Survey of Energy Computing in the Smart Grid Domain

Rajesh Kumar[1] and **Arun Agarwala**[2]

Submitted in September 2012, Accepted in March 2013

Abstract - Resource optimization, with advance computing tools, improves the efficient use of energy resources. The renewable energy resources are instantaneous and needs to be conserve at the same time. To optimize real time process, the complex design, includes plan of resources and control for effective utilization. The advances in information communication technology tools enables data formatting and analysis results in optimization of use the renewable resources for sustainable energy solution on smart grid.

The paper presents energy computing models for optimally allocating different types of renewable in the distribution system so as to minimize energy loss. The proposed energy computing model optimizes the integration of renewable energy resources with technical and financial feasibility. An econometric model identifies the potential of renewable energy sources, mapping them for computational analysis, which enables the study to forecast the demand and supply scenario. The enriched database on renewable sources and Government policies customize delivery model for potential to transcend the costs vs. benefits barrier. The simulation and modeling techniques have overtaken the drawbacks of traditional information and communication technology (ICT) in tackling the new challenges in maximizing the benefits with smart hybrid grid. Data management has to start at the initial reception of the energy source data, reviewing it for events that should trigger alarms into outage management systems and other real-time systems such as portfolio management of a virtual hybrid power plant operator. The paper highlighted two renewable source, solar and wind, for the study in this paper, which can extend to other renewable sources.

Index Terms - Energy Computation, Energy Mapping, Techno-Economical feasibility of Renewable Energy, Renewable energy model, Energy Efficiency

1. INTRODUCTION

Supervisory Control and Data Acquisition (SCADA) systems for control on hybrid sources of energy have two components: Energy Management Systems (EMS) and Distribution Management Systems (DMS). A hybrid EMS/DMS system requires higher level security analysis functions such as state estimation and contingency analysis for EMS and feeder voltage and loss optimization for DMS systems.

[1, 2] IDDC, Indian Institute of Technology (IIT) Delhi, New Delhi
E-mail: [1]rajeshkr38@nic.in and [2]agarwala@iddc.iitd.ernet.in

Energy Distributive system model for adequate accurate predictive analysis plays important role for sustainable country energy resources, in consideration of all influential factors in energy generation and distribution. For prediction purposes the important parameters are geographical location, seasonal influence, effect of climate change and state or area concession. Renewable energy potential for mitigation action on climate change reported by IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation run on four models namely, IEA-WEO2009-Baseline, ReMIND-RECIPE, MiniCAM-EMF22, ER-2010 for potential scenarios [1]. With the abundant data and relative economic indicator, energy prediction is performed with close loop predictive system based on a timing algorithm. The energy economics in free trade market like India, where the peak load varies abruptly due to season and community demand, its hourly prediction model is more useful.

The energy prediction model proposed in this paper has a large scope to take on innovative role for country's growth in the energy security regime. Scientists are working on commercial application of energy modeling. The computation and mapping tool is unique in that city planners and government to integrate renewable energy on the grid. The tool is helpful for planning new substations and infrastructure in the ever-growing city.

The study optimizes the integration of the various renewable energy resources with financial feasibility. The model overcomes the constraints like hourly available sources, the voltage limits, the feeders' capacity, and the discrete size of the available distributive generation and distribution units. This paper addresses the following issues:

- Power grid planners need to account for the impacts brought by different kinds of energy sources like power factor, hybrid energy voltage, load management programs, energy efficiency, high renewable energy penetrations, and energy storage.
- Evaluation of the cost/benefit of the different technologies.
- Setup a planning tool to run a base case and a comparable case that has a new technology implemented.
- Generate a cost effective/optimal expansion plan.

The paper is organized to present the modeling approach in computing complex energy scenario of demand and supply. The paper has computation and algorithms for modeling results of solar and wind renewable resources for conclusion and recommendation.

