	Irradiance
V_{OC}	Open-circuit voltage

Σ	Self-discharge rate
DOD_{max}	Maximum battery depth of discharge
A	Firing angle
P_{pv}	Photovoltaic power
P_{wind}	Wind power
P_{load}	Load power

ABSTRACT

The wide CO_2 released into the atmosphere and millions of people worldwide are not able to access electricity which is most basic goods for human survival. From the last century coal, oil, gas and nuclear energy are used for power production at a large scale. This type of source requires very high maintenance for power generation and leads to a large amount of wastage. Renewable energy sources are a natural source of power and they can produce power from nature at an economical rate. Renewable energy sources such as wind, solar, hydro, Biogas and biomass are used for power production. From these sources wind and PV has high potential and produces highly efficient output power. We can't produce over-capacity power from a single source, so we have to integrate two or more than two sources as hybrid wind-solar-battery to meet load profile.

A hybrid wind-PV-battery system dynamic model developed in MATLAB/Simulink software, the control strategy for energy management proposed by the fuzzy logic rule viewer. A PV panel, wind panel and dynamic models of lithium-ion storage connected together with the DC link and all these sources are working on the basis of fuzzy rule based control. The DC link is connected through the power electronic interfacing circuit (converters) and converters connected to a source for a diverse electricity generation. All sources work on the basis of the MPPT control algorithm, which will work if and only if the panel operates at the peak point of power generation.

The hybrid generation systems that can maintain continuous load power demand and provide satisfied operation on the main constraints. The developed control strategy can control various devices and different power interface circuitry. The main objective of this thesis is that to ensure a continuous power by coordinating appropriate control strategy with all sources. The simulation studies have been carried out to determine system performance with different scenarios of the sources such as typical solar radiation, temperature, air and battery charge or discharge conditions. Simulation test results show variable power generation and verify the performance of the integrated system with control strategy is overall effective for real-time installation. The developed system is essential in an isolated region where an existing grid is unable to supply secure power generation and system is beneficial with smartly feed ultimate power generation sources.

सारांश

वायुमंडल में जारी व्यापक सीओ 2 और दुनिया भर के लाखों लोग बिजली का उपयोग करने में सक्षम नहीं हैं जो मानव अस्तित्व के लिए सबसे बुनियादी सामान हैं। पिछली शताब्दी से कोयले, तेल, गैस और परमाणु ऊर्जा का उपयोग बड़े पैमाने पर बिजली उत्पादन के लिए किया जाता है। इस प्रकार के स्रोत को बिजली उत्पादन के लिए बहुत अधिक रखरखाव की आवश्यकता होती है और बड़ी मात्रा में बर्बादी होती है। नवीकरणीय ऊर्जा स्रोत शक्ति का एक प्राकृतिक स्रोत हैं और वे प्रकृति से बिजली को आर्थिक दर पर उत्पन्न कर सकते हैं। बिजली उत्पादन के लिए पवन, सौर, हाइड्रो, बायोगैस और बायोमास जैसे नवीकरणीय ऊर्जा स्रोतों का उपयोग किया जाता है। इन स्रोतों से पवन और पीवी में उच्च क्षमता है और अत्यधिक कुशल आउटपुट पावर का उत्पादन होता है। हम एक स्रोत से अधिक क्षमता वाली शक्ति का उत्पादन नहीं कर सकते हैं, इसलिए हमें लोड प्रोफाइल को पूरा करने के लिए हाइब्रिड विंड-सौर-बैटरी के रूप में दो या दो से अधिक स्रोतों को एकीकृत करना होगा।

मेट्लेब/सिमुलिंक सॉफ़्टवेयर में विकसित एक हाइब्रिड विंड-पीवी-बैटरी सिस्टम गतिशील मॉडल, अस्पष्ट तर्क नियम दर्शक द्वारा प्रस्तावित ऊर्जा प्रबंधन के लिए नियंत्रण रणनीति। एक पीवी पैनल, पवन पैनल और डीथ लिंक के साथ जुड़े लिथियम-आयन स्टोरेज के गतिशील मॉडल और ये सभी स्रोत फ़ज़ी नियम आधारित नियंत्रण के आधार पर काम कर रहे हैं। डीसी लिंक बिजली इलेक्ट्रॉनिक इंटरफेसिंग सर्किट (कन्वर्टर्स) और विभिन्न बिजली उत्पादन के लिए स्रोत से जुड़े कन्वर्टर्स के माध्यम से जुड़ा हुआ है। सभी स्रोत एमपीपीटी नियंत्रण एल्गोरिदम के आधार पर काम करते हैं, जो काम करेगा यदि केवल और यदि पैनल बिजली उत्पादन के चरम बिंदु पर काम करता है।

हाइब्रिड पीढ़ी के सिस्टम जो लगातार लोड बिजली की मांग को बनाए रख सकते हैं और मुख्य बाधाओं पर संतुष्ट संचालन प्रदान कर सकते हैं। विकसित नियंत्रण रणनीति विभिन्न उपकरणों और विभिन्न पावर इंटरफेस सर्किट्री को नियंत्रित कर सकती है। इस थीसिस का मुख्य उद्देश्य यह है कि सभी स्रोतों के साथ उचित नियंत्रण रणनीति समन्वय करके निरंतर शक्ति सुनिश्चित करना। सामान्य सौर विकिरण, तापमान, वायु और बैटरी चार्ज या निर्वहन की स्थिति जैसे स्रोतों के विभिन्न परिदृश्यों के साथ सिस्टम प्रदर्शन निर्धारित करने के लिए सिमुलेशन अध्ययन किए गए हैं। सिमुलेशन परीक्षण के परिणाम परिवर्तनीय बिजली उत्पादन दिखाते हैं और नियंत्रण प्रणाली के साथ एकीकृत प्रणाली के प्रदर्शन को सत्यापित करते हैं, वास्तविक समय स्थापना के लिए समग्र प्रभावी है। विकसित प्रणाली एक अलग क्षेत्र में आवश्यक है जहां एक मौजूदा ग्रिड सुरक्षित बिजली उत्पादन की आपूर्ति करने में असमर्थ है और प्रणाली बुनियादी बिजली उत्पादन स्रोतों से स्मार्ट रूप से फ़ीड करने के लिए फायदेमंद है।

CHAPTER 1

INTRODUCTION

This chapter presents renewable resource, various states generated power scenarios in India and future planning of these power resources in MW, wind power system, photovoltaic power system and their status in India, a hybrid power system with MPPT control strategy for power management and energy storage (battery) system. This chapter also discussed the research objectives and organization of the thesis.

1.1 General Introduction

All the equipments surrounding us operate on the electricity, without electricity all equipment is dreams only. For sustainable energy growth in any nation or state, it must fulfill all requirement of the electricity supply. Due to the emission of a CO_2 global warming arises, temperature increases of the Earth and glacier melting at high rate, content that is responsible for global warming issues using the vehicle, using the hearth, industries, burning of house-hold waste and generation of power from coal etc. The pollution also emitting more and more due to energy generated from coal, oil and from gas. Using power generation from coal, oil and gas, this type of generation sources is known as the conventional sources. Conventional source power plant has high maintenance, and produce high waste products.

The costumers are unable to feed high rate of electricity bills which arises due to higher generation and transmission cost always impact on consumer electricity prices. The large consumer lives in hilly or islanded areas they did not covered by the distribution system. Due to highly unfavorable results by conventional power sources, we would move on new power generation technologies such as a non-conventional plant with renewable sources and ability to produce huge power at low cost. Types of renewable energy sources which used in power generation such as solar (PV or photovoltaic), wind, biomass, hydropower, geothermal power, and biogas. Those types of source has great advantages such as no environmental pollution, no maintenance required, cost-effective for longer life, low waste production and act as a UPS. Also non-conventional source has some disadvantages like no guarantee to produce electricity in weather predicted condition and larger space is required for installation. The generated power from an existing system is unable to feed electricity to an isolated region, which is very far from the existing grid. Mostly our priority is to integrate solar and wind plant with battery because of solar and wind alone are not provides sufficient power, so we have to integrate two sources with battery builds a micro-grid generation for an isolated sites to provides autonomous power plant.

1.2 Renewable Energy sources

The world is moving towards extensive utilization of renewable energy in recent days as a solution for the energy crisis. Growing electricity demand, increasing fuel prices, and greenhouse gas emissions have led us to turn to renewable energy resources, such as wind and solar power, for their higher potential to solve these issues. However, renewable energy faces two major dispatch ability issues: technical and financial. Battery energy storage systems (BESS) are known in the hybrid system for improving the grid performance and reliability. Further, hybrid system, BESS combined with the renewable sources with a single unit, solves many RES issues. Renewable energy is an energy sources that can replace rapidly conventional sources by a natural process such as solar, wind, hydro, geothermal etc. and provides sustainable energy. Renewable energy is generated from a variety of natural processes that are naturally replenished. These natural resources include sunlight, wind, tides, water, geothermal heat and other forms of biomass as shows in figure 1.1. Fossil fuels are widely used in the energy industry to provide both electricity and heat for homes, offices and other buildings. This form of energy is renewable means it is drawn from finite resources that will eventually run out.

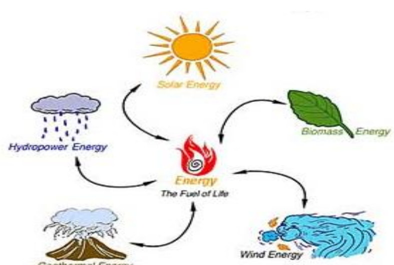


Fig. 1.1: Types of renewable energy resource.

1.2.1 Renewable energy status in India

Due to no improvement in production and demand rising, renewable energy source provides a great deal to meet load demand and that lead the country in forward direction.

Power produces in India from three different sectors are state, central and private sector, the total power generation from all three sectors 3,44,002 MW and the contribution of all the sectors as follows in table 1.1:

Table 1.1: Total generated power from all three sectors.

Sector	**MW**	**% of Total**
State sector	84,517	24.6%
Central sector	103,975	30.2%
Private sector	155,510	45.2%
Total	**3,44,002**	

The power generation in India from all conventional and non-conventional sources percentage shown in figure 1.2 as a pie chart:

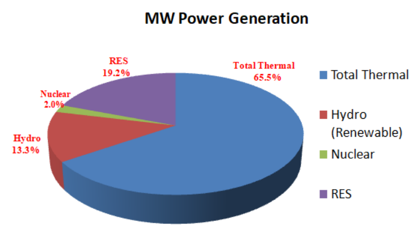


Fig. 1.2: Generation of power from all major sources.

The ministry of non-conventional energy resources took a new approach for energy generation to build micro-grid by integrating two different renewable sources. The total installed power generation capacity from renewable sources in India was 57.24 GW (57,244 MW), contribution from 57.24 GW is 32.2 GW (32,279 MW) of that wind (56.39%), 12.2 GW (12,288 MW) of that solar (21.47%), 4.3 GW (4,379 MW) of that small hydro (7.65%), 8.1 GW (8,181 MW) of that bio-power (14.29%) and 0.11 GW (114 MW of waste-to-energy) (0.2%) as shown in figure 1.3.

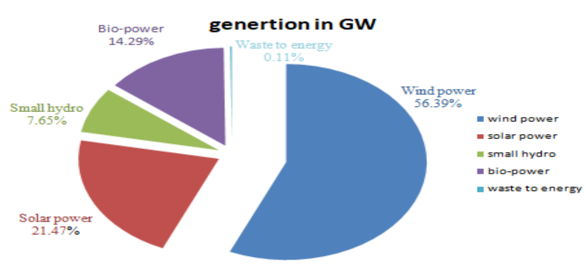


Fig. 1.3: Renewable power sources generation contribution.

The capacity added in FY during 2016-17 was a record 11,320 MW (5525 MW solar, 5502 MW wind, 161 MW bio-powers, 106 MW from small hydro and 23 MW from waste-to-energy). In FY2016-17, electricity generation from renewable was 81.88 BU, a 24.47% increase from 67.58 BU generated in FY2015-16. For the first time in India, capacity addition from renewable (11.3 GW) surplus added in the capacity from non-conventional sources (10.3 GW) in FY2016-17.

Table 1.2: Installed capacity from the power sources.

Fuel	MW	% of total
Total thermal	2,22,693	64.8
Coal	1,96,958	57.3
gas	24,897	7.2
oil	838	0.2
Hydro (renewable)	45,403	13.2
Nuclear	6,780	2.0
RES* (MNRE)	69,022	20.1
total	**343,899**	

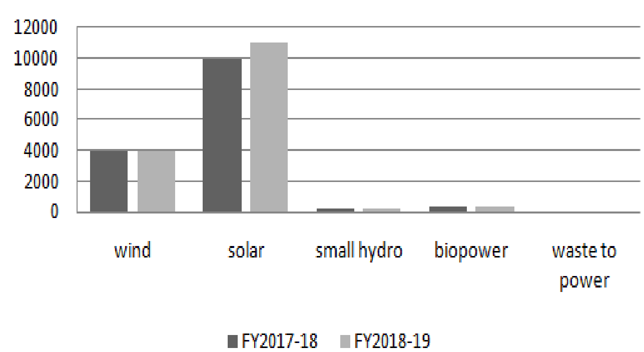


Fig. 1.4: Renewable energy capacity addition target, FY2017-18, and FY2018-19.

Table 1.3:-Target of renewable energy source for three years.

Source	2016-17	2017-18	2018-19
Solar Power	12,000	15,000	16,000
Wind Power	4,000	4,600	5,200
Biomass	500	750	850
Small Hydro Power	225	100	100

Grand Total	16,725*	20,450*	22,150*

*capacity in MW

Renewable sources now contribute 6.59% of the electricity generated in the country. Total renewable energy source installment and targets of FY2017-18 and FY2018-19 as shown in figure 1.4 and in table 1.3. Achievements and targets under the different program of the Government provide a schedule of generation of power form year 2017-2018 and target plans of power generation in FY 2018 sown in table 1.4 as follows:

Table 1.4: Provide information about power generation in FY 2017-2018 and achieved target as on 31.03.2018.

Program/scheme wise Physical progress in 2017-2018 & Cumulative up-to-the Month of March 2018			
Sector	**FY-2017-18**		**Cumulative Achievements**
	Target	**Achievements (April-March, 2018)**	**(as on 31.3.2018)**
GRID INTERACTIVE POWER (CAPACITIES IN MW)			
Wind Power	4000.00	1766.25	34046.00
Solar Power- Ground Mounted	9000.00	9009.81	20587.83
Solar Power – Roof Top	1000.00	352.83	1063.63
Small Hydro Power	100.00	105.95	4485.80
Bio-power (Biomass & Gasification and Bagasse Cogeneration)	340.00	519.10	8700.80
Waste to Power	10.00	0.00	138.30
Total	**14450.00**	**11753.94**	**69022.36**
OFF-GRID/CAPTIVE POWER (CAPACITIES IN MW_{EQ})			
Waste to Energy	15.00	5.50	172.15
Biomass (non-bagasse)	60.00	9.50	662.61

cogeneration			
Biomass Gasifiers	7.50	0.92	163.37
Aero-Generators/Hybrid Systems	0.50	0.14	3.29
SPV Systems	150.00	216.63	671.41
Total	**233.00**	**232.69**	**1672.83**
OTHER RENEWABLE ENERGY SYSTEMS			
Family Biogas Plants (numbers in lakh)	1.10	0.23	49.82
Watermill/micro hydel (Nos)	150/25	0.00	2690/72

A major development is the decision to allow settling up of 15,000 MW of grid-connected solar PV plants of the National Thermal Power Corporation (NTPC). Of this, total 3,000 MW Capacity has been allotted across Andhra Pradesh, Karnataka, Rajasthan, Telangana and Uttar Pradesh, as on 31 December 2016. NTPC is also executing EPC projects for installing grid-connected solar projects under various schemes.

1.2.2 India's 2022 Renewable energy Target

The Government of India aims to increase renewable energy target capacity of 175 GW by the year 2022, which gives various opportunities for erecting renewable hybrid power plant which will offer massive investments. The contribution of solar energy in 100 GW, wind energy 60 GW, 10 GW through small hydro, and 5 GW through biomass-based power projects. From all the renewable sources with the ambitious target, India will become the largest green energy producers in the world, with a surplus amount of power generation. The recent estimates of India's solar energy potential is higher than 750 GW and its announced wind potential target is 302 GW (actual could be higher than 1000 GW). Security scenarios energy of India 2047 shows a possibility of achieving a high 410 GW of wind and 479 GW of solar PV by 2047.

1.2.3 Proposed targets of Renewable Energy in the various States of India

The tentative State-wise break-up of Renewable Power target to be achieved by the year 2022 So that cumulative achievement is 1,75,000 MW. Proposed state-wise renewable energy targets from different sources are shown in table 1.5.

Table 1.5: Proposed state-wise targets from different source.

State /UTs	Solar power (MW)	Wind power (MW)	SHP (MW)	Biomass power (MW)
Delhi	2762			
Haryana	4142		25	209
Himachal Pradesh	776		1500	
Jammu & Kashmir	1155		150	
Panjab	4772		50	244
Rajasthan	5762	8600		
Utter Pradesh	10697		25	3499
Uttrakhand	900		700	197
Chandigarh	153			
Northern Region	**31,120**	**8,600**	**2,450**	**4,149**
Goa	358			
Gujarat	8020	8800	25	288
Chattisgarh	1783		25	
Madhya Pradesh	5675	6200	25	118
Maharashtra	11926	7600	50	2469
D. & N. Haveli	449			
Daman & Diu	199			
Western Region	**28,410**	**22,600**	**125**	**2,875**
Andhra Pradesh	9834	8100		543
Telangana		2000		
Karnataka	5697	6200	1500	1420
Kerala	1870		100	
Tamil Nadu	8884	11900	75	649
Puducherry	246			

Southern Region	**26,531**	**28,200**	**1,675**	**2,612**
Bihar	2493		25	244
Jharkhand	1995		10	
Orissa	2377			
West Bengal	5336		50	
Sikkim	36		50	
Eastern Region	**12,237**		**135**	**244**
Assam	663		25	
Manipur	105			
Meghalaya	161		50	
Nagaland	61		15	
Tripura	105			
Arunachal Pradesh	39		500	
Mizoram	72		25	
North Eastern Region	**12,237**		**615**	
Andaman & Nicobar Islands	27			
Lakshadweep	4			
Other (New States)		600		120
All India	**99,533**	**60,000**	**5,000**	**10,000**

1.3 Solar Power System

The sun is a very powerful one of the most important renewable energy sources. Solar energy present in nature at infinite amount, this energy resource can meet up long-term global energy crisis. The recent energy crisis of a coal and oil, environmental burden are becoming increasingly due to the emission of CO_2 drawing enormous attention to solar-energy utilization. From all the research study is intended to review recent advances in developing the STE and SPV technologies for solar power generation. By capturing and using just the sunlight on PV module which hits the earth, as well as a module in one day, could provide enough energy for the entire world for all year, Figure 1.5 shows that PV panel module and figure 1.6 shows that solar irradiation in the daytime.

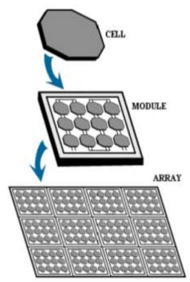


Fig. 1.5: Solar panel PV module.

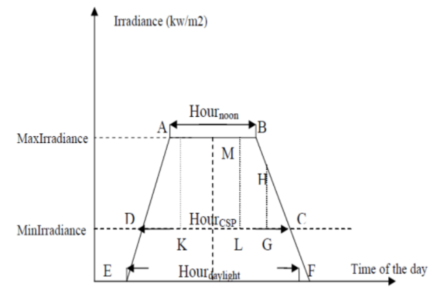


Fig. 1.6: Solar irradiation level in the daytime.

Solar power system has two major types:

1. A grid-connected solar system as shown in figure 1.7.
2. A stand-alone solar system as shown in figure 1.8.

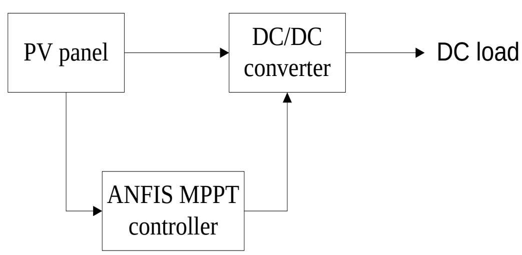


Fig. 1.7: Schematic diagram of standalone PV panel.

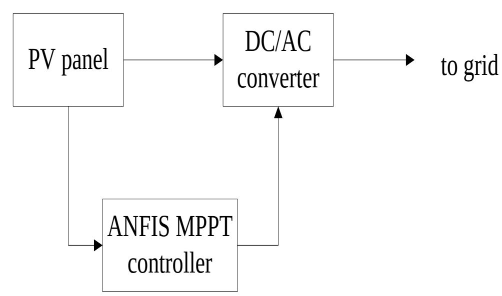


Fig. 1.8: Schematic diagram of a grid-connected solar power plant.

The solar power system has the immense capacity to bring instability to the fluctuating electricity tariffs in India as it is cheaper than thermal and domestic coal (due to increasing prices) and depletion also happens in a fossil fuel. We have to realize that solar radiation falling on major part of India, it is better than the best part of Europe. In India, the electricity demand at a peak value and we have no other options better than the renewable source.

The solar thermal energy source is a finite energy resource to meet-up long-term global energy crisis due to oil environmental hazards are drawing enormous attention to use solar energy utilization. The National Action Plan on Climate Change (NAPCC) also points out: “India is a tropical country, where sunshine is available for longer hours per day with great intensity. Solar energy, therefore, has great potential today as well as near future energy source. It also has the benefits of permitting the decentralized distribution of energy, thereby empowering people at the grassroots level”, figure 1.9 shows working of solar panel.

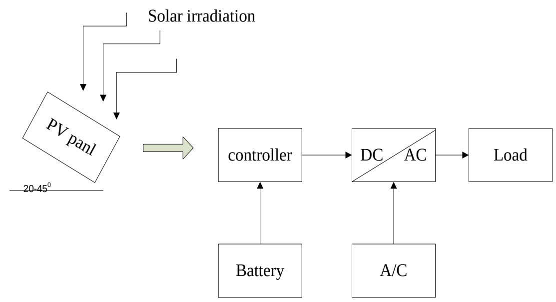


Fig. 1.9: Solar power generation diagram.

1.3.1 Solar energy status in India

From all the countries China is leading in solar power with 31.5GW, at second position India’s installed generation is 12.2 GW, now in 2017 solar installation capacity stand at 18.4GW, with rooftop projects accounting 1.6GW. Renewable energy currently accounts for 16% of Tamilnadu's electricity generation, its second largest source of energy after coal. Andhra Pradesh and Rajasthan are already leading from Tamilnadu when it comes on solar power, the cumulative capacity assessment in MW from 2010-2018 shown in figure 1.10.

During the winter season, the lowest solar radiation is received in North India and the highest in South India. During the summer season, a reversal occurs with high values in North and low in South. The total energy generation from solar is 7.5 KWh/m^2/day of solar energy is received over the country as a whole year, for on the major portion of the year, of which the maximum about 210 KWh/m^2/month is received during cloud-free or in winter months and pre-monsoon months and the minimum 140 KWh/m2/month is received during monsoon seasons.

Solar radiation is diffused with a minimum 740 KWh/m2 over Rajasthan increasing eastwards to 840 KWh/m2 in Assam and to 920 KWh/m2 in the extreme south of the peninsula, solar energy received by the subcontinents is over total 60 x 1013 MWh. In most of the country parts, there is sunshine between 250 to 300 days of usual per year. The solar energy thus emerges as a positive alternative energy source in recent time with certain unique advantages for the Indian condition.

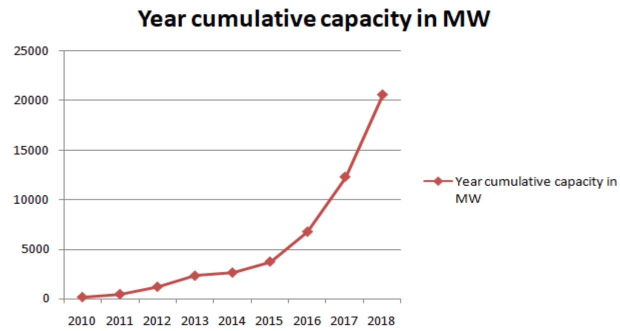


Fig. 1.10: Shows a status of a solar power in India.

India is leading in generating power through solar power plant with high capacity generating range. At present total installed capacity in India is 20.58 GW from this solar power and top source of new power capacity addition in 2017, preliminary figures show that solar installation reached 9.6GW and 45% of total capacity. Top states for solar installations were Telangana followed by Karnataka, Andhra Pradesh, and Rajasthan. India's rooftop projects growth is also increasing in the last few years.

1.3.2 Solar energy target in India 2022

The government has been planned 100GW energy generation from solar in 2022. This target will be complete in 2022. The India achieve a 20GW milestone in eight cumulative years, national solar mission initially set the target of 100GW installed capacity by 2022 and figure 1.11 shows that targets of solar power for 2022.

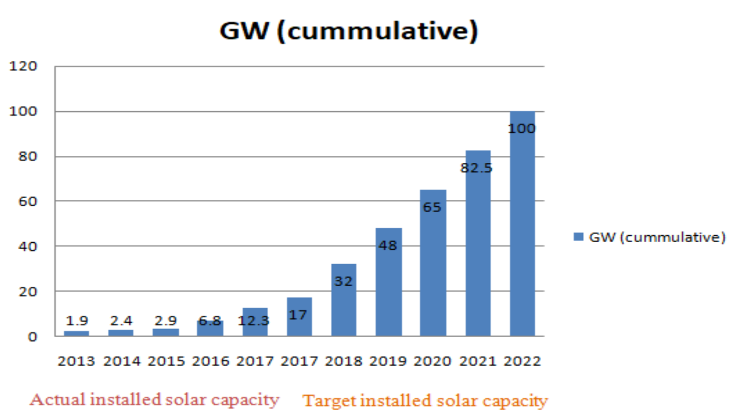


Fig. 1.11: Shows targets for solar for 2022.

1.4 Wind Power Conversion System

Wind power is more essential for green and clean energy and it produced power which is in the form of AC power, a structure of wind panel shown in figure 1.13 and 1.14 shows types of wind turbine. The wind turbine generates the kinetic energy of a wind converts into electrical energy. When the wind blows, the wind to pass through the turbine blade, blades will rotate, the turbine run, the mechanical work change in form of energy. Wind is caused due to uneven heating of an atmosphere by the sun, irregularities of an earth surface. The wind flowing pattern is modified by the earth terrain, bodies of water and vegetative cover. In India, many states are powerful in the generation of power from wind in southern region state Tamilnadu world leader whenever if power produced by wind renewable energy. The wind turbine combines installation capacity of 7.9GW, this capacity puts ahead of many countries regarded as champions of green energy. Some countries like Sweden becoming aiming to generate 100% of its electricity generation from the renewable energy source, but its wind power capacity is 6.7GW which is tenth less than the Tamilnadu.

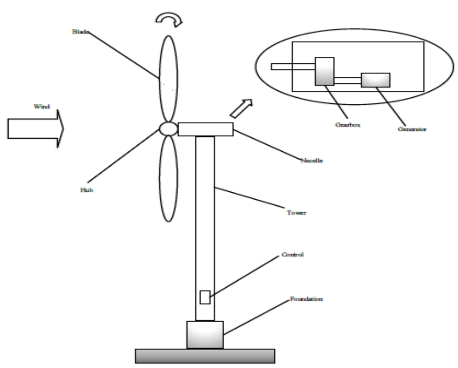


Fig. 1.13: Structure of wind panel.

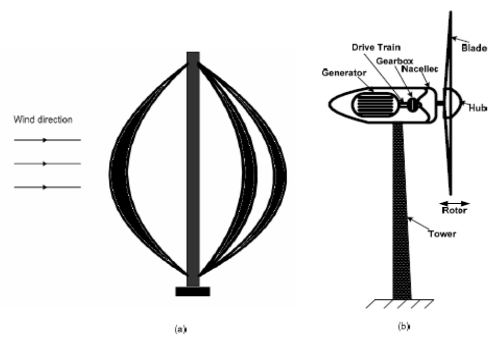


Fig. 1.14: Types of a wind turbine.

Figure out from global wind energy shows that there are only five European nations plus China, the US, Canada and Brazil that has large wind capacities then Tamilnadu in 2017. As well as leading of Tamilnadu in wind power, it is also top position in rooftop solar projects. More than two third of the renewable energy in India comes from wind turbine power. Tamilnadu Targeted 15GW by 2027 wind power capacity which is double from existing power. five states installed more new wind turbine power as 262MW of capacity, last year installed capacity for wind power are: Andhra Pradesh (2.2GW), Gujarat (1.3GW), Karnataka (882MW), Madhya Pradesh (357MW), and Rajasthan

(888MW). India installed capacity of 5.5GW from new wind plant in 2017 which is higher than the target of 4GW for the year. The government has targeted 175GW total renewable energy capacity by the end of 2022. From wind power installation capacity target is 60GW as shown in figure 1.12.

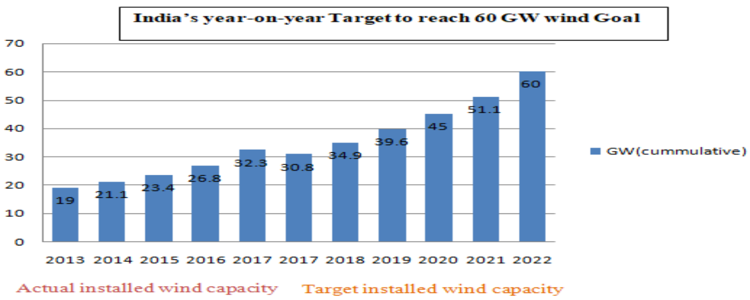


Fig. 1.12: Shows the target of wind power from 2022.

The wind turbine power source has several parts like a blade, spin, and shaft which is connected to the generator and they produce electricity. Wind power is also a renewable energy source and it has more benefits such as energy generated with the nonpolluting source, cost of wind plant dramatically decreased in last 10 years, it provides green energy, supply and transportation are at low cost. Wind power generation is also used for On-Grid and Off-Grid plant.

1.5 Battery Storage System

The Extra power generated from hybrid source can be stored in a battery bank and used as a backup power source and due to stored power as in energy storage system (ESS) is known as a battery and use this backup power whenever generation is low. Recent advancement and development in technologies can be harvesting more and more energy from renewable resources along with the introducing of new concepts in the utility grids have opened many new applications for energy storage devices, in general, and electrochemical batteries in particular applications. In a stand-alone system, battery works as a cyclic basis its charge and discharge depend on the generated power.

Table 1.6:- Comparative analysis for various types of batteries.

Specifications	Lead Acid	NiCd	NiMH	Li-ion		
				Cobalt	Manganese	Phosphate
Specific energy	30-50	45-80	60-120	150-250	100-150	90-120

(Wh/Kg)						
Internal resistance	Very Low	Very Low	Low	Moderate	Low	Very Low
Cycle life(80% DoD)	200-300	1000	300-500	500-1000	500-1000	1000-2000
Charge time	8-16h	1-2h	2-4h	2-4h	1-2h	1-2h
Overcharging tolerance	High	Moderate	Low	Low, No trickle charge		
Self-discharge/ month (room temp)	5%	20%	30%	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V	1.2V	3.6V	3.7V	3.2-3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50-3.00V		2.50V
Peak load current Best result	5C 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	-20 to 50^{0}C (-4 to 122^{0}F)	0 to 45^{0}C (32 to 113^{0}F)		0 to 45^{0}C (32 to 113^{0}F)		
Discharge temperature	-20 to 50^{0}C (-4 to ^{0}F)	-20 to 65^{0}C (-4 to 49^{0}F)		-20 to 60^{0}C (-4 to 140^{0}F)		
Maintenance requirements	3-6 months (toping chg)	Full discharge every 90 days when in full use		Maintenance free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory		

In use since	The late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High		

The requirements of the batteries have been considered as almost ideal energy storage devices and their charging and discharging characteristics have been overlooked and all other specification given in table 1.6. Therefore, the actual backup time of batteries could be lower than the expected (or calculated) value which would result in lower reliability. BESS can provide several key ancillary services, such as load shifting, dynamic local voltage support, short-term frequency smoothing, grid contingency support, and reduce the need for fossil-fuel-based generation. The technical and economic advantages of energy storage systems on a smaller scale are as follows:

1 Greater use of generally cleaner and more efficient energy sources.

2 Improvement of reliability and quality of electricity supply.

3 Provision of backup power for critical loads.

1.6 Hybrid Power System

The renewable energy source is a small “hybrid” micro-grid electrical system that integrating home wind electric and home solar electric (photovoltaic or PV system) technology offers many favorable benefits rather than single renewable systems. Wind speed have a different configuration in a different season, high wind in summer and low wind in the winter season, on the other hand, sun or PV system also have a different configuration in different weather condition like the sun is highly brightening in the summer season and low brightening in the winter season. Both sources have a different configuration in the rainy season. Because of the different peak operating times of the wind and solar are different in the day, month and in the year so the solar system is more likely to produce power when the load requires power needs.

When hybrid system has lack of electricity generation then battery comes in action and supplies surplus demand power. When both are at peak operating condition and load demand is low then energy management strategy takes a step for an extra generated power supplies to the battery for stored power in the battery. Storage capacity must be extreme enough to supply electrical needs during non-charging periods. For high load condition, peak power supplied by the battery bank, battery banks are typically sized to supply the electric load for one to three days.

In a remote location such as hilly or islanded area, the stand-alone system can be highly cost-effective rather than erecting power lines from electrical grid (costing range from 10,02,000 to 33,40,000 per mile). These systems can be used by people who lives far from grid areas and wants to be live independent from power provider companies and commitment with the nonpolluting source. The strategies to be used in a renewable hybrid system or fossil fuel like oil, reducing the amount of electricity required to meet the load profile. For installing hybrid system (PV and wind panel), we will require to invest on extra equipment (called "balance of system”) to conditioning and safely transmits the electric power to the load from the hybrid wind-PV-battery system as shown in figure 1.15.

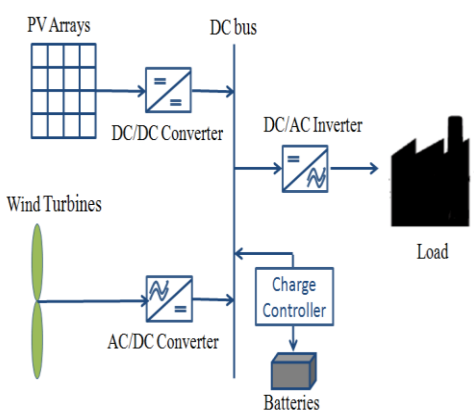


Fig. 1.15: Hybrid power system.

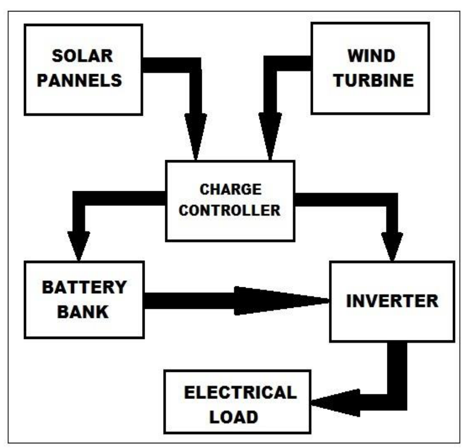


Fig. 1.16: A hybrid Off-Grid power system with a DC bus coupling schematic diagram.

Extra equipment (electronic devices) can include as shown in block diagram 1.16:

1. Batteries.
2. Converters.
3. Charge controller.
4. Power conditioning devices.
5. Safety equipment.
6. Meters and instruments.

1.7 MPPT Algorithm for control hybrid system

MPPT algorithm is a better solution for providing higher efficiency in any solar, wind and battery system. MPPT have a various methodology used for maximum power generation from the renewable energy sources as shown in figure 1.17. Maximum power point tracking (MPPT) used in improving solar and wind panel efficiency by adjusting the panel at maximum point. Few of the most popular techniques are described as Perturb and Observe (hill climbing method), Incremental Conductance method, Fractional short-circuit current method, Fractional open circuit voltage method, Neural networks, and Fuzzy logic. The MPPT Techniques depends on the initial rotor reference speed for the wind turbine and an initial reference voltage for the photovoltaic array.

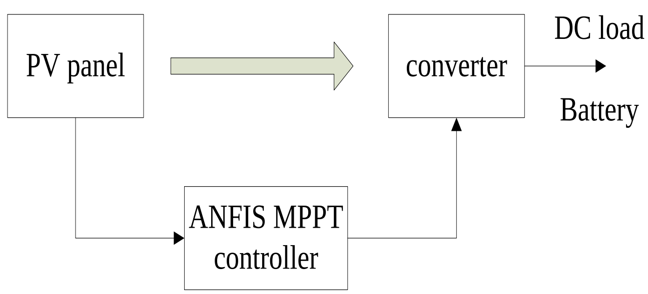


Fig. 1.17: A schematic block diagram of the MPPT control algorithm.

1.8 Fuzzy logic based energy management

New techniques in artificial intelligent is fuzzy logic based technique that is most recent and updated techniques. Fuzzy logic is also a hybrid algorithm and an essential method for solving problems in all domains. This gives a tremendous impact on the designing of the autonomous intelligent system when working on a hybrid power system. All input to output, every function is mapped at the starting point. Fuzzy logic controllers require a first matrix which is possibly built in a Mamdani fis. We can use fuzzy logic toolbox in MATLAB Simulink software and basic control structure diagram shown in figure 1.18.

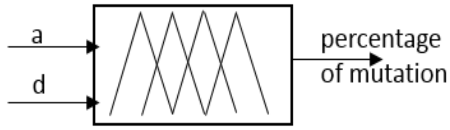


Fig. 1.18: Fuzzy logic control structure.

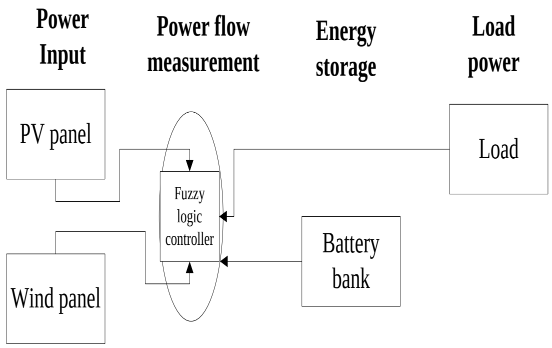


Fig. 1.19: Managing data from the different source.

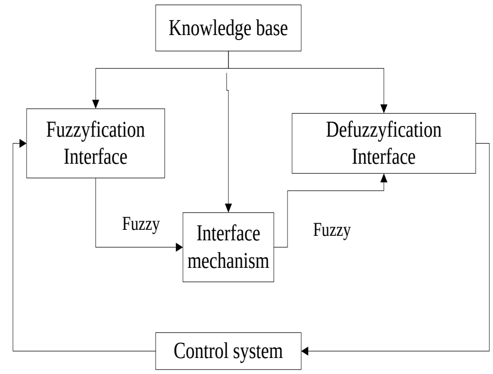


Fig. 1.20: Fuzzy logic working overview.

Fuzzy logic is a logical system, this logical system have an extension of multivalve logic, intelligent behavior of any system can be emerged by the cooperation of simple-agent as shown in figure 1.19. Due to complex, open and distributed nature of a hybrid energy system, the new technology of fuzzy logic appears as a natural solution of a control strategy for energy management propose in hybrid energy system as shown in figure 1.20. Such performance can be defined as:

1. Always supply load.
2. Minimize operational cost.
3. Maximize global efficiency.
4. Higher control ability.

1.9 Either Stand-alone or Grid-connected

Renewable power systems are generally two type On-grid and Off-grid. Power generation by the hybrid renewable energy system with two or more source can be On-Grid or Off-Grid. In the On-Grid system, it is connected to the grid and power takes and supplies whenever required. The Off-Grid system is independent from the utility grid, this system used the battery as storage for fulfilling power supply when generation is low and demand is high. Optimal erection and configuration of both the system are different. The Off-Grid system is used for locations where no other choice available for power generations in a remote area like isolated and islanded region. Off-Grid systems are definitely more complex then On-Grid. The standalone system can be made by the combination of two or multi renewable sources with an energy storage system in back-up.

This combination may be a hybrid wind-PV- battery system or hybrid PV-diesel-battery according to the facility of the remote location, but recent trend to use clean energy combination as wind-PV-battery standalone plant. Standalone plants need high back up storage comparing grid-connected plant shows in figure 1.21 block diagram and figure 1.22 architecture of the hybrid wind-PV-battery system.

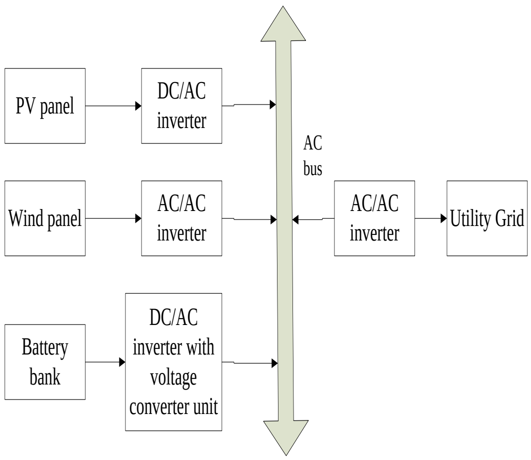


Fig. 1.21: Grid-connected power system.

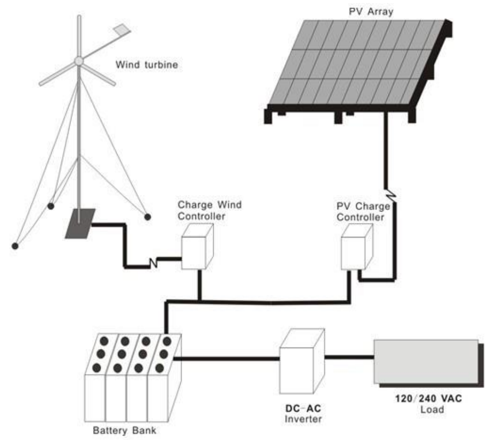


Fig. 1.22: Stand-alone power system.

1.10 AC Power coupling or DC Power coupling plant

When we use a combination of multisource with battery connected system, one of the most important barrier is that AC or DC coupling in the hybrid system. In AC coupling AC architecture requires two or more inverters. This means both the solar panels and batteries connected through DC-to-AC inverters with voltage controller, which then feed current into two separate inverters for AC power output. As in the DC coupling, it requires only one inverter (DC to AC) at load side or system directly connected through DC load which is more economical than another system. All of the sources are representative where the battery is connected with AC bus or DC bus as shown in figure 1.21 and 1.22. In this research DC coupling is used because DC coupling has the following advantages: It provides high efficiency, Coupling is very simple due to all converters are DC to DC and Synchronism is not needed.

1.11 Application of Hybrid power system

Renewable hybrid power system (HPS) can reduce the cost of electricity by adopting highly available renewable energy sources. This results in increasing utility grid in a region where power distribution from existing grid is very difficult and this system have an ability to take advantage for the complementary diurnal (night/day) for a location by building a micro-grid is a great solution rather than installing big grid. On the other hand, high initial capital of the single renewable source with battery system is a barrier to adopt the system, but the hybrid system has following advantages which fulfill needs such as system is long lasting, reliable and cost-effective system, all these capabilities present in the hybrid wind-PV-battery system. Hybrid energy system provides electricity in village house-holds, residential building, hospitals, schools, farm houses, hotels, an irrigation system and a desalination system.

1.12 Advantages of Hybrid power system

The main advantage of the hybrid system can be summarized as follow:

- The possibility is to combine two or more source can provide diurnal (night/day) supply with cost reduction benefits and the hybrid energy sources are now virtually limitless unlike fossil fuels.
- As viewed on a yearly basis, the seasonal variations on production are offset by using the hybrid system.
- If the installation is off-grid for a hybrid system then smaller battery bank required. The hybrid power system is best for remote area.
- Two or more different source provides a diversity of supply, reducing the risk of the power supply. The hybrid system provides green energy with the reliable and stable operation. It can also provide 24-hour power generation.
- Operates in all weather conditions, high production with low waste and low pollution, fuel is intermittent, secure and qualitative power supplies.
- Improves the load factors and helps in saving on maintenance and replacement costs.

1.13 Objectives

The objective of the present work as follows:

1. To develop a Dynamic model of Hybrid Wind-PV-Battery system.
2. To develop a Control Strategy for Energy Management in Hybrid Wind-PV-Battery Power for an isolated system.
3. To investigate the proposed system under various conditions.

1.14 Thesis Outline

This thesis is categorized into five chapters.

Chapter 1: This chapter provides information about the needs of the renewable energy sources, types of renewable source which generates pollution free and cost-effective electricity generation. Total installed capacity, targets, and needs of the power plant for sufficient power for consumers. Control strategy for energy management also discussed in this chapter.

Chapter 2: This chapter discuss about the review literature on the basis of the hybrid wind-PV-battery system, PV-battery, and wind-battery system also, this chapter also covers extra field required in the Hybrid system.

Chapter 3: This chapter provides information about the modeling of the hybrid wind, solar and battery system. Converter modeling with MPPT and fuzzy logic techniques is also presented in this chapter. Dynamic modeling of hybrid wind-PV-battery system and power electronic interface system modeling is also presented.

Chapter 4: This chapter discusses the MATLAB Simulink block model for the photovoltaic-wind-hybrid power system. All the result were analyzed and discussed to determine the output of the hybrid system.

Chapter 5: This chapter provides a list of the conclusion and scope for future research works.

1.15 Closure

The basic overview of the photovoltaic system (solar system), wind, hybrid system (wind-PV-battery and wind-battery or PV-battery) and power electronic interface for the hybrid system is presented. The applications, advantages, and problems of the hybrid systems are discussed.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the literature review available for the hybrid wind-PV-battery system (WPVBS), optimal operation and sizing for micro-grid, energy management for hybrid system, control strategy for hybrid system, economic operation of hybrid system, stand-alone hybrid renewable energy system and battery storage system. All of these topics are reviewed.

2.1 Hybrid Wind-PV-Battery system

Adejumobi *et al.* (2011) proposed a hybrid wind-PV system for a socio-economic development of any nation like rural communities which are far away from remote areas. The proposed system is used for a rural community in information communication technology Infrastructure. If any village is electrified means it has a hospital, bank and its ICT center is electrified. The remote villages very far away from the grid area so make its new source of energy which feasible and economical than power provider from the existing grid. This paper gives information about controllers which control all the sources and modeling and calculation of a hybrid system are also provided by this paper.

Marisarla *et al*. (2013) proposed a hybrid system with wind, photovoltaic and with a backup energy storage using a battery for an isolated system. This system designed with the purpose of UPS (uninterruptible power source) with a renewable energy source. This system operated in two modes such as with battery and without battery. In a without battery mode this system provides user-friendly operation and in with battery system can store power when both systems fail battery can provide power to load to make the system as an uninterruptable power source. These all three sources connected through PWM inverter that can provide fixed value output which comes from the different converter to balance input and output for DC links.

Dash *et al.* (2014) proposed a hybrid system for meeting global energy demand with solar (PV) and wind system. An Off-grid hybrid system was more useful as compared to a grid-connected system for supplying the rural areas and grid isolated system. Both hybrid and the conventional system can be worked together to increase the stability and reliability of the power system and hence economical solution in terms of the devices and battery storing system. This paper has described the classification of the hybrid system and their related technologies. This paper was designed the hybrid system mainly depends upon the type of source, environment condition and the number of users to whom it supplies. A hommor software-based simulation was carried out for a test result in the feasibility of the system as well as the economic value of the system.

Maheshwari *et al.* (2014) proposed a hybrid (Wind and Solar) renewable energy resource in the distribution system on a current status. A renewable hybrid energy system consisted of two or additional energy sources, an influence learning instrumentality, a controller which control whole system and an elective energy storage system. The aims were this paper is to be reviews this state of the planning, operation and management demand of the completed PV (solar)–wind hybrid energy systems with standard backup supply i.e. diesel or grid.

Rahman *et al.* (2014) proposed a hydro-PV-wind-battery-diesel based hybrid power system to show their economic viability of an off-grid isolated renewable energy system for remote locations. Surrounding the Earth global warming arises, due to man-made waste product produces greenhouse gases (GHGs), appear to be a major concern of the world. The system was modeled in renewable energy based hybrid energy systems software (HOMER) and it was used to carry out the analysis.

Ingole *et al.* (2015) proposed a hybrid power generation by integrating two sources solar and wind. Hybrid power was generated from two non-conventional sources such as wind and solar. This paper gives information about the calculation of a costing in the hybrid plant for different resources. The hybrid system is a good and effective solution with one-time investment at an affordable cost. This system provided a high-efficiency solution at a remote place where government unable to reach.

Rini *et al.* (2015) proposed the analysis of power to observed the reliability of a solar-wind hybrid energy system which consists of a Photovoltaic (PV) array, a wind turbine have a Permanent Magnet Synchronous Machine (PMSM), a three-phase diode bridge rectifier, an LTC3784 controller and a grid interface inverter. Both input and output power has been verified by checking the reliability of the system. The proposed model is mathematically designed and simulated by PSIM and LT-spice software.

Zubi *et al.* (2015) proposed the multi-renewable power source system based on multi-stage fuzzy controlled technique. In this paper, the selection technique was proposed and described based on fuzzy inference system controller. A multi-stage fuzzy inference system was proposed for three power sources to reduced computation complexity, multi-stage fuzzy inference system was adopted to determine the power flow management operation in electrical load (pump) from a hybrid renewable energy source (wind and solar) with a battery back-up depending upon the availability of the power source(s).

Agarkar *et al.* (2016) proposed a review on hybrid solar/wind/hydro power generation system. This paper was provided with various renewable energy resources & which will be used for the development of electricity in a non-electrified locations, the main source for energy generation was solar, wind, hydro and battery. This paper was provided a review of the hybrid power generation i.e. integration of two or more than two energy sources.

Nayak *et al.* (2016) proposed a performance study of common DC link connected wind and PV (solar) hybrid system. Power control strategies were used in the extraction of the maximum power from the source. Maximum power point tracking (MPPT) control algorithm was essential for ensuring the output from the photovoltaic power generation system at the maximum power output as possible. The paper was provided the information about DC link connected model for wind and PV system and it was presented in Matlab/Simulink software environment.

Prakash *et al.* (2016) proposed an autonomous PV-array excited wind driven induction generator for micro-grid application in India. This paper was given a simplified control scheme has been presented for a stand-alone hybrid PV array-excited wind driven induction generator considering a three-phase variable load with or without unbalance. One of the stand-alone systems were employed battery bank if the system was supposed to deliver power even in the absence of battery and the battery SOC less mode of operation was also presented in this paper.

Swarnkar *et al.* (2016) proposed an analysis of hybrid energy system for supplying residential electrical load by using HOMER and RETScreen software for a case in Rajasthan, India. The proposed system was modeled and optimized for hybrid energy system was done by using HOMER (Hybrid Optimization Model for Electric Renewable) and developed by NREL (National Renewable Energy Laboratory). This paper was given HOMER software for the optimum configuration of a hybrid energy system for minimizing the Net Present Cost (NPC) of the system.

Althubaiti *et al.* (2017) proposed a fuzzy logic controller for hybrid renewable energy system with multiple types of storage. A supervisory or online control system was built for the hybrid system and it was designed to handle various changes in power supply and load demand by managing power intermittency, power peak shaving, and long-term energy storage. The proposed fuzzy methodology was used in optimizing the system and able to adapt its working environment and deliver best results under given circumstances. This paper also provided information about modeling of the system and simulated in MATLAB Sim-Power software to verify the effectiveness of the proposed scheme under different condition.

Dhaoui *et al.* (2017) proposed a strategy for controlled energy management power flow in hybrid multisource driven generation system. This paper aimed to provide maximum power extraction from renewable sources like wind and solar with minimum efforts. This paper also provided an algorithm for high-level safety, security, reliability and for the greater lifespan of the hybrid system. This paper was also given information about the converter because different source generates different types of power and they feed to a single DC bus.

Merabet *et al.* (2017) proposed a control strategy for energy management for the laboratory scale micro-grid renewable source-based wind-PV-battery system. The energy management strategies were used between different sources by balanced input and output power for small micro-grid. This system also operated in autonomous mode and tested this system with an open architecture for different control configuration. On the other hand, systems were checked for real-time validate with renewable source experimentally. This paper also gives information about mathematical expression for all system with power management strategy and also gives real-time monitoring and control.

Parida *et al.* (2017) proposed a micro-grid based on the hybrid system provided electricity for remote rural villages in the form of co-operative grid isolated system. That system provided an economical solution for long distance maintaining energy efficiency with stand-alone micro-grid or mini-grid. These types of technical solution provided intermittent energy for growing a country in forwarding direction. The hybrid system was modeled and implemented within MATLAB Simulink software and HOMER pro-3.2 simulation tool and also validated with a different condition.

Vasant *et al.* (2017) proposed an MPPT algorithm for a hybrid wind-PV system with battery banks were used whenever load demand is high. The sources like solar, wind, bio-fuel and battery were hybridized to get maximum energy for a balanced load with generation because demand increasing from all the equipments which run on electricity. This paper was also given an MPPT algorithm for the better solution and it provides peak power by controlling different-different panels. By this solution controlled power flows in the DC links. The hybrid systems were modeled and Simulink in MATLAB software for enhancing solar and battery power in the hybrid system.

