Scope for Distributed Renewable Energy Systems in South India

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***Abstract*—Decentralized electricity generation is gaining importance due to environmental problems with the supply oriented approaches in planning driven by conventional centralized power generation and distribution. Dispersed generation based on renewable energy (RE) sources addresses the issues related with reliability, voltage profile management and associated economic aspects. Micro grids help in exploiting locally available RE sources, which are also the fundamental units of the smart grid architecture. However, available energy potential of the region and seasonal variability assessment is the primary step to map the viable regions for power harvesting. The present study analyses the distributed energy harvesting option for southern states of India by assessing the taluk wise solar and wind energy potential. Power density assessment and variability analysis essentially helps for the investors to architect the generation plants and to optimize the higher energy yielding regions. The paper also describes the use of long term spatial data for renewable potential assessment using open source Geographical Information System (GIS) platform.**

***Index Terms*—Renewable energy, Decentralized generation, Potential analysis, Geographical Information System (GIS), Renewable power density**

I. INTRODUCTION

Decentralized generation (DG) is the electric energy production at the distribution side of the power supply network or in the load center itself. Distributed energy generation can play pivotal role to meet the electricity demand in a reliable and environmental friendly way. Dispersed generation exploits locally available energy resources which will reduce the exploitation of conventional energy resources and also the congestion of generating units. DG based electricity generation promotes higher penetration of renewable energy (RE) resources in the grid. DG plants have the unique advantage of operating in islanded mode (grid isolation mode), during the outage of the central grid. Grid connection can be restored as the central grid is energized and electricity can either be transferred to the grid or drawn from the grid. Micro grids are the building units of dispersed generation, which essentially exploits locally available RE resources. Micro grid is an emerging technology and has evolved as smart grid with higher reliability, limited greenhouse gas (GHG) emission, reduced transmission and distribution (T & D) losses. Smart grid architecture is in the infancy stage, which integrates renewable energy based distributed generation with the conventional system using control strategies over a two-way communication link.

India has one of the biggest power supply networks, having the installed capacity of more than 243 GW. Though electricity is one of the cleaner energy forms, the generation is mainly dependent on thermal power plants (168.25 GW, 69%). Thermal power plants are mostly located near the resource rich regions in order to reduce the transportation cost of the fuel. However, load centers are sparsely located, which are being catered electricity through long transmission and distribution networks. Power supply network in the country will remain stressed to supply higher demand during peak hours and even during non-peak hours due to losses (~23%), which may also cause the grid instability [1]. Indian power sector recently witnessed one of the biggest blackouts (July 2012); peak power shortfall of 12,159 MW (9%) and energy shortage of 86,905 GWh (8.7%) during 2012-13 [2]. The conventional concentrated generation (central grid structure) dominated by fossil energy resources has caused enormous pollution and over exploitation of natural resources. However, narrowing the supply demand gap, reducing the T & D losses and cutting down the GHG emissions are the immediate need for the Indian power system. Distributed electricity generation through renewable energy resources can help in strengthening the power system and also certainly reduces carbon footprint of energy generation. It reduces the line losses, improves the voltage profile, and enhances the system reliability, security and quality of power [3]. The associated economic benefits of DG are reduced operation and maintenance cost, increased productivity, reduction in fuel cost due to the exploitation of RE sources and increased efficiency. There are health benefits due to pollution control and also the up-gradation of the current system can be avoided [4, 5].

India is blessed with very good renewable energy potential which is not exploited in large scale yet. On the other hand, country is facing severe energy crisis and importing fossil fuels, which is affecting the country's economic growth. Southern part of the country is harvesting electricity mainly from hydro and limited coal resources (Navyeli in Tamil Nadu). The region has 3 metropolises (Bangalore, Chennai and Hyderabad) and many industrial, agriculture and commercial consumers, which are posing the higher peak load and energy demand to the grid. Southern Region Load Despatch Center (SRLDC) is facing very high energy (59,297 GWh, 19.1%) and peak power (11,669 MW, 26.1%) crisis over the years, which led to decreased power quality and load shedding [2]. Many studies have described the application of renewable energy for decentralized generation [6, 7], as micro grid [8, 9] and standalone generation for remote area electrification [10, 11, 12]. Energy potential analysis using spatial data are also carried out by researchers which gave new avenue for energy research [13, 14]. However, most of the studies were done for a specified application in a region or for the cluster of villages. The present study analyses the solar and wind energy potential for entire southern India, which can contribute significantly in DG planning. Taluk wise RE resources assessment has been carried out considering the seasonal variability of the resources and clustering the high energy yielding regions. Solar energy potential of the region ranges from 5.2 to 6.0 kWh/m^2/day annually. Region also experiences higher wind potential, where the wind speed varies from 2.0 to 3.33 m/s annually. The excess electricity required in the region can be met using decentralized renewable energy based generation which also plays a significant role in energy independence and the region's energy security.

