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Rural Electrification in India: A Decentralized Approach

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Abstract - *Renewable energy technologies have substantial potential to provide reliable and secure energy supply as an alternative to grid extension or as a supplement to grid power and therefore suitable for electrification of rural and especially remote areas which are still lacking access to modern energy sources like electricity; perceived major barrier for rural development. In India, locally available, renewable energy sources such as solar energy, biomass, wind, or hydro energy can go a long way in alleviating the problem of lack of electricity and can play a prominent role in extending access to energy. Though India has embarked upon an ambitious programme of rural electrification which may expand the grid connectivity rapidly to several uncovered areas, the actual supply of electricity through the established grid would still remain unpredictable and limited. This review paper studies existing literature to map out the factors that have led to the successful implementation of Decentralized systems and explores how these systems can lead to social and economical upliftment of the rural community.*

Key Words: **Renewable Energy, Off-Grid, Rural Electrification, social and economic implications, Decentralized systems**

1. INTRODUCTION

The energy system is currently undergoing a fundamental transformation. From fossil to renewable energy, from central power plants to distributed, decentralized generation facilities such as rooftop solar panels or wind parks, from utilities to private residents as producers of energy, and from analogue to digital[1].

In developing countries decentralized renewable generation may lead to leapfrogging of certain stages of infrastructure development, analogous to the usage of cell phones instead of building a fixed network for landline telephony services. Especially in rural areas, it may provide a complementary service to the existing energy infrastructure, with individual households establishing micro-grids that enhance commercial activities and, literally, improve the quality of life of local residents[1].

Centralized and non-renewable systems, namely, large-scale plants using fossil fuels as oil and coke, are environmentally unsustainable because they are based on exhausting resources, so forth fastening resources depletion. Furthermore, these exhausting resources result in high greenhouse gases emission (CO_2 emissions), through several processes along their life cycle, which determine global warming. Finally, they are responsible for other pollution problems during extraction and transportation processes due to their linking[3].

Renewable and distributed resources on the other hand, such as small-scale solar and wind generation units, are more environmentally sustainable because they use locally available and renewable energy sources, thus resulting in a reduced environmental impact compared to the various processes of extraction, transformation and distribution of fossil fuels. Furthermore, they have much lower greenhouse gases emissions in use. To conclude, compared to centralized systems, local energy production and distribution increase reliability and reduce distribution losses[3].

The price of renewable electricity technologies, such as onshore and off-shore wind and solar photovoltaic, has fallen rapidly in the last decade. This is because of lower prices due to increased competition, a shift in production to lower-wage economies (from Europe to Asia), technology improvements, and economies of scale. In Europe, the cost of solar modules decreased by 83 per cent between 2010 and 2017. According to an International Renewable Energy Agency (IRENA) estimate, the global weighted average LCOE of utility-scale PV plants has fallen by 74 percent between 2010 and 2018, from US$3,300–7,900 per kW range in 2010 to US$800–2,700 per kW in 2018. The utility scale solar PV projects commissioned in 2018 had a global weighted-average LCOE (Levelized Cost Of Electricity) of $0.085 per kWh, which was around 13 percent lower than the equivalent figure for 2017[2].

2. REVIEW OF EXISTING LITERATURE

India, as one of the world's largest and most rapidly emerging economies, sits at the intersection of two major challenges when it comes to electricity: how to provide reliable electricity to rural communities who currently lack access; and how to control the environmental impact of powering such a large population and expanding economy. The Government of India has made it a priority to increase access to electricity for rural communities, emphasizing renewable and decentralized sources. It has done so by mandating construction of electricity infrastructure across thousands of villages, setting ambitious renewable energy targets, and committing sizable budgets[4].

In South-Asia, India still has the largest energy access deficit (99 million people). Other countries such as

Bangladesh (20 million), Pakistan (57 million) and Nepal (2 million) also remain priority countries[5].

Provision of reliable power supply for productive purposes has not been the focus of grid-based rural electrification in India. Mini-grids can play a role in providing reliable power supply, but we also found that their use remained largely limited to basic lighting and cooling purposes only. Given 3

the high cost of operation of mini-grids, scaling up their use to meet motive loads remains a challenge. As extension of grid infrastructure remains the focus of rural electrification policy in India, grid-interactive mini-grid technologies could be used to serve rural enterprises as they value reliable power supply[9].

2.1. Policy and Framework

Under the Electricity Act, 2003, the central and state governments have the joint responsibility of providing electricity to rural areas. The 2003 Act also mandates that the central government should, in consultation with the state governments, (i) provide for a national policy on stand-alone power systems for rural areas (systems that are not connected to the electricity grid), and (ii) electrification and local distribution in rural areas. Consequently, the Rural Electrification Policy was notified in August 2006[6].

The Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), launched in 2005, was the first scheme on rural electrification. In December 2014, the Ministry of Power launched the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY), which subsumed the RGGVY[7]. Components of DDUGJY include: (i) separation of agricultural and non-agricultural electricity feeders to improve supply for consumers in rural areas, (ii) improving sub-transmission and distribution infrastructure in rural areas, and (iii) rural electrification by carrying forward targets specified under the RGGVY.

On 25th September, 2017 the central government launched the Pradhan Mantri Sahaj Bijli Har Ghar Yojana (or Saubhagya)[8]. The scheme seeks to ensure universal household electrification (in both rural and urban areas) by providing last mile connectivity. The scheme is expected to cover around thirty-million households[8]. As per the data[10], out of the 26,303,084 households selected by this scheme to be electrified, 99.3%(2,62,84,350) of the households have been electrified(as of 8 May 2020). Only 0.07%(18,734 households) need to be electrified, all in the state of Chattisgarh[10].

On the face of it, this seems like a massive achievement. But a closer look tells a different story. According to the DDUGJY Act[7], an electrified village is defined as one that has the following: (i) provision of basic infrastructure such as distribution transformers and lines in the inhabited locality, (ii) provision of electricity in public places like schools, panchayat office, health centers, dispensaries, and community centers, and (iii) at least 10% of the total number of households in the village are electrified.

This means that a village is considered to be electrified if 10% of the total number of households in the village have been electrified. This is apart from the basic infrastructure and electrification of certain public centers in the village. In other words, a village is deemed "Electrified" even if 90% of its households have no connection.

2.2. Moving Towards a Decentralized System

Decentralized solutions such as mini-grids present an important opportunity to provide electricity access in rural areas that generally remain underserved. This is because it is economically unviable to extend the central grid in these areas due to their remote location, low purchasing power and low energy demand of the inhabitants [11]. Owing to these reasons, in South Africa, solar home systems (SHS) were preferred instead of a central grid to provide immediate access to those rural households that could not get electrified in the first phase of the national electrification program [13]. Many countries such as Nigeria, Peru, and Tanzania have now included mini-grids in their national electrification plans [14]. [9]

At the risk of oversimplifying, there are three primary components of any rural household electricity system. One needs a source of electricity (generation), a means to deliver it (infrastructure) and a system to operate, maintain, bill, etc. it. Except for a household-level stand-alone system (such as a solar home system), popular with many rural homes, these three components are present and similar regardless of whether one is dealing with the traditional grid or a micro grid. Even in a micro grid, operational expenses (opex) are mostly fixed costs for manpower and maintenance contracts. Thus, lower energy consumption in a micro grid does not save that much money in an absolute sense-the per unit electricity cost rises non-linearly. In fact, at the margin, in a solar photovoltaic (PV) micro grid, lower consumption does not save any money[12].

3. THE POTENTIAL DRIVERS OF DECENTRALIZED SYSTEMS

A thriving marketplace exists all over India that provides these alternatives to individual customers under a wide range of contractual arrangements such as leasing diesel gensets, outