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Investigations on Review of Software Tools for the Integration of Renewable Energy Systems for Sustainable Energy Development

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Abstract **Renewable energy sources are being utilized for supplying the electrical energy in remote rural areas, where grid extension is difficult. It also offers certain advantages like clean and green energy, pollution free environment, no greenhouse gas emissions, etc. Due to the intermittent nature of renewable energy sources, the integration of various energy sources may serves as an alternative for meeting the energy demand. A hybrid energy system is one which utilizes more than one energy sources in combination. While integrating the various energy sources, it is quite difficult to integrate them. Hence a proper design is required to analyze the techno-economical aspects of integrated renewable energy systems. Many software tools were available for analyzing the integration of renewable energy systems to design, evaluating their performance, determining the optimal design, economic viability of the various energy systems. This paper addresses about the various software tools available for analyzing the integration of various renewable energy sources with the grid for the sustainable development of a nation. The main objective of this paper is to provide the information/insight to a researcher as well as for energy planners regarding the selection of energy sources for the development of integrated renewable energy systems.**

Keywords — Hybrid Energy Sources, Hybrid Optimization Model for Electric Renewables (HOMER), Improved Hybrid Optimization by Genetic Algorithm (iHOGA). Integrated Renewable Energy Systems, Linear Programming, Renewable Energy.

I. INTRODUCTION

In developing countries like India, most of the rural areas have no access to electricity due to the uneconomical grid extension and non-availability of energy sources. Energy demand is increasing day by day due to the increase in population, decreased energy production due to the increase in fuel cost, etc and so on. In earlier 1970s, due to the oil crisis, a tremendous interest have been showed towards the utilization of renewable energy sources for supplying the energy to the remote areas and also to the places where there is abundant of energy sources. Among the various energy sources, solar and wind energies are most widely used and predominant in nature. The main disadvantages of these two resources are intermittent nature, site specific, seasonally dependent, etc. and so on. Some of the other energy sources used for electricity production are water, biomass, biogas, geothermal heat, etc. Usually, renewable energy systems are based on single energy sources or multiple energy sources. Single energy source based systems utilizes one sources based on solar/wind/biomass/biogas based on their availability, whereas multiple energy source based systems incorporates more than one energy sources along with the battery and a suitable power electronic systems for the power conversion. Several hybrid energy systems are reviewed in literature such as solar-wind, solar-wind-battery, solar-wind-biomass-battery, solar-wind-biogas-battery, etc. and so on.

While designing/integrating the various renewable energy systems, a proper design is required with the utmost care. Because of the integration of multiple energy sources, it is quite complex to match the sources with one another. Hence, optimal planning of integration of energy sources is essential to reduce the installation cost. This requirement can be met out by using the various software tools for analyzing the integration of energy sources. Several of software tools were available to evaluate their designs, analyze their performance to find the optimal solution.

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There were about more than 68 tools available for analyzing the performance of integrated renewable energy systems, out of which 37 tools are most widely used. Some of them are Aeolius, EMPS, Energy Plan, HOMER, Hysim, Hybrid 2, iHOGA, INSEL, RET Screen, SOLSIM, TRNSYS1.6, etc and so on. This paper aids the researchers and energy planners for the selection of suitable energy tool for analyzing the techno-economic feasibility of integrated renewable energy systems.

II. LITERATURE REVIEW

An up-to-date review of software tools available for renewable energy systems is essential for the optimal planning of IRES. In 1995, Rama Kumar et al. discussed about the design scenarios and design formulation of integrated renewable energy systems using the knowledge-based design tool IRES-KB with the aid of KAPPA-PC development tool [1]. A remote village with no access to electricity is chosen for the study and pointed out the impact of IRES for electrifying the selected remote area. Also, the versatility of IRES-KB is brought out in the discussion results [2]. Several approaches have been reported in the literature including linear programming, goal programming, probabilistic approach involving LPP, trade off methods, knowledge based approach, etc.

Sunanda sinha et al. reviewed the various software tools available for the hybrid energy systems to help the researchers to choose a proper tool for the development and analysis of integrated renewable energy systems [3]. Only 19 software tools were reviewed, but failed to discuss about the several tools for optimal planning of HES. In this paper, a comparative study is being carried out to analyze and evaluate the performance of HOMER and RET Screen for the selected area and also highlighted the importance of energy planning tools for the development of HES.

Anurag Chauhan et al. presented the renewable energy based strategies for off grid rural electrification in the state of Uttarakhand [4]. This paper also addresses the availability of energy resources, technology options and discusses the barriers and issues in integrating them. Several papers have been reported in literature, focusing on one or two software tools for analyzing IRES, but most of them failed to explain the comprehensive review of the tools available for renewable energy systems [5]. On taking into account, this paper mainly focusses on the review of various software tools for analyzing the integration of renewable energy sources.

Ajai Gupta et al. developed an integrated renewable energy system model for a remote area and insisted the importance of IRES for cost effective power generation and the development of a nation [6]. In this paper, the main objective function is to minimize the cost of energy by utilizing the available energy resources effectively.

Swati Negi et al. highlighted the importance of various methodologies, unit sizing, optimization, energy storage systems and energy management of IRES along with the energy sustainability [7][8]. Kanase patil et al. developed an IREOM model for unit sizing and optimization of renewable energy systems based on the seasonal variation in the load profiles of the study area [9][11][12]. Wind source and photo voltaic source to supply the load separately or simultaneously depending on their availability [15][16]. The Z-source inverter (ZSI) has been reported suitable for residential PV system because of the capability of voltage boost and inversion in a single stage [17][18][19].] Usually, renewable energy systems are based on single energy sources or multiple energy sources [20][21]. MATLAB / Simulink based simulation is carried out and the results are tabulated for the comparison purposes [22].

This paper attempts to develop correlation between renewable energy system sizes and their capital cost for the user specified system sizes.

III. SOFTWARE TOOLS FOR IRES

A. RET Screen

RET Screen is an Excel based clean energy management software tool that helps the energy planners and decision makers to determine the technical and economical viability of renewable energy potential, energy efficiency and cogeneration projects. It is a most widely used tool for performing the feasibility studies in IRES and is freely downloadable software developed by Ministry of Natural Resources, Canada. It uses visual basic and C language as platform and was released in the year 1988. This software can be accessible in more than 30 languages and has two separate versions RET Screen 4 and RET Screen plus. In this software, there are a number of worksheets available for performing project analysis including modeling, analysis, optimization, etc and so on. RET Screen has certain limitations which includes data sharing problems, limited options for search and retrieval features, etc.

B. HOMER

Hybrid Optimization Model for Electric Renewables (HOMER) is user friendly, freely available and most widely used software, which was developed by National Renewable Energy Laboratory (NREL), USA in the year 1993. Is uses visual C++ as a programming language. HOMER uses the inputs like resource availability, manufacturer's data, component costs, etc and generates the list of feasible configurations based on the Net Present Cost (NPC). It also displays a variety of tables and charts along with graphs which helps the user to compare the various configurations and analyze them based on their economic merits. HOMER has fewer disadvantages which includes, allowing single objective function for minimizing NPC,

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does not considering depth of discharge (DOD) of battery, etc and so on.

C. HYBRID 2

HYBRID 2 was developed by Renewable Energy Research Laboratory (RERL) in University of Massachusetts, USA along with National Renewable Energy Laboratory, USA in the year 1996, whereas HYBRID 1 was developed in the year 1994. It uses Microsoft Visual basic as a programming language and uses a Microsoft Access database. HYBRID 2 is a probabilistic/time series based computer model which uses statistical model to analyze the performance of IRES. HYBRID 2 consists of four parts namely Graphical User Interface, Simulation Module, Economics Module and Graphical results Interface.

D. iHOGA

Improved Hybrid Optimization by Genetic Algorithm is a C++ based hybrid system optimization tool developed by University of Zaragoza, Spain. This software uses solar PVs, WTGs, MHPs, fossil fuels, etc for modeling the IRES with either single or multiobjective function for optimization. It has two versions namely PRO+ and EDU. Some of the limitations of iHOGA includes, it can simulate within a total average daily load of 10kWh.

E. INSEL

Integrated Simulation Environment Language was developed by University of Oldenburg, Germany which allows the users to make a structure with the help of its library with a specified execution time. INSEL is a modular simulation environment which offers more than a conventional simulation program. This software can be used to understand, plan, monitor and visualize the energy systems. It supports the users with datasets for PV modules, thermal collectors and meteorological parameters, which is fully compatible with MATLAB and Simulink. This software is not most widely used, which is under continuous improvement during the last 2 decades.

F. TRNSYS

Transient Energy System Simulation Program was jointly developed by University of Wisconsin and University of Colorado in the year 1975. Initially, this software was developed for thermal systems simulations and later it has been promoted to include solar PV systems and some other energy systems along with thermal systems. It allows the user to program in FORTRAN code, which does not provides optimization of energy sources, but it can be used for carrying out the simulation part in designing the renewable energy systems. TRNSYS 17.0 was released during the year 2010 and TRNSYS 17.1 was released during the year 2012.

G. EMPS

EMPS is (EFI's Multiarea Power market Simulator is a computer tool developed for forecasting and energy planning in electricity markets. It has been actually developed for simulating and optimizing the hydrothermal energies with hydro power. It also considers the transmission constraints and hydrological differences between two areas. Its main objective is to minimize the total expected cost of the whole systems considering all the constraints like fuel cost, cost of energy, emissions, etc. EMPS software can also be used for analyzing the overflow losses, calculating energy balances, forecasting electricity prices, scheduling of power, etc.