2.2 Optimal operation and sizing of smart grid

Belfair *et al.* (2007) proposed a new methodology for optimal sizing in the autonomous stand-alone hybrid wind-PV-battery system. The proposed methods were used to determine the optimized algorithm based on the deterministic algorithm. The proposed methodology was helped in optimizing wind, PV panel, and storage unit to ensure total system cost was minimized and provides permanent guaranteed power solution for the load. Hybrid systems were modeled and implemented using a deterministic algorithm (DIRECT algorithm) in MATLAB software to optimize the hybrid wind-PV system. This paper was used MPPT algorithm for maximum utilize renewable source for energy generation.

Asato *et al.* (2010) proposed an optimized operation of a micro-grid (smart-grid) that was configured in isolated regions which are far from an existing grid. The system load was different in day or night time and system methodology was developed for effective optimization approach by using tabu search and genetic algorithm optimization. This paper was provided a controlled approach in two parts first actual load control by controllable load and the second part is scheduling all sources in different time using the best cost optimization algorithm like a unit commitment for a higher generation. The hybrid systems were modeled and Simulink by best optimization method in MATLAB software with the best result for optimization hybrid system in the isolated region.

Jemaa *et al.* (2013) proposed an optimal sizing for hybrid PV/wind/Battery system using the fuzzy adaptive Genetic algorithm. The new approach was adopted for automatic fuzzy rule base generation and optimization system by means of a fuzzy-adaptive genetic algorithm, which can provide dynamically change in crossover and mutation rates. This fuzzy base genetic algorithm provided an optimal number of the photovoltaic panel, wind turbine, and storage units. For stochastically model of wind turbine, photovoltaic panel and load can be modeled by historical hourly data of wind speed, solar irradiance, and load data. This paper gives the total cost of the objective function and the technical size is a constraint.

Jemaa *et al.* (2014) proposed optimal sizing for hybrid PV/wind/battery system and installation using a fuzzy PSO. The methodology used in sizing for optimal configuration of the hybrid energy system adopted a new approach by automatic fuzzy rule-based generation and by means of fuzzy-adaptive particle swarm optimization (PSO). This system can be changed dynamically with acceleration coefficient rates ensuring the convergence. This system was also helpful in obtaining an optimal number of the photovoltaic panel, wind turbines, and storage units. The system is modeled by a database of wind speed taken hourly, solar irradiance and load data.

Zidane *et al.* (2016) proposed an optimal sizing for the wind-PV hybrid system by the LPSP method. The system was also simulated in MATLAB software to perform optimization for the hybrid stand-alone wind-PV system with storage. The methodology was LPSP (loss of power supply probability) used for calculation in an optimal number of battery module based on two optimization criteria namely: reliability (based on the concept of the loss of power supply probability) and the cost of the system. This paper was aimed at finding the size of the system components, which completed the requirements of reliability desired system with the lowest value of the average cost of energy.

Nian *et al.* (2013) proposed a method for optimal sizing of a stand-alone hybrid PV/wind/battery system. The mainly hybrid system consists of a wind and PV energy source. In this paper proposed a general modeling and operational modes of micro-grid, the hybrid model was consists of the photovoltaic panel (PV), wind power system (WT) and energy storage (battery). The optimized model of wind-PV-battery system calculation provides innovative research method but also contribute further research and applications. With the help of MATLAB software, branch and bound algorithm were used to minimize the cost of micro-grid. This paper gives an optimal installed capacity of PV, WT and BATT was presented.

Akram *et al.* (2018) proposed an improved optimal sizing methodology for the future autonomous residential smart power system. This system was also affected by the sizing of the power generation system. The paper was presented methodology of a joint capacity optimization for typical residential stand-alone micro-grid (MG) employing renewable energy sources, i.e., PV, wind, diesel generators and battery energy storage devices. The mathematical model of all the sources and load were formulated by capacity optimization methodology. The labyrinthine optimization problem is formulated and solved innovatively with different constraints.

2.3 Energy Management for hybrid wind-PV-battery system

Yang *et al.* (2004) proposed an energy management system based on the hierarchical fuzzy controller for the distributed hybrid wind-solar system was designed. By the suitable manager of power generations, companies can provide efficient generation ratio from wind power and photovoltaic cells. The management system can be implemented by a microprocessor and Data Acquisition System. The energy management theory was applied to experimental equipment which is hybridized. This paper also presented hybrid generation systems controlled by the fuzzy energy management system by the appearance of a random variation of wind speed and solar radiation data supplied with stable electric power.

Mousavi *et al.* (2009) proposed an energy management for wind/PV/battery hybrid system with consideration of memory effects in the battery. In this paper, the linear short-term prediction for wind and solar were used in regarded with energy management for wind/PV/battery system and with its new control strategy. By achieving the goals at the first time, each subsystem was modeled and analyzed, then the system controlled with consideration of memory effect were modeled and simulated and the finally submitted, if its needs were other prediction methods then system was compared to the result of our system. These systems were modeled in MATLAB-Simulink software and put strategy for controlling the system for economically optimized hybrid system.

Winney *et al.* (2012) proposed an intelligent uninterrupted isolated power management system based on an ARM microcontroller. The ARM controller CORTEX-M3 is a very powerful controller that provided multilevel control in various equipment and management energy for all sources through the controller which provides us with many intuitive solutions. The controller implemented through MPPT control algorithm for extracting the maximum peak power from the PV cell, PV cell can consider as the primary source of energy and as a secondary source wind turbine was utilized especially in night time, third source for continuous power Battery bank's was utilized only if the other sources was unable to satisfy the load demand.

Faquir *et al.* (2013) proposed an energy management in an electric hybrid system using fuzzy interference control system. The system uses of the multi-sources system (wind/PV) progressed in lots of different industrial sectors and in a distributed generation system. Between all sources of energy that we have batteries and renewable sources of energy such as photovoltaic and wind contains the highest specified energy. The system was investigated for control strategy using fuzzy logic to ensure and management of power in various equipments to load and in an adequate and with automated manner, the two storage devices used: batteries and super-capacitors in a hybrid system.

Abdeltawab *et al.* (2015) proposed a market-oriented energy management for the hybrid wind-battery energy storage system via model predictive control with constraints optimizer. This paper was presented as an energy management system (EMS) for a hybrid system in the real-time model predictive control system (MPC). The EMS systems were achieved by net maximum profit for variant electricity generation market. The EMS system was increase and aim to be increased lifetime of battery by applying basic constraints in MPC algorithm problem by a daily number of cycles (DNC) and depth of discharge (DOD). The MPC algorithm was provided optimal designed with economic profit with minimum cost.

Dahmane *et al.* (2015) proposed a power management strategy for the renewable hybrid stand-alone power system. In this paper hybrid system were used for energy generation and considered as an interesting fact such as an alternative energy source for power supply in remote areas and non-connected sites from the existing grid. This paper was also focused on the designing for the intelligent algorithm and optimized strategy for power management in renewable hybrid wind-PV-battery-diesel generation system. The hybrid source (WG/PV) as main energy sources and the battery bank as a storage system, simulated results were highlighted for the feasibility of our approach.

Eyese *et al.* (2016) proposed an optimal energy management strategy for an isolated industrial micro-grid using modified particle swarm optimization (PSO). The main aim of this paper was that micro-grid EMS optimized model is to be minimized with cost-effective production and maximize the economic benefit with energy storage. The better and efficient optimization technique such as modified particle swarm was proposed to solve the optimization model and model takes into consideration for the fluctuating of renewable energy resources. To investigate and validate the performance of the proposed strategy for the hybrid system by MPSO and simulation results were also obtained using Genetic Algorithm (GA).

Hosni *et al.* (2016) proposed a power flow management strategy for renewable hybrid energy system. This paper was used diesel generators regular to produce electricity in remote areas and by using this method for power generation was relatively inefficient, highly expensive and responsible for the emission of large greenhouse gases

(CO2 and other gases). The main objective of the presented system determine the most efficient controlled strategy for the power supply in isolated sites with the intelligent algorithm (MPPT or Fuzzy) for optimized power flow in the hybrid system. Once the system was modeled and analyzed for results are complete then optimization was done by the best control strategy that found with varying number and size of the diesel generators.

Shahinzadeh *et al.* (2016) proposed an optimal sizing and energy management for a grid-connected Micro-grids using HOMER software. The Micro-grid gives a solution by providing appropriate choice for power generation regarding with economic aspects. Micro-grids were appropriate uses multi sources such as wind, PV, diesel, and fuel cell with battery storage to meet various kinds of loads. The main aim of this paper has produced a method in which system was optimized for sizing and energy management with storage units. The simulation results showed that the effectiveness of the proposed model by considering optimal sizing and battery energy management.

Taha *et al.* (2016) proposed a robust MPC-based energy management system for a hybrid energy source for remote communities. This paper was provided a robust energy management system (EMS) for a hybrid energy source for a remote community. Optimized algorithm for the hybrid system was formulated by mixed-integer nonlinear (MINL) programming with three objectives: (1) to minimize the total operating cost, (2) to minimize the pollutant gas emissions, and (3) to minimize the dump energy, especially working in isolated mode.

Han *et al.* (2017) proposed a multisource coordination energy management strategy based on SOC consensus for a PEMFC-battery-super-capacitor hybrid tramway. This paper was presented a multi-source energy system by supplying continuous power demand with the state of charge (SOC), battery charge and discharge depends on the different operating and load condition. The control strategy between the coordination of energy management and battery storage was done by the self-convergence droop control method. The hybrid system sources including fuel cell, battery, and super-capacitors build a power source for low-floor light rail tramway vehicle. The result obtained from the tramway hybrid power system by RT-LAB software and tested for improvements in the overall efficiency of the tramway.

Joung *et al.* (2017) proposed an energy management system for stable operation of isolated micro-grid. This paper has been presented the study of an energy management system (EMS) for the stable and reliable operation of isolated micro-grid under different seasonal condition. The simulated model was presented for isolated micro-grid and developed with DIGSILENT software, system validation was verified by the performance of the proposed EMS and case studies are performed using practical data.

Leithon *et al.* (2017) proposed a demand response and renewable energy management using continuous-time optimization. This paper was presented as a control strategy for reduction in time-varying electricity prices and minimizes the unexpected energy cost. This paper also provides information about the generalized model for battery due to its non-linear relationship between charging and discharging states. The system model control strategy developed on the basis of continuous time optimization to obtain better results in comparison with existing control strategy. The simulated results show that the output of the proposed control strategy especially when battery discharge mode operates in a non-linear shape.

2.4 Control Strategy for hybrid wind-PV-battery system

Liu *et al.* (2011) proposed a hybrid AC/DC micro-grid and it is a coordination control strategy. This paper focused on a hybrid system with AC or DC link connected micro-grid with multiple converters and aims of that paper were to be reduced the multiple converter strategies due to high switching losses. The control strategy was proposed in this system is that the coordination control algorithm for smooth and efficient power transfer. The hybrid system was modeled and simulated in MATLAB Simulink software and results were showed that the system was operated in flexible mode and stable power generation in all generation and load condition.

Yan *et al.* (2013) proposed a design of control strategy for improving the service life of the battery in wind-PV-ES hybrid generation system. This paper was presented that the service life of the battery and evaluation index in the optimization of the battery. Power management in the battery was an important parameter and piecewise average algorithm used for power management for each connected batteries. In the hybrid system battery life improved by using the dual structure of the battery and applied control strategy when li-ion battery operated on charge-discharges modes.

Belila *et al.* (2015) proposed a control strategy for a hybrid system diesel-photovoltaic-battery for a stand-alone application. This paper presented that the PV and battery storage was the primary source of energy where diesel generator connected through AC bus, when power demand arises and PV panel insufficient to supply load demand then DG used to supply load and extra power was stored in the battery bank. The hybrid systems control strategy was modeled and simulated in MATLAB Simulink software and efficient results shown in this paper.

Kusakana *et al.* (2015) proposed an optimal scheduled power flow for distributed photovoltaic/wind/diesel generators with battery storage system. This paper was presented that the continuous power supplied by the 'ON and OFF' functioning of the switches by hybrid system modeling in the hybrid PV-wind-diesel-battery system. The main aim of this paper was that the model efficiency increased and overall cost reduced with the optimized hybrid system. These constraints were modeled and minimized by the applying control algorithm such as 'fmincon' for continuous power and 'intlinprog' function used for the ON/OFF of the diesel generator in the hybrid system. The systems were modeled in MATLAB Simulink software and results showed that the system was optimized model and verify for real-time installments.

Maity *et al.* (2016) proposed a control of stand-alone wind/PV hybrid renewable power generation system. The paper gives information about the effectiveness of a wind/PV hybrid system in real time installment and system used as a stand-alone micro-grid. The performance analysis evaluated by the MATLAB Simulink software and control method provides high-quality sinusoidal output for current and for average power flow.

2.5 Isolated System

Kesraoui *et al.* (2009) proposed a designing of a wind/solar/biomass electricity supply system for an Algerian isolated village. This paper has presented a designing of a hybrid solar/wind/Biomass electrical energy by using highly potential sources at that place. Hybrid solar-wind-biomass sources sizes were also presented in this paper for electrical hybrid circuits. Simulation results show that the PV panel and wind panel output with different temperature and wind speed. The simulation results also showed that the optimized control and power management strategy for the various seasonal condition.

Gaonkar *et al.* (2014) proposed a performance study for rooftop wind-solar micro-grid system in isolated modes of operations. The hybrid system was integrated due to the high potential of wind and PV and provides advantages by using distributed generation resources. This paper was presented performance study of wind and solar micro-grid individually or in the integrated wind-PV form in the isolated area. The micro-grid system was investigated under different input conditions and results were reported in this paper.

Mayhorn *et al.* (2016) proposed a multi-timescale coordination of distributed energy resources in the isolated power system. The hybrid systems were presented with considerable changes in coordinating with associated renewable sources with significant uncertainty and variability. This paper was presented that the control strategy of tertiary control for ensuring feedback and look-ahead capability for handle variability and uncertainty. The system was simulated for the proposed approach in the designing of multi-timescale optimization in an isolated system.

2.6 Economic operation of the hybrid system

Abbes *et al.* (2012) proposed an eco-design optimization of an autonomous hybrid wind-photovoltaic system with battery storage. This paper was presented that the study of a new technology used regularly at low level from 70's and named as an autonomous wind-PV hybrid system integrating with battery. The Primary aim was this system that integrates renewable source with the battery then design objective with minimized losses by power supply probability (LPSP) method. A secondary aim of that the systems was Modeled as a hybrid system with renewable energy and results obtained for the LPSP control strategy. At the end of the aims, the optimal configuration has been carried out using a mathematical model. This system works by applying two different algorithms for single objective optimization and multi-objective optimization.

Vineetha *et al.* (2014) proposed an economic analysis of an off-grid and on-grid hybrid power system. This paper was presented that generation of electrical energy from renewable energy sources increased linearly from the last decades. In the recent trends grid connected through distributed renewable energy generation by rooftop projects. The green building build by the solar panel was also accepted as a viable source of electrical energy and build a charging station grid for an electrical vehicle. The system was modeled and analyzed in MATLAB Simulink software with cost-effective optimization solution. The results show that, results were feasible than the convention grid.

Adefarati *et al.* (2017) proposed a techno-economic analysis for a hybrid PV-Wind-Battery-Diesel standalone power system in remote areas. Hybrid resources have a great advantage and it has no greenhouse gas emission. Renewable sources have higher potential in rural communities where if we erecting transmission and distribution line from existing grid is not favorable considering financial and economic aspects. The system built by the higher potential source from wind, PV, battery system. The optimized hybrid system was simulated in HOMER software and results showed with a different condition.

Ardin *et al.* (2017) proposed electricity prices and subsidy scenarios for hybrid power generations on the off-grid system. There was the only source of electricity is to install standalone micro-grid rather than transporting electricity from the existing grid. Both conventional and non-conventional sources were used for electricity generation. Non-conventional (wind and PV) was used due to high potential renewable sources and conventional sources (diesel generator) were used due to provide continuous power with a battery bank. The result was shown that annual electricity subsidies provided to the districts Rp 5.6 billion to meet total load demand.

2.7 Modeling and Simulation of hybrid system

Kim *et al.* (2008) proposed a dynamic modeling and control strategy for grid-connected hybrid generation system with versatile power transfer. This paper was presented power-control strategies for grid-connected hybrid renewable energy generation system with battery bank and system versatile power transfer strategy under different load conditions. This paper defines that versatile power transfer means multi modes of operation in which either normal operation without battery or abnormal operation with use of a battery. The experimental results were shown that the simulation of the model under dynamic performance and with proposed modes of operation.

Mtshali *et al.* (2011) proposed a simulation and modeling of PV-wind-battery hybrid power system. The renewable energy generation source easily installed in hilly or islanded area that was known as the decentralized energy generation system and it was either grid-connected or stand-alone. Especially hybrid renewable source was used in rural communities which provided a better impact on existing infrastructure of any country. This paper was designed hybrid system by using high potential source such as wind, photovoltaic (PV) system with battery storage. This system was modeled in MATLAB/Simulink software and tested for various weather conditions and temperatures.

Badawe *et al*. (2012) proposed an optimization modeling for a stand-alone wind/PV hybrid energy system. This system was also presented as one of the main energy consumers in the telecommunication industry such as microwave repeater. The main aim of this paper was to be optimized a model for hybrid energy system by considering microwave repeater consumers and this study were performed in an area located in islanded and hilly areas. The proposed models were finalized in MATLAB SIMULINK software and results were presented to demonstrate the system dynamic performance.

Zargar *et al.* (2016) proposed a modeling and control strategy for the wind-solar hybrid generation system using energy storage. In this paper also gives information that wind power was produced by Permanent magnet synchronous generator (PMSG). The control strategy also defined such as maximum power point tracking (MPPT) used for PV panel. MPPT control has a number of techniques to obtain maximum or peak power but in this paper perturb and observe the methodology used for MPPT and this provides pulses for the boost converter. The simulated result presented that overall effectiveness of the model.

2.8 Stand-alone Hybrid Renewable energy system

Tudu *et al.* (2014) proposed a stand-alone hybrid renewable energy system as an alternative source of increased energy demand. This system provided initial modeled with solar PV, battery and diesel generator and the system was optimized for certain local load demand and system results obtained from HOMER simulation tool software. The system adopted a new control strategy for an economic system with maximum power generation, the system energy cost as compared with the existing cost of energy and it was feasible when using the hybrid system.

Al-Barazanchi *et al.* (2015) proposed a modeling and intelligent control strategy for stand-alone PV-wind-diesel-battery hybrid system. The presented systems were aimed that the designing of control strategy by soft computing techniques such as fuzzy logic and PI controllers have been adopted. The system was simulated in MATLAB/Simulink software to simulate the power outcomes. By adopting suitable controller the dynamic performance of PI controller compares a fuzzy logic controller for voltage and frequency behavior under micro-grid disturbances.

Faquir *et al.* (2015) proposed a type-1 fuzzy logic algorithm to manage the power flow in a stand-alone PV/wind/battery hybrid energy system. Integrating more than two renewable sources known as the hybrid system, the renewable energy sources with storage (battery) units to form a multi-source system was provided a more economical, and reliable supply of electricity in all load demand under the weather and environmental conditions. This paper has also presented a study of an HRES composed of Photovoltaic panels and a wind turbine emulator as primary energy sources with batteries energy storage system units.

Sharma *et al.* (2015) proposed a standalone hybrid energy system modeling for an academic institution. This paper was presented that the continuously increasing power demands all over the worlds with strictness environmental regulations resulting the researcher get attention for utilization of renewable sources. The hybrid system was contained a wind turbines, solar (PV) system and diesel generator with a battery bank. The hybrid system firstly modeled and proposed model were simulated under different seasonal condition and simulation software was HOMER and model was techno-economical.

2.9 Battery Storage system

Mcdowall *et al.* (1999) proposed a substation battery operation: present and future. The alternative vented lead-acid batteries for substation duties are presented in this paper for various types of batteries. The currently available battery was optioned included valve-regulated lead-acid and nickel-cadmium. This paper also presented future options include nickel-metal hydride, lithium-ion, and lithium polymer. Advantages and disadvantages are also discussed for each type, as they related to this application.

Miller *et al.* (2002) proposed a lithium-ion battery used in automotive applications and its requirements. This paper presented Li-ion (Lithium-ion) battery potential requirement in automotive applications, various applications were considered in terms of the battery system requirements. The USABC and PNGV were two goals of Li-ion battery and goal were referenced as they provided general specifications which can apply to most original equipment manufacturers. As same as all other batteries Li-ion battery have implementation issues such as abuse tolerance, cycle and calendar life, operating temperature range, environmental impact, reliability, and price.

Raman *et al.* (2014) proposed a review of charge equalization schemes for Li-ion battery and super-capacitor energy storage systems. The charge equalization method important was in a storage element such as battery energy storage as well as in super-capacitor. This paper was provided reviews on charge equalization electronic converter topology used for battery storage system and in super-capacitor of Li-ion based energy storage system. Charge equalization methods were two types active and passive and operating principle was discussed.

Ayoub *et al.* (2015) proposed a review of the charging techniques of Li-ion battery. This paper deals with various charging methods for Lithium-Ion (Li-Ion) batteries was presented. This paper was also provided working of the battery along its principle and dynamic behavior of the Li-ion battery under various conditions. The each of the implementation method will be explained and studied. This paper also provided information about various charging techniques such as trickle charge-constant current-constant voltage, five-step charging pattern, pulse charging method and boost charging methods, these method identified li-ion batteries, given methods was acceptable and to be adopted in commercial or in residential uses.

2.10 Closure

In this chapter gives a comprehensive overview of literature from IEEE and several other journals and conferences paper on hybrid wind-PV-battery, hybrid wind-battery and hybrid PV-battery system, photovoltaic and wind system with MPPT control and its performance optimization are presented. Another area also covered by this literature review chapter which is important in the hybrid system such as hybrid energy storage system and control strategy for power management.

CHAPTER 3

MATERIAL AND METHODS

In this section, the mathematical modeling of various components like a wind turbine, PMSG, PV, Battery Energy Storage system and also the power electronic interfacing devices have been presented. It gives the overall performance by developing an idea about the development of mathematical modeling of hybrid Wind-PV-Battery system, the control strategy for power management for hybrid system and the energy storage system.

3.1 Wind Energy Generation

Wind energy source becoming a most important renewable energy source for power generation to meet load demand. Essential equipments which needed for wind power generation are a wind turbine, two mass drive train and Permanent magnet synchronous generator (PMSG) and boosting converter also. For maximum power extraction from the wind turbine MPPT control technique is used. The drawback of renewable energy generation from wind source is irregularities of wind blows with lesser speed and the power generation at a time is very low. The wind turbine is used for the power generation by natural process as turbine can convert the kinetic energy of wind into electrical energy by doing some mechanical work. By harvesting wind energy into electrical energy is processed to provide non-polluting electricity using this type of generator. There are two types of wind generator are used for energy conversion:

1. Doubly Feed Induction Generator (DFIG)
2. Permanent Magnet Synchronous Generator (PMSG)

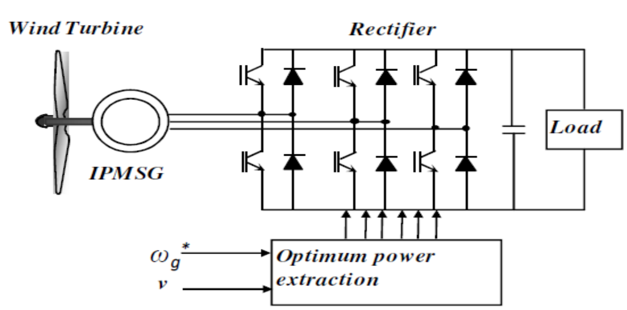


Fig. 3.1: Schematic diagram of the wind energy conversion system.

PMSG can provide better reliable operation, higher power density, greater performance with longer life, on the other hand, DFIG has an extension of slip power recovery, and this machine acts like a generator at both subs synchronous and super synchronous speed. PMSG can provide multiple pole design with gearless construction gives slow speed operation and maintenance free due to it is brushless. It has other advantages like it not require excitation system, its control ability is high for maximum power extraction, easily interface with grid and easiness in performing fault ride through and grid support. Due to higher advantages of PMSG, it is highly used for wind energy conversion system. The need for any wind energy conversion system (WECS) turbine is to be automatically adjusted their rotation speed according to the wind speed at a time. For maximum power extraction, variable speed wind turbine operates at high speed for proving high efficiency. The schematic diagrams of a wind energy conversion system using the PMSG generator, converter system and boost rectifier shown in figure 3.1. Dynamic modeling for wind energy systems major components:

1. Wind model.
2. Turbine model.
3. Shaft & gearbox model.
4. Generator model.
5. Control system model.

Turbines have a rotor with two or three blades with nacelle. They are mechanically connected to a generator. Two types of generators are generally used.

1. Horizontal axis wind turbine (HAWT).
2. Vertical axis wind turbine (VAWT).

The simplified dynamic of a wind turbine by using state-space averaging technique and model is implemented in MATLAB/Simulink software.

Wind Turbine Modeling

The d-q axis diagram shown in figure 3.2, under constant acceleration, a kinetic energy E of an object having mass m and velocity v is equal to the work done W in displacing that object from rest to a distance under a force F,

i.e.

$$E = W = Fs \tag{1}$$

According to the second law of motion given by Newton,

$$F = ma \tag{2}$$

Kinetic energy becomes,

$$E = mas \tag{3}$$

From the law of kinematics of solid motion,

$$v^2 = u^2 + 2as \tag{4}$$

Where,

u = initial velocity of the object.