2. REVIEW OF ENERGY MODELS

Energy is a vital input for social and economic development of the community and the state. In technology driven economies the demand for energy in agricultural, industrial and domestic activities has increased remarkably, especially in emergent countries, which also increases greenhouse gases. The cost economics of energy forces the use of renewable energy sources more effectively, i.e. energy which comes from natural resources and is also naturally replenished. The dependability of renewable energy resources on the climate enhance the need for complex design, planning and control optimization methods [7].

Power system planning involves planning of generation, transmission, and distribution systems. Generation planning begins with mid-term (months to several years) and long-term (several years to 10 years) load forecasts because generation expansion often requires 2 to 10 years to complete. When load forecast is available, reliability evaluations will be the next step to assess where and when to install the new generation. Finally, economic evaluations are performed to determine the optimal generation expansion planning. Accurate load forecast leads to an economical capacity expansion plan that meets reliability requirements [10].

Leading vendors of power system planning tools are: Multi Area Production Simulation Software program (MAPS) from General Electric (GE), Plexos for Power Systems from Energy Exemplar, GridView from ABB, and PROMOD from Ventyx [20].

National Instruments Labview and the Labview Control Design and Simulation Module can be used to simulate a full wind turbine system, including the turbine, mechanical drive train, generator, power grid and controller. AROMA model method has been employed in a predictive model [11].

HOMER is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist in the design of micro-power systems. HOMER finds the feasibility of the system by assessing whether it can adequately serve the electric and thermal loads through an hourly time series simulation over one year. It also estimates the life-cycle cost of the system, which is the total net present cost of installing and operating the system over its lifetime.[6]

The RET Screen Plus Performance Analysis Module can be used worldwide to monitor, analyse, and report key energy performance data to facility operators, managers and senior decision-makers.

The MARKAL model uses an integrated energy system optimization framework that enables policymakers and researchers to examine the best technological options for each stage of energy processing, conversion, and use. This modeling framework was used to represent a detailed technological database for the Indian energy sector with regard to energy resources (indigenous extraction, imports, and conversion) as well as energy use across the five major end-use sectors (agricultural, commercial, residential, transport, and industrial)[6].

LINGO is a comprehensive tool designed to make building designs. It can solve Linear, Nonlinear (convex & nonconvex/Global), Quadratic, Quadratically Constrained, Second Order Cone, Stochastic, and Integer optimization models efficiently. [26]

Renewable energy potential for mitigation action on climate change reported by IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation run on four models namely, IEA-WEO2009-Baseline, ReMIND-RECIPE, MiniCAM-EMF22, ER-2010 for potential scenarios. There is enormous variation in the detail and structure of the models used to construct the scenarios. Many authors have, in the past, attempted to categorize models as either bottom-up or top-down [1].

These models have constraints including hourly available sources, the voltage limits, the feeders' capacity, the maximum penetration limit, and the discrete size of the available DG units, with in the legal constraints applicable [14].

3. ENERGY COMPUTATION AND MAPPING MODEL

Accurate predictive analysis influential factors in energy application have been taken into consideration during design of energy model in this paper[20]. Taking the collected abundant data and related economic indicator model is accepted by international trade standards as the base, further strict calculation can lead to relative economic indicators. For prediction, full consideration of seasonal influence on renewable energy application must be considered with a closed-loop predictive system formed based on timing algorithm, to make the predictive model able to provide perfect prediction in the light of varied data [4][5].

The computing and mapping is addressed to the energy demand and the potential energy resources. Available data are collected based on a particular sampling procedure on field works and survey in 2007 and continued in 2010. This mapping is expected capable of informing accurate data about renewable energy diversification distribution all over the province. The global data sets and analytical tools at National Renewable Energy Laboratory (NREL) and for India specific at Centre for wind Energy Technology (C-WET) and Indian Metrology Department (IMD) permit modeling of wind and solar radiation resource predictions [19].

The proposed model for energy computing and mapping is extensions of AROMA model in Indian conditions. ARIMA prediction algorithms model by Peng Chen et-al provide a reliable base for popularization of renewable energy source application in building construction, key technologies, which include the multi-level system framework, functional modules, database design [11]. The present study is focused on two types of renewable i.e. Solar and Wind [14].