II. Objective

The present study analyses (Taluk wise) the potential of wind and solar energy sources in southern states of India. The analysis also includes the power density mapping and variability assessment of the available renewable energy sources for the integrated DG planning.

III. Study area and Method

A. Study area

Indian power sector comprises of five regional load despatch centers (RLDCs) which are northern, western, eastern, north-eastern and southern with a National Load Despatch Center (NLDC) at Delhi. Southern load despatch center (SRLDC) monitors the electric energy scheduling and load balancing of Karnataka, Andhra Pradesh, Kerala, Tamil Nadu and Pondicherry (4 states and a UT). SRLDC covers 3rd largest geographical area among other RLDCs, which includes about 22% of total country's population and 29% of total installed capacity. Installed capacity of RE based power plants is lesser in the region (7521 MW, 15%) which illustrates lower exploitation of renewable energy potential. Taluk wise renewable energy (wind and solar) potential assessment is carried out for 4 states to assess the hotspots for decentralized electric energy generation.

B. Method

Long term Spatio-temporal data are used to analyze the available renewable energy potential in open source GIS platform. The assessment also gives the seasonal and geographical variability of the energy resources. Long term data sets acquired from NASA SSE and Climate Research Unit (CRU) are consistent and depicts the seasonal variability which is closely correlated with ground measurement [15, 16].

1) *Solar Energy Potential Assessment:* NASA Solar Surface Exploration (SSE) Global insolation datasets are obtained from a physical model based on the radiative transfer in the atmosphere considering its absorption and scattering properties. The model considers visible and infrared radiation, cloud and surface properties, temperature, perceptible water column, ozone amount and the atmospheric variables includes temperature and pressure measured using various satellite instruments. The long wave and shortwave solar radiations recorded in the satellite sensors along with the effecting parameters are studied to generate global insolation for different locations and durations. The 0.1°X0.1° spatial resolution SSE global insolation data derived from NASA SSE web portal (http://eosweb.larc.nasa.gov/sse/), for the period of 22 years (July 1st, 1983 to June 30th, 2005) were validated (RMSE of 10.28%) with Baseline Surface Radiation Network (BSRN) data, which is available daily, monthly and annual averages obtained from measured values every 3 hours [17, 18]. Further, grids which essentially cover the entire southern region of the country are extracted and a geo-statistical Inverse Distance Weighting (IDW) interpolation is employed to produce monthly average Global Hourly Insolation (GHI) maps for the region. Taluk wise availability of solar potential is computed by over laying the delineated taluk boundary map and calculating the zonal statistics.

2) *Wind energy potential assessment:* Synthesized wind data is available from various sources, which provides overview of the wind regime of a region. Climate Research Unit (CRU) at the University of East Anglia, maintains a record of climatic average datasets of meteorological variables which also contains wind speed data for the period between 1961 and 1990, compiled from different sources. The Global Land One-km Base Elevation project (GLOBE) data of the National Geophysical Data Center (NGDC) were re-sampled into 10'×10' (ten minute spatial resolution or 0.16°X0.16°) elevation grids. The climatic average of wind speeds measured at 2 to 20 m anemometer heights (assumed to be standardized during collection) collated from 3,950 global meteorological stations together with the information on latitude, longitude and elevation, which were interpolated based on a geo-statistical technique called Inverse Distance Weighting (IDW). Elevation as a co-predictor considers topographic influence on the wind speed, whereas, proximity of a region to the measuring station improves the reliability of the interpolated data. During interpolation, inconsistent data were removed appropriately. This technique was identified to be steadfast in situations of data sparseness or irregularity [19]. The 10'×10' spatial resolution wind speed data as climatic averages were available for all global regions (excluding Antarctica) [20].

