INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN 2278 – 0211 (Online)

Optimal Sizing of Stand-Alone Hybrid Solar/Wind/Battery/Diesel Energy System

Pallavi Gajbhiye
M. Tech. Scholar, Department of Electrical and Electronics Engineering,
NRI Institute of Information Science and Technology, Bhopal, (MP), India
Payal Suhane
Associate Professor, Department of Electrical and Electronics Engineering,
NRI Institute of Information Science and Technology, Bhopal, (MP), India

Abstract:
The main objective of this paper is the cost optimization of Hybrid Energy System (HES) - a combination of a solar Photovoltaic (PV), Wind Turbine (WT), battery and a Diesel Generator (DG). In recent years, HES has become one of the most significant and promising system, which requires safer means of maintaining the system's security, stability and reliability and with a large number of distributed generation access, it cannot be ignored. These have become common in remote space, power generation applications as a result of advancements in renewable energy technologies. The main aim is to cover the load demand under varying weather conditions and to control the power delivered by a 100 KW HES and also overall Power Management Strategy (PMS) is designed for HES to manage the power flows among the different energy sources and the storage unit in the system. The control of internal powers and PMS should be implemented to satisfy the stand-alone requirements while maximizing the benefit of Renewable Energy Source (RES) and optimizing the operation of each storage unit. HOMER is used to evaluate the optimal sizing of the components in HES and reliability is also fulfilled at the same time. In this, the electrification costs like capital, replacement, operation and maintenance cost and fuel cost are considered for optimal designing.

Keywords: *Hybrid Energy System (HES), Photovoltaic (PV), Wind Turbine (WT), battery, Diesel Generator (DG), Power Management Strategy (PMS)*

1. Introduction

As increase in population and industrialization [1] energy plays an important role in human, social and economic development hence it is a basic requirement of the nation. In parallel to developing technology, more energy demand makes us seek new energy sources [2].
Since the early eighties, power generation from fossil fuels have been accepted and used as an electricity generating system in geographically remote and demographically sparse areas, hence it serves an entire isolated load [3][4]. But the main target was to secure both fuel saving and the reliable power supply and which in a way are conflicting objectives. The majority of energy production is strongly based on very limited non-renewable energy resources like diesel. But diesel power generation is not always the best option as every liter of diesel releases about three kilograms of carbon dioxide (CO_2) which obviously pollutes the environment and therefore the alternate option is RES [5]. From last four decades, it is one of the most efficient solution for sustainable energy development, hence there is an urgent need of it. The increasing number of RES and distributed generators requires new strategies for their operations in order to maintain or improve the power-supply stability and quality [6].
From all RES, Solar and Wind are world's fastest growing sources and is a perfect match, because wind speed tends to lower in summer, when solar energy can compensate, and higher in winter, when sunshine falls to very low levels. They have low or zero emission of pollutant gases means most environment-friendly type, most abundant and omnipresent, inexhaustible sources, less operational and maintenance cost, and has easy availability [7][8], but unfortunately they have two major problems: the conversion efficiency of electric power generation is very low (9-17%), especially under low irradiation conditions and the electric power generated by solar and wind changes continuously with weather conditions because they depend on daily and seasonal patterns [6] i.e. uncontrollable meteorological conditions [9]. And therefore, they are integrated together as HES which combine RES and conventional energy (diesel) as a small scale alternative source of electrical energy, where conventional generation is not practical e.g. remote villages in developing countries or ranches located far away from the main power lines [4]. It is considered as a complete

“green” power generation system because the main energy sources and storage system are all environmentally friendly [10]. In most remote areas, solar and wind are available but, they are not fully controllable as their availability depends on daily and seasonal patterns. Therefore, conventional energy source like DG and also energy storage system are used in conjunction with renewable energy for reliable operation or is a good option for 24 hours load for base load and also for critical loads and this system founds an optimal control strategy model to operate the hybrid system [4].