The proposed method has been employed in predictive model have higher accuracy of time sequence. In this study, the auto regressive integrating moving average model, will be study and analyse for the adoption within considered condition [9]. Then predictive monitor will done by employing model, plus comparison of predictive monitoring results and historical data, so as to achieve even better predictive monitoring results. The formula used in ARIMA model is described as the following,

$X_t = \psi_1 X_{t-1} + \ldots\ldots + \psi_p X_{t-p} + a_t + \theta_1 a_{t-1} + \ldots. + \theta_q a_{t-q}$ ---- (1)

which $\psi_1 \ldots \psi_p$ is the autoregressive coefficient, p is autoregressive order, $\theta_1 \ldots \theta q$ is moving average coefficient, q is moving average order, { a_t …}is noise sequence, X_t is the original data sequence, y_t is a stationary sequence formed through d times differential [11].

3.1 Solar Energy Mapping

Solar radiation assessment stations provide measurements of global solar radiation available and this methodology is called directly and for locations where the data was not available, indirect methods were used [19]. The indirect methods are as follows;

- From extra-terrestrial radiation, allowing for its depletion by absorption and scattering by atmospheric gases, dusts, aerosols and clouds. This is theoretically based and requires some approximation of the absorbing and the scattering property of the atmosphere.
- From other meteorological elements, such as duration of sunshine and cloudiness using regression technique. This method is empirical based, and the form usually used involves actual and potential hours of sunshine, which gives the regression constants for global and diffused solar radiation at the particular location or site.

The solar energy data is collected, documented and analysed by Ministry of New & Renewable Energy (MNRE) and Indian Metrological Department, MNRE has published the solar radiation potential map for India [8]. The solar energy is converted into useful energy with two techniques explained here.

A) Photovoltaic Power

Solar energy photovoltaic power is the direct solar energy utilization form with non-pollution, effective and easy power generation which can be either independent running or parallel running. The independent running of solar energy photovoltaic power generation system requires battery as the energy storage device, chiefly adopted in remote areas without power grid and dispersedly populated areas. But, the whole system is rather costly. In areas where power grid is available, the parallel running shall not only lower down the cost greatly, but also highly efficient with a friendly environment features. Systematically collect the global solar radiation, the solar radiation capacity and the parameter of effective radiation surface area of the solar cell array for evaluation of solar energy photovoltaic efficiency applied in buildings, the economic indicators shall be calculated as follows:

1. The global solar radiation I_R obtained from the surface of the solar cell array
2. The energy in the form electrical voltage and current produced by solar cell array is P_V
3. The inverter loss during conversion to usable energy L
4. Substituted quantity S_{PV} of conventional energy power conversion

As the important data of evaluating solar energy photovoltaic power efficiency applied in buildings, based on the above-listed economic indicators, to obtain the solar energy photovoltaic power model economic indicators assemble solar energy photovoltaic power

E_{SPV} { I_R, P_V, L, S_{PV} } --- (2)

The solar photovoltaic (PV) market saw another year of extraordinary growth. Almost 30 GW of new solar PV capacity came into operation worldwide in 2011, increasing the global total by 74% to almost 70 GW as shown in figure 1 [16].

B) Solar Thermal

The solar thermal system is another form of solar energy utilization. The system is to collect solar radiation energy through a device named heat arrester to heat exchanger. Such installation is presently the most economical and technically mature product which is already commercialized [3][21]. While evaluating efficiency of the solar energy arrester, the following five economic indicators shall be considered:

1. Solar energy assurance factor φ
2. Solar energy heat collecting system efficiency η_1
3. Heat exchanger efficiency η_2
4. Useful heat quantity of solar heat collecting system Q_{uf}
5. Substitution quantity of conventional energy sources S_{PV}

Based of the above-listed five economic indicators, the assemble indicator of solar water heating is thus obtained as

E_{ewh} { φ, η_1, η_2, Q_{uf} , S_{PV} } --- (3)