IV. Results and Discussion

Figure 1 shows the taluk wise seasonal variation of solar energy potential in southern states. During summer (February to May), solar energy reception varies from 5.6 to 7.1 kWh/m^2/day. Region receives highest insolation in April, while taluks in the northern and central region receive insolation more than 6.8 kWh/m^2/day. Solar insolation reception decreases as the south west monsoon arrives during June, which continues till mid of September (Monsoon season). Taluks of west coast are immediately affected by monsoon, which receive lower insolation (4.2-5.0 kWh/m^2/day) throughout the season. However, insolation received in all the taluks is lesser during monsoon months, which slowly increases as the winter approaches. During winter (October to January), western and interior taluks receive higher insolation (5.3-5.9 kWh/m^2/day) compared to the east coast taluks (4.1-5.1 kWh/m^2/day).

Rooftop PV and PV micro grid with wind and/or bio-energy based electricity generation would be ideal to meet the domestic electricity demand in a decentralized way. However, agricultural demand can be met by community based energy generation or installing higher capacity power plants in the available wasteland, which may also can be synchronized with grid.

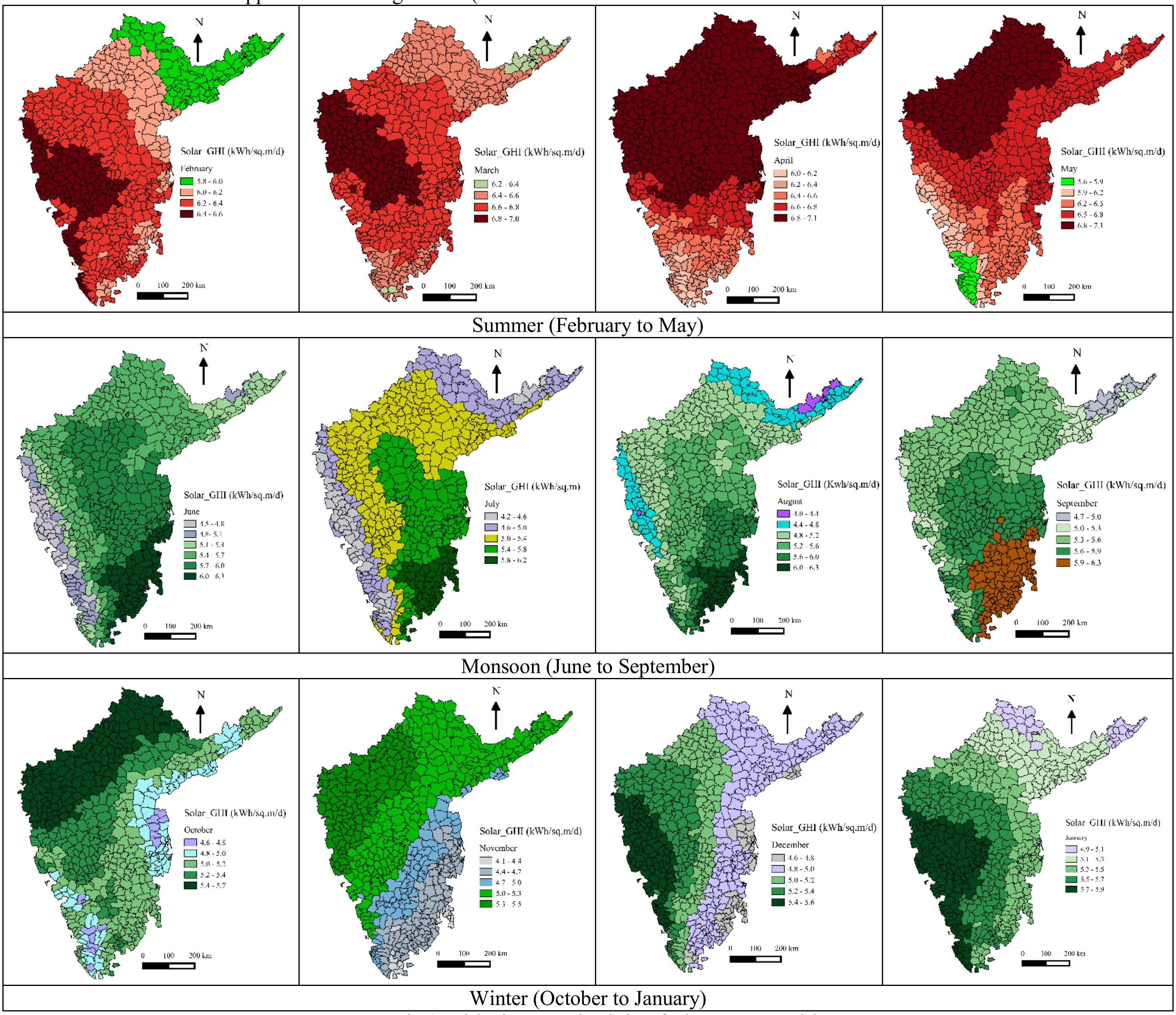

Fig. 1. Taluk wise seasonal variation of solar energy potential

Figure 2 gives the taluk wise seasonal variation of wind speed in southern India which varies from 2 to 3.4 m/s annually. During summer (February to May), region experiences wind speed from 1.5 to 4.5 m/s, while the taluks in the southern part and east coast experience higher wind speed (3-4.5 m/s). Southern India is comparatively more affected by monsoon, so do the wind profile. Wind speed varies from 2.5 to 4.1 m/s during monsoon (June to September), northern and coastal taluks experience speedy winds. During winter southern states receive lower wind speed which ranges from 1.4 to 4.4 m/s. In October, taluks in the southern states experience lowest wind speed which varies from 1.6 to 2.35 m/s. Taluks of east coast (Tamil Nadu) receive higher wind speed throughout the year, followed by southern interior taluks. However, costal taluks and planes are preferred for wind energy harvesting than the interior region which has rich flora and fauna (Western and Eastern Ghats).

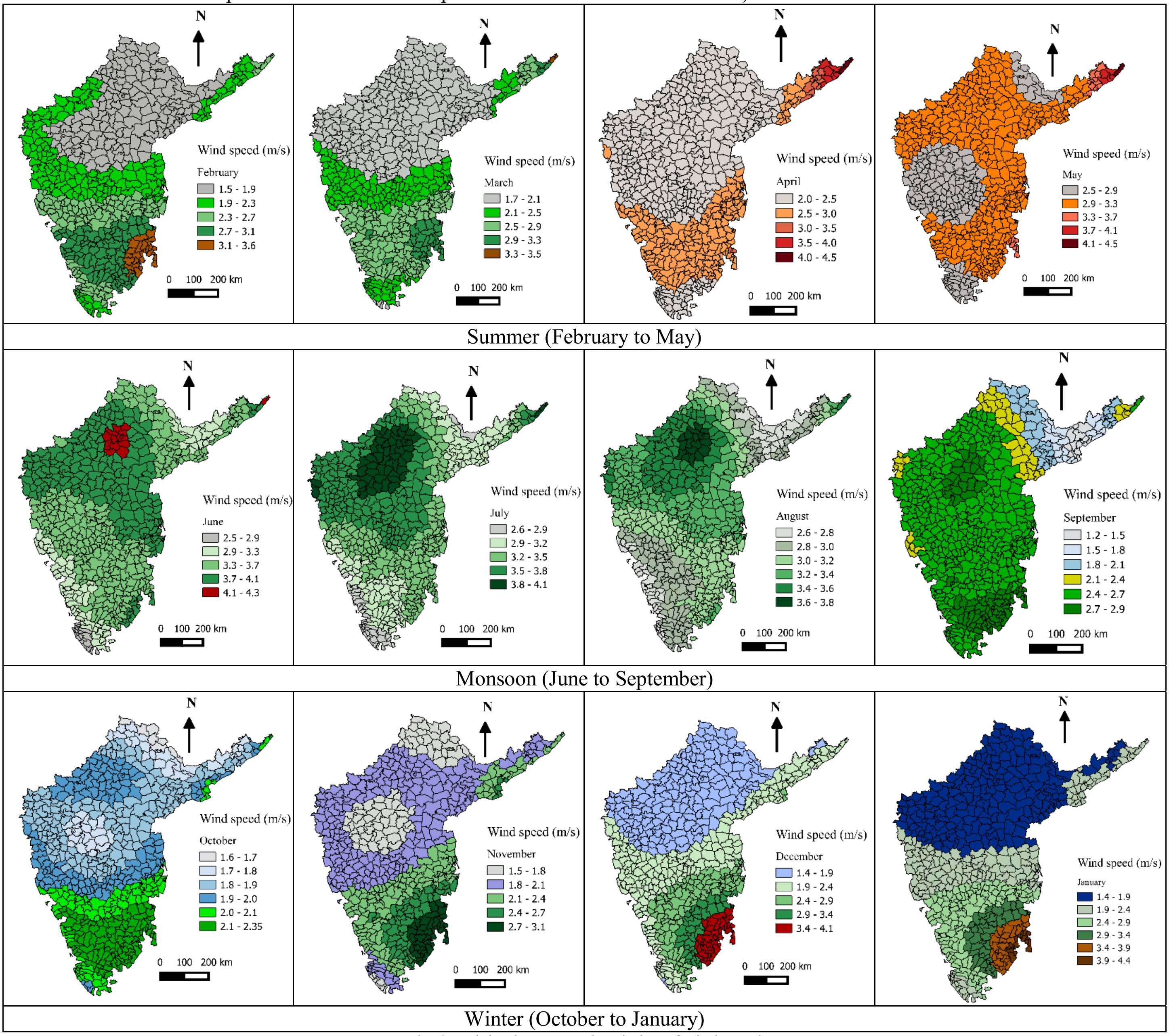

Fig. 2. Taluk wise seasonal variation of wind speed

Figure 3 shows the solar and wind power density map for the region. Solar power density varies from 750 to 850 W/m^2 in the region where, interior taluks receive higher solar power (810-850 W/m^2) compared to the coastal taluks (750-810 W/m^2). Wind energy potential is variable in the region which affects the wind power density, which ranges from 5 to 25 W/m^2 of the blade swept area. Taluks in the west coast shows higher wind power density (17 to 25 W/m^2) followed by interior (planes) taluks (13-17 W/m^2). Wind power potential decreases towards the northern taluks (5-10 W/m^2) which are not viable for wind energy applications. Taluk wise power density analysis can be used to assess the higher energy yielding areas and also helpful in energy integration. Distributed generation and micro grid planning can be done with this knowledge which also help in predicting the probable energy output of the region.

V. VARIABILITY ANALYSIS OF RE SOURCES

Seasonal variability analysis is carried out, dividing the entire area into 3 regions, i.e. West coast, East coast and Interior taluks, depending upon the geography of the region. Figure 4 depicts the variation in solar insolation across the seasons for all 3 regions. Insolation reception is highly variable in monsoon and winter due to the cloud movements in all the regions. However, insolation is less variable during summer in all the regions and west coast shows lesser variability of insolation in all the seasons.