Ghassan Halasa et al. [11] presented the electrical power generation using solar and wind energy for the country of Jordan. Sights are chosen to produce electricity using, the wind in the Mountains. Presently, with the oil prices are on the ascent, the cost of electrical output power is really gamey. Chaitanya Marisarla et al. [12] propose a HES consisting of wind, photovoltaic and fuel cell. Battery storage is designed to supply continuous power and provide the deficit power when the combined wind and photovoltaic sources cannot meet the net load demand. Balamurugan T. et al. [13] reported the optimum power flow internal control for Grid Connected Photovoltaic/Wind Turbine/Diesel Generator (GCPWD) Hybrid System with hybrid storage system. HES is for continuous power flow management and a DG is additional to make sure uninterrupted power. The developed GCPWD Hybrid System gives continuous power to the AC/DC, hundreds and it has two power sink (AC & amp ; DC loads). Ugur Fesli et al. [14] work covers the realization of a hybrid renewable energy system for a domestic application, which runs under a microcontroller to utilize the solar and wind power. Boucetta. Abdallah et al. [15] deals with power management of a solar and wind hybrid generation system for interconnection operation with electrical distribution system.

The speedy development in solar and wind power is due to favorable world political climate towards these energies and in America, some nations have enacted Renewable Portfolio Commonplace (RPS) law that entails utilities to sell a particular % of the energy from property energy sources at intervals cheap stipulated times, despite the fact that Europe and North America have the biggest put in capability of turbine capability, China, India, and developing world bear the biggest potential for wind generation [2].

2. System Components

HES components should be selected carefully and must ensure that they are well managed and monitored properly. It comprises of PV, WT, battery bank and DG as shown in Figure 1.

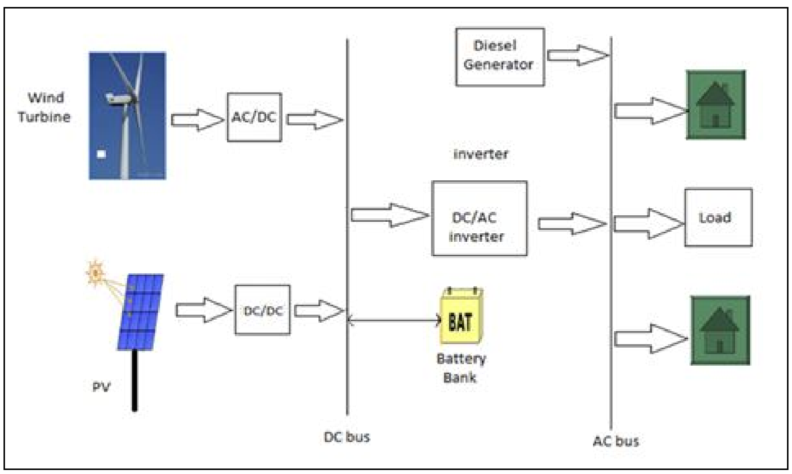


Figure 1: Block Diagram of HES

These components are integrated and complement each other to meet the load demand. In this, PV panel and WT are connected to DC bus and DG is connected to AC bus and energy from PV panel, WT and DG are converted into electricity then sent to loads or stored in a battery bank.

2.1. PV System

PV system is made up of PV cells and devices, which convert light energy into electricity directly [16]. PV cells are commonly known as solar cells, it converts energy from sunlight into DC electricity then into AC by DC-DC converters and inverters [17]. If several such cells are connected in series and parallel circuits on a panel (module), then high power is achieved. In other words, solar array or panel is a group of several modules, which are electrically connected in series-parallel combination to get the required current and voltage [7]. Output of PV panel includes the impact of geographic location like solar radiation and temperature [18] means output power begins from zero at sunrise, rises to a peak at noon time, and returns to zero at sunset [19].

For standalone PV system, consumers should clear that they want to use DC from PV or convert the power into AC, because appliances and lights for AC are much more common and cheaper, but the DC into AC power conversion can consume up to 20 % of all the power produced by the PV system [16]. The total development of solar PV system has exceeded 151 MW, ranking India in 4th place in the world after Japan, USA and Germany.

2.2. WT System

WT converts kinetic energy from wind (also called wind energy) into mechanical energy and the process is known as wind power. Wind power is basically electricity produced by generator, driven by a turbine according to flowing air's aerodynamics [16] and it's been practiced for many years for sailing, grinding grain and for irrigation [2]. If this mechanical energy is used to produce electricity, then the device is called as WT or wind power plant. For WT, appropriate wind speed and direction are the key elements and it should be subjected to non-turbulent wind and mounted higher than trees and other obstacles [16]. They are usually connected in parallel, not in a series. Several WT can be connected in parallel to match the system current requirements. The energy and output current of WT for each time instant is calculated on the basis of local weather conditions and actual installation height of turbines [18].

PV and wind is a perfect match, because PV-wind hybrid system suits to conditions where sun light and wind has seasonal shifts i.e., in summer the daytime is long and sun light is strong enough, while in winter the days are shorter and there are more clouds [16].

2.3. DG System

DG set convert fuel energy (diesel or bio-diesel, in this case diesel) into mechanical energy by means of internal combustion engine then into electric energy by means of electric machine which works as generator [17] i.e. it consumes fuel to produce electricity, which is the blood of the engine [16]. It causes significant impacts on environment because every litre of diesel releases about three kilograms of CO_2 but the continuous operation of DG is not needed because it consumes high amount of fuel [5]. Its properties are - maximum and minimum electrical output power, expected lifetime in operating hours, type of fuel it consumes and its fuel curve, which relates the quantity of fuel consumed to the electrical power produced [16].

2.4. Battery System

A battery is defined as a combination of individual cells. A cell is the elemental combination of materials and electrolyte constituting the basic electro-chemical energy storer. A storage cell is recharged after discharge by passing a direct current through the cell in the opposite direction to the discharge current. In other words, battery is used as a backup for long run applications means it stores the excess energy generated by HES and supply that energy during low generation period [18].

In this, priority is given to solar and wind energy system and recommended to keep always online. Battery and diesel power generation are designed to operate depending on load demand and availability of power [20].

3. Power Management Strategy (PMS)

Contemporary management technique supervises the operation of standard HES which permits the employment of natural resource to be optimized. Advanced management techniques also will improve the performance of such systems by up energy management [2].

Energy management system is designed for multiple energy resources in stand-alone HES, in which a PMS introduced to control the power distribution among the power generating system and developed to provide some services to the stand-alone i.e. to improve the reliability and power quality of the stand-alone HES system [20]. PMS manages the power flow of energy system and battery to fulfill the load demand, i.e. it controls the power flow of energy of individual power generating system and battery (it controls the charging/discharging of the battery bank). It is designed such that the use of battery is as low as possible. Hybrid power generation system needs, PMS to control the proper active power flow from and to the battery storage system. The combination of hybrid system with battery and efficient PMS makes the best
use of the advantages of each power generating system [21].

If load demand changes, then power supplied by the hybrid system must be properly changed or power delivered from the PV, WT system as well as from the DG must be coordinated to meet load demand [22].

3.1. PMSs are given below

3.1.1. Total Power Generation (solar + wind) > load demand

Load will be supplied + Battery charging

If total power generation (combination of solar and wind) of hybrid system is greater than load demand then load will be supplied and excess power is used to charge the battery, i.e. battery is in the State of Charging (SOC) and the charged quantity of the battery at the moment of (t) is given by [23]:

$$P_b(t) = P_b(t-1).(1-\sigma) + [P_z(t) - P_l(t)/\eta_{inv}] .\eta_{bc} \quad (1)$$

where,

$P_b(t)$: battery charged quantity at time (t)

$P_b(t-1)$: battery charged quantity at time (t-1)

σ : self-discharge rate per hour

$P_z(t)$: total output power of PV cell and WT in time interval (t-1, t)

$P_l(t)$: total load power in time interval (t-1, t)

η_{inv} : inverter efficiency

η_{bc}: battery charging efficiency

Battery Energy Storage System (BESS) is made up of a battery bank, a bi-directional DC/DC converter and control system. It has its independent control objective, and by controlling each part, the entire system is operating safely. BESS should be able to operate in two directions-battery can be charged to store the extra energy and also can discharge the energy to loads means it can charge and discharge to balance the power between the generation system and the load demands and thus improve the stability of the entire system [24]. In other words, power management of HES depends on SOC of battery, correspondingly the battery can be charged or discharged [21]. Life of a battery is more if it is kept at near 100% of its capacity, or returned to that state quickly after a partial or deep discharge [19]. To get efficient power distribution, battery should operate in the high efficiency region and battery SOC should be maintained at a reasonable level i.e. between 40 to 80% [21]. The battery bank serves as a short-duration power source to meet the load demands which cannot be fully met, particularly during fluctuations or transient periods [24].

