An analysis on Variable Renewable Energy and the importance of Hybrid systems in India

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Introduction

The global energy sector today is in transition into clean and renewable energy, due to increasing concern over climate change and pollution. While most of 'developed' countries have a saturated electricity demand, India, along with several other 'developing' countries, has been consistently facing the challenge of rapid increase in electricity demand while managing to sustain its economic growth. Along with the goal for battling energy related emissions, renewable energy capacity expansion has always been India's best solution to the rapidly increasing electricity demand [1]. After the agreement at the Climate Change Conference COP 21, Paris,2015, India is determined to reduce its carbon intensity by 33 percent from its 2005 levels by the year 2030 (a). On this regard an ambitious plan to integrate 175 GW of Solar Photo-Voltaic (PV) (100 GW) and wind (75 GW) power capacities by the year 2027 is already set in motion (b). However, such a strategy involving a high penetration of Variable Renewable Energy (VRE) like solar PV and wind, leads to severe complications, due to their unpredictable nature in availability and reliability. The most suitable option for sustainable VRE integration is to include Large-scale Energy Storage (LES) capacities, which involves building highly capital-intensive infrastructure. Considering the fact that the Indian energy sector is already in heavy financial debt [2], such capital intensive expansion would just elevate the already available debt. So, an intelligent solution is necessary for the sustained operation of the new Indian power system.

This study involves the analysis of the several possible VRE hybrid systems in the country, effectively targeting the sustainable addition of such a large capacity of VRE within such a short duration. As the addition of solar PV and wind capacities have already started, further is the stress to implement a sustainable strategy. Several studies [3] suggest that a hybrid system of VRE and 'Dispatch-able' Renewable Energy (DRE) technologies have proven to be sustainable, however, in the scope of this study other possibilities like VRE+ Electro mobility, VRE + Smart grids and VRE + Clean conventional technologies are considered, and in the end a validated comparison has also been made to provide a possible solution.

Key Words: India, VRE, DRE, hybrid energy systems, sustainability, energy transition

The Indian electricity sector

India is considered to be a large country both in terms of area and population. Similarly, the Indian electricity is also huge in size, with an annual electricity demand of 983,6 TWh in the year 2016. With the closely coupled economic development in the increase, the electricity demand is expected to grow with a rate of 6,9% annually to a value of 3800 TWh in 2030 [1]. Presently, the electricity generation sector is dominated by conventional thermal power technology. Electricity production from coal occupies a large scale of 65 percent in the generation mix, followed by Hydro power and other technologies. The Fig.(1) shows a brief classification of installed capacity by types in India. This large share of coal power generation capacity is the result of continuous unchecked addition of capacities after the 1990 economic reforms, when the demand started increasing drastically due to rapid industrialization in the country. Thus, a dependency of the economic development on the generation from coal based capacities was established. However, in the recent years, there has been a considerable improvement in the renewable energy capacity addition, mostly with wind power and solar PV.

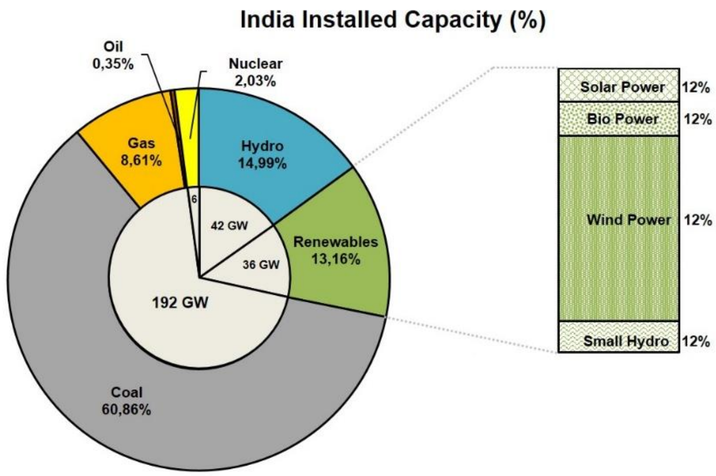

Fig.(1) Installed capacity by generation technology, as on 31.12.2015. Source: CEA, MoP, GoI

With further developments and motivation in the renewable energy sector, India plans to install an additional 175 GW of wind and solar PV capacity, by the year 2027, promising a steep decline in the electricity generated from coal. Several efficiency directives and measures to promote the improvement of renewable energy are active today in India, one of which states that all new thermal power plants should plan and accommodate an additional renewable energy plant for at least 10 percent of its generating capacity.