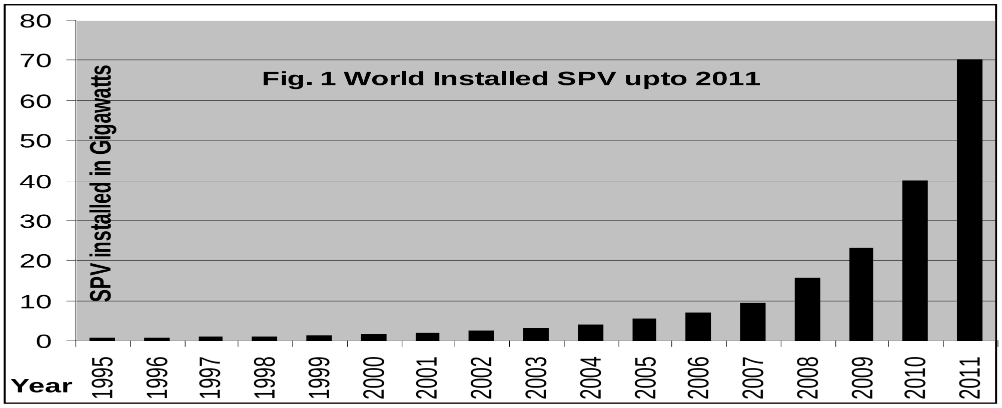

Figure 1: World installed SPV upto 2011

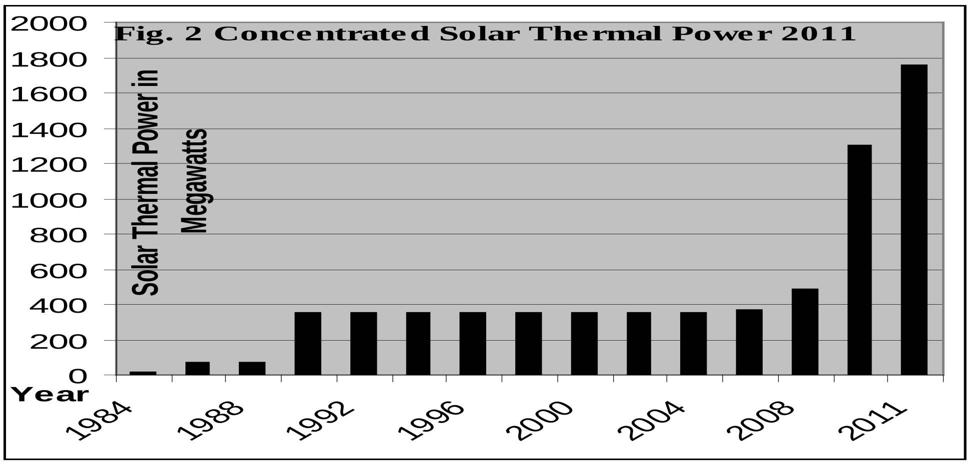

Figure 2: Concentrate Solar Thermal Power 2011

The concentrating solar thermal power (CSP) market continued its steady growth in 2011. More than 450 MW of CSP was installed, increasing total global capacity by 35% to nearly 1,760 MW [16]. The market was down relative to 2010, but significant capacity was under construction n at year's end. Over the five-year period of 2006–2011, total global capacity grew at an average annual rate of almost 37%. (See Figure 2.)

3.2 Wind Energy Computation

Wind energy potential is calculated based on the wind data on annual average wind speed. Annual average wind velocity data for wind-monitoring stations across Indian states are collected by the India Meteorological Department (IMD). To analyze variations across seasons, data was grouped season wise as summer (February–May), monsoon (June–September)and winter (October–January). Season wise wind velocity and standard deviation are computed for wind-monitoring stations. GIS is used for mapping wind resources spatially and to quantify and analyse temporal changes. Based on these, GIS thematic layers are generated, which would help in assessing the variability. The map helps to identify the most and the least suitable potential areas for harnessing wind energy.