This implies that,

$$a = \frac{v^2 - u^2}{2s} \tag{5}$$

Assuming the initial velocity of the object is 0,

We have that,

$$a = \frac{v^2}{2s} \tag{6}$$

Hence from equation (3)

$$E = \frac{1}{2} mv^2 \tag{7}$$

The power P in the wind is given by the rate of change of kinetic energy, i.e.

$$P = \frac{dE}{dt} = \frac{1}{2} \frac{dm}{dt} v_w^2 \tag{8}$$

But mass flow rate $\frac{dm}{dt}$ is given by

$$\frac{dm}{dt} = \rho A v_m^3 \tag{9}$$

Where,

A = area through which wind the wind in this cause is flowing,

ρ = density of air

The equation becomes,

$$P = \frac{1}{2}\rho A v_w^3 \tag{10}$$

The actual mechanical power Pw extracted by the rotor blades in watts is the difference between the upstream and the downstream wind powers, i.e.

$$P_w = \frac{1}{2}\rho A v_w\left(v_u^2 - v_d^2\right) \tag{11}$$

Where,

v_u = upstream wind velocity at the entrance of the rotor blades in m/s,

v_d = downstream wind velocity at the exit of the rotor blades in m/s,

These two velocities give rise to the blade tip speed ratio. Now from the mass flow rate, we may write,

$$\rho A v_w = \frac{\rho A(v_u+v_d)}{2} \tag{12}$$

v_w being the average of the velocities at the entry and exit of rotor blades of a turbine

$$P_w = \frac{1}{2}\rho A\left(v_n^2 - v_d^2\right)\frac{v_n+v_d}{2} \tag{13}$$

Which may simplified as,

$$P_w = \frac{1}{2}\left[\rho A\left\{\frac{v_u}{2}\left(v_u^2 - v_d^2\right) + \frac{v_d}{2}\left(v_u^2 - v_d^2\right)\right\}\right] \tag{14}$$

$$= \frac{1}{2}\left[\rho A\left\{\frac{v_u^3}{2} - \frac{v_u v_d^2}{2} + \frac{v_d v_u^2}{2} - \frac{v_d^3}{2}\right\}\right] \tag{15}$$

$$= \frac{1}{2}\left[\rho A v_u^3\left\{\frac{1-\left(\frac{v_d}{v_u}\right)^2+\left(\frac{v_d}{v_u}\right)-\left(\frac{v_d}{v_u}\right)}{2}\right\}\right] \tag{16}$$

$$P_m = \frac{1}{2}\rho A V_u^3 C_p \qquad (17)$$

Where,

$$C_p = \frac{1-\left(\frac{v_d}{v_u}\right)^2+\left(\frac{v_d}{v_u}\right)-\left(\frac{v_d}{v_u}\right)^3}{2} \qquad (18)$$

Or

$$C_p = \frac{\left(1+\frac{v_d}{v_u}\right)\left(1-\left(\frac{v_d}{v_u}\right)^2\right)}{2} \qquad (19)$$

Where,

C_p = fraction of upstream wind power captured by the rotor blades,

The power coefficient is not a static value it can change or varies with the tip speed ratio of the wind turbine. Let λ represent the ratio of wind speed v_d downstream to wind speed v_u upstream of the turbine, i.e.

$$\lambda = \frac{v_d}{v_n} \qquad (20)$$

$$\lambda = \frac{\text{Blade tip speed}}{\text{Wind speed}} \qquad (21)$$

Where,

λ = Tip speed ratio of a wind turbine,

The blade tip speed in meter per second can be calculated from the rotational speed of the turbine and the length of the blades used in the turbine, i.e.

$$\text{Blade tip speed} = \frac{\text{Angular speed of turbine (w)} \times R}{\text{Wind speed}} \qquad (22)$$

Where,

R = Radius of a turbine.

$$C_p = \frac{(1+\lambda)(1-\lambda^2)}{2} \quad (23)$$

By differentiating C_p with respect to λ and put = 0 that makes C_P is maximum,

$$\frac{dCp}{d\lambda} = \frac{(1+\lambda)(-2\lambda)+(1-\lambda^2).1}{2} = 0 \quad (24)$$

This is in accordance,

$$P = \rho RT \quad (25)$$

Where,

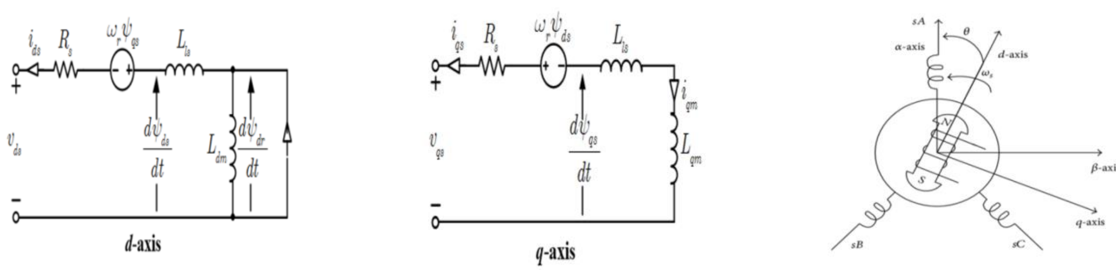
R = gas constant.

Site location is very important for wind power generation because it produced a major effect on wind power generation. At atmospheric pressure, P_{atm}= 14.7psi, temperature is T = 600F and density is ρ = 1.225kg/m^3. Temperature and pressure both vary with elevation. This affects the air density for propose of the following relation is,

$$\rho = \rho_0 e^{\frac{-0.297}{3048}H_m} \quad (26)$$

Where,

H_m = site evaluation in meters.



(a) d-axis PMSG **(b) q-axis PMSG** **(c) d and q axis in PMSG generator**

Fig. 3.2: A d-q axis of Permanent Magnet Synchronous Generator.

Power Coefficient Analysis

Equation (8) can relates parameters which are required in power production by a wind turbine. For example, C_P as a function of tip speed ratio and θ is blade pitch angle in degree,

$$C_p(\lambda, \theta) = C_1\left(C_2\frac{1}{\beta} - C_3\beta\theta - C_4\theta^x - C_5\right)e^{C_6\frac{1}{\beta}} \quad (27)$$

The θ is an angle between the plane of rotation and blade cross-section chord. For particular turbine type C_1=0.5, C_2=116, C_3=0.4, C_4=0, C_5=5, C_6=21 and β is defined as,

$$\frac{1}{\beta} = \frac{1}{\lambda + 0.08\theta} - \frac{0.035}{1+\theta^3} \quad (28)$$

The relational curve between C_P and tip speed ratio λ with varying value of β can be shown in figure 3.3.

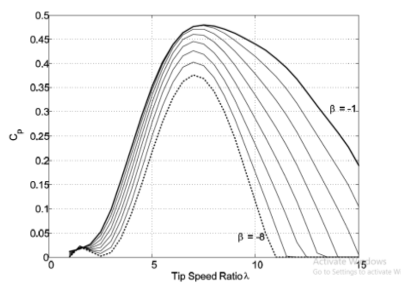


Fig. 3.3: A relational curve between C_P and tip speed ratio λ.

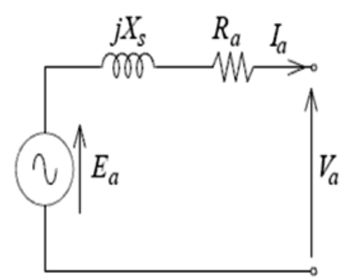


Fig. 3.4: Equivalent circuit diagram of PMSG.

Modeling of Permanent Magnet Synchronous Generator (PMSG)

In 2-phase synchronous reference frame is used to drive dynamic model of PMSG in which d-axis is the 90^0 behind the q-axis with respect to the direction of the rotation. The equivalent circuit diagram of PMSG can be shown in fig 3.4.

The electrical model of PMSG in the synchronous reference frame is given by,

$$\frac{di_d}{dt} = -\frac{R_a}{L_d}i_d + \omega_e\frac{L_d}{L_q}i_q + \frac{1}{L_d}v_d \quad (29)$$

$$\frac{di_q}{dt} = -\frac{R_a}{L_q}i_q - \omega_e\left(\frac{L_d}{L_q}i_q + \frac{1}{L_d}\Psi_{PM}\right) + \frac{1}{L_q}v_q \quad (30)$$

Where subscripts d and q refers to the values that have been transformed into d-q synchronously rotating reference frame,

Where,

R_a = armature resistance,

ω_e = electrical rotating speed which is related to the mechanical rotating speed of generator as,

$$\omega_e = n_p . \omega_g \tag{31}$$

Where,

n_p= number of pole pairs,

Ψ_{PM} = magnetic flux of permanent magnet.

Electrical torque can be derived as follow:

$$T_e = 1.5\eta_p\left[\left(L_d - L_q\right)i_d i_q + \Psi_{PM} i_q\right] \tag{32}$$

There is no saliency if we use PMSG,

Then $L_d = L_q = L$ equation can be written as,

$$\frac{di_d}{dt} = -\frac{R_a}{L} i_q + \omega_e i_q + \frac{1}{L} v_d \tag{33}$$

$$\frac{dy}{dx} = -\frac{R_a}{L} i_q - \omega_e \left(i_d + \frac{1}{L}\Psi_{PM}\right) + \frac{1}{L} v_q \tag{34}$$

And electromagnetic torque can be regulated by i_q as,

$$T_e = 1.5\eta_p \Psi_{PM} i_q \tag{35}$$

3.2 MPPT Technique for WECS

MPPT control algorithm is widely used for a PMSG generator in WECS. In the proposed method does not require knowledge of wind speed, air density or turbine parameter. The MPPT controller generates an output at its optimum speed command for speed control loop of rotor flux oriented vector controlled machine side converter control system using only the instantaneous active power as its input. Optimum speed commands which can enable WECS to track peak power point, these are generated in accordance with the variation of the active power output due to a change in command speed generated by the controller. MPPT controller computes optimum speed for maximum power point using information of magnitude and direction change in power output due to change in command speed. The flow chart in figure 3.5 shows for MPPT controller executed.

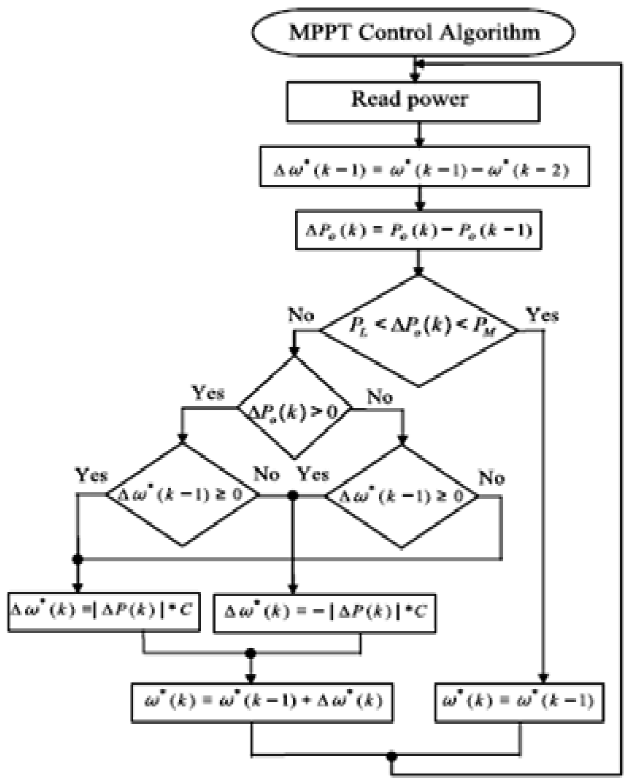


Fig. 3.5: flow chart of an MPPT control algorithm for WECS.

3.3 Photovoltaic (solar or PV) system

In this section, detail modeling of PV system is developed and control technique is also implemented. In this modeling nonlinear I-V equation parameter based on data such as open circuit voltage, short circuit current, voltage and current at maximum power point and temperature coefficient for voltage and current for standard test condition. The solar panel is a most promising device for power generation by direct converting sunlight into electricity by heat, this heat or UV radiation absorbed by PV panel. For maximum power generation by a solar panel, MPPT technique is used for maximum power extraction from a solar panel with the better control strategy.

3.3.1 Modeling of a PV system

Modeling is described through an equivalent circuit including a photocurrent source, a diode, a series resistor and a shunt resistor shown in single diode model for PV cell in figure 3.6. PV module is a sort of semiconductor diode, whose p-n junction is exposed when light emit on the diode, basically, it is a phenomenon is the absorption of a solar radiation. When light incident on photon it is sufficient to break p-n junction and generate electron in a semiconductor device, this charge generated in PV cell can conduct or flow of electron in a module. Due to a flow of electron, current will be generated and produce electricity.

Basic current-voltage characteristics of PV module can be expressed as:

$$I = I_{ph} - I_0 \left[\exp\left(\frac{V+R_s I}{V_T}\right) - 1\right] - \frac{V+R_s I}{R_p} \quad (36)$$

Where,

I & V = current and voltage of PV panel, $I_{ph} = N_p.I_{ph,cell}$ = Photo generated current in PV module (N_p = cell connected in parallel, $I_{ph,cell}$ = each cell generate photo current), $I_0 = N_p.I_{0,cell}$ = Reverse saturation current of PV module (N_p = cell connected in parallel, $I_{0,cell}$ = each cell reverse saturation current),($V_T = a.N_s.(KT/q)$ = Thermal voltage of array (N_s = cell connected in series, a = (1.0~1.5) identity factor of diode, K = ($1.38e^{-23}$J/K) Boltzmann’s constant, q = ($1.602e^{-19}$C) electronic charge, T = temperature of array in Kelvin), R_s = Equivalent series Resistance of PV array, R_p = Equivalent parallel resistance of PV array,

Depending on the operating point the PV is operating at the hybrid behavior of current and voltage source in practical PV. In practical PV R_s operate as a strong influence on the performance of PV module in voltage source region, and for R_p operate as a stronger influence on the performance of PV module in the current source region of operation. The R_s is very low and R_p is very high so in modeling purpose neglect both the resistance, figure 3.7 shows equivalent circuit of PV module.

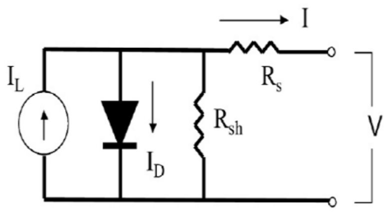


Fig. 3.6: single diode model for PV cell.

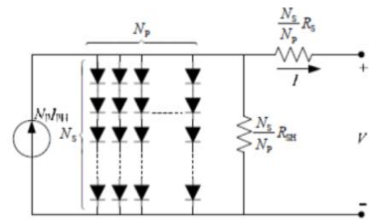


Fig. 3.7: Equivalent circuit of PV module.

PV array temperature may be affected by solar irradiation and ambient temperature, i.e.,

$$T = 3.12 + 0.25\frac{S}{S_n} + 0.899T_a - 1.3V_a + 273 \tag{37}$$

Where,

S and S_n = (1000W/m^2) solar irradiation at the operating condition and nominal test condition, T_a = Ambient temperature, V_a = Wind velocity, and T = Temperature will be influenced by solar and wind velocity,

For solar power generation, PV module depends on internal characteristics (R_s, R_p) as well as external characteristics such as solar irradiance level and ambient temperature. Current generated in PV module by a light incident depends on linearly solar irradiance and ambient temperature:

$$I_{ph} = \left(I_{f,n} + \alpha_1 \Delta T\right)\frac{S}{S_n} \tag{38}$$

Where,

$I_{ph,n}$ = Light generated current a STC,

$\Delta T = T - T_n$, (T = Panel temperature irradiance, T_n = Nominal temperature),

Assumption $I_{sc} \sim I_{ph}$ due to photocurrent is difficult to determine, practically parallel resistance is high and series resistance is very small, this assumption used in PV modeling.

Open circuit voltage assumed to be affected by temperature is given by:

$$V_{oc} = V_{oc,n}(1 + \alpha_v \Delta T) + V_T \ln\left(\frac{S}{S_n}\right) \tag{39}$$

Where,

$V_{oc,n}$ = Open circuit voltage measured at nominal condition,

α_v = Voltage temperature coefficient,

The datasheet of PV array gives varies important data regarding to panel which measured at standard test condition (STC) of temperature T=298K and solar irradiance at 1000W/m^2, at STC basic equation can be rewritten as:

$$I = I_{ph,n} - I_{0,n}\left[\exp\left(\frac{V+R_sI}{V_{T,n}}\right) - 1\right] - \frac{V+R_sI}{R_p} \tag{40}$$

Where, subscript n shows that it is used for values are measured at STC. It is assumed that series and parallel resistance are independent from temperature, subscript n do not used for this. For simplification R_p is very large so ignore it then equation becomes:

$$I = I_{ph,n} - I_{0,n}\left[\exp\left(\frac{V+R_sI}{V_{T,n}}\right) - 1\right] \tag{41}$$

In modeling of solar panel I-V curve of a solar cell three important points: short circuit (0, I_{sc}), open circuit (V_{oc}, 0) and maximum power point (V_{mp}, I_{mpp}), at these point equations are:

$$I_{sc,n} = I_{ph,n} - I_{0,n}\left[\exp\left(\frac{R_sI_{sc,n}}{V_{T,n}}\right) - 1\right] \tag{42}$$

$$0 = I_{ph,n} - I_{0,n}\left[\exp\left(\frac{V_{oc,n}}{V_{T,n}}\right) - 1\right] \tag{43}$$

$$I_{mpp,n} = I_{ph,n} - I_{0,n}\left[\exp\left(\frac{V_{mpp,n}+R_sI_{mpp,n}}{V_{T,n}}\right) - 1\right] \tag{44}$$

Diode saturation current at the STC is related to the pho-current at STC given by,

$$I_{0,n} = \frac{I_{ph,n}}{\left[\exp\left(\frac{V_{oc,n}}{V_{T,n}}\right) - 1\right]} \tag{46}$$

PV module can be improved by,

$$I_0 = \frac{I_{sc,n}+\alpha_1\Delta T}{\exp\left((V_{oc,n}+\alpha_v\Delta T)/V_T\right)-1} \quad (47)$$

By taking assumption of $V_{oc,n}/V_{T,n}>>1$, $I_{0,n}$ can be replaced as follow:

$$I_{0,n} = I_{ph,n}\exp\left(-\frac{V_{oc,n}}{V_{T,n}}\right) \quad (48)$$

We can calculate V,

$$V = V_{T,n}\ln\left(1+\frac{I_{ph,n}-1}{I_{0,n}}\right) - R_s I \quad (49)$$

Assuming $\exp((V+R_sI)/V_{T,n})>>1$ and equation becomes,

$$V = V_{oc,n} + V_{T,n}\ln\left(1-\frac{I}{I_{ph,n}}\right) - R_s I \quad (50)$$

In PV module series resistance is assumed to be independent on cell temperature but the thermal voltage depends on panel temperature so the thermal voltage at panel temperature T can be calculated as,

$$V_T = V_{T,n}\frac{T}{T_n} \quad (57)$$

Where,

$V_{T,n}$ = Thermal voltage of module at standard temperature,

T_n = 298K cell temperature at STC.

3.2.2 MPPT Technique for PV system

MPPT algorithm is a very important algorithm for a solar panel to get maximum power extraction from a solar panel. Solar have a variable nature, MPP of a solar panel varies with irradiance and temperature by MPP we have a great deal to get maximum power. From past decades MPPT algorithms have been developed and published. New technologies were Perturb and Observe, Hill-Climbing, and incremental conductance method all these depend on the MPPT algorithm. These techniques are highly decorative, similar and simple algorithm but differ in many aspects such as required sensors, complexity, cost, the range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature change, hardware needed for the implementation or popularity, among others. Figure 3.8 shows that flow chart of MPPT algorithm.

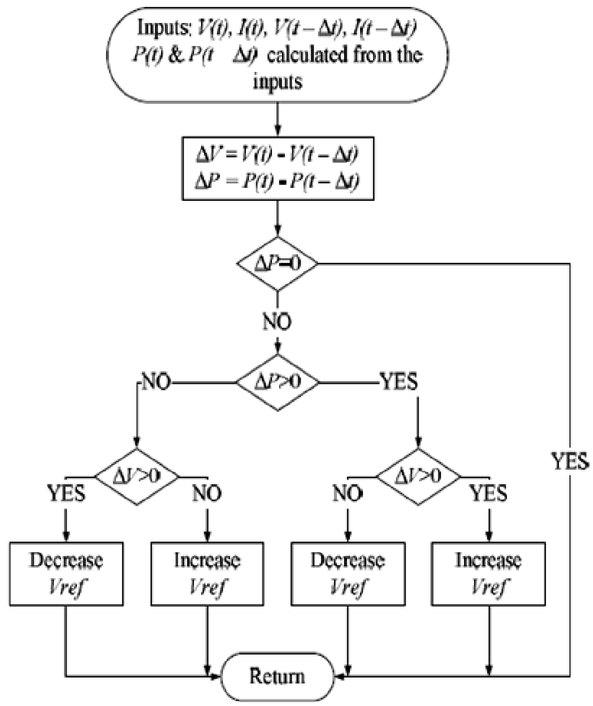


Fig. 3.8: Flow chart for the MPPT algorithm.

3.3 Energy Storage system

In an energy storage modeling, that is based on the observation of a physicochemical phenomenon of charge and discharge of the storage system. For battery storage system equivalent circuit uses as given in figure 3.9 as an equivalent circuit diagram:

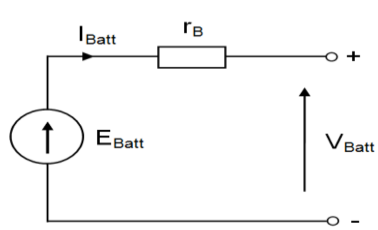


Fig. 3.9: Battery storage equivalent model.

A mathematical model is given by:

$$V_{Batt} = E_{Batt} - R_B I_{Batt} \tag{58}$$

I_{Batt} is an algebraic value of the current (positive in case of charge and negative in case of discharge). Storage bench nominal capacity as a function of the unit capacity of the battery expressed as:

$$C_n(t) = \frac{N_B}{N_{Bs}}.C_B = N_{Bp}.C_B \tag{59}$$

Where,

N_B = Total number of batteries,

N_{Bs} = Number of batteries connected in series,

N_{Bp} = Number of batteries connected in parallel,

C_B (Ah) = Unit capacity of a battery,

Batteries are connected in way of series and parallel connection, series connection due to reach desired DC bus voltage, parallel connection is due to reach desired storage capacity (in Ah).

$$N_{Bs} = \frac{V_{Bus}}{V_B} \tag{60}$$

This equation gives a number of batteries to be connected in series from the DC bus voltage and the nominal voltage of each V_{Batt} battery. Different technologies are used for the controlling the state of charge and discharge, the voltage measured based technique is used for measured terminal voltage for a battery as the only provider of its state of charge ‘State Of Charge – SOC'. Chose battery only allows 35% of discharge (SOC_{min}=35%). It has a greater efficiency of η_B of 100% for landfill and 80% for a load.

A one another technique is used for controlling battery is called the battery coulomb measurement technique, it provides SOC state control technology for measurement and calculation of incoming and outgoing electricity quantities in both charge and discharge process in ampere-hour thermals.

State of charge batteries SOC is subjected to the following constraints:

$$\mathrm{SOC_{min}} \le \mathrm{SOC} \le \mathrm{SOC_{max}} \tag{61}$$

Where,

SOC_{min} = Minimum charge limit of batteries, SOC_{max} = Maximum charge limit of batteries.

3.5 Control Strategy for Power Management

Controlling of the hybrid system is used for the management of power flow in the hybrid system. The controlled system receives all time data collected from various measurement devices from the hybrid system, which must be generated. The power fluxes must be precisely controlled from different sources in order to carry out the power reference imposed by centrally placed micro-network controller (which is load profile) as shown in figure 3.10.

This must be ensured to achieve the objective of pilotage:

1. Power delivered by each source must be a fast and accurate measurement of power,
2. Charging and discharging conditions is always checked, respecting the limits of their state of charge and maximum charging/discharging currents.

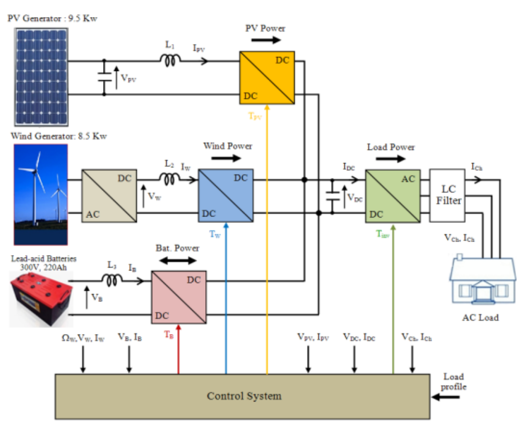


Fig. 3.10: a block diagram of a proposed control strategy for the hybrid system.

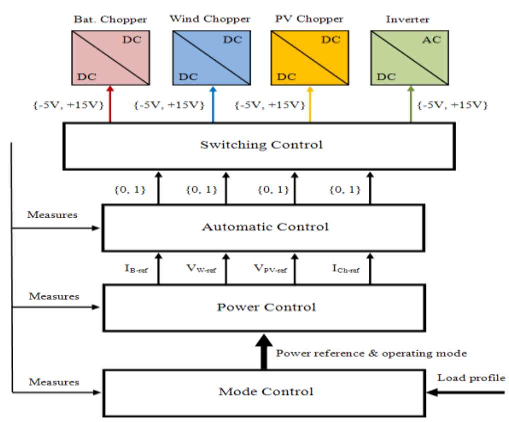


Fig. 3.11: Controlling of power electronics equipment.

For their clarity in design and organization, we use a hierarchical command which is now recalled whenever required. According to measured data and power demand, a control system gives command instruction to the electronic converter of three sources (choppers) and load side inverter.

This controlling is done through four level of control:

- Control of operating modes (mode control),
- The remote control (power control),
- Close control of each inverter (Automatic control),
- Switching control,

As from figure 3.11 shows that automatic control strategy gives instruction to each converter to control current in storage elements, the voltage at PV panel terminals (followed by maximum or limited power point according to the operating mode), control DC bus voltage, and load consumed current. At last switching control block gives the semiconductor switching signals to perform the desired command.

Energy Management

There are three modes of operation, selecting according to the availability of each source and the state of charge of the batteries. Three modes of operation are as follows:

- Normal mode,
- Limitation mode,
- Disconnect mode,

Fuzzy logic based power management

Fuzzy logic is a controller which controls power flow in various equipments connected as a hybrid system. Basically fuzzy logic works on the principle of a rule-based system. Rules of fuzzy logic build in two types of fis (fuzzy interface system) function and it is called when fuzzy logic needs fuzzy fis file as shown in flow chart 3.12. Mostly in MATLAB fuzzy logic toolbox rules build in Mamdani fis function, sometime Sugeno fis also used. In this thesis fuzzy logic controller such as Mamdani fis used for energy management in the hybrid wind-PV-battery system. FLC can proper split power in between load and storage batteries according to the pre-defined rules in FIS function.

The battery storage system in the hybrid micro-grid system was controlled by FLC. The controller controls battery on the basis of the state of charge and discharge of the battery.