Parameters defining the Indian electricity sector

The Indian electricity sector, being large in size, has many parameters that differentiate it from most of the other electricity sectors in the world. Like many other 'developing' countries, the country's economic development is closely linked to the energy use. However, considering the available/ installed power plant capacity, India is among the leading countries eclipsing most of the 'developing' countries, with an installed capacity of 320,3GW [6]. The population of the country is so huge, that even with such a large installed capacity, there are up to 300 million people without access to electricity. With the continuously increasing population and economic development, the energy/ electricity demand also has a staggering growth every year. Thus, covering at least the base load (50 percent of the electricity demand) has been one of the main priorities of the Government of India (GoI). However, the seasonal variations in the electricity demand are not that prominent, which makes it easier to cover the load throughout the year with the same set of power plant technologies. It has to be noted that load is a characteristic of electricity demand, rather than a necessity of the supply side [4]. The corresponding figure Fig.(2) illustrates the yearly variations in electrical load in the year 2011.

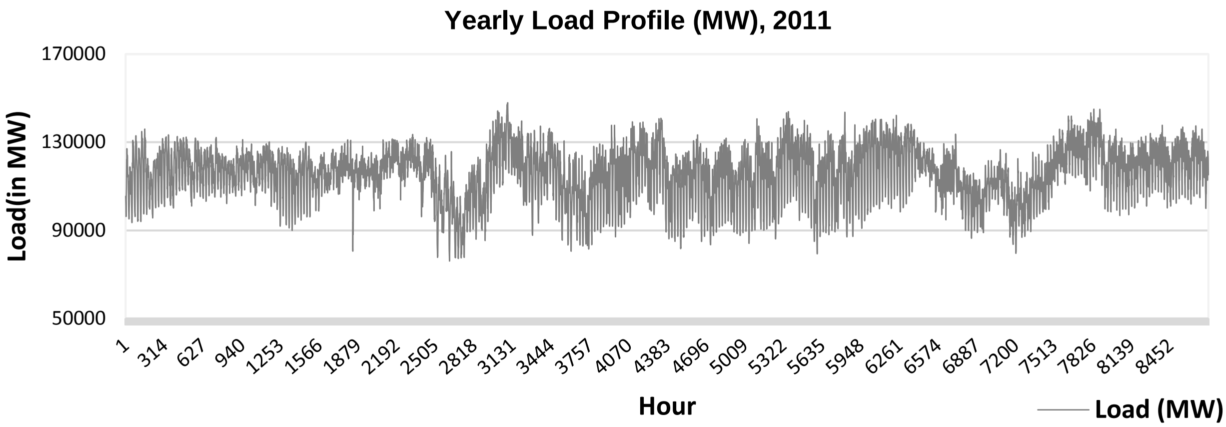

Fig.(2) Electrical Load profile for the overall country for the year 2011. Source: CEA, GoI

The simplest solution is to add up more capacities of the cheapest power source in the country- coal. With the goal that pushes India to reduce their carbon intensity of energy usage (COP21), is presently leading the country into a renewable transition. The availability of renewable potential in India is so high that the technical potential of Solar PV alone can help meet its energy needs. Unfortunately, the electricity sector of India is already in crippling debts due to losses in transmission & distribution network, and unorganized maintenance. In 2012, a 22% loss in T&D was recorded (as shown in the Fig.(3)), which would mean that the supplying utility would have to produce more than one extra units to satisfy a demand of five units. The government of India has now taken up the task to improve the T&D network before the addition of new power plant capacity. Thus, investments in large scale renewable capacity addition is a tremendously complicated task for India in the coming decades. However, the framework for the addition of renewables has already been prepared by the government, by introducing measures such as minimum compulsory renewable capacity addition for every new thermal power plant being set up, in most sub-regions in the country. Also, completion of many 'stopped' (construction paused due to capital issues or water sharing problems) hydro power plants in the north east region, which is rightly named the 'power cradle of India' is also under way. Thus, it can be agreed that there exists a unique situation in the Indian electricity sector.

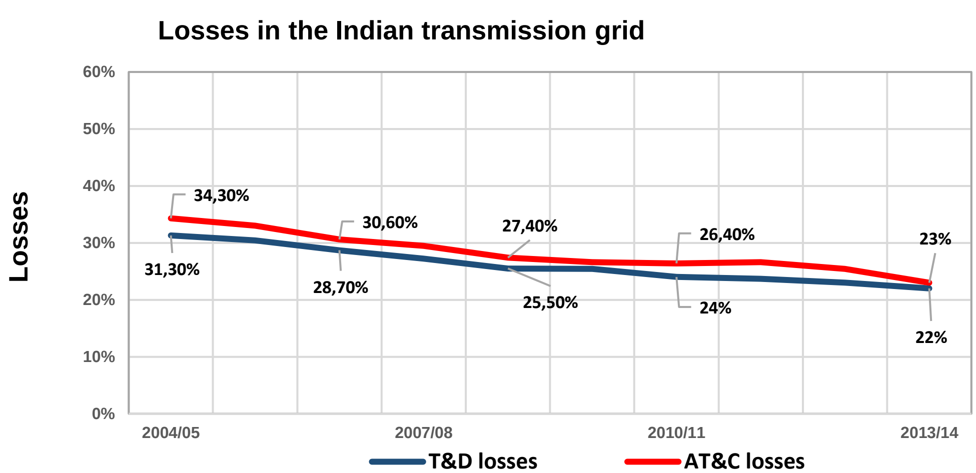

Fig.(3) Transmission and Distribution losses in the Indian electricity sector over the years. Source: IEA, Buckley, T.

Variable Renewable Energy:

Variable Renewable Energy (VRE) sources in nature are highly fluctuating and variable in their availability. As discussed before, around 800 GWp technical potential for solar PV in India can single-handedly be used to reach the country's energy needs. However, solar energy is highly fluctuating in nature, due to several uncontrollable factors such as cloud movements, precipitation and many such factors. This introduces more complexity into the already complex interplay of energy components in the energy system, and to compensate this complexity, so called 'integration costs' are incurred. With larger VRE systems, higher integration costs are incurred, while on an isolated small scale, they are almost close to zero. With smaller fluctuations in generation and more availability and reliability, Dispatch-able Renewable Energy sources tend to have lesser or almost zero integration costs.

The solar resource, however, is free of cost, i.e., variable costs for such VRE systems are almost equal to zero. With 100 GW of solar PV planned in just a decade, it becomes priority to deal with these integration costs before the situation goes out of hand (the electricity sector starts spending more money to just sustain the system), when the whole point of such an integration was to reduce the cost intensity of electricity generation. A study [5] estimates that in 2019, solar power would reach the same cost as power from imported coal, and continue to decrease further due to the technology learning effect. The evolution of the Levelized Cost of Electricity generation (LCoEg) are as shown in the following figure Fig.(4). Wind power, however, remains the cheapest, until the target year 2023.

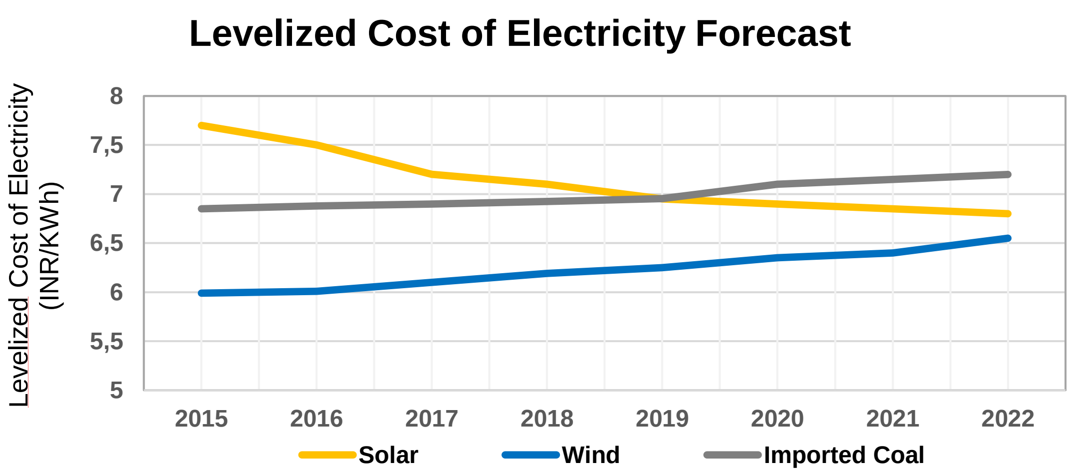

Fig.(4) Levelized Cost of electricity generation of Solar PV, Wind and imported coal Source: Shrimali,G. 2015 [5]

With lesser fluctuations in generation of power, the 'integration costs' also tend to decrease. Thus DRE sources become more important. Such technologies are usually capital intensive, but their useful ness over their lifetimes make them very valuable. Furthermore, DRE technologies like Hydro power usually have very long lifetimes of (in some cases) more than a 100 years.

Variable Renewable Energy in India:

India has a vast potential for VRE sources like solar PV, solar thermal, offshore and on-shore wind. Interestingly, these potentially rich areas are distributed across the map, throughout the country. The fact that the VRE availability is spread across the country further cements the fact that complete renewable generation is a possible future. As discussed earlier, with the consideration of only around

2-20 percent rooftop area and 3 percent of waste land area per region for usage, India has a calculated technical potential of 784 GWp for solar PV (c).

Utility scale solar, Distributed solar and Off-grid solar strategies are already sketched out by the planning commission to meet the target of 100 GWe in the next decade. Off-grid solar is planned to ensure electricity access and decreased grid dependency of rural remote areas in several regions [7]. Wind energy, however, is limited to regions in the southern and western India, where the topology of the land creates a wind channel. Several test projects testing the availability of wind, both onshore and offshore are already established, which could be further exploited. An installed capacity of 32,28 GWe (2016) already feeds in 46011,52 GWh (2016-2017) in to the grid [6]. Several potential- rich regions are labelled as development zones, where measurement and testing of wind speeds availability is already underway. Offshore wind potential is limited to the south-eastern shore and the north western coast, as shown in the Fig.(5).

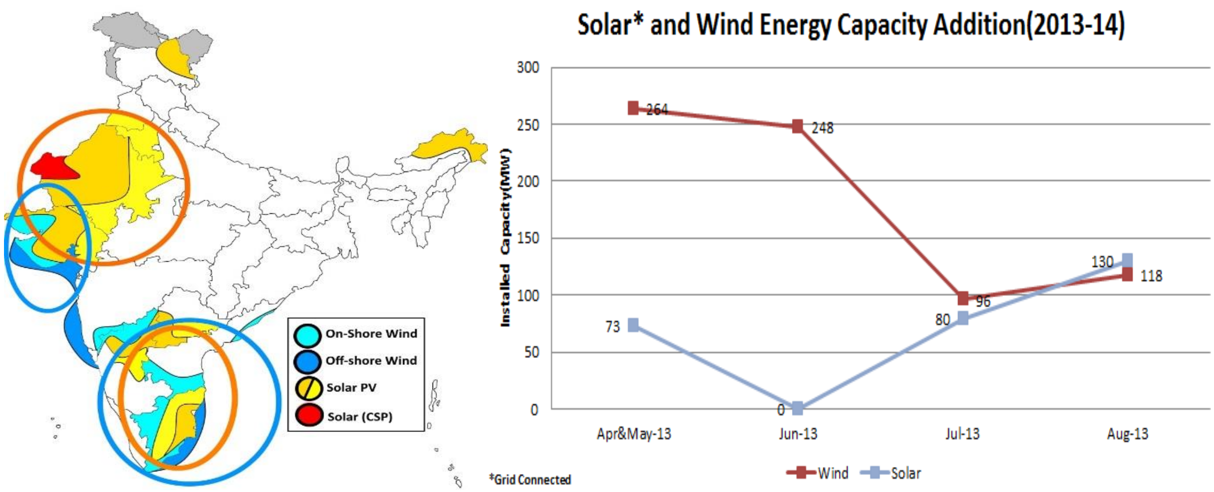

Fig.(5) Availability of solar PV and wind energy potential in India, solar and wind capacity addition Source: MoP, GoI

Hybrid systems

A combination of different energy conversion technologies and components working sustainably together can be defined as a 'Hybrid' system. Basically, it would mean diversifying the power plant portfolio, integrating 'smart' components in to the energy system, and further improvement of performance by compensating each other. Hybrid energy systems could be the answer for a sustainable and economic integration of VRE capacities on a large scale in India. Several possibilities for hybrid systems are discussed further in the scope of this study.