The wind turbines power curve is defined as the power output of the machine as a function of wind speed. The behavior of the output power of the machine is generally dependent on four characteristic parameters. It is assumed that power generation starts at the cut-in wind speed V_C (m/s), that the output power increases as the wind speed increases from to the rated wind speed V_R (m/s), and that a constant value of the output power, namely the rated power P_R (kW), is produced when the wind speed varies from V_R to the cut-out wind speed V_F (m/s), which is the maximum wind speed value at which the turbine can correctly work.

The linear wind model assumes a linear (affine) dependence (within the interval [V_C & V_R]) of the wind turbine power output, P^t , on the current wind speed at the hub height V^t

As t=0 ,….. T-1, being T the time horizon in hours. In detail:

$$P^t = \begin{cases} 0 & V^t < V_C \\ P_R(a+bV^t) & V_C \le V^t \le V_R \\ P_R & V_R \le V^t \le V_F \\ 0 & V^t > V_F \end{cases} \qquad T=0, \ldots, T-1 \qquad (2)$$

It should be observed that wind speed V^t in (2) is that corresponding to the wind turbine hub height, H_{hub}, Since, in general, wind speed data can be measured or forecasted with reference to a height H_{data}that is different from the hub height, it is necessary to use an equation relating the wind speed at hub height with the wind speed V^t_{data} at H_{data} , taking into account the surface roughness length, which is a parameter that can be estimated on the basis of the land use at the wind farm location.

$$Ew\{ P_R, V_C, V^t, V_F, H_{hub} \} \quad (3)$$

During 2011, an estimated 40 GW of wind power capacity was put into operation, more than any other renewable technology, increasing global wind capacity by y 20% to approximately 238 GW as shown in figure 3.

Around 50 countries added capacity during 2011 and enhanced power capacity more than 10 MW in 68 countries and out of these 22 have cross 1 GW capacity. The top 10 countries account for nearly 87% of total capacity. Over the period from end-2006 to end-2011, annual growth rates of cumulative wind power capacity averaged 26% [16].

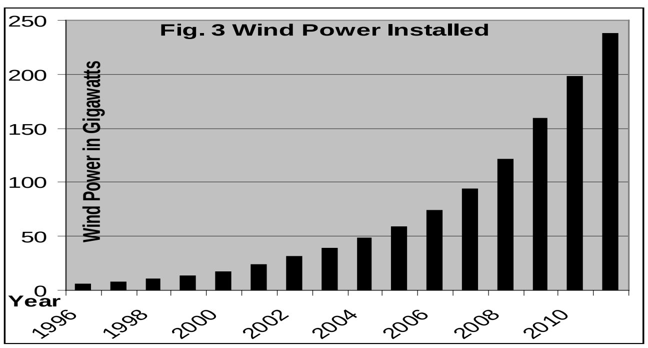

Figure 3: Wind Power installed

4. ECONOMICS OF ENERGY COMPUTATION

To achieve the accurate predictive analysis concerned influential factors in energy application have been considered during design of energy model in this article. The collected abundant data and economic indicator models by computation model obtain best solution for energy economics. A closed-loop predictive system is formed based on timing algorithm, to make the predictive model able to provide accurate prediction in the light of varied data [18][22][23].

To sum up above, taking the three types of energy sources as examples, in considering the platform needs to predict, statistic and analysis of the data, the overall model of energy is designed as shown in fig 3. The proposed computing models have been designed to target the following requirements of the Distributive Generation System (DGS) [2][24][25]:

- Analyze the situation and decide the data collection strategy and methodology on new and renewable sources. Collect and collate the relevant data required for modeling.
- Apply conceptual modeling for the design of integrated system like input on energy sources for the design of hybrid power plant to exploit maximum renewable energy sources at reasonable price.
- Either apply proposed models or in addition develop mathematical models for simulating environmental impact.
- Generate different scenarios ultimately to arrive at effective environment management plan with a view to support the decision makers.

The Control Design and Simulation Module (CDSM) provides a numerical simulation environment that enables users to test the model. CDMS is used to analyse the interactions between hybrid power solution comprises of mechanical-electrical systems [25] . Furthermore, the quality of existing models can be improved and other control strategies can be investigated by simulating deep-bar induction generators and more complex models of drive trains [15].

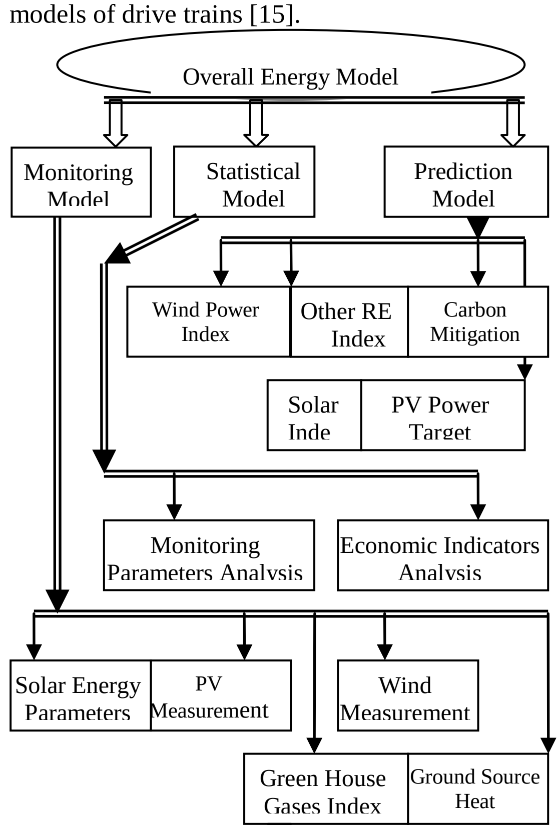

Figure 4: Integrated Energy Model

5. CONCLUSION

The computing proposes to develop algorithmic formulas for diversified renewable energy sources and building integrated projects. The proposed platform will also be able to conduct predictive analysis on the vast accumulated historical data, to aid finalization of the energy resource that is most economically and efficient. Furthermore, a statistical and analytical function is envisaged for this platform which can make comparative display of the same indicators of different projects or different indicators of the same project, hence providing a basis for popularization of renewable energy saving in different areas.

REFERENCES

[1]. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, IPCC, 2011

[2]. Aurobi Das, Dr. V. Balakrishnan "Energy Service Companies (ESCOs) to optimize Power in Peak Demand