H. EnergyPLAN

EnergyPLAN is a computer model designed for performing energy system analysis. It is a deterministic model which can optimize the operation of a given energy system based on the inputs and outputs defined by the users. It was developed and maintained by Sustainable Energy Planning Research Group at Alaborg University, Denmark in the year 2000. It simulates the operation of national energy systems on hourly basis including all the energy sectors. The main advantage of EnergyPLAN tool is that it aids to design and develop the 100% renewable energy systems.

I. HySim

HySim is a hydrological simulation model which can uses rainfall and potential evaporation datas to simulate and execute the hydrological cycle on a continuous basis. It can ues data on rainfall, potential evaporation, snow melt and abstractions from discharges, etc. It is also flexible in terms of sub catchments and the reaches for outflow routing can be either channels or reservoirs. The main advantages of HySim are: useful for predicting long term rainfall and data, flow naturalization, flood studies, etc.

J. SolSim

SolSim was initially introduced in Germany by Fachhochschule Konstanz for integrating the renewables like solar PV, wind turbines, DG sets, biogas and biomass energy systems. It performs economic analysis with limited control options and uses large amount of data to perform the simulation of IRES. Nowadays, SolSim is not widely used to perform the energy generating options.

K. Hybrid Designer

Hybrid Designer was developed and initially used by the Energy and Development Research Centre of University of Cape Town in South Africa for simulating the renewable energy models in off grid mode employing genetic algorithm concepts for minimizing the net present cost of an system.

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L. SOMES

Simulation and Optimization Model for Renewable Energy Systems (SOMES) was developed in the year 1987 at Utrecht University, Netherlands. It can simulate hourly basis energy generating options with an average electricity production from renewable energy sources. Also, it can perform optimization of levelized cost of energy from the combination of various energy sources.

M. SOLSTOR

SOLSTOR was introduced by Sandia National Laboratory in the year 1980s to perform the simulation, optimization and economic analysis of integrated renewable energy systems. It can minimize the life cycle cost of energy by choosing optimum number of solar panels, optimum tilt angles, optimal wind energy system components. It can be suited for both on grid and off grid applications, but it is not widely used by the researchers for simulating the energy systems.

N. iGRHYSO

iGRHYSO (improved Grid Connected Renewable Hybrid System Optimization) is an improved version of GRHYSO, uses C++ as the platform for optimizing the energy systems. It can simulate and perform the analysis to find the net present cost at low value. It has an advantage over other simulation softwares that the effect of temperature on solar photovoltaics, effect of wind velocity in wind power generation can be taken into account.

O. HybSim

HybSim was developed by Sandia National Laboratory for performing the economic analysis of a remotely located area, wherein the energy demands were met out by the renewable energy sources along with the conventional fossil fuel generators. It requires detailed load demand profile along with weather characteristics, solar radiation, wind velocities, etc.

P. IPSYS

Integrated Power System tool, sometimes called as IPSYS uses C++ language as the platform for simulating the various energy sources for a remote located area. It is possible to simulate the various energy sources like solar PV, wind energy generators, micro hydropower plants, biogas reservoirs, biomass plants, etc and so on.

Q. ARES

Autonomous Renewable Energy Systems (ARES) is a program developed by Cardiff School of Engineering, University of Wales, UK for performing the simulation and analysis of solar-wind-battery based energy systems. It can calculate the LPSP (loss of power supply probability) based on the input datas provided by the user. It employs a separate subroutine program for each of the sources considered. It is not widely used.

IV. OTHER SOFTWARE BASED STUDIES FOR IRES

Among the various simulation softwares discussed above, many of the researchers were using HOMER for simulating the integrated renewable energy systems with various parameters and constraints. In the field of IRES, apart from computer based simulation softwares like HOMER, RET Screen, etc for integrating the renewables, some of the conventional methodologies like artificial intelligence, multiobjective design, analytical approach, iterative technique, probabilistic approach, graphical construction method, etc were used.

A. Artificial Intelligence Approach

Artificial Intelligence approaches includes artificial neural networks, genetic algorithms, particle swarm optimization, biogeography based optimization, ant colony optimization, fuzzy logic control were mostly used by the researchers and energy planners to simulate and analyze the various renewable energy systems.

B. Multi Objective deign

In multiobjective design approach, there are two common approaches used, ie. One approach is to merge all the individual objective functions into a single composite and the second one is an entire Pareto optimal solution set is to be determined. A solution is said to be pareto, if the obtained solution is dominant over the other solutions obtained. A pareto optimal solution cannot be improved with regards to any objective without deteriorating atleast one objective.

C. Iterative approach

An iterative approach uses a recursive program which ends when the optimum system design is obtained while evaluating the performance of integrated renewable energy systems. In this methods, the system cost is minimized either by linearly changing the values of parameters or by linear programming techniques.

D. Analytical Method

In analytical method. Computational models are being used for characterizing each of the components of integrated renewable energy systems to find the feasibility of the system. Hence, the effect of feasibility can be improved by changing the blocks inside the computational models in each of the considered components.

E. Probabilistic approach

While modeling the integrated renewable energy systems, the effect of insolation, change in temperature, changes in wind speeds were taken into account by using the probabilistic based approaches. But, this optimization technique cannot characterize the dynamic changing performance of the system considered.

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F. Graphical Construction method

In graphical construction method, only two decision variables were considered for optimization I.E. either solar and battery or SPV and wind turbine. But it does not considers the parameters like the number of SPV modules, tilt angle, wind velocity, wind turbine installation height, etc.

V. RESULTS AND DISCUSSION

The hybrid system analysis software tools have been used by a number of researchers worldwide. HOMER is found to be most widely used tool in the research studies followed by RETScreen, TRNSYS, INSEL and ARES.

5.1 Comparison of HOMER and RET Screen Softwares

A comparison of two widely used software HOMER and RETScreen is shown in this section. HOMER and RETScreen have some similarities like both take only global irradiation as input, and synthesize the diffuse irradiation internally.

RETScreen uses Microsoft Excel to perform analysis based upon monthly statistical averages with lots of meteorological and geographical inbuilt information. RETScreen uses Evans electrical model with month-averaged ambient temperature and the PV panel material characteristics data to calculate power output, whereas HOMER uses basic relation model. The main difference between HOMER and RETScreen is shown in Table 2. The main strength of RETScreen is the detailed economic analysis and robust database whereas HOMER is better suited for a more advanced user and can handle a much denser simulation which makes HOMER one of the most widely used hybrid system optimization tool.

TOOLS	Economical Analysis	Technical Analyst	PV System	Wind System	Generator set	Storage device	Bio-energy	Hydro energy	Thermal System
RETScreen	✓	✓	✓	✓	-	✓	-	-	-
INSEL	-	✓	✓	✓	✓	✓	-	-	✓
TRNSYS	✓	✓	✓	✓	✓	✓	-	-	✓
HOMER	✓	✓	✓	✓	✓	✓	✓	✓	-
ARES	-	✓	✓	✓	✓	✓	-	-	-
HYBRID2	-	✓	✓	✓	✓	✓	-	-	✓
iHOGA	✓	✓	✓	✓	✓	✓	-	✓	-
HYBRIDS	-	✓	✓	-	-	✓	-	-	-
RAPSIM	-	✓	✓	✓	✓	✓	-	-	-
SOMES	✓	✓	✓	✓	-	✓	-	-	-
SOLSIM	✓	✓	✓	✓	✓	✓	✓	-	-
IPSYS	-	✓	✓	✓	✓	✓	-	✓	-

Table 1: Analysis capabilities of hybrid system software tools

Parameters	HOMER	RETScreen
Data import	Time series data import option	No option for time series data
Temperature effect	Temperature effect on solar PV system is included	Temperature effect is not included
Financial evaluation	Detailed financial analysis like RETScreen cannot be done by HOMER. But it calculates Net Present Cost, Cost of Energy, Operating Cost and Initial Cost	Detailed analysis like cost analysis, financial analysis, risk analysis and emission analysis and it is the strength of this software
Excess electricity production	Calculate excess electricity generated	No option to calculate excess electricity generated
Performance evaluation capability	Hourly basis data handling capability	Evaluated performance based upon monthly averages
Capacity Shortage option	Maximum annual capacity shortage can be included	No option for capacity shortage
Data base	Much more way of data input although it has some database	It has its own database and less data input way
Computational time	HOMER shows the computational time taken to simulate a study	RETScreen do not show the computational time taken as it is excel based software.

Table 2: Trade-off inference between HOMER and RETScreen

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VI CONCLUSION

In this paper, a complete review of the various software tools used for sizing of integrated renewable energy systems were presented. Also, apart from the computer based simulation software tools, conventional methods were also presented. It is found that among the various software tools, HOMER is found to be the most widely used tool as it has the maximum number of combination of renewable energy systems and performs optimization and sensitivity analysis which makes it easier and faster to evaluate and analyze as many possible system configurations. Also, the performance of software tools for IRES can be improved through various control strategies like load demand management, economic planning, inclusion of non-renewables and renewables with various energy storage systems in order to reduce the total cost of the system with optimum components.

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