3.1.2. Total Power Generation (solar + wind) < load demand

Total power generation (solar + wind) + Battery > load demand

Load will be supplied + Battery discharging

If total power generation (combination of solar and wind) of hybrid system is less than load demand (if solar and wind are insufficient to meet the load demand, then battery power is needed) or if total power generation (combination of solar and wind) of hybrid system and battery is greater than load demand then load will be supplied and battery is allowed to share the required real power (discharge the stored power to supply loads) i.e. battery is in the state of discharging and the charged quantity of the battery at the moment of (t) is given by [23]:

$$P_b(t) = P_b(t-1).(1-\sigma) + [P_l(t)/\eta_{inv} - P_Z(t)] / \eta_{bf} \quad (2)$$

where,

η_{bf}: battery discharging efficiency

As the output of solar and wind is of random behavior, therefore the battery storage capacity is constantly changing correspondingly in hybrid systems [23].

3.1.3. Total Power Generation (solar + wind) + Battery < load demand

DG will be operated.

If total power generation (combination of solar and wind) of hybrid system and battery is less than load demand then only DG will be operated. In another way, if renewable resources and the batteries are not able to satisfy the load demand, then only DG is used [18]. If wind power output is insufficient to meet the load demand, then DG supplies the power because DGs installed capacity is sized to meet the peak power demand. In such systems, rejection of random power disturbances at the output of WT can cause relatively large frequency and voltage fluctuations [25].

4. Experimental Set Up and Results

Based on the model and control methods, the proposed HES can be implemented in Hybrid Optimization Model for Electric Renewable (HOMER) software as shown in Figure 2. In this part, HOMER results have been presented in Figure 3 and cost summary is also given in Figure 4.

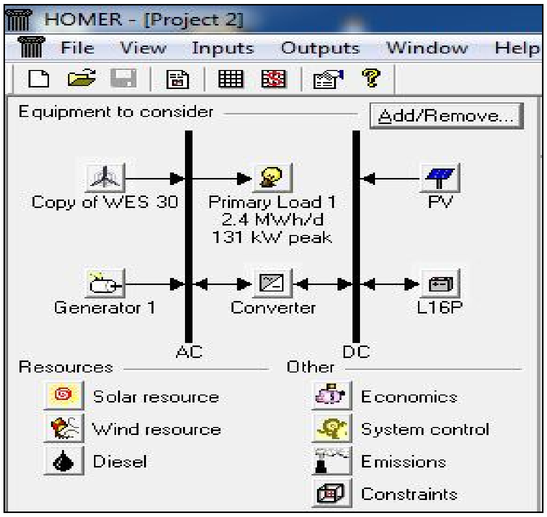
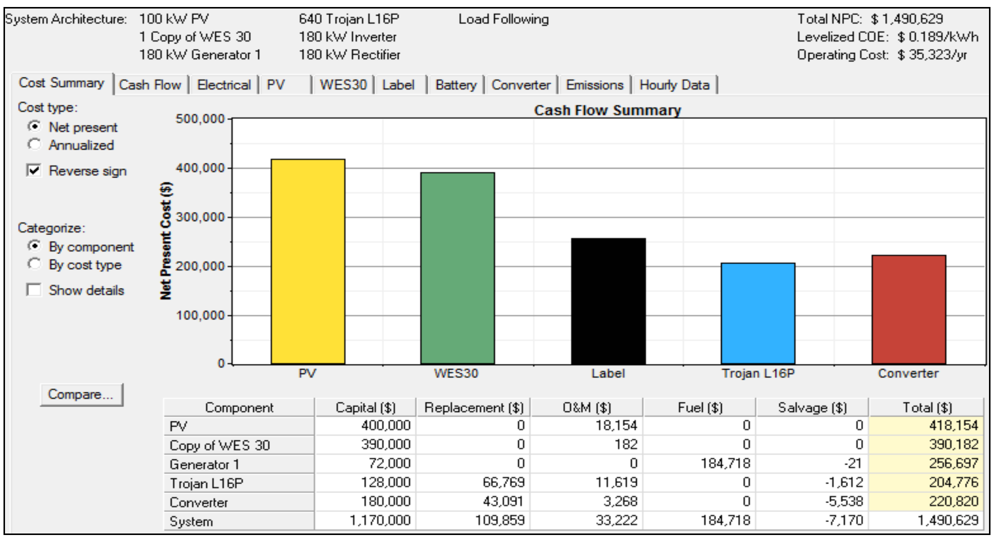


Figure 2: Proposed HES in HOMER

PV (kW)	WES30	Label (kW)	L16P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
100	1	180	680	180	LF	$ 1,178,000	34,138	$ 1,487,871	0.188	0.97	19,060	598
100	1	180	640	180	LF	$ 1,170,000	35,323	$ 1,490,629	0.189	0.97	20,350	638
100	1	180	600	180	LF	$ 1,162,000	36,603	$ 1,494,247	0.189	0.97	21,656	679
100	1	180	560	180	LF	$ 1,154,000	38,073	$ 1,499,594	0.190	0.97	23,151	725
100	1	180	520	180	LF	$ 1,146,000	40,008	$ 1,509,158	0.191	0.97	25,064	789
100	1	180	480	180	LF	$ 1,138,000	41,971	$ 1,518,971	0.192	0.96	27,060	850
100	1	180	440	180	LF	$ 1,130,000	44,171	$ 1,530,938	0.194	0.96	29,278	921
100	1	180	400	180	LF	$ 1,122,000	46,384	$ 1,543,033	0.195	0.96	31,567	993
120	1	180	680	180	LF	$ 1,258,000	32,633	$ 1,554,210	0.197	0.98	17,164	540
120	1	180	640	180	LF	$ 1,250,000	33,827	$ 1,557,048	0.197	0.98	18,476	580
100	1	180	360	180	LF	$ 1,114,000	48,930	$ 1,558,138	0.197	0.96	34,152	1,077
120	1	180	600	180	LF	$ 1,242,000	35,100	$ 1,560,605	0.197	0.97	19,885	624
120	1	180	560	180	LF	$ 1,234,000	36,532	$ 1,565,601	0.198	0.97	21,388	670
120	1	180	520	180	LF	$ 1,226,000	38,258	$ 1,573,268	0.199	0.97	23,111	725
100	1	180	320	180	LF	$ 1,106,000	51,531	$ 1,573,745	0.199	0.95	36,872	1,160
120	1	180	480	180	LF	$ 1,218,000	40,218	$ 1,583,064	0.200	0.97	25,103	788
130	1	180	680	180	LF	$ 1,298,000	31,852	$ 1,587,118	0.201	0.98	16,207	505
130	1	180	640	180	LF	$ 1,290,000	33,018	$ 1,589,706	0.201	0.98	17,480	546
130	1	180	600	180	LF	$ 1,282,000	34,346	$ 1,593,757	0.202	0.98	18,970	593
120	1	180	440	180	LF	$ 1,210,000	42,371	$ 1,594,599	0.202	0.96	27,281	856
100	1	180	280	180	LF	$ 1,098,000	54,819	$ 1,595,592	0.202	0.95	40,268	1,271
130	1	180	560	180	LF	$ 1,274,000	35,755	$ 1,598,554	0.202	0.97	20,531	641
100	1	180	680	180	CC	$ 1,178,000	47,076	$ 1,605,308	0.203	0.96	30,193	803