VRE+DRE

Dispatch-able sources of renewable energy (DRE) include Hydro power and Biomass resources. These technologies have a higher reliability factor, unlike VRE sources. India has a vast unexploited potential of hydroelectricity which can be integrated, especially in the North east region. Since agriculture is one of the main occupations in India, water from the rivers are considered more valuable to be used in the fields, rather to restrict the flow of water for hydroelectricity, by build large dams. Several challenges like water sharing, flood control, silt formation and irrigation necessities exists for the further expansion of reservoir-based hydroelectricity in India

Thus, small hydro power plants come into the limelight, and when such hydro power plants support agriculture, the agricultural byproducts could be sustainably used in electricity generation from biomass. Several model villages in India operate a shared-biomass energy system for de-centralized electricity generation. Together, the two DRE technologies could provide the most economically sustainable way for the integration and sustainable working of VRE capacity. The GoI has already recognized the importance of small hydro power and biomass DRE technology, as several subsidies for electricity feed in from such resources are already subsidized.

The availability of such resources also decide the usefulness of the technologies. The main aspect of DRE sources is the constant nature of their output. The large area of India provides a nice advantage on the availability of the DRE sources, as the dry season and wet season compensate each other in different geographical areas of the country. An illustration of availability and the compensating nature of VRE sources like wind and solar PV resources with DRE sources like hydro power throughout India is as shown in the Fig.(6).

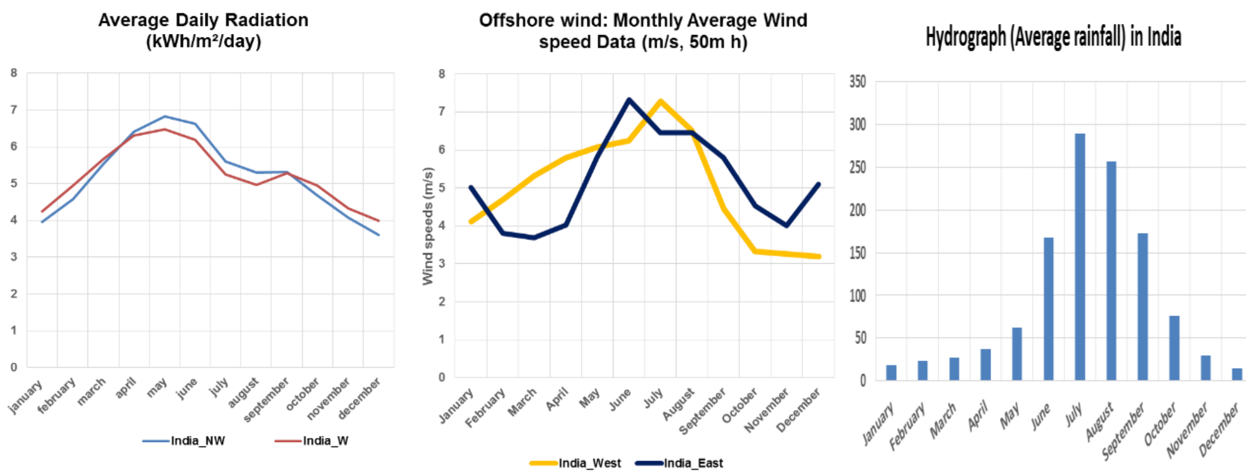

Fig (6) Seasonal availability of Solar, Offshore wind and Hydro power resources in India Source: CEA, GoI

VRE+ LES

Large scale Energy Storage (LES) technologies are the most simple solution for a sustainable VRE integration, as excess electricity generation from VRE sources is stored and then as per requirement be used to compensate during fluctuating generation from the VRE sources. Most of such technologies are highly capital intensive, which makes them a less-favored choice. Also, the advancements/developments in such technologies are also slow (i.e., battery technology), making them unfavorable again to most ‘developing’ countries again. A Fig.(7) illustrates the Capital cost comparisons between Pumped Hydro Energy Storage (PHES), Compressed Air Energy storage (CAES) and Hydrogen Fuel Cell Storage System (HFCSS).

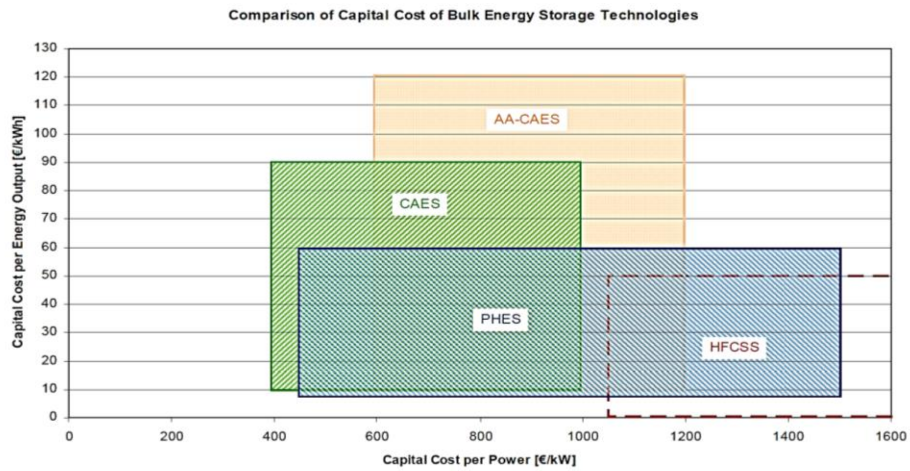

Fig.(7) Capital cost comparisons between several commercially available LES technologies Source: Wietschel, 2011

The most used LES technology is the pumped Hydroelectricity technology, which has a high energy density and power density. Storing of large amount of energy for a longer duration of time has always been the goal of energy storage research, and pumped storage is the technology which has reached the closest to this goal. Also, longer life time's makes the technology the most preferred one.

Several pumped hydro power plants add up to a capacity of 5 GW in India, which is very small compared to the amount of VRE expected to be added. Several challenges are expected, with land acquisition to flood control in the regions around the planned plants. Possibilities to exploit the mountainous regions of neighboring countries like Nepal, Pakistan and Bhutan are currently being explored, in exchange for electricity trade and internet bandwidth. CAES technology has also been considered, as there are several mountainous regions with stable rock formations in the northern part of the country. However, due to high capital requirement, and low efficiency, this option is not really favoured.

Large scale battery systems are also now popular in many industrial demand centers in India. An overall capacity of 125 MWe in testing phase targets the challenge of energy security for industries. Electro-chemical Capacitors and batteries are usually coupled in small scale with solar PV power plants, especially in the southern part of the country. These ensure the dampening of the fluctuations in the power produced due to interference from the cloud activity.

Most of the LES capacity which are connected to the central grid are state-owned, as they are highly capital intensive (especially PHES). An effort to decrease the Capital cost intensity of such LES technology must be made considering their importance in the energy system, with the usage of a liberalized market, where there is input of investments from private utilities and foreign investors.

VRE+ Smart Grids

Utilities make investments to maintain reliability which is sufficient to accommodate the growth in load, as well as new investments which help in building a part of the futuristic power delivery system. With the use of 'smart' grids, the reliability factor is maintained without the need for continuous large investments on upgrade of ageing components, and in turn the grid also manages to accommodate the growing electrical load. To handle the complexity created by the fluctuating nature of VRE sources, addition of a 'smart' component in to the system could be very effective.

Since almost half of the country's area is yet to be built [2], energy intelligent infrastructure can be easily integrated at an early stage. Smart grids are one such infrastructure, which not only manages to compensate/manage the fluctuating nature of the electricity generation from VRE, but also efficiently reduces the T&D losses. Several smart grid forums in India have popped up, once their value surfaced. The Indian Smart Grid Forum (ISGF) has several pilot projects throughout the country, out of many which are already in the testing phase (d).

Smart Grids in India can support the decentralized generation from VRE sources, also support several other strategies like charging plans for E-mobility, demand side management and supply optimization. However, the capital costs when compared to a conventional electrical grid is quite high, which makes it an expensive strategy, considering the vast area of the country to be covered. In some studies [7][8] it is explained how smart grids can also be used for primary control of the grid, by controlling the fluctuations in the grid frequency due to the fluctuating generation from the VRE sources. Such a frequency controlling mechanism can be immensely valuable as there exists a direct impact of the frequency fluctuation on power quality and the grid component lifetimes.

The work involving deploying smart grids usually comes under the responsibilities of the retail distribution utility in the power region. Electric Power Research Institute (EPRI) [8] estimates that the cost of deploying digital controls and applications on the grid would average $17 billion to $24 billion a year. 70 percent (of the higher estimate) of such costs however would be required to up-grade the substations, lines, poles, meters, communication systems and to replace the ageing infrastructure. However, such an up-grade would help in improvement of energy efficiency and electricity usage, leading to the stagnation of the continuously increasing electricity demand in the country.

VRE+ E-mobility

Almost 60 percent of VRE addition in India is planned to be de-centralized, to satisfy the local demand rather feed in to the central grid. Especially within the strategy for solar PV, the GoI has planned a major addition in distributed PV capacity. Furthermore, in the case of small isolated energy systems, E-mobility can be effectively used as an electrical storage strategy, by using unique charging plans focusing on over-production from VRE during off-peak hours.