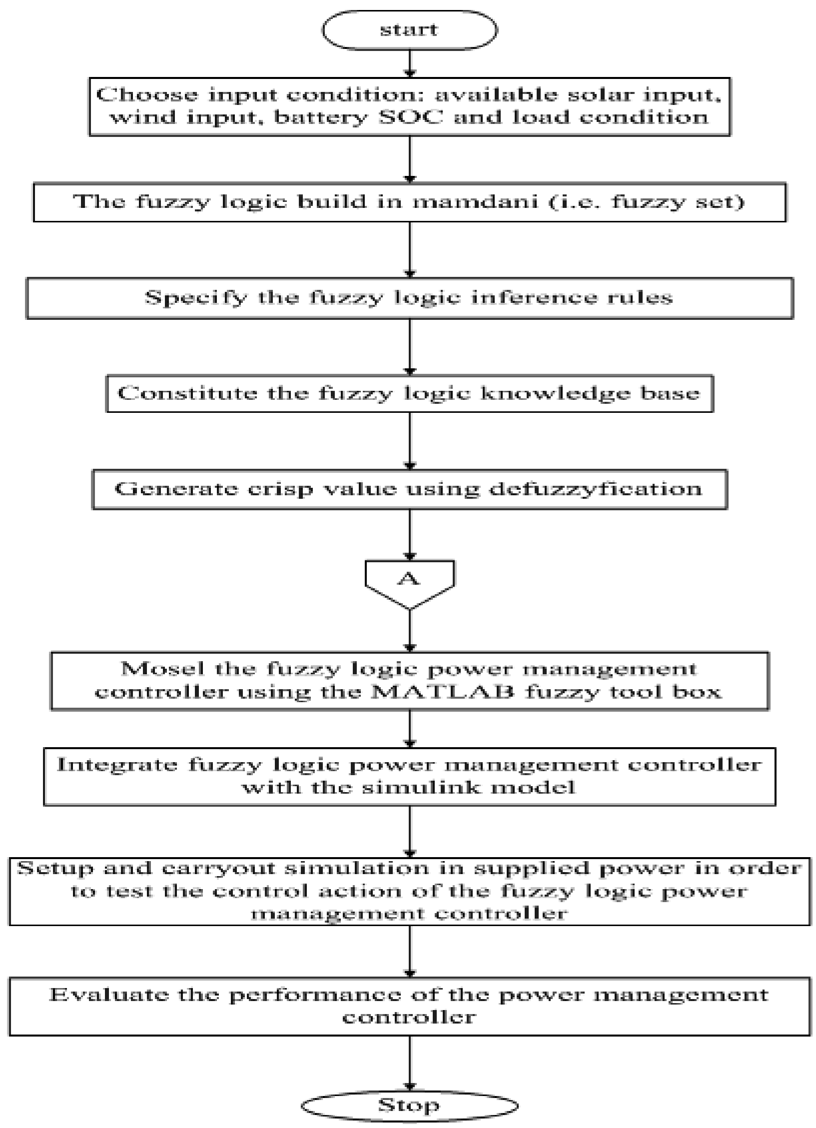


Fig. 3.12: Flow chart of fuzzy logic based power management algorithm.

3.6 Power Electronic Interfacing Circuits

Power electronic interfacing circuits are also known as the power conditioning circuit, these circuits are necessary for the interfacing of the hybrid system. Without interfacing circuit, different hybrid sources are not connected. In this section electrical circuit diagram of interfacing circuits are described by their state space models, effective averages models (for long time simulation studies) for the main power electronic interfacing circuits in the proposed hybrid wind-PV-battery system are discussed.

3.6.1 AC/DC Rectifiers

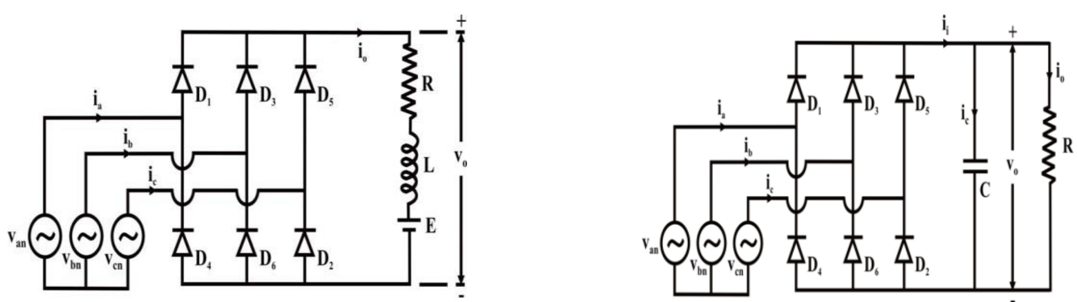
In the case of AC to DC conversion, known as a rectification of power. Basically, two types of rectifier use at present according to their circuit requirement, mainly types are uncontrolled rectifier and controlled rectifier. Controlled rectifier is constructed by thyristor's or other switch topologies and the uncontrolled rectifier is constructed by the diode. This type of converter most extensively used rectifier topologies from low (>5KW) to moderately high power (<100KW) power applications. Figure 3.13 shows a typical three phase full diode bridge rectifier.

If $L_s = 0$ in the above figure, the average value of the output DC voltage V_{dc} gives as:

$$V_{dc} = \frac{3}{\pi}\sqrt{2}V_{LL} \quad (64)$$

Where,

V_{LL} = AC source line to line RMS voltage.



(a)

(b)

Fig. 3.13: Three phase uncontrolled rectifier with capacitive load and three phase uncontrolled bridge rectifier with the R-L-E load.

Quality of DC output voltage is fairly good. The voltage ripple is within ±5%. However, the input ac current, i_a for example, is distorted. The AC side inductor L_s can be increased to reduce the current distortion. But this will cause an extra voltage drop across the inductor.

The thyristors switch used on the place of the diode by replacing diodes by thyristor in the converter topologies. Figure 3.20 shows a six pulse thyristor rectifier. The output DC voltage can be regulated by controlling the firing angles of the thyristors. The firing angle, shown in fig.3.18, is the angular delay between the time when a thyristor is forward biased and the time when a positive current pulse applied to its gate.

For six pulse thyristor rectifier, the output DC voltage is

$$V_{dc} = \frac{3}{\pi}\sqrt{2}V_{LL}\cos(\alpha) \quad (65)$$

Where,

α = firing angle,

If $\cos(\alpha)$ is taken as the control variable, it is noted from the above equation that the output voltage of a thyristor rectifier is proportional to the control input.

3.6.2 DC/DC Converters

There are many types of dc to dc converter like a buck, boost, buck-boost converter etc. but in this section typically boost converter is used for dc to dc conversion.

Circuit Topology

Buck-boost converter is typically DC to DC converter normally used power supply with the adjustable output voltage (V_o), it can be higher or lower than the supply voltage (V_{cc}) as shown in figure 3.14.

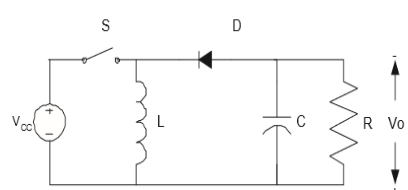


Fig. 3.14: Ideal Buck-Boost converter.

The buck-boost converter can operate in two modes. For a buck-boost converter, first define q as a signal that characterized the dynamic behavior of the switch:

$$S:\begin{cases} q(t) = 0, & \text{if the switch is open} \\ q(t) = 1, & \text{if the switch is closed} \end{cases}$$

Three set of differential equation describes the behavior of a buck-boost converter.

If q=0 in figure ideal buck-boost converter the capacitor discharge through L and R and there are two different cases. If $i_L \neq 0$ (continuous conduction mode).

$$\frac{di_L}{dt} = \frac{1}{L} v_c \tag{66}$$

$$\frac{dV_c}{dt} = \frac{1}{C}\left(-i_L - \frac{v_C}{R}\right) \tag{67}$$

$$V_0 = -v_C \tag{68}$$

However if $i_L = 0$ (discontinuous conduction mode)

$$\frac{di_L}{dt} = 0 \tag{69}$$

$$\frac{dv_C}{dt} = -\frac{v_C}{RC} \tag{70}$$

$$V_0 = -v_C \tag{71}$$

Finally q=1 the diode isolates R and L:

$$\frac{di_L}{dt} = \frac{1}{L} V_{CC} \tag{72}$$

$$\frac{dv_C}{dt} = -\frac{1}{C}\frac{v_C}{R} \tag{73}$$

$$V_0 = -v_C \tag{74}$$

Application of the method of state space averaging model to the above equations, we get:

$$\begin{cases} \dot{x}_1 = \frac{(1-d)}{L} x_2 - \frac{d}{L} V_d \\ \dot{x}_2 = -\frac{(1-d)}{C} x_1 - \frac{1}{RC} x_2 \end{cases} \quad (75)$$

Where: x_1 and x_2 are moving an average of i_L and V_0 respectively.

3.6.3 DC/AC Inverters

In power, electronics provides various types of inverters for single phase, three phases, and three phases with four wire inverters. Inverters are tools to provide AC power from Dc bus link. There are two types of an inverters voltage source inverter and a current source inverter.

Circuit topology

Generalized state space averaging method depends on the Fourier transform. If time domain is periodic signal x(t) satisfies the following condition:

$$\int_0^T |x(t)|^2 dt < \infty, \quad (76)$$

It can be approximated on the time interval [t-T, T] to arbitrary accuracy with a Fourier series representation of the form

$$x(t) = \sum_{K=-\infty}^{\infty} \langle x \rangle_k (t) e^{jk\omega t} \quad (77)$$

Where,

$\omega = 2\pi/T$ is fundamental angular frequency,
$\langle x \rangle_k$ = are the k^{th} Fourier coefficient,
Which are determined by

$$\langle x \rangle_k (t) = \frac{1}{T} \int_{t-T}^{T} x(\tau) e^{-jk\omega t} d\tau \quad (78)$$

If x (t) is a real signal, it has

$$\langle x \rangle_k = \langle x \rangle_k^{Re} + j \langle x \rangle_k^{lm} = \langle x \rangle_{-k}^{*} = \langle x \rangle_{-k}^{Re} - j \langle x \rangle_{-k}^{lm} \quad (79)$$

Two important characteristics of Fourier transform will be utilized in modeling as:

$$\frac{d}{dt}\langle x\rangle_k(t) = \langle\frac{d}{dt}x\rangle_k(t) - jkw\langle x\rangle_k(t) \quad (80)$$

$$\langle xy\rangle_k = \sum_{i=-\infty}^{\infty}\langle x\rangle_{k-i}\langle y\rangle_i \quad (81)$$

The circuit three- phase three-wire voltage source inverter shown in figure 3.15.

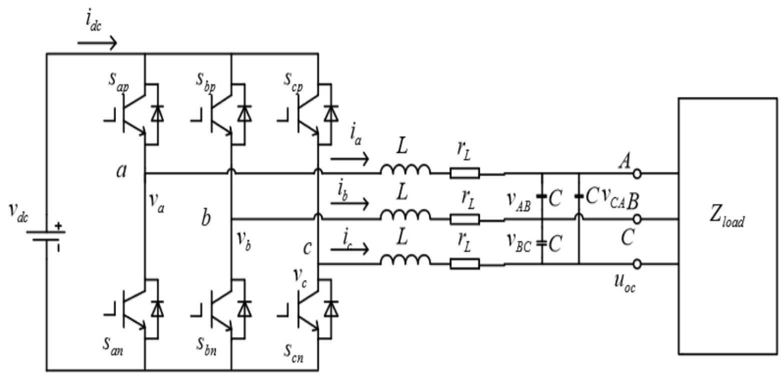


Fig. 3.15: Three phase three wire voltage source inverter.

Switch function is defined by,

$$S_{ik}\begin{cases}1 & \text{switch is closed}\\ 0 & \text{switch is open}\end{cases} \quad (82)$$

Where,

$i \in \{a, b, c\}$,

$k \in \{p, n\}$,

$s_{ip}+s_{in}=1$

Especially the following relationship is not hard to be attained

$$S_i = S_{ip} = 1 - S_{in} \quad (83)$$

Inverters are classified as a single-phase inverter and three-phase inverter. It also has both with VSI and CSI. Single phase voltage source converter cover low range power application and three phase VSI cover medium to high power application.

State space model of three phase inverter

Output phase potential of the invert v_a, v_b, v_c can be obtained as:

$$\begin{cases} v_a = v_{an} + v_n \\ v_b = v_{bn} + v_n \\ v_c = v_{cn} + v_n \end{cases} \tag{84}$$

Where,

$v_{an} = \frac{d_1^*}{2} V_{dc}$, $v_{bn} = \frac{d_2^*}{2} V_{dc}$, $v_{cn} = \frac{d_3^*}{2} V_{dc}$

Where,

v_n = voltage between the point n and the common reference neutral point N.

Since,

$$v_n = -\frac{V_{dc}}{6} \sum_{k-1}^{3} d_k^* \tag{85}$$

Writing state-space form:

$$\dot{X}_{abc} = A_{abc}X_{abc}+B_{abc}U_{abc} \tag{86}$$

Its d-q representation is

$$\dot{X}_{dq} = A_{dq}X_{dq}+B_{dq}U_{dq} \tag{87}$$

Ideal model for three phase VSI

$$\begin{cases} v_a(t) = m\sin(2\pi ft + \emptyset_0) \\ v_b(t) = m\sin(2\pi ft + \frac{2\pi}{3} + \emptyset_0) \\ v_c(t) = m\sin(2\pi ft + \frac{4\pi}{3} + \emptyset_0) \end{cases} \tag{88}$$

Ideal model used for long time simulation studies. The “abc signal formation” block gives the base signal for the three phase, $v_a(t)$, $v_b(t)$ and $v_c(t)$.

Table 3.1: Summary of operating points.

Mode	Conditions	Operating condition
		The output of PV power less than the load demand

Mode 1	Sufficient power generation with battery is initially full charged.	($P_{PV}<P_{load}$) Both source and battery are used for a supply load demand ($P_{PV}+P_{wind}+P_{ba}$). Battery storage level is high ($SOC>SOC_{max}$).
Mode 2	Sufficient power generation from both source and excess power stored in the battery.	Battery storage is $SOC \sim SOC_{max}$. PV power and wind power act as a main energy source and supply the load demand ($P_{PV}+P_{wind}>P_{load}$). Excess power (If $P_{gp}>P_L$) stored in the battery.
Mode 3	PV panel is sufficient to supply demand and wind panel is goes in Off-MPPT mode. (shiny day or in summer season) .	The output of PV power is sufficient to supply load ($P_{PV}>P_{load}$). In the summer season or shiny day wind panel used to store power in a battery or goes in Off-MPPT mode or ($P_{wind}<P_l$). If $SOC<SOC_{max}$ charge battery by wind source or $SOC>SOC_{max}$ put standby power source.
Mode 4	PV source is insufficient to supply load and wind panel in Off-MPPT mode battery storage used as the main source.	The output of PV power is insufficient to supply load so battery and PV panel both used for power supply ($P_{PV}+P_{ba}$). Wind panel used for either store power in a battery or goes in off-MPPT mode. Battery either store ($SOC<SOC_{max}$) or release power ($SOC>SOC_{max}$).
Mode 5	Excess of wind power and solar power goes in Off-MPPT mode (in winter season or at night time), it provides supply and battery either charge or recharge.	The output of the PV panel is insufficient or not operate or in case of failure in the winter season and at the night ($P_{PV}=0$). Wind source is only sourcing with good wind speed is sufficient to provide a load ($P_{wind}=P_l$) Battery store power from the wind source when $SOC<SOC_{max}$ otherwise used as a standby power source and used whenever the load is higher than a

		generation (P_{wind}<P_l)
Mode 6	Both wind and solar source are insufficient then battery and both source combined and supply load demand.	The output from the PV panel is insufficient to supply load demand (P_{PV}<P_l). The output from wind panel is insufficient to supply load demand (P_{wind}<P_l). Battery with both source supply load demand (SOC_{min}<SOC<SOC_{max}) (P_{PV}+P_{wind}+P_{ba}>P_l).
Mode 7	Both sources fail to operate than only battery storage used to supply (SOC>SOC_{max}) & (P_{ba}>P_l).	Both source wind and PV are fails or unfavorable weather condition. Battery storage is used as a major source for supply load demand (SOC>P_l).

3.7 CLOSURE

Modeling of the system is done including the model development of WECS, PV system and BESS and also power electronic interfacing circuitry such as AC/DC converter, DC/DC converter, and DC/AC inverters. For maximum power extraction from all source used MPPT algorithm, for controlled power management fuzzy logic strategy used. This chapter presents a dynamic model for the hybrid wind-PV-battery system.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this chapter presents that the detailed model in MATLAB/Simulink software for simulation of the hybrid photovoltaic-wind-battery system developed for an isolated area. The simulation results were shows that how much reliable and stable of the modeled system. Simulation and modeling results play important role in the designing, analysis, and evaluation of power system which require complex control on the hybrid wind-PV-battery system.

Based on components used in hybrid wind-PV-battery system and control strategy discussed in chapter 3, the simulation results show test results on the proposed control strategy for power system management for a standalone hybrid power generation system, with continuous power supply, has been developed and verified in MATLAB/Simulink software using sim-power system block-set for real-time supervisory. The result is different with the ability to provide continuous power supply and act as a UPS system with renewable sources and provides automatic power control through fuzzy logic rule viewer and for maximum power extraction from the source used ANFIS MPPT algorithm. This system presents, following different Simulink studies designed to investigate the applications of the proposed control strategy with energy management model for hybrid generation system in stand-alone power generation mode.

4.1 Control strategy for power management used in the stand-alone hybrid wind-PV-battery system.

4.2 Power management in the hybrid wind-PV-battery system for an isolated system with different operating conditions.

Various results and discussion are presented in this chapter.

4.1 Stand-alone Hybrid wind-PV-battery system

The configuration shows that various components are presented in MATLAB/Simulink software which has Simulink blocks and their required interfacing circuitry used for better power generation from hybrid wind-PV-battery system shows in fig.4.1. This system consists of two renewable energy sources which generate continuous power with battery back-up. These sources can generate different type of a power structure like DC or AC by using converter technology. This converted or DC/AC link power feed through a bus which is AC or DC bus. This feeding power should be at the same bus (AC or DC) then use however our load requirement but in this system, DC link will used. The solar panel generates DC power but it is variable in nature due to irradiations are sometimes high and sometimes very low depends on the different seasonal weather condition. The maximum power production hour is 9AM-5PM in winter and 8AM-6PM in summer and in rainy season power may be productive and may not be produced it is depend on the weather characteristics. The power will be passed through a boost converter which can provide constant power for DC link and which make power at a constant value. Wind panel generates AC power through rotating wind turbine and the wind is also variable in nature, however, panel power pass-through AC to DC converter due to DC bus use for interfacing power from the generator to load. The battery is used for storing DC power, so it requires DC to DC bidirectional boost converter for constant power store.

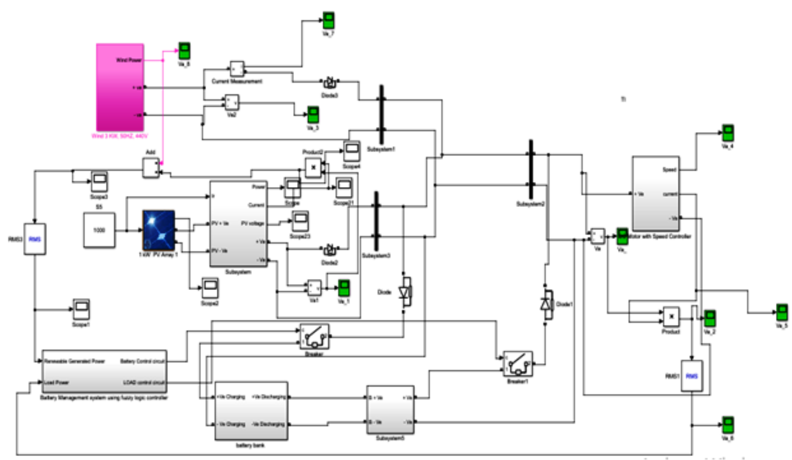


Fig. 4.1: Simulink model for the hybrid wind-PV-battery system.

4.2 Modes of the operating condition

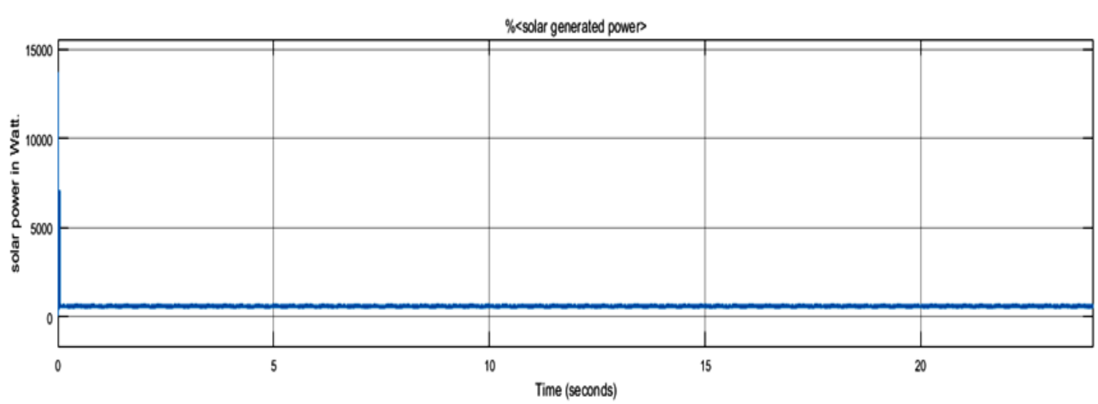
In this block, input conditions are changed according to the weather and environment conditions. These weather conditions are like summer, winter and rainy season and environmental conditions such as day and night. In different season wind and sun nature is also change with time but in rainy season sun may be producing power and wind also produce power merely depends on the weather condition at a time. Solar can generate power only for a few hours in a day because the sun has a six-hour to show their higher intensity. In this hybrid system, two more cases are arises in which load varies from low to high value

4.2.1 Nature of the source varies

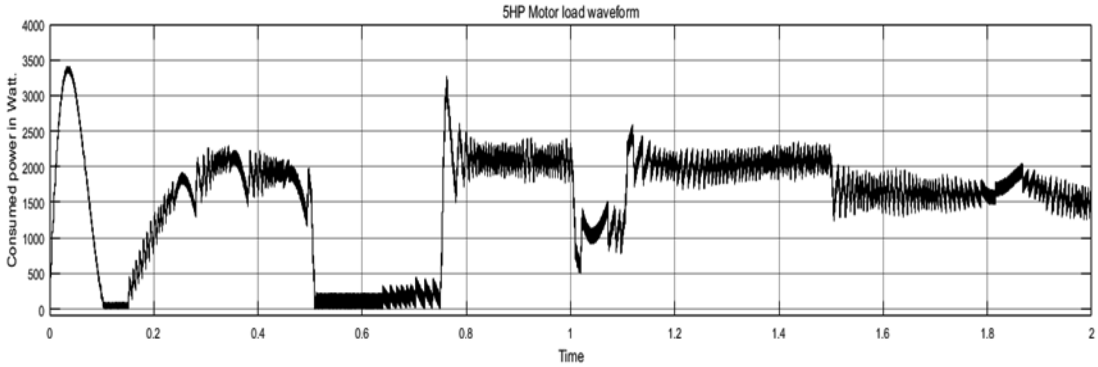
In this condition, it has six modes of operation for hybrid generation system with different weather conditions in addition to charging and discharging mode of a battery.

Case I: Power generated output at 1000W/m^2 solar irradiance and 13m/s wind speed

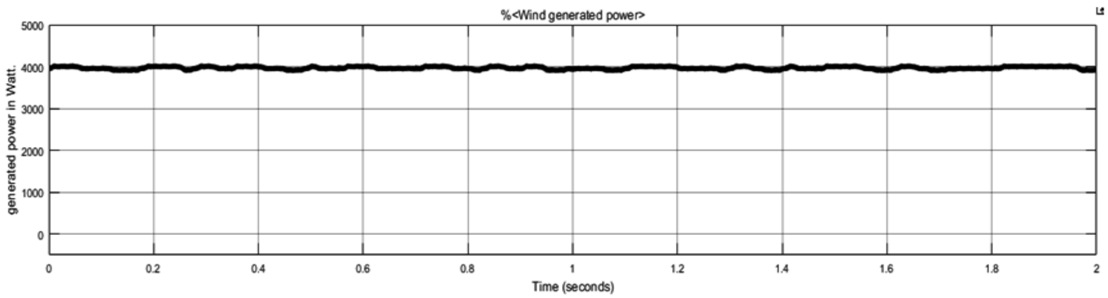
In this case, solar irradiation at 1000W/m^2 fall on solar panel and wind blow at 13 m/s. In this case, solar output power by falling solar irradiation and temperature on solar panel shows in the waveform of figure 4.2 (a) shows solar generated power. In this case, generated power is sufficient to supply load demand with 240V constant voltage. In figure 4.2 (b) shows the load power demand in watt. Figure 4.2 (c) shows that wind panel generated power in watt. Figure (d) shows that power generated from single wind and single solar is not sufficient for providing load demand so the combination of wind and PV source can generate sufficient power for supply the load demand, total power generated from both sources show in figure 4.2 (d), 4.2 (e) shows battery initial condition, (f) shows DC link voltage.



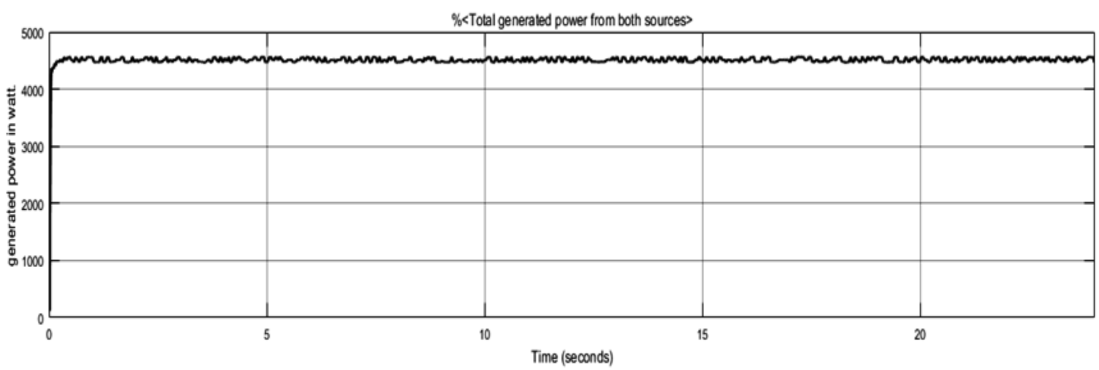
(a) Solar panel generated power (W).



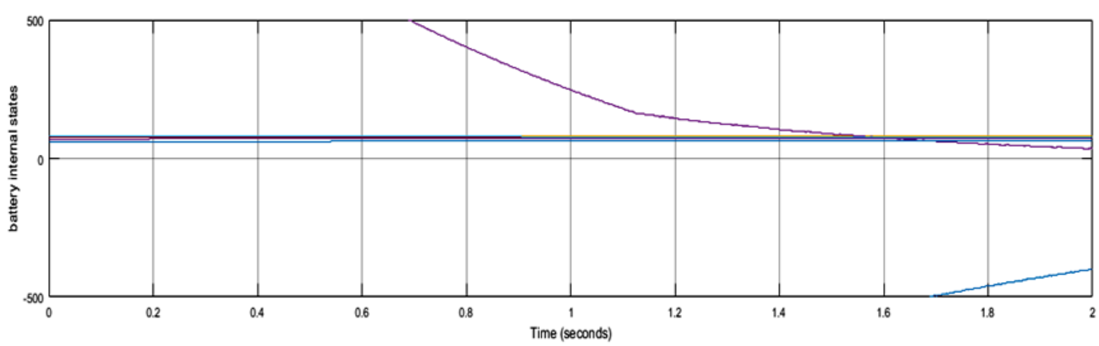
(b) Total load demand power (W).