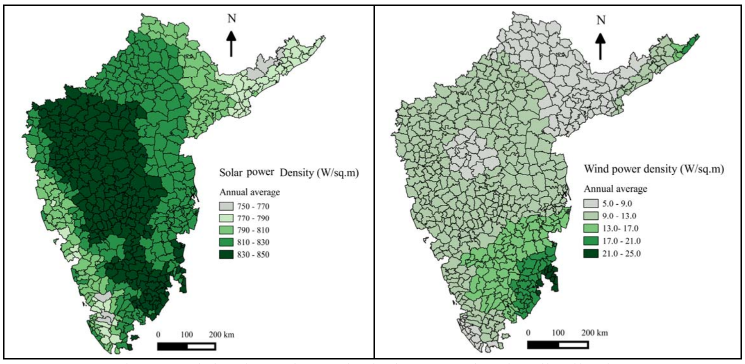

Fig. 3. Taluk wise solar and wind energy density distribution

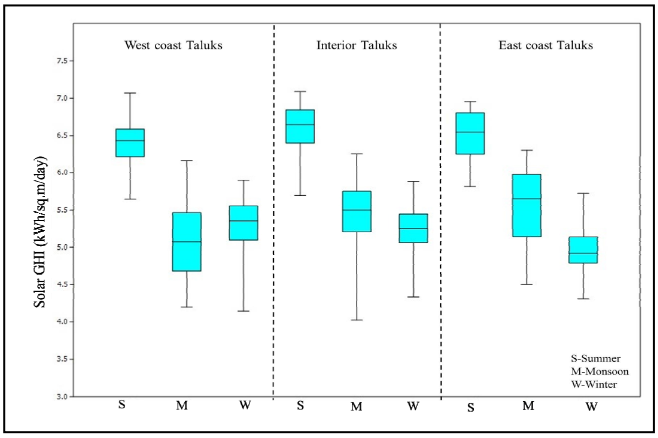

Fig. 4. Seasonal variability of solar energy potential

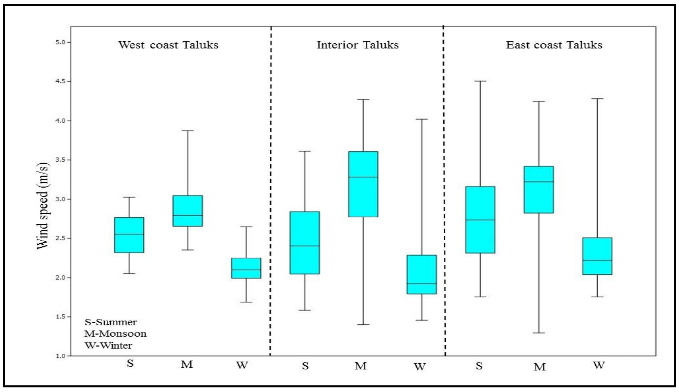

Fig. 5. Seasonal variability of wind speed

Seasonal variation of wind speed in all the regions is illustrated in Fig. 5. Taluks of east coast shows higher variation of wind speed in all the seasons whereas west shows the lower variability. Though during monsoon, all the regions experience higher wind speed, variability is also higher, may affect the energy production.

Figure 6 gives the region wise occurrence of wind speeds across the seasons. In west coast taluks (Fig. 5 (a)), wind speed ≥2.5 m/s occurs more frequently compared to the lower or higher order winds. Similarly, in east coast taluks (Fig. 5 (b)), wind speed between 2.3 and 2.5, 2.7 and 2.8 and 3.2 and 3.3 m/s occurs more often, which also depicts the higher dynamicity of occurrence of winds.

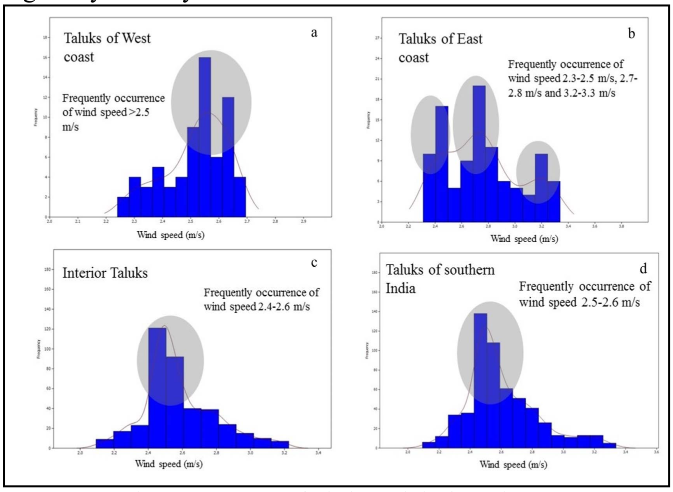

Fig. 6. Occurrence of wind speeds in the region

In interior taluks (Fig. 5 (c)), winds having speed 2.4-2.6 m/s occurs frequently, which is lesser compared the other regions. However, taluks in the southern region experience winds of 2.5-2.6 m/s more often (Fig. 5 (d)), where the installation of small scale wind turbines are recommended.

VI. CONCLUSION

Assessment of renewable energy potential reveals that the southern part of the country receives solar insolation more than 5.2 kWh/m^2/day for more than 300 days in a year. The region also experiences wind speed of 2.0 to 3.3 m/s throughout the year where, occurrence of wind with speed 2.5-2.6 m/s are more frequent. During monsoon, southern states receive lower insolation and are compensated by higher wind energy potential. As the region is facing severe energy and peak power crisis, decentralized solar and wind energy integration to the grid would narrow down the supply demand gap. Micro grids need to be promoted to meet the community level demand through locally available energy resources, which can also avoid the transmission network up gradation to import electricity. Wastelands in the interior taluks are best suited for grid connected hybrid energy generation, while, micro grids and rooftop generations shall be promoted in metropolis and biodiversity rich Western/Eastern Ghats taluks. Share of energy sources in installed capacity can be decided depending on the variability and the geographical location. Renewable energy exploitation with grid integration needs to be promoted through appropriate policy interventions to mitigate the GHG emission through reduced dependence on fossil fuels.