When the E-vehicles are used as mobile-battery systems, two paths for the flow of electricity are considered. Grid-to-Vehicle (G2V) is when the E-vehicle is charging its batteries with the electricity from the grid. Vehicle-to-Grid (V2G) is when the E-vehicle feeds in electrical energy from its charged batteries in to the grid, when there is a requirement in the grid. The V2G and G2V strategies involve a much higher degree of complexity, as time-location-specific charging and discharging has to be scheduled, and in a larger system, the battery lifetime decreases significantly, due to the repeated charging and discharging of the vehicle battery. These strategies are smart, but it further increases the complexity of a system with high VRE penetration, increasing the already high integration costs.

However, when power regions are isolated in a small scale, this hybrid system functions sustainably, with a slightly smaller decrease in the battery lifetime. This is because, the scheduling in a small scale energy system can be easily done and followed, as the number of variables in the system is comparably fewer than in a single, integrated large system. Several studies for V2G and G2V strategies [3][9] suggest that even with smaller isolated systems, the resulting challenges in the system are formidable. A study on the effects of E-mobility in India was conducted, both for isolated power regions in India and for an overall Indian energy system. Fig.(8) shows the effects of an off-peak charging strategy on several qualitative parameters in the overall Indian energy system [9].

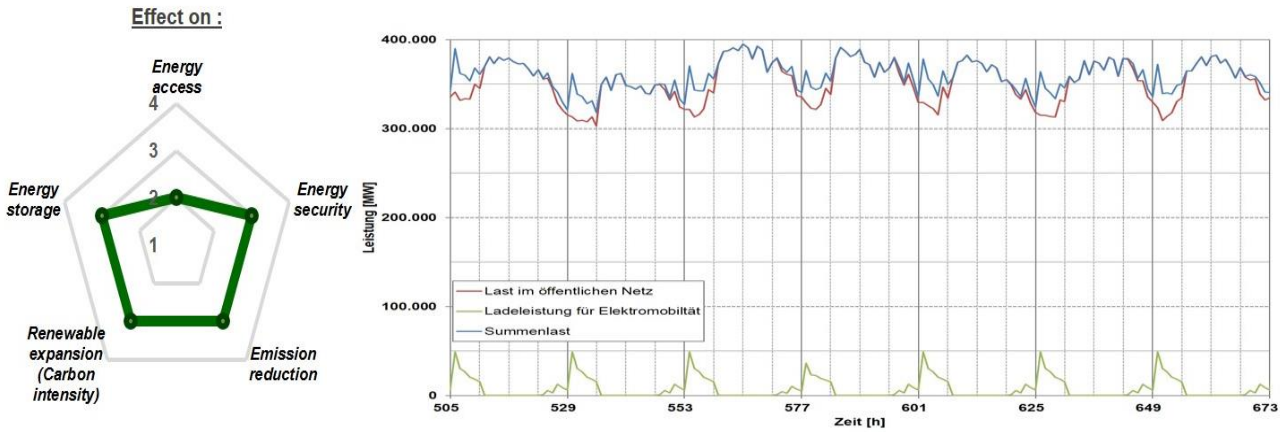

Fig.(8) Off-peak charging strategy for E-mobility in India (9) Source: IEE, TUG

VRE+ clean conventional technology

As discussed earlier, almost 60 percent of India's electricity generation comes from coal based technology. A majority of such coal power plants are owned by the state, and several (30%) 'new' power plants are owned by the private sector. A complete transition of the electricity sector to renewable would lead to 'stranded' assets [2], which would further push the sector into financial losses. Coal based technology is highly reliable in nature, but the dependency created on imported coal could have major impacts on the development of economy as it is closely linked to the energy usage.

The other main limitation of such technology is that they are highly carbon intensive. 'Clean' thermal power plants are those which optimize the fuel usage and have a comparable lesser carbon output. The exhaust gasses from the plant are also scrubbed/treated to remove poisonous content like SOx and NOx emissions. Coupling of such reliable but clean thermal technologies with the VRE capacity could prove highly useful, albeit the dependency of the country's economy on imported coal still remains.