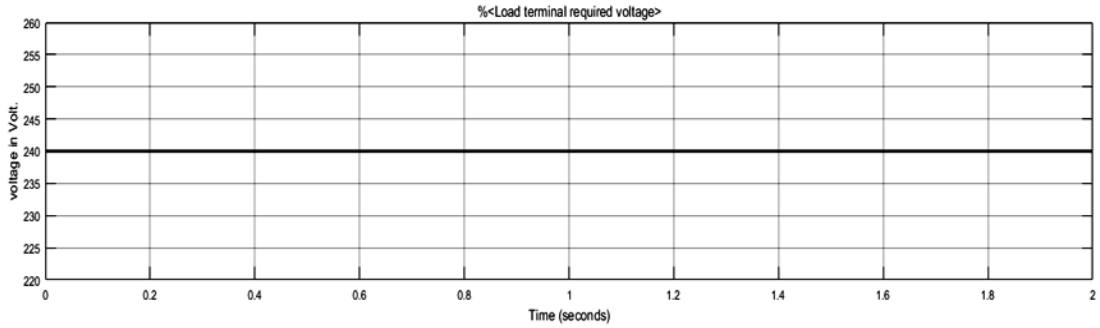
(c) Wind panel generated power (W).



(d) Total power generated from both sources (W).



(e) Battery initial condition.

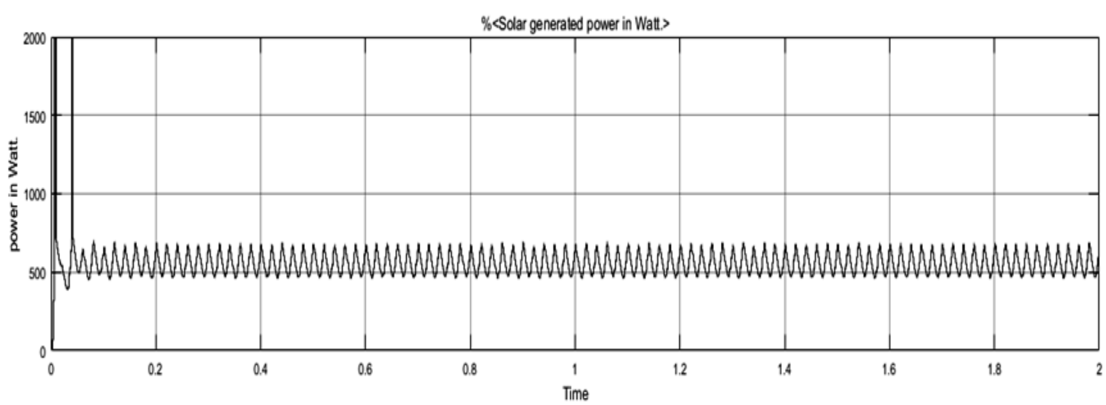


(f) DC link terminal voltage (volt).

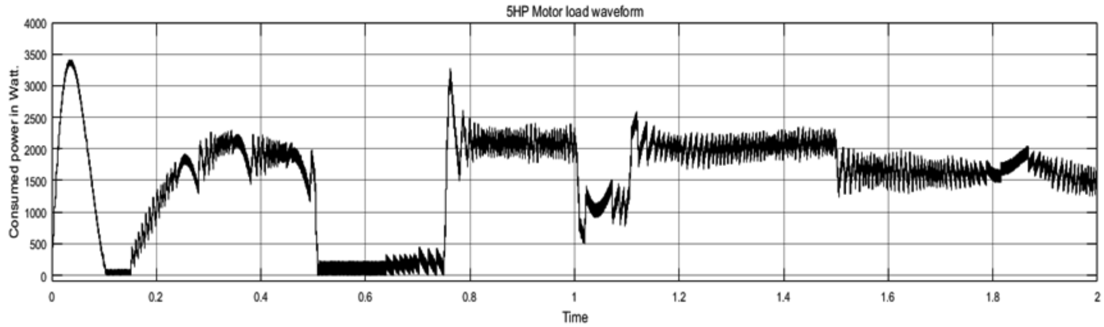
Fig. 4.2: Waveforms of the output power, battery initial condition, DC link voltage and load demand at 1000W/m^2 solar irradiation with 25^{0}C temperature and wind speed at 13m/s.

Case II: Power output at 1000W/m^2 solar irradiation and 10m/s wind speed

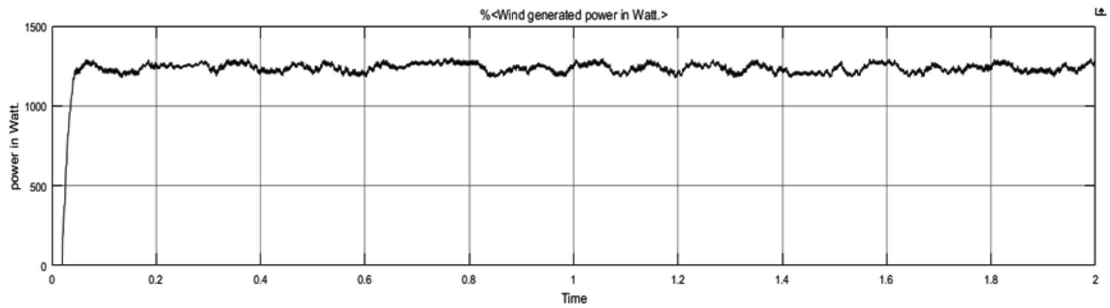
In this case, solar irradiation at a 1000W/m^2 and wind speed in this case is 10m/s and battery initial is charged or capable to discharge. Load condition is same for a hybrid wind-PV-battery system form previous case and battery is initially charged. Solar or sun irradiation is at 1000W/m^2 and generated power varies between 650-750W solar panel insufficient to supply load power demand shown in figure 4.3 (a) and load demand power shown in figure 4.3 (d) it will not constant and it varies with respect to time. Both sources can generate sufficient power by integrating both sources (wind and PV). From figure 4.3 (d) shows that the waveform of power generated from both sources is supplied total load demand and battery bank is also involved. If the load is very high and range of supply power is far away from generated power than system may be cut-out and supply power only for battery storage.



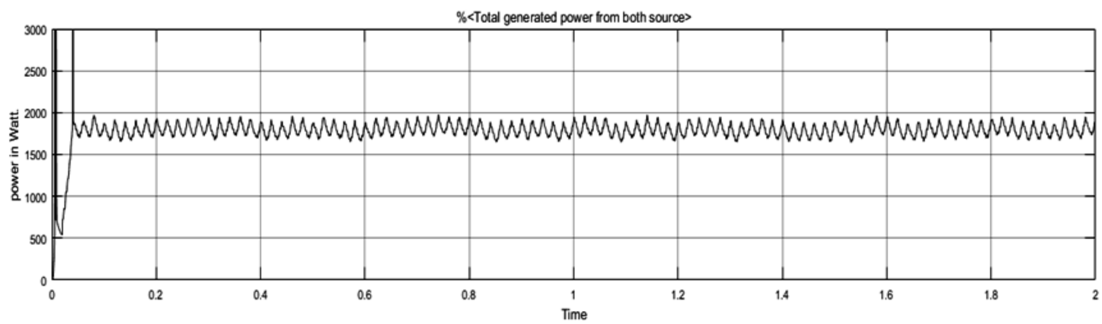
(a) Solar generated power in watt.



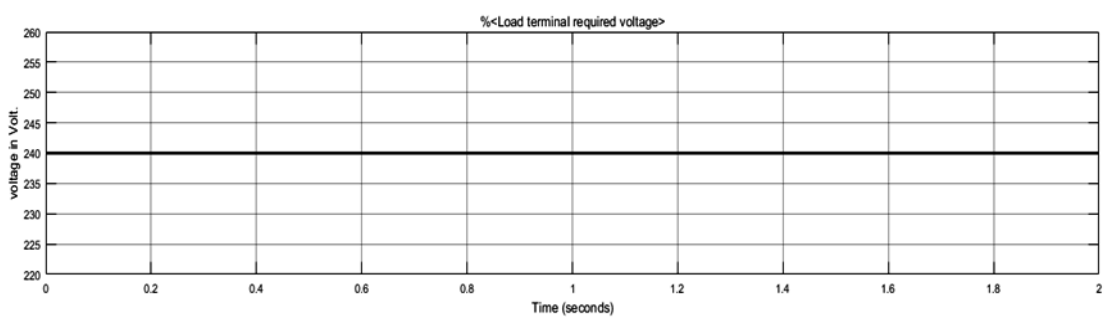
(b) Load power in watt.



(c) Wind panel generated power in Watt.



(d) Total generated power from both sources in watt.



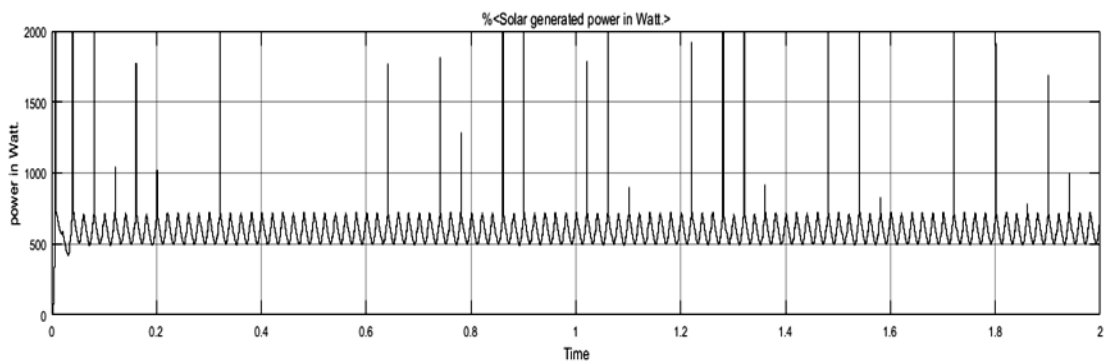
(e) DC link constant voltage in volt.

Fig. 4.3: Waveform of the output power, Battery internal status DC link voltage and load demand at 1000W/m^2 solar irradiation and 10m/s wind speed.

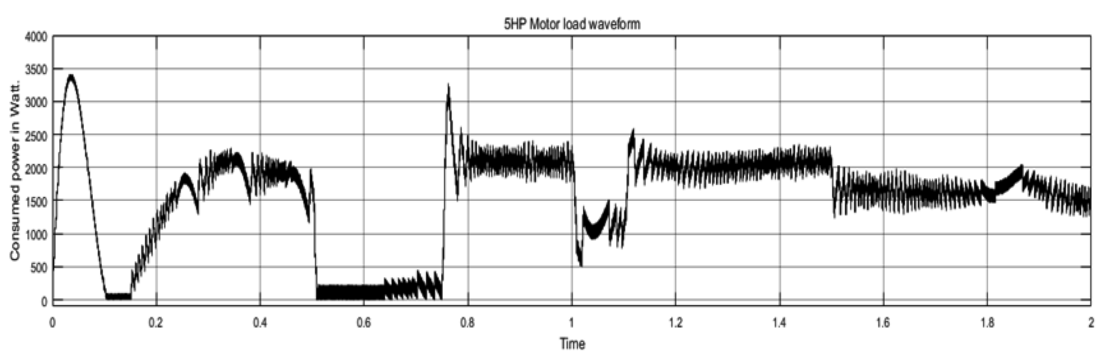
As shown in figure (d) load power when load requirement is very low or nearby 0W than generated power automatically stored in battery storage. The load demand varies from 0 to 3500W as shown in figure. Load terminal or DC link voltage 240V continuously supplying constant voltage for the load by either with battery bank or without a battery bank or by sources are shown in figure 4.3 (e) DC link voltage.

Case III:- When solar irradiation at 1600W/m^2 and wind speed same 12m/s

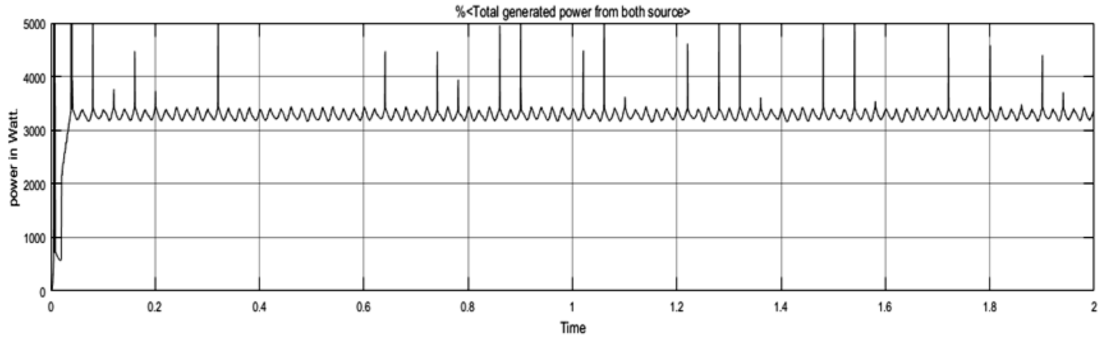
In this case, solar irradiation at 1600w/m^2 especially in summer season, the temperature is also increased in summer season so high power generated from solar panel as compare to previous case shown in figure 4.4 (a). This generated power is insufficient to supply load demand and solar panel generated power varies between 500-1200W and load power at the time of simulation starting is very high and varies in between 0-3500W. wind generated power varies between 2700-2800W and it is singly insufficient to supply load demand As shown in figure 4.4 (d), it can provide supply load demand in either daytime or in night time, wind panel used for supply load demand for 24-hour if the plant location is in highly windy side.



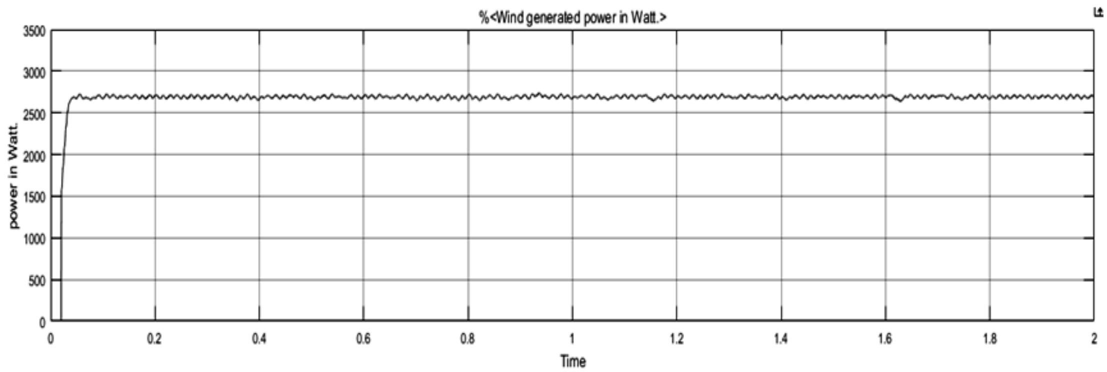
(a) Solar panel generated power in watt.



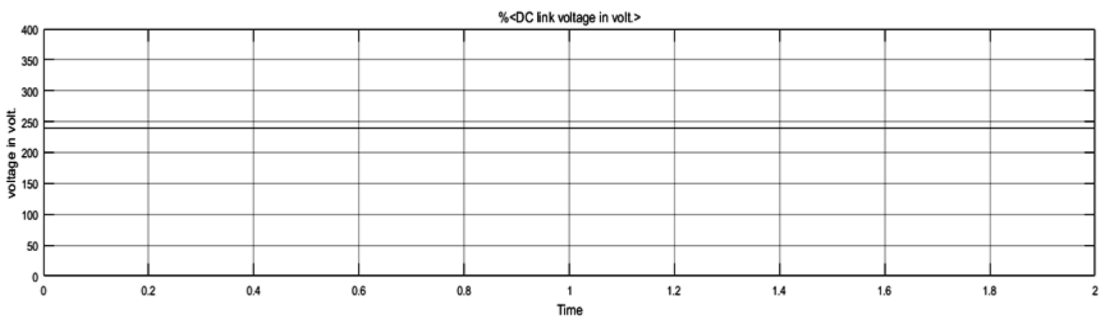
(b) Load power in Watt.



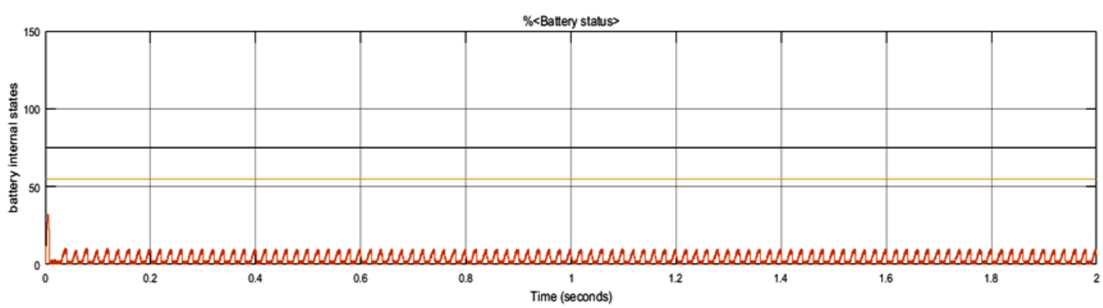
(c) Total power generation from both sources in Watt.



(d) Wind-generated power in Watt.



(e) DC link voltage in volt.



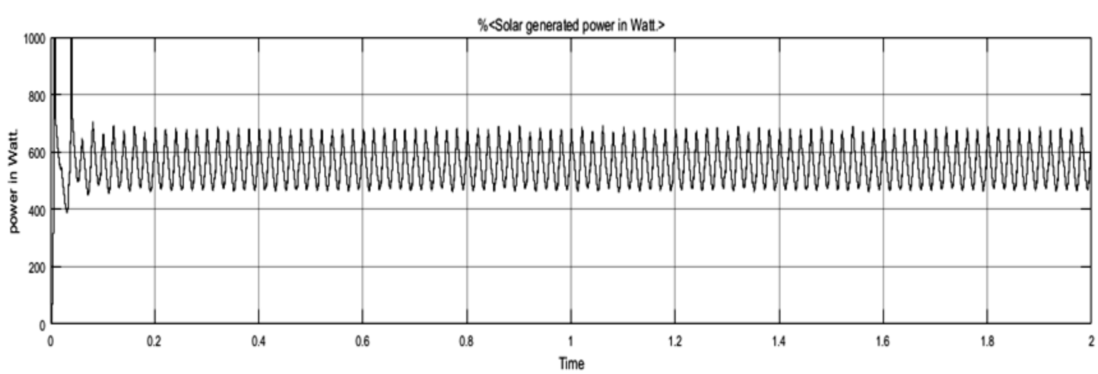
(f) Battery initial status.

Fig. 4.4: Waveform of generated power, DC link voltage and load demand at 1600W/m^2 solar irradiation and 12m/s wind speed.

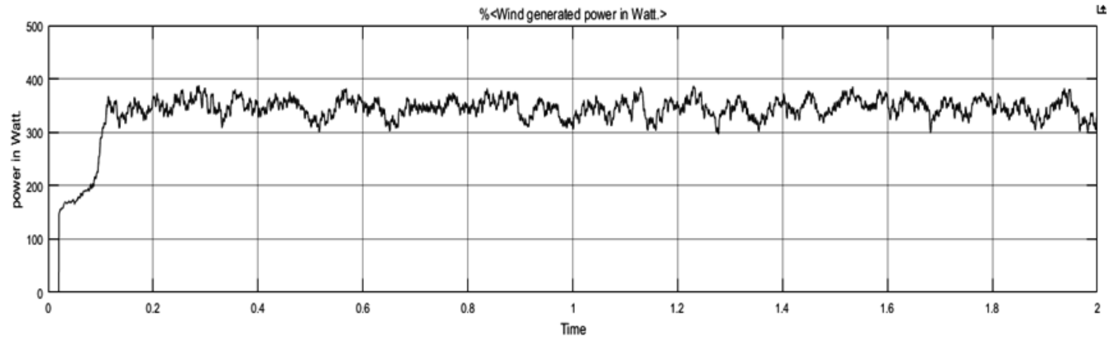
The load power requirement also has a variable nature it may be high or less as compare to generation, depends on input condition and required load power demand waveform shown in figure 4.4 (b). Two combinations is possible for supply load demand if this situation arises in daytime than PV-battery or PV-wind and in night time the system will be supplied by wind-battery, but in night time less load occurs and wind speed is also good in night. The load demand partially supplied by battery if extra load occurs, this supply time can occur in day or night or morning or evening. In day time PV and wind panel both works, but in night, evening and morning only wind and battery system is activated. Figure 4.4 (c) shows that total power generation from both sources. If extra power generated from the hybrid wind-PV system than extra power will be stored in a battery bank. Wind panel generated power in watt shown in figure 4.4 (d), DC link voltage is shown in figure 4.4 (e) it will be constant at voltage 240V and 4.4 (f) shows battery internal status

Case IV:- When solar panel at 1000W/m^2 irradiation and wind speed at 5m/s

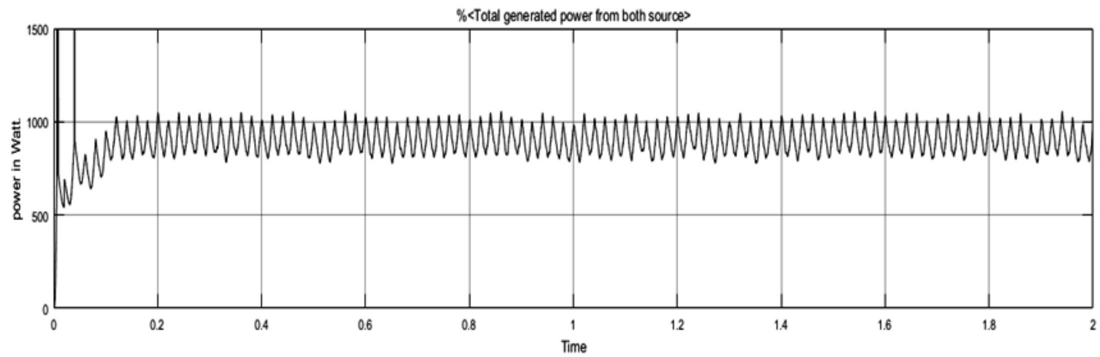
In this case, solar irradiation at 1000W/m^2 but wind speed is very low as 5m/s. The solar irradiation is standard but it generates less power and wind panel is also generate less power, the total generated power unable to supply load demand, than wind-PV-battery can supply the all load demand. Solar generated power varies between 400-700W and wind-generated power varies between 300-380W and total generated power varies between 500-1100W, at that time load power varies between 0-3500W power. As compare to generated power, load power is high at starting point but in later time it is low as shown in figure 4.5 (d).



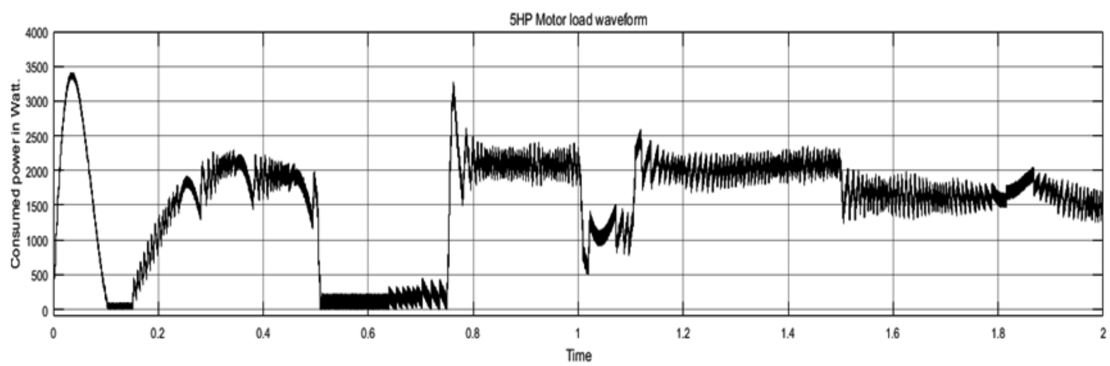
(a) Solar panel generated power in Watt.



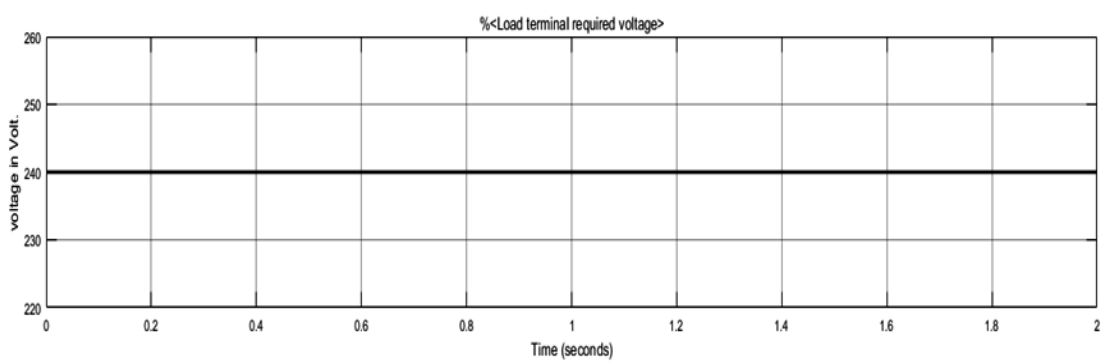
(b) Wind-generated power in Watt.



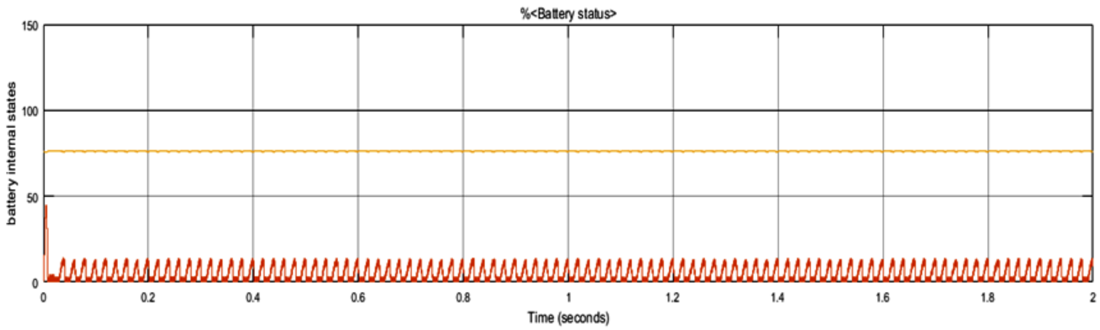
(c) Total generated power from both sources in Watt.



(d) Load power in Watt.