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REFERENCES

[1] Sachin Jain and Vivek Agarwal, "An Integrated Hybrid Power Supply for Distributed Generation Applications Fed by Nonconventional Energy Sources," IEEE Transactions on Energy Conversion, vol. 23, June 2008.

[2] LGBR, CEA, 2013-14

[3] R. E. Brown and L. A. A. Freeman, "Analyzing the reliability impact on distributed generation," in IEEE Power Engineering Society Summer Meeting, vol. 2, pp. 1013–1018, July 2001.

[4] R. E. Brown, J. Pan, X. Feng, and K. Koutlev, "Siting distributed generation to defer T&D expansion," Transmission and Distribution Conference and Expo. vol. 2, pp. 622–627, October 2001.

[5] Pathomthat Chiradeja and R. Ramakumar, 2004. "An Approach to Quantify the Technical Benefits of Distributed Generation," IEEE Transactions on Energy Conversion, vol. 19, December 2004.

[6] T. V. Ramachandra and Gautham Krishnadas, "Prospects and challenges of decentralized wind applications in the Himalayan terrain," Journal of Energy Bioscience, vol. 3, pp. 1-12, September 2012.

[7] T. V. Ramachandra and B. V. Shruthi, "Spatial mapping of renewable energy potential," Renewable and Sustainable Energy Reviews, vol. 11, pp. 1460-1480, December 2005.

[8] T. V. Ramachandra Ganesh Hegde and Gautham Krishnadas, "Potential Assessment and Decentralized Applications of Wind Energy in Uttara Kannada, Karnataka," International Journal of Renewable Energy Research, vol. 4, April 2014.

[9] T. V. Ramachandra, Ganesh Hegde, Bharath Setturu, and Gautham Krishnadas, "Bioenergy: A sustainable Energy Option for Rural India," Advances in Forestry Letters (AFL), vol. 3, pp. 1-15, March 2014.

[10] Omar Hafez and Kankar Bhattacharya, "Optimal planning and design of a renewable energy based supply system for microgrids," Renewable Energy, vol. 45, pp. 7-15, March 2012.

[11] Muhammad Ibrahim, M. Anisuzzaman, S. Kumar and S. C. Bhattacharya, "Demonstration of PV Micro-Utility System for Rural Electrification," Solar Energy, vol. 72, pp. 521-530, March 2002.

[12] P. Balamurugan, S. Ashok and T. L. Jose, "Optimal Operation of Biomass/Wind/PV Hybrid Energy System for Rural Areas," International Journal of Green Energy, vol. 6, pp. 104-116, February 2009.

[13] A. B. Kanase-Patil, R. P. Saini and M. P. Sharma, "Integrated renewable energy systems for off grid rural electrification of remote area," Renewable Energy, vol. 35, pp. 1342-1349, November 2009.

[14] S. Kumaravel and S. Ashok, "An Optimal Stand-Alone Biomass/Solar-PV/Pico-Hydel Hybrid Energy System for Remote Rural Area Electrification of Isolated Village in Western-Ghats Region of India," International Journal of Green Energy, vol. 9, pp. 398-408, August 2012.

[15] Surface Meteorology and Solar Energy Release 6.0 Methodology, NASA. Viewed on October 17, 2012. (http://eosweb.larc.nasa.gov/sse/documents/SSE6Methodology.pdf).

[16] NREL GHI data furnished by National Renewable energy Laboratory, 2010.

[17] T. V. Ramachandra, Rishabh Jain and Gautham Krishnadas, "Hotspots of solar potential in India," Renewable and Sustainable Energy Reviews, vol. 15, pp. 3178–3186, April 2011.

[18] T. V. Ramachandra, "Solar energy potential assessment using GIS," Energy Education Science and Technology, vol. 18, pp. 101-114, December 2006.

[19] World Meteorological Organization, Guide to Meteorological Instrument and Observing Practices, 4th Edition, WMO, No. 8, TP. 3 Geneva, Switzerland, 1964.

[20] Climate Research Unit, University of East Anglia, Accessed on 10th June 2013. (http://www.cru.uea.ac.uk/cru/data/hrg/tmc/).