Figure 3: Experimental results with HOMER



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	400,000	0	18,154	0	0	418,154
Copy of WES 30	390,000	0	182	0	0	390,182
Generator 1	72,000	0	0	184,718	-21	256,697
Trojan L16P	128,000	66,769	11,619	0	-1,612	204,776
Converter	180,000	43,091	3,268	0	-5,538	220,820
System	1,170,000	109,859	33,222	184,718	-7,170	1,490,629

Figure 4: Cost summary in HOMER

5. Conclusion

It includes the relevant papers on design, modeling, control and optimization of HES, which helps to review that the most frequent systems are made up of PV system and/or WT system and/or DG system with energy storage in the battery, where solar and wind generation systems are the main power generation devices. This system is a good option for 24 hours load for base load and also for critical loads under varying weather conditions with minimum cost in rural and remote areas. The main aim of this paper is to calculate the optimal sizing of HES components using HOMER and to design an energy management system for multiple energy resources in which a PMS is introduced to improve the reliability and power quality of the stand-alone HES system. The system configuration and characteristics of the main components for HES has also been presented. HES power fluctuation is less dependent on the environmental conditions as compared to the power generated by individual PV and WT systems, this power fluctuation is suppressed by battery and DG in this, and it will be the subject of future work.

6. References

i. A. M. Zaki, S. I. Amer and M. Mostafa, "Maximum Power Point Tracking for PV System Using Advanced Neural Networks Technique", International Journal of Emerging Technology and Advanced Engineering, Vol. 2, Issue 12, ISSN: 2250-2459, pp. 58-63, December-2012, www.ijetae.com.

ii. Pradeep Maheshwari and Dr. Sushma Gupta, "The Hybrid (Wind and Solar) Renewable Energy Resources in Distribution System: A Current Status", International Journal of Science and Research (IJSR), Vol. 3, Issue 6, ISSN (Online): 2319-7064, June-2014.

iii. Ajay Kumar Bansal, Rajesh Kumar and R. A. Gupta, "Economic Analysis and Power Management of a Small Autonomous Hybrid Power System (SAHPS) Using Biogeography Based Optimization (BBO) Algorithm", IEEE Transactions On Smart Grid, Vol. 4, No. 1, March-2013.

iv. Nabil A. Ahmed and Masafumi Miyatake "A Stand-Alone Hybrid Generation System Combining Solar Photovoltaic and Wind Turbine with Simple Maximum Power Point Tracking Control", IEEE 2006.

v. Abu Mohammad Osman Haruni, Ameen Gargoom, Md. Enamul Haque, and Michael Negnevitsky, "Voltage and Frequency Stabilisation of Wind-Diesel Hybrid Remote Area Power Systems", Centre for Renewable Energy and Power Systems, School of Engineering, University of Tasmania Hobart, TAS 7001, Australia.

vi. Punemsujith Chandra and S.C.Gupta, "Power Control Strategy of a Grid Connected Hybrid System", International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), Vol. 3, Special Issue 3, ISSN (Online): 2319 – 8753, ISSN (Print): 2347 – 6710, March-2014.

vii. M. Suresh and Yerra Sreenivasa Rao, "Maximum Power point Tracking in Hybrid Photo-voltaic and Wind Energy Conversion System", Proceedings of International Journal of Engineering Research & Technology (IJERT), Vol. 1 Issue 5, July-2012.

viii. R. Sankarganesh and S. Thangavel, "Maximum Power Point Tracking in PV System using Intelligence based P&O Technique and Hybrid Cuk Converter", Proceedings of International Conference on Emerging Trends in Science, Engineering and Technology, ISBN: 978-1-4673-5144-7/12/$31.00, IEEE 2012.

ix. Tao Zhou and Bruno François, "Energy Management and Power Control of a Hybrid Active Wind Generator for Distributed Power Generation and Grid Integration", IEEE Transactions on Industrial Electronics, 2010.

x. Caisheng Wang and M. Hashem Nehrir, "Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System", IEEE Transactions on Energy Conversion, Vol. 23, No. 3, September-2008.

xi. Ghassan Halasa, "Wind-Solar Hybrid Electrical Power Generation in Jordan", Jordan Journal of Mechanical and Industrial Engineering, Vol. 4, No. 1, pp. 205-209, Jan-2010.

xii. Chaitanya Marisarla, K. Ravi Kumar, "A Hybrid Wind and Solar Energy System with Battery Energy Storage for an Isolated System", International Journal of Engineering and Innovative Technology (IJEIT), Vol. 3, Issue 3, pp. 99-104, September-2013.

xiii. Balamurugan T., Manoharan S., "Optimal Power Flow Management Control for Grid Connected Photovoltaic/Wind turbine/Diesel generator (GCPWD) Hybrid System with Batteries," International Journal of Renewable Energy Research, Vol. 3, No. 4, 2013.

xiv. Ugur Fesli, Raif BAYIR, Mahmut OZER, "Design and Implementation of a Domestic Solar-Wind Hybrid Energy System", Proceeding of Transmission and Distribution Conference and Exhibition, IEEE PES- 2006, pp. 29-36, IEEE, 2006.

xv. Boucetta. Abdallah, Labed. Djamel, "Modeling and Control of a Wind/PV Hybrid System Gridconnected", International Journal of Scientific & Engineering Research, Volume 4, Issue 8, pp. 1394-1398, August-2013.

xvi. Rakesh Gurjar and Amita Mahor, "Renewable Energy: Solar–Wind Hybrid System Power Supply For Telecommunication Sector" VSRD International Journal of Electrical, Electronics & Communication Engineering, Vol. 3, ISSN: 2231-3346, pp. 2.

xvii. Aparna Pachori and Payal Suhane, "Modeling and Simulation of Photovoltaic/Wind/Diesel/Battery Hybrid Power Generation System", International Journal of Electrical, Electronics and Computer Engineering (IJEECE), Vol. 3, Issue 1, ISSN: 2277-2626, pp. 122-125, 24 May 2014.

xviii. Rajesh Kumar, R.A. Gupta and Ajay Kumar Bansal, "Economic analysis and power management of a stand-alone wind/ photovoltaic hybrid energy system using biogeography based optimization algorithm", pp. 33-43, ElSEVIER, 2013.

xix. Bogdan S. Borowy and Ziyad M. Salameh, "Optimum Photovoltaic Array Size for a Hybrid Wind/PV System", IEEE Transactions on Energy Conversion, Vol. 9, No. 3, September-1994.

xx. Md. Aminul Islam, Adel Merabet, Rachid Beguenane, Hussein Ibrahim, "Power Management Strategy for Solar-Wind-Diesel Stand-alone Hybrid Energy System", International Journal of Electrical, Computer, Electronics and Communication Engineering, Vol. 8, No. 6, 2014.

xxi. Sweeka Meshram, Ganga Agnihotri, and Sushma Gupta, "Power Management Strategy for Active Power Sharing in Hydro/PV/Battery Hybrid Energy System", Chinese Journal of Engineering, Hindawi Publishing Corporation, Vol. 2013, Article ID 723860, 7 pages, http://dx.doi.org/10.1155/2013/723860.

xxii. P.PRADEEP and B.KIRAN BABU, "Power-Management Strategies for a Grid-Connected PV-FC Hybrid System By Using Fuzzy Logic Controller", Proceedings of International Journal of Modern Engineering Research (IJMER), Vol. 2, Issue. 2, pp-358-364, ISSN: 2249-6645, Mar-Apr 2012.

xxiii. Mohammad Reza Javadi, Abolfazl Jalilvand, Reza Noroozian and Majid Valizadeh, "Optimal Design and Economic Assessment of Battery Based Stand-Alone Wind/PV Generating System using ABC".

xxiv. B.K. Prusty, Dr. S M Ali and D.K. Sahoo, "Modeling and Control of Grid-Connected Hybrid Photovoltaic/Battery Distributed Generation System", Proceedings of International Journal of Engineering Research & Technology (IJERT), Vol. 1 Issue 9, ISSN: 2278-0181, November- 2012.

xxv. Sami H. Karaki, Riad B. Chedid and Rania Ramadan, "Probabilistic Production Costing of Diesel-Wind Energy Conversion Systems", IEEE Transactions on Energy Conversion, Vol. 15, No. 3, September- 2000.