(e) DC link voltage in volt.



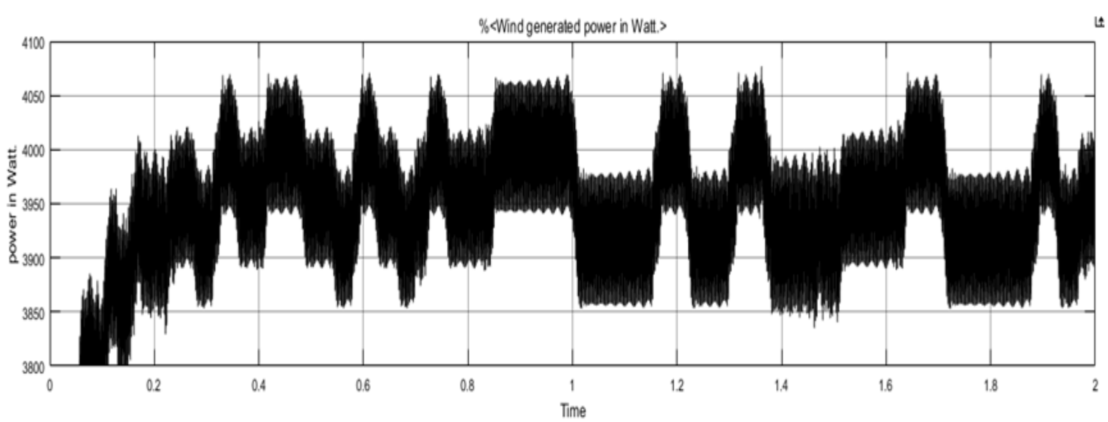
(f) Battery initial status.

Fig. 4.5: Waveform of generated power, load power, generated voltage, generated current, DC link voltage and load current at 1000W/m^2 solar irradiation and 5m/s wind speed.

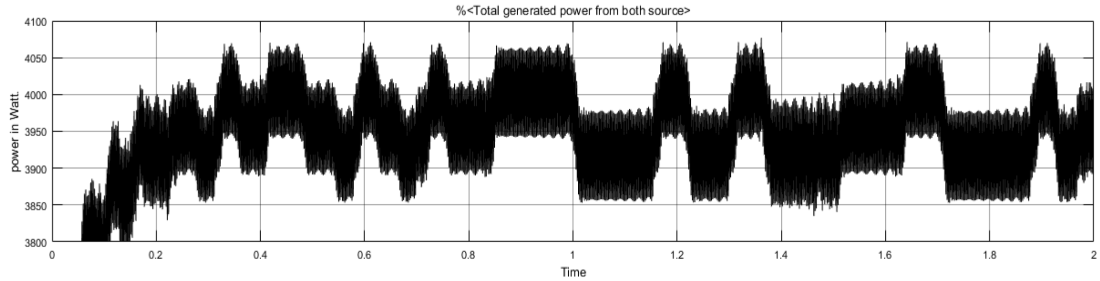
Figure 4.5 (a) shows solar-generated power, 4.5 (b) shows that wind generated power, 4.5 (d) shows that load demand and 4.5 (c) show that total power generated from both sources. Figure 4.5 (e), (f) DC link voltage and battery internal status.

Case V:- When solar irradiation at zero W/m^2 and wind speed at 12m/s

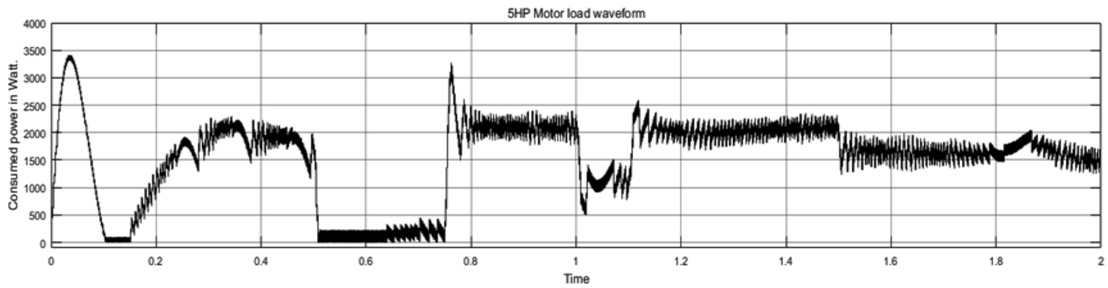
In this case, night time solar generated power is zero, wind speed at 12m/s. In this case, only the wind power system is used with the battery bank. The load power is in variable nature so the battery will be charged or discharge depends on the generated power and load profile. Generated power from wind panel is varied between 0-4100W which is capable of supplying load demand and battery is initially charged in this case and extra generated power stored in the battery bank. The load power demand varies between 0-3500W.



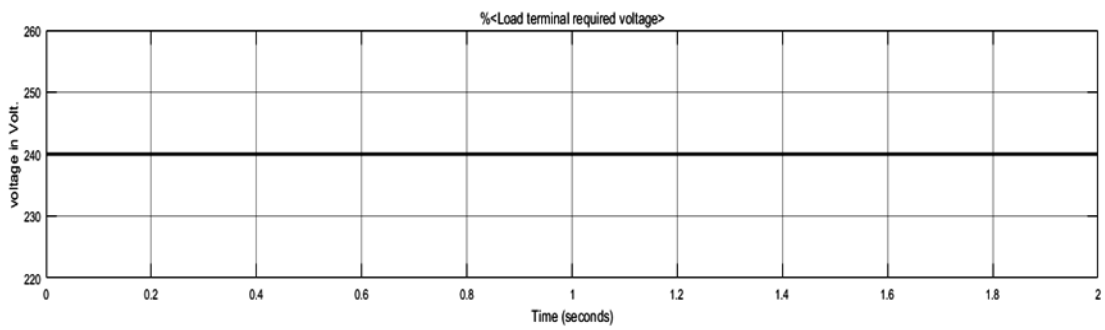
(a) Generated power from wind in Watt.



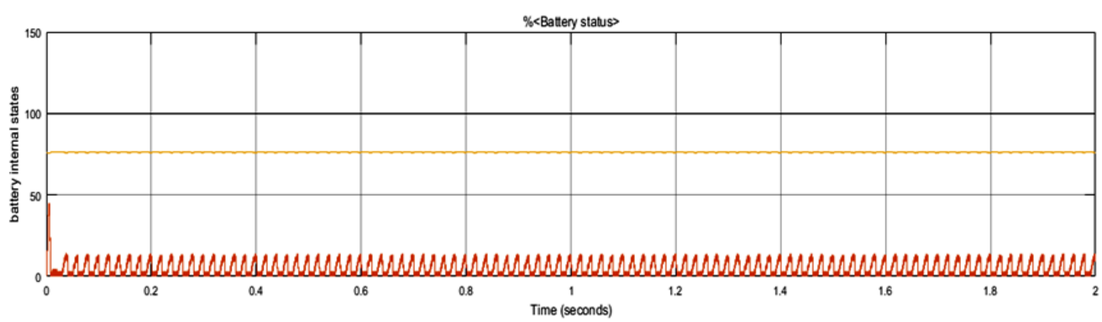
(b) Total generated power from both sources in Watt.



(c) Load power in watt.



(d) DC link voltage in volt.



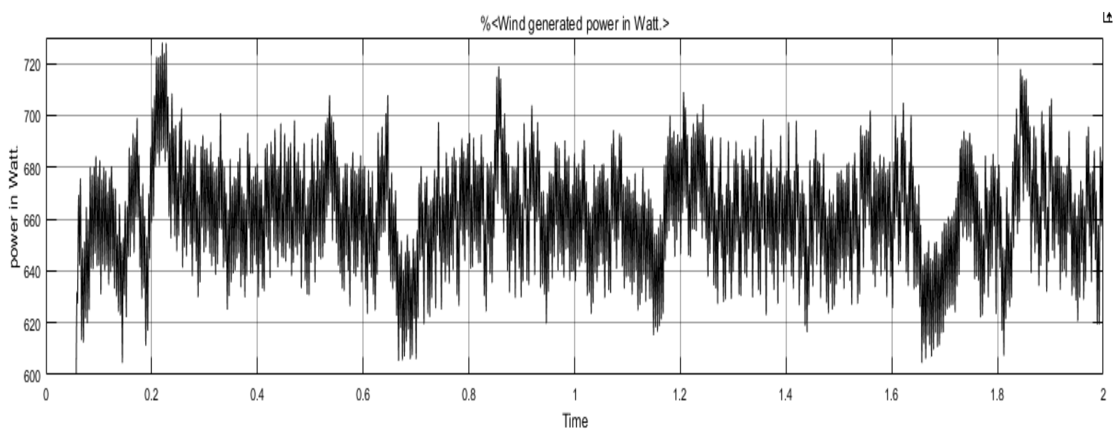
(e) Battery initial status.

Fig. 4.6: Waveform of generated power, load power, generated voltage, generated current, DC link voltage and load current at zero W/m^2 solar irradiation and 12 m/s wind speed.

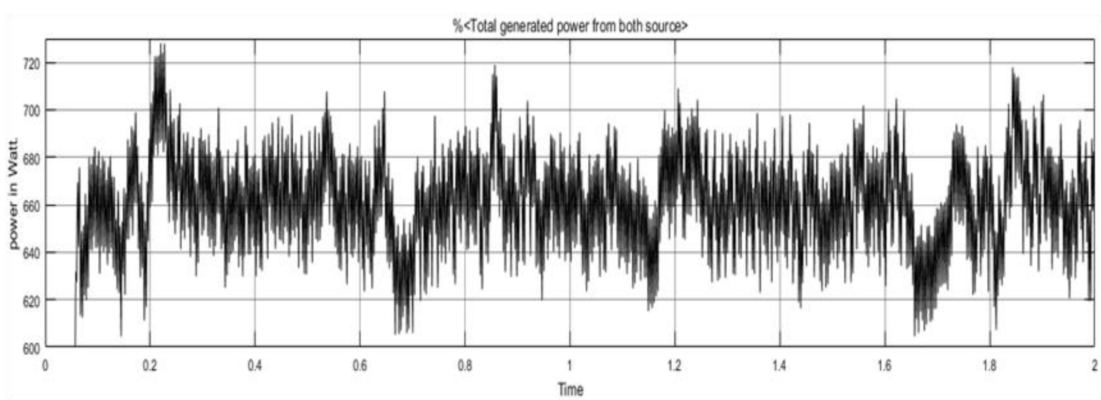
The wind generated power is capable of supplying load power demand, but at the starting of simulation load power is high and wind generated power is less as compare to load than the battery bank act as a source, after sometime later wind generated power capable to supply load and battery bank act as a consumer. The high load period occur maybe for one hour or maybe for several hours, figure 4.6 (a) shows that the generated power from wind source (b) shows that total generated power from both sources, (c) shows load power demand. In this case when sun or PV energy fails to operate especially at night and in a rainy season then one of the sources is used to provide power (wind source) otherwise battery provides whole load demand. Figure 4.6 (d), (e) shows DC link voltage and battery internal status.

Case V (A): When solar irradiation is zero and wind speed at 8.96m/s

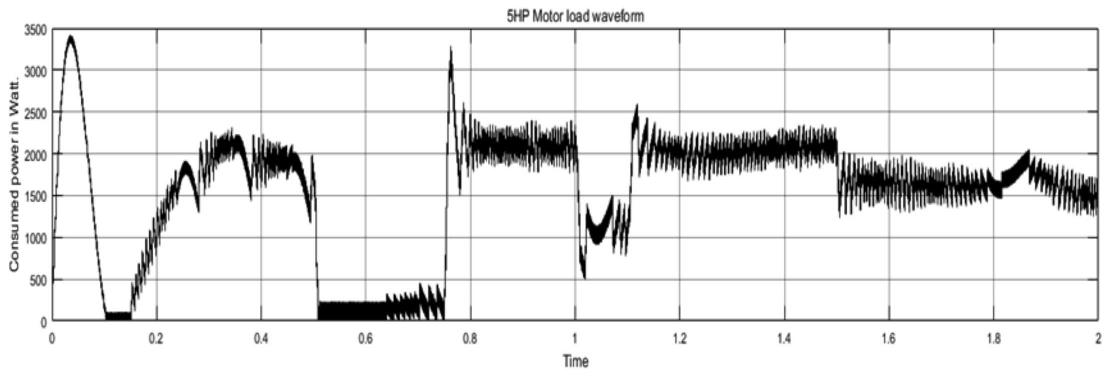
In this case, wind speed suddenly changes from 12m/s to 8.96m/s, the required load demand supplied by the battery-wind system combination.



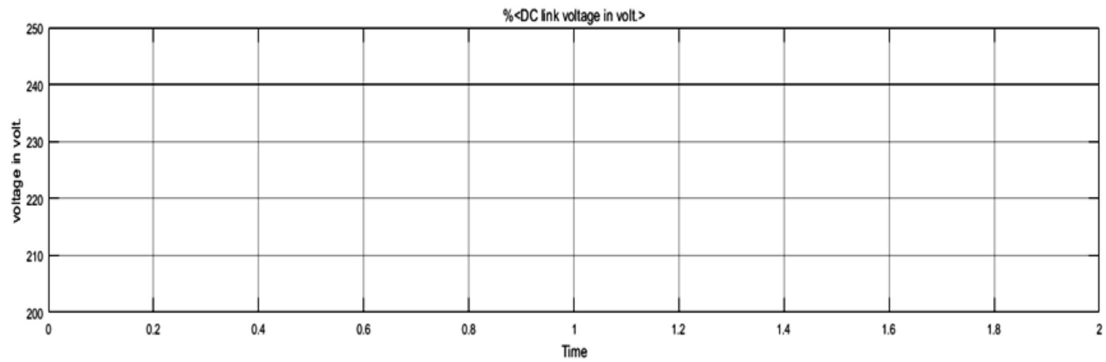
(a) Wind-generated power in Watt.



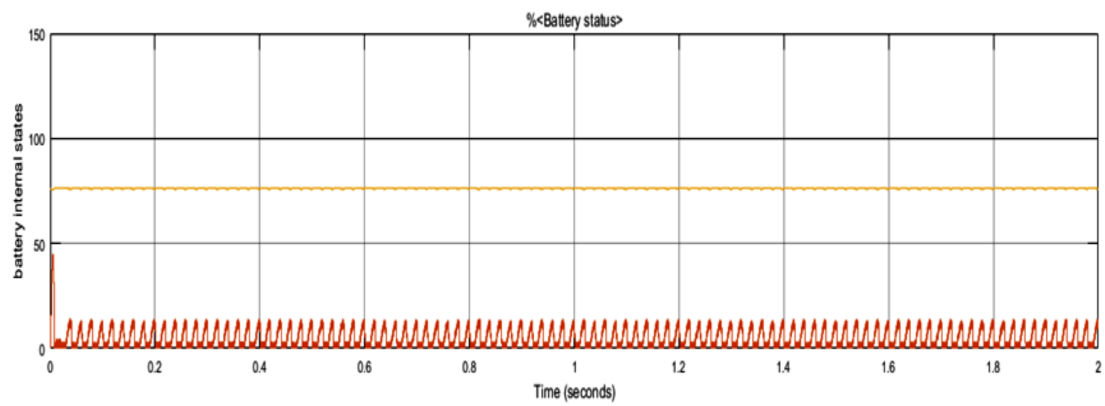
(b) Total generated power in Watt.



(c) Load power in Watt.



(d) DC link voltage in volt.



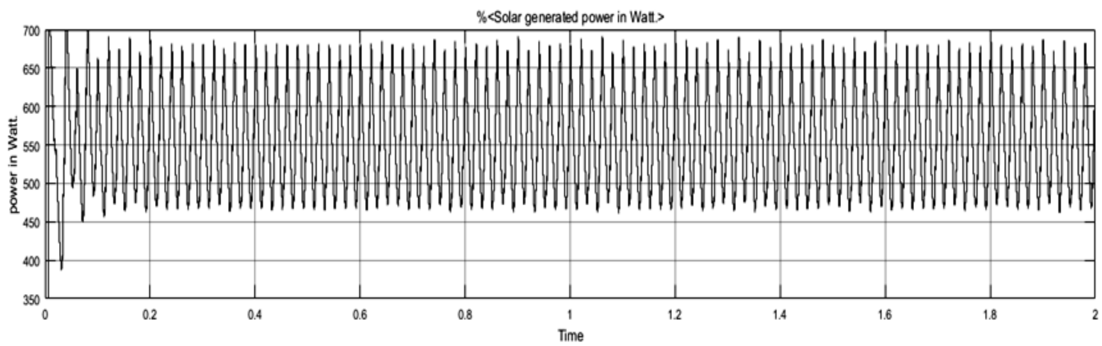
(e) Battery internal status.

Fig. 4.7: Waveform of wind-generated power, the total power generated, load power, DC link voltage and battery internal status at 8.96m/s wind speed.

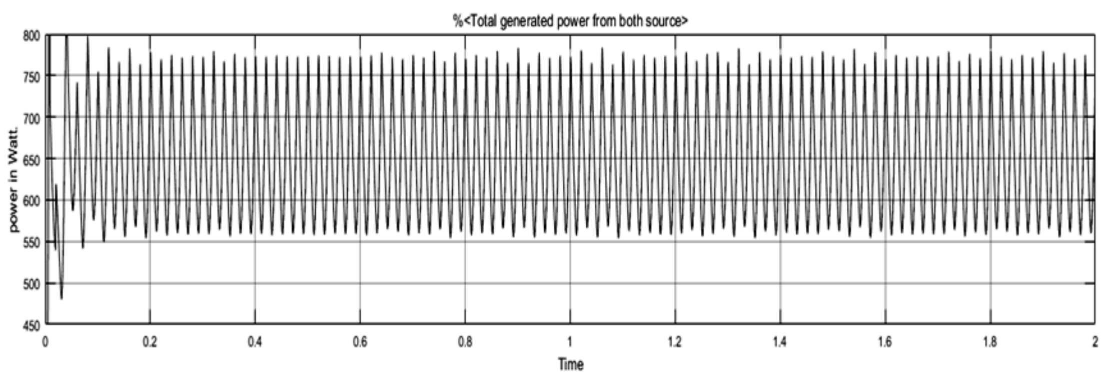
Generated power is varied between 0-750W as shown in figure 4.7 (a) and load demand varies between 0-3500W shown in figure 4.7 (c), the load demand supplied by the battery bank and wind panel. From figure 4.7 (c) shows that the load is not constant it varies with time it may be high or low depends on the load requirement.

Case VI: When solar irradiation at 1000W/m^2 and wind speed at zero m/s

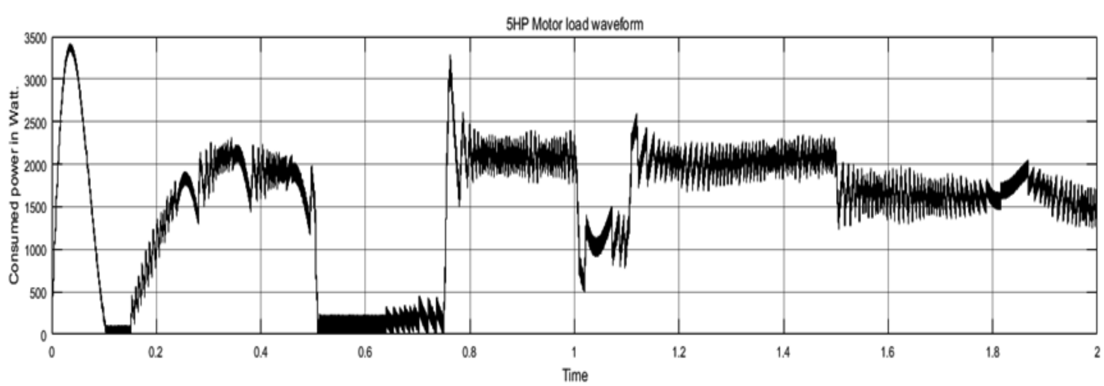
In this case hybrid system works at 1000W/m^2 solar irradiation and wind speed at zero speed. We assume that battery is initially charged and supply power when PV power is not sufficient for load demand and combining two PV and battery than supply load demand. Figure 4.8 (a) shows that generated power from the PV source, (b) shows that total generated power and (c) shows that load demand power.



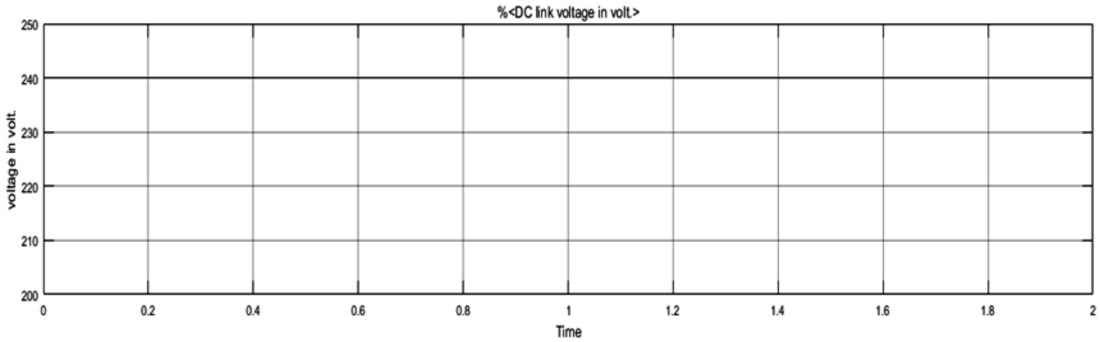
(a) Solar generated power in Watt.



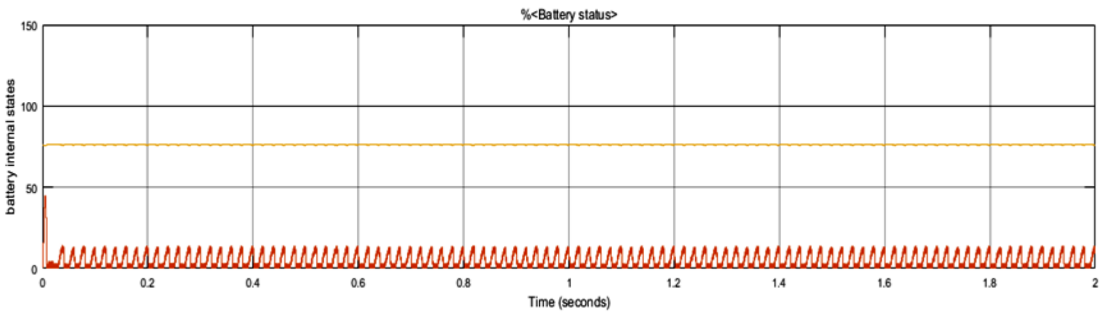
(b) Total generated power in Watt.



(c) Load power in Watt.



(d) DC link voltage in volt.



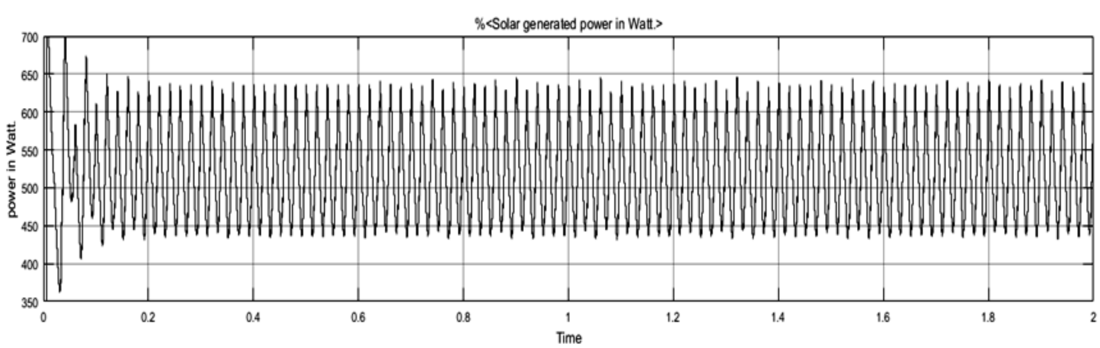
(e) Battery internal status.

Fig. 4.8:- Shows waveform of generated power, total generated power, load power, DC link voltage and battery internal satus at 1000W/m^2 solar irradiation and 12m/s wind speed.

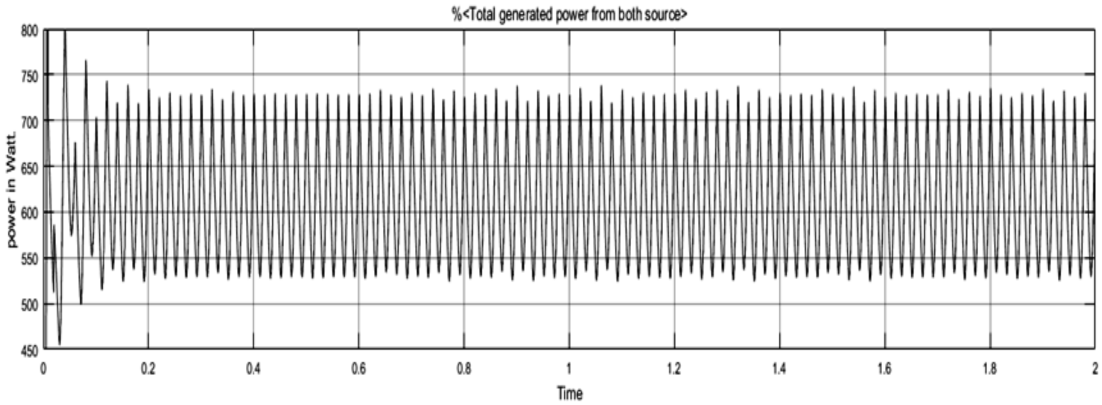
Due to wind is not blowing so wind turbine output is zero, wind-generated voltage and current is also zero that's why waveforms are not shown in this case and neglected power from wind source.

Case VI (A): When solar irradiation at 600W/m2 and wind speed is zero m/s

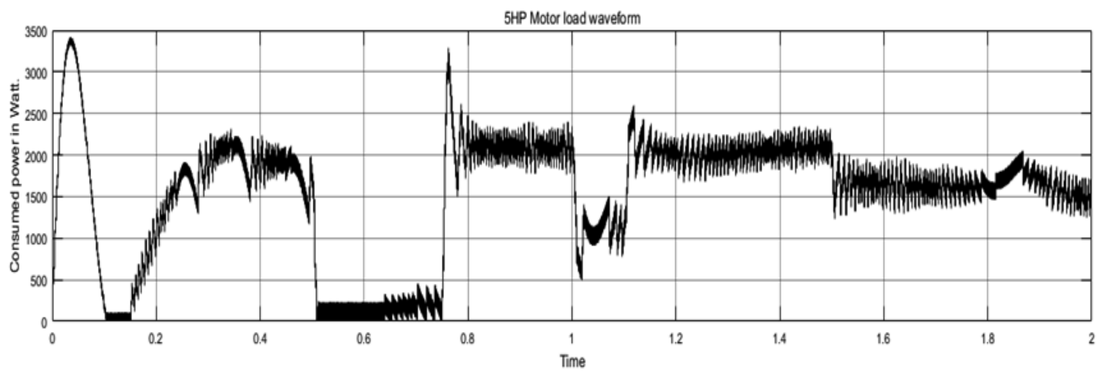
In this case solar irradiation at 600W/m^2 and wind speed is zero.