Period in Hybrid Energy System- An Impact on Climate Change" 978-1-4244-5275-0/10/$26.00 ©2010 IEEE
[3]. Deepali Kamthania, G. N. Tiwari,"Determination of Efficiency of Hybrid Photovoltaic Thermal Air Collectors Using Aritificial Neural Network Approach for Different PV Technology" BIJIT - BVICAM's International Journal of Information Technology, Issue 7: (January-July, 2012 Vol.4 No.1)
[4]. Godfrey Boyle, "Renewable Energy" book published by Oxford University Press, 2004, ISBN978-0-19-958651-6
[5]. Hanane Dagdougui, Riccardo Minciardi, Member, IEEE, Ahmed Ouammi, Michela Robba, and Roberto Sacile, "A Dynamic Decision Model for the Real-Time Control of Hybrid Renewable Energy Production Systems", IEEE Systems Journal, Vol. 4, No. 3, September 2010, page 323-338.
[6]. Jinxu Ding and Arun Somani, "A Long-term investment planning model for mixed energy infrastructure integrated with renewable energy", 978-1-4244-5275-0/10/2010/ IEEE
[7]. L. Suganthia, Anand A. Samuelb, "Energy models for demand forecasting—A review" Renewable and Sustainable Energy Reviews 16 (2012) 1223– 1240
[8]. MNRE : National Solar Mission Document www.mnre.gov.in
[9]. M.E.H. Benbouzid, D. Diallo, Y. Amirat, H. Mangel and A. Mamoune "Entice students to power engineering using renewable energies undergraduate projects: example of development and application of wind turbines prototyping software under Matlab/Simulink®" 1, Rev. Energ. Ren. Vol. 8 (2005) 123 – 135
[10]. M. Soliman O.P. Malik D.T. Westwick, "Multiple model multiple-input multiple-output predictive control for variable speed variable pitch wind energy conversion systems", IET Renewable Power Generation, IET Renew. Power Gener., 2011, Vol. 5, Iss. 2, pp. 124–136
[11]. Peng Chen, Jie Liu*, Chongchong Yu, Li Tan, "Design and Implementation of Renewable Energy and Building Integrated Data Analysis Platform", 978-1-4244-4813-5/10 @2010 IEEE
[12]. Professor Lajos Göőz "Optimized Integration of Renewable Energy", EXPRES 2011 • 3rd IEEE International Symposium on Exploitation of Renewable Energy Sources • March 11-12, *2011*, Subotica, Serbia
[13]. R. Banosa, F. Manzano-Agugliarob, F.G. Montoyab, C. Gila, A. Alcaydeb, J. Gomezc, "Optimization methods applied to renewable and sustainable energy: A review" Renewable and Sustainable Energy Reviews 15 (2011) 1753–1766
[14]. Rajesh Kumar and Arun Agarwala, "Energy Computing Models for Techno-Economic Feasibility" INDIACom-2012; ISSN 0973-7529; ISBN 978-93-80544-03-8
[15]. Rajesh Kumar and Arun Agarwala, "RET Diffusion Model for Techno-Economics feasibility, International Conference on "SOLARIS -2012 - Energy security Global Warming and Sustainable Climate" organized by IIT Delhi and BERS on 7-9th February, 2012
[16]. REN21 Renewables 2012, Global Status Report, published by Paris: REN21 Secretariat.
[17]. S.C.Kaushik "Policy & Measure of economic efficiency, energy security and environment protection", Journal of Scientific & Industrial Research, Vol.66, November *2007*, pp 928-934
[18]. S.Saravanan, S.Vidya and Dr.S.Thangavel, "Design and Development of Multiple-Input Converter for Renewable Energy Integration", 978-1-61284-764-1/11/*2011* IEEE
[19]. T.V. Ramachandraa,b,B.V. Shruthib, "Spatial mapping of renewable energy potential" Renewable and Sustainable Energy Reviews, 11 (2007) 1460–1480
[20]. Tony B Nguyen, Ning Lu, and Chunlian Jin, "Modeling Impacts of Climate Change Mitigation Technologies on Power Grids" 978-1-4577-1002-5/11/$26.00 ©2011 IEEE
[21]. Deepali Kamthania and G. N. Tiwari, "Determination of Efficiency of Hybrid Photovoltaic Thermal Air Collectors Using Artificial Neural Network Approach for Different PV Technology", BIJIT - BVICAM's International Journal of Information Technology, Issue 7: (January-July, 2012) Vol.4 No.1,: ISSN 0973-5658
[22]. U. Navon, I Zur, D. Weiner, "Simulation model for optimising energy allocation to hydro-electric and thermal plants in a mixed thermaVhydro-electric power system", IEE PROCEEDINGS, Vol. 135, Pt. C, No. 3, MAY 1988
[23]. Rashmi Jha and A.K. Saini, "Process Benchmarking Through Lean Six Sigma for ERP Sustainability in Small & Medium Enterprises" BIJIT - BVICAM's International Journal of Information Technology, Issue 6: (July-December, 2011) Vol.3 No.2; ISSN 0973-5658
[24]. S.K.Muttoo, Sushil Kumar, "Data Hiding in JPEG Images" BIJIT - BVICAM's International Journal of Information Technology, Issue 1: (January-July, 2009) Vol.1 No.1 ; ISSN 0973-5658
[25]. Y. M. Atwa, E. F. El-Saadany, M. M. A. Salama, and R. Seethapathy Optimal Renewable Resources Mix for Distribution System Energy Loss Minimization, IEEE Transactions On Power Systems, Vol. 25, No. 1, February 2010 page 360-370
[26]. http://www.lindo.com/index.php?option=com_content&view=article&id=28&Itemid=4