No large investments in additional infrastructure are required, as most of the work is related to up-grading the technology and/or retrofitting components to the already available infrastructure. Even with a complete renewable energy system, conventional (gas-fired/ coal fired) Combined Heat and Power capacities have a high value as heat is the by-product of the conversion process, and has a higher degree of usage in industrial processes and district heating in winter.

Results

In a nutshell, an overall comparison of the several hybrid systems discussed in this study can be considered as the end result of this study. A table showing the comparisons of the several hybrid systems in the scope of this study is as shown in the table 1, and the parameters defining the comparisons could be taken as indicators to the effectiveness of the systems.

Hybrid System	Complexity	Capital Intensity	Added benefits	Effectiveness
VRE+DRE	**Low**	**Relatively Low**	Agriculture, Biomass	**Short and Long term**
VRE+ LES	**Relatively Low**	**Very High**	Back-up Power, Water Management	**Long term**
VRE+Smart Grids	**Relatively Low**	**High**	Energy Efficiency, Reduced financial loss	**Long term**
VRE+E-Mobility	**Very High**	**Relatively Low**	Transport sector – Pollution reduction	**Long term**
VRE+Clean Conventional	**Low**	**Low**	Avoid stranded assets	**Short term**

Table 1: Comparison of VRE-hybrid energy systems with respect to their complexity, capital intensity and added benefits

Furthermore, it becomes a tradeoff between complexity, capital intensity and effectiveness of the hybrid system in question. LES are capital intensive, but usually have longer technical lifetimes than their economic lifetimes (capital stock) which could benefit future generations [10]. Similarly with smart grids, optimization and loss minimization could be the short term benefits, while central integration and sustainable operation could be a long term effect. In a nutshell, LES and smart grids are strategies with very long time benefits, which could prove beneficial for the future of the energy system. Clean conventional technology plays a vital but temporary role with which the transition to complete renewable generation can be managed. E-mobility is also a good strategy, but when integrated on a large scale, the complexity of the system increases drastically, which brings in the role of smart grids. DRE could be the most viable answer, as a sustainable generation along with the supporting of agriculture, which is one of the major occupations in the country, is possible. DRE technologies like hydroelectricity also have the long term benefits like LES systems with very long life times.

Conclusion

Electricity from VRE sources are defining the future of the Indian electricity sector, and strategies for the effective, sustainable and economic integration of such technologies has to be given utmost priority. Within the scope of this study, several hybrid systems are discussed, and with consideration of the benefits and the limitations, it is concluded that not one but many such possible hybrid systems has to be implemented for a successful integration of large scale VRE capacity.

However, a larger capacity of DRE integration could prove very useful, as small hydro power systems can be easily and effortlessly integrated considering the agricultural dominance in India. Irrigation canals could also be used to generate hydroelectricity, along with supporting agriculture- which in turn provides biomass fuel as a byproduct. Clean conventional technologies could save the 'new'er coal power plant assets from being stranded and also prove valuable as a buffer, providing reliable electricity during the time and capital intensive VRE integration process.

With an overall perspective, it can be indicated that hybrid electricity systems define and play an important role in the future of India's energy sector. As a conclusion, the study suggests the maximized usage of DRE technologies, smart grids, LES technologies and E-mobility as long term plans for the integration of large scale VRE in the Indian energy sector, while managing and retrofitting coal/ gas power plants with clean conventional technology, decentralized small hydro along with electricity generation from biomass could prove economically valuable from a temporary perspective.

Future works

Technical and economic validation of the importance of the discussed hybrid systems in India could be done with the help of the techno-economic modelling software ATLANTIS [11] which is ongoing work at the IEE now. Several possibilities discussed in this study could be modelled in ATLANTIS, and a futuristic estimation on the working of the overall energy system in India could be evaluated in a much more realistic and practical way.

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(c) http://mnre.gov.in/file-manager/UserFiles/Statewise-Solar-Potential-NISE.pdf
(d) http://www.indiasmartgrid.org/nsgm.php

Abbreviations

1. VRE : Variable Renewable Energy
2. DRE: Dispatch-able Renewable Energy
3. LES: Large scale Energy Storage
4. EPRI: Electric Power Research Institute
5. GoI: Government of India
6. CEA: Central Electricity Authority, India
7. PHES: Pumped Hydro Energy Storage
8. CAES: Compressed Air Energy Storage
9. HFCSS: Hydrogen Fuel Cell Storage System
10. ISGF: Indian Smart Grid Forum
11. IEE: Institute for Electricity economics and Energy innovation, Graz University of Technology