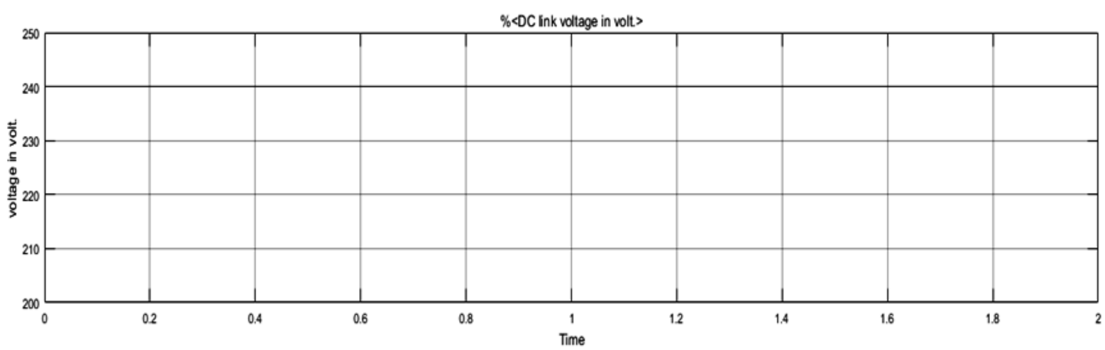
(a) PV generated power in Watt.



(b) Total generated power from both sources in Watt.



(c) Load power in Watt.



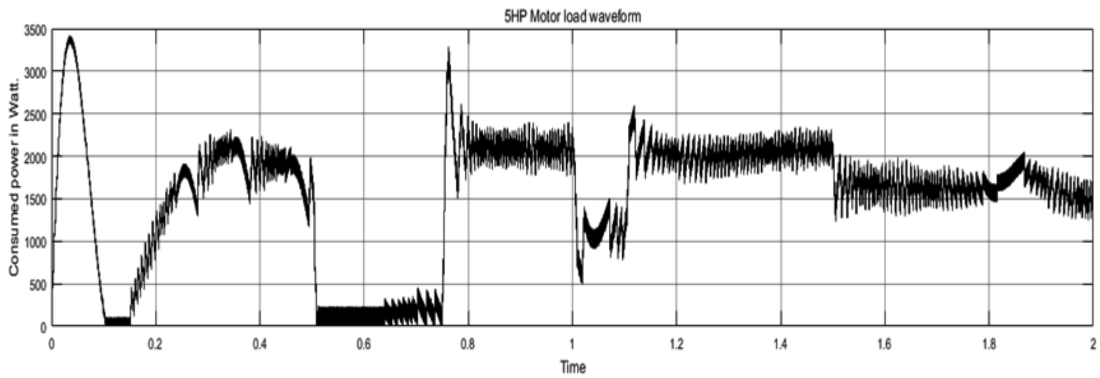
(d) DC link voltage in volt.

Fig. 4.9: Waveform of solar-generated power, total power generated, load power, DC link voltage at 600w/m^2 solar irradiance and zero m/s wind speed.

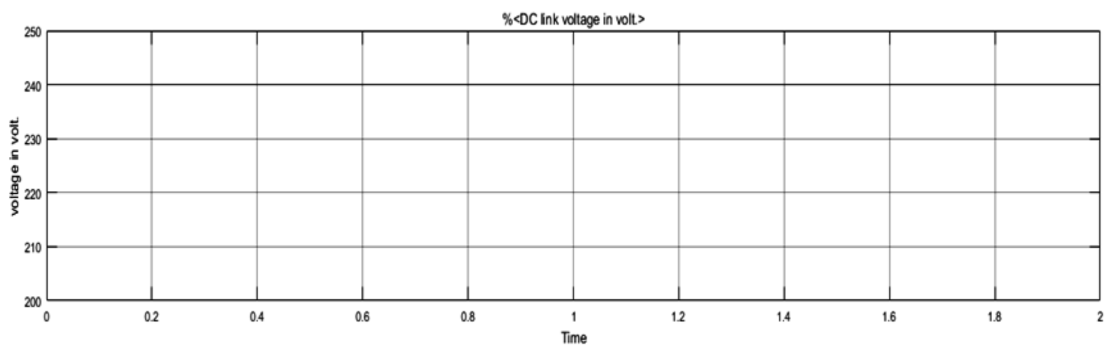
This case especially occurred in rainy season when solar irradiation level is low with low temperature and wind speed is suddenly stops. Figure 4.9 (a), (b), (c) and (d) shows the PV generated power, total generated power, load power and DC link voltage respectively.

Case VII: When both PV and wind source at zero W/m2 and zero m/s respectively

In this case, both sources fail to operate due to neither solar irradiation (night) nor wind speed, this condition arises for a few seconds to several hours.



(a) Load power in Watt.



(b) DC link voltage in volt.

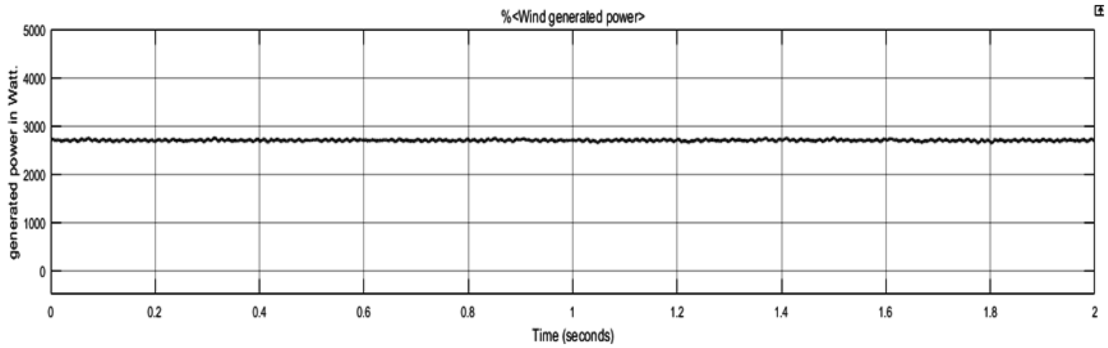
Fig. 4.10: Waveform of load demand and DC link voltage and battery internal status at zero solar irradiation and zero wind speed.

4.2 When load changes

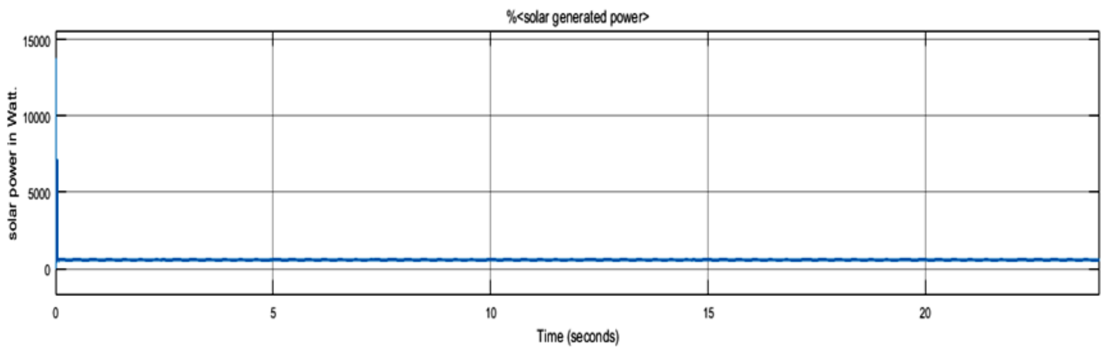
In this condition have two more case arises in which load change from zero to maximum.

Case I:- Load is zero and generated power is continuous

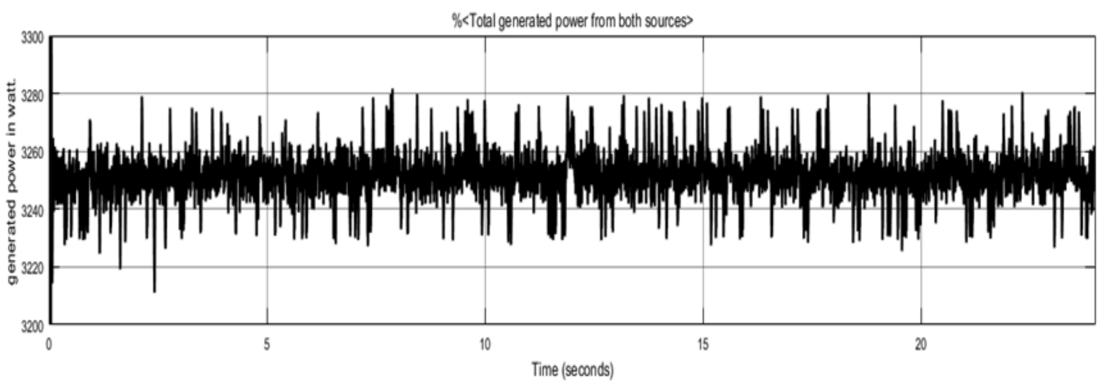
In this case, power production from a renewable source is continuous but the load is zero and all generated power from two sources managed by PMS and stored in the battery bank. Figure 4.11 (a) shows that wind-generated power, (b) shows that PV generated power, (c) total generated power from both sources, (d) shows the battery charging rate of a hybrid system.



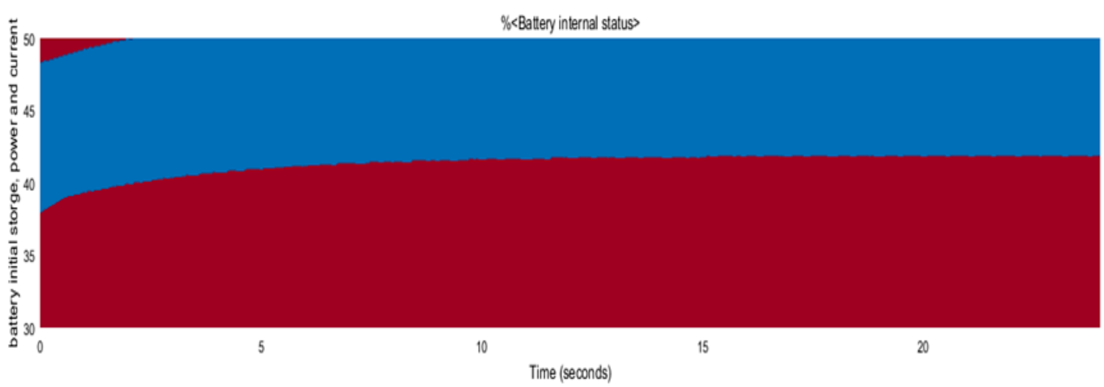
(a) Wind-generated power in Watt.



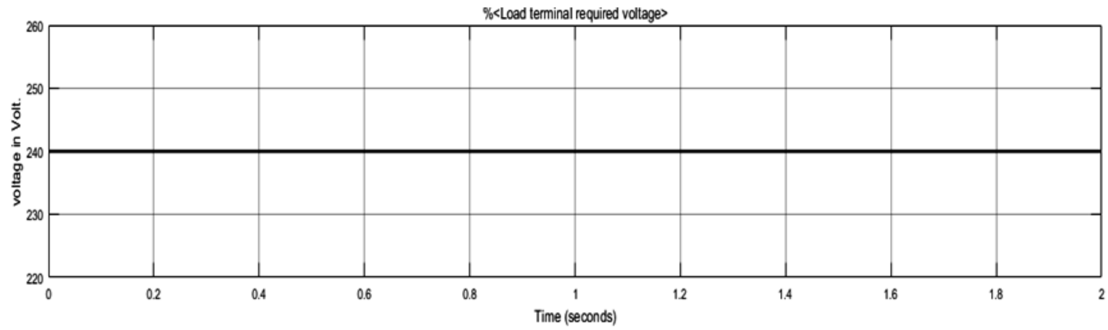
(b) PV generated power in Watt.



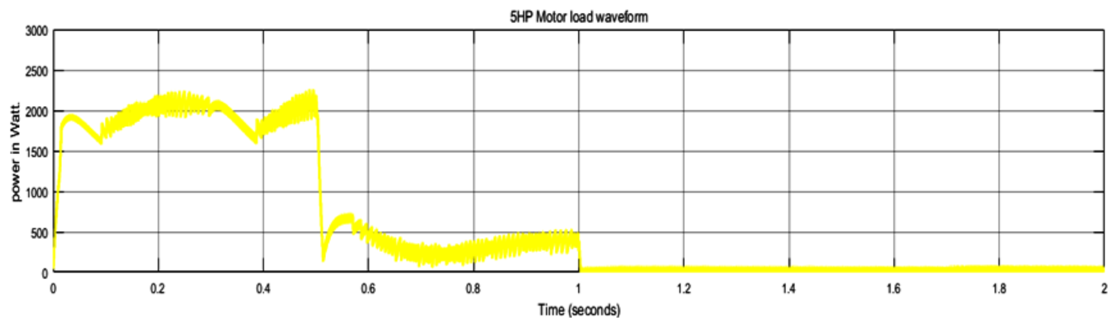
(c) Total power generated from both source in Watt.



(d) Battery charging state.



(e) DC link voltage in volt.

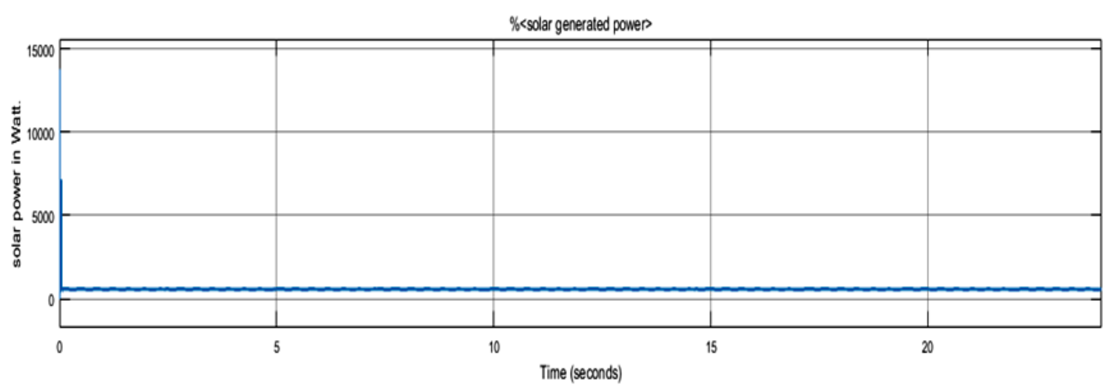


(f) Load demand power in Watt.

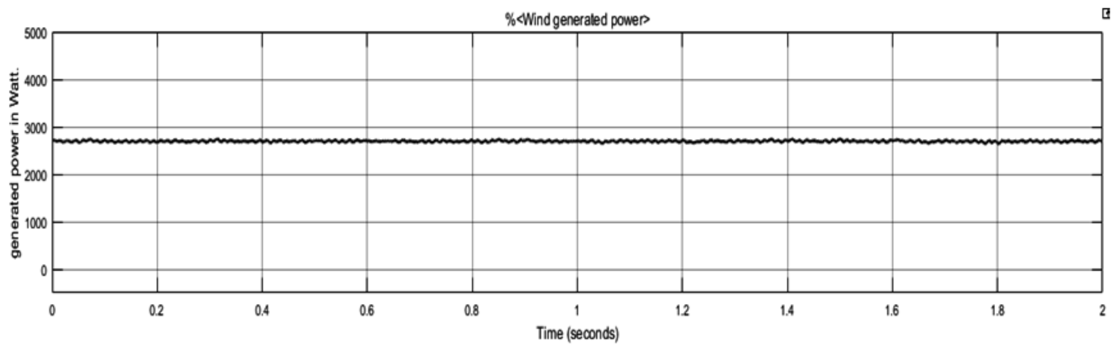
Fig. 4.11: waveform of PV generated power, wind-generated power, the total generated power, DC link voltage, and battery charging states.

Case II:- When load goes to a minimum value to a very high value

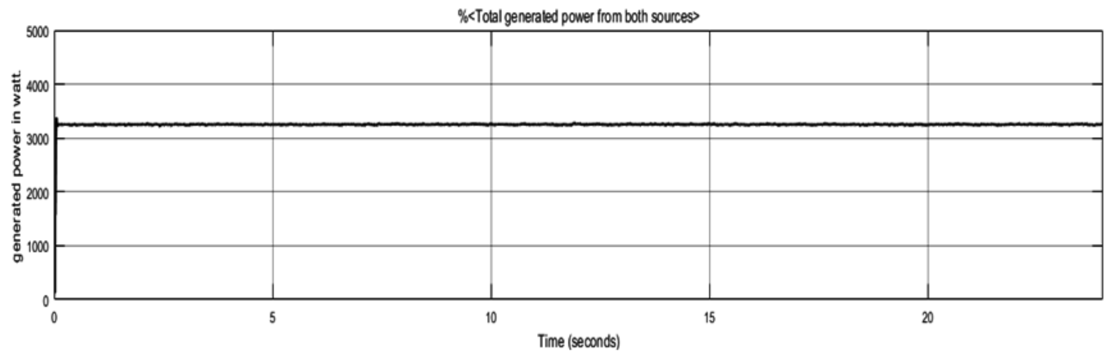
In this case, the load is a very high and it may be supplied by the hybrid wind-PV-battery system or not depends on input condition of the source, due to very high load demand and insufficient generated power battery bank act as a source.



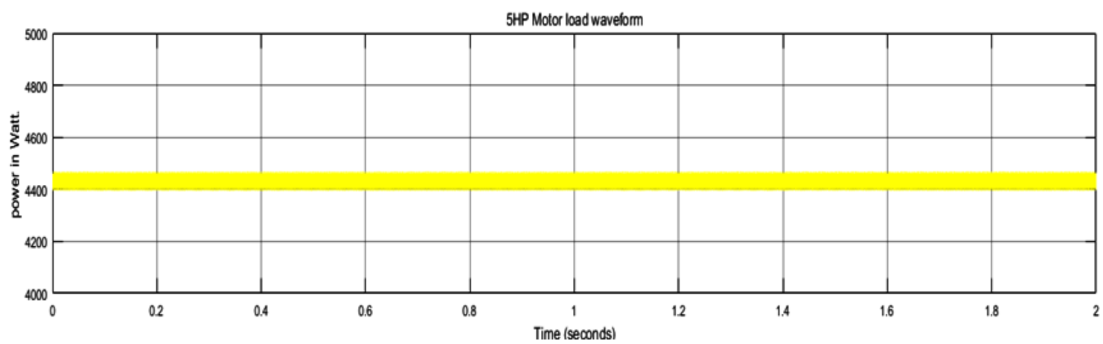
(a) Generated power from PV in Watt.



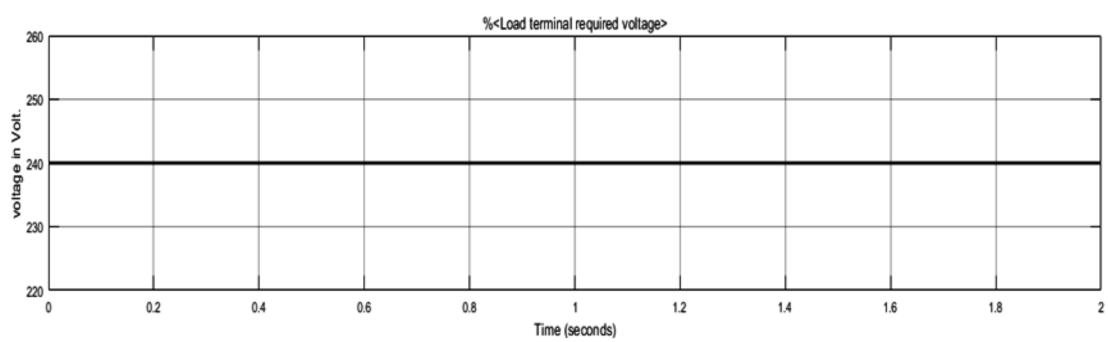
(b) Wind-generated power in Watt.



(c) Total generated power from both sources in Watt.



(d) Load demand power in Watt.



(e) DC link voltage in volt.

Fig. 4.12: Waveforms of PV generated power, wind generated, total generated power, load demand power, DC link voltage and load current.

In this case, the battery is assumed to be initially charged and discharge for a high load condition, this high load condition arises from one second to several hours or system may go under load shading mode. Figure 4.12 (a) shows the generated power from PV source, (b) shows the generated power from wind source, (d) shows the total power generated from both source and (e) shows the total load demand at that time. If high load condition remains for several hour and generation is very less in comparison with load demand then the system goes in a load shedding mode and total generated power will be stored in the battery bank. Figure 4.12 (f) shows that load current in the amp.

The above result shows that hybrid wind-PV-battery system provides efficient, stable, reliable and continuous operation in isolated mode. In isolated system load may be residential, industrial, agricultural and motor or electric vehicle load but in this case, the system provides a residential load for home appliances. This system works on different weather and environmental conditions and result provide an efficient power transfer from source to load through different components. The above results show the developed control strategy is able to distribute the load demand among different individual sources effectively. The power transfer in different components is automatically handled by the fuzzy logic rule viewer.

This system works with renewable sources so if the system goes in load shading mode, than the residential load suffer this load shading mode from few minutes to several hours in daytime or maybe in night time. This system provides a better quality of power with different renewable sources and battery system. The load may be a residential load such as 10-30 houses in an isolated village which has a home appliance like fan, light, motor, refrigerator, TV, and radio. The load may be agricultural types for farming crops. If a generation is low and the load is high then extra or partial load may be cut out from distribution system. The extra load can cut in the daytime from residential load and supply agricultural load for farming and for small industry, and in night time agricultural load can cut out and supply home appliances. The load may be disconnected in day for some hour and saves energy in battery storage. The system shows as a mini-grid and provides few KW of power supplies. The hybrid wind-PV-battery system works as a UPS (uninterruptable power source) and supply power for 24-hour effectively.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

CONCLUSION

The present work is carried out for wind panel, PV panel and backup power as a battery. Those all sources combined and build hybrid renewable energy source and act as an uninterruptable power source (UPS). Individual PV and Wind resource unable to provide power for 24 hours because these are natural resources, solar power source is limitless but due to the limitations of PV panel can't operate in night time and wind power depends on that time of environmental condition, when the system fails, battery back-up builds a bond with power management to provide continuous power at that time of unavailable power period. The hybrid wind-PV-battery system model was developed in MATLAB/Simulink software and control strategy for energy management of the developed hybrid Wind/PV/Battery system is also presented. On the basis of simulation results and the performance parameter analysis carried out the following point can be concluded:

- A dynamic model of the proposed hybrid wind-PV-battery system has been successfully developed.
- The proposed control strategy was improved the power management as compared to the conventional method and the control strategy provided overall effectiveness as shown in simulated results.
- The hybrid system provided flexible power for continuous load demand with smooth power transfer from DC link to load.
- The number of energy storage (source) requirement in the hybrid system reduces as compared to individual wind or PV system.

FUTURE SCOPE

In considering with literature reviewed and present scope of thesis works the following issues remains for the developments. For efficient and practically implementing stand-alone hybrid wind-PV-battery system in the isolated region the following solution gives better and cost-effective power in near future.

- By using super-capacitor with battery new approach may be implemented.
- New control approaches other than the MPPT algorithm will be implemented for better extracting power.
- Supervisory (feedback) control method for online competitive analysis may be used.
- For maximizing battery life new techniques can be implemented considering cost optimized algorithm.
- Due to high switching losses, new converter topology with lesser switches can also implement with the new control strategy.

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APPENDIX-I

PHOTOVOLTAIC SYSTEM STANDARDS

Some of the International Electrotechnical Commission (ICE) standards for standalone PV system (http://www.iec.ch) are followings:

IEC 60146-1	Semiconductor convertors – General requirements and line commutated Converters
IEC 60269-6	Low-voltage fuses – Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems
ICE 60364-7-712	Electrical installations of buildings – Requirements for special installation or locations – Solar photovoltaic power supply systems
IEC 60891	Procedures for temperature and irradiance corrections to measured I-V characteristics
IEC 60904-1	Measurements of photovoltaic current-voltage characteristics
IEC 60904-2	Requirements for reference solar devices
IEC 60904-3	Measurement principles for terrestrial photovoltaic solar devices with reference spectral irradiance data
IEC 60904-4	Reference solar devices – Procedures for establishing calibration Traceability
IEC 60904-5	Determination of equivalent cell temperature of photovoltaic devices by the open-circuit voltage method
IEC 60904-6	Requirements for reference solar modules
IEC 60904-7	Computation of the spectral mismatch correction for measurements of photovoltaic devices
IEC 60904-8	Measurement of spectral responsively of a photovoltaic device
IEC 60904-9	Solar simulator performance requirements
IEC 60904-10	Method of linearity measurement
IEC 61215	Crystalline silicon terrestrial photovoltaic modules – Design qualification and type approval
IEC 61646	Thin-film terrestrial photovoltaic modules – Design qualification and type Approval

IEC 61683	Photovoltaic system – Power conditioners – Procedure for measuring efficiency
IEC 61730-1,2	Photovoltaic module safety qualification – Requirements for construction
IEC 61836	Solar photovoltaic energy system – Terms, definitions and symbols
IEC 62093	Balance-of-system components for photovoltaic systems – Design qualification natural environments
IEC 62109-1,2	Safety of power converters for use in photovoltaic power systems – General requirements
IEC 62124	Photovoltaic stand-alone systems design verification
IEC 62446	Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection
IEC 62509	Battery charge controller for photovoltaic systems – performance and Functioning
IEC 62548	Design requirements for photovoltaic arrays

APPENDIX-II

Permanent Magnet Synchronous Generator	
Number of Pole pair	4
Rated speed (rpm)	1260
Rated Power (kW)	1
Stator Resistance (ohm)	5.8
Direct Inductance (mH)	0.0448
Quadrature Inductance (mH)	0.1024
Inertia	0.011
Wind Turbine	
Rated Power (kW)	1
Base Wind Speed (m/s)	12
RC Filter	
Series Inductance (mH)	13
Shunt Capacitance (micro F)	20
PV Panel	
Rated Power (kW)	1
Base Irradiation (kW/m^2)	1

PUBLICATIONS

- **Kiran Kumar Nagda and Dr. R. R. Joshi, "Dynamic Modeling of Hybrid System for Efficient Power Transfer under Different Condition",** paper published in International Journal of Electrical Engineering and Ethics (IJEEE), Volume 1, Issue 4, pp. 1-7, July 2018. (ISSN: 2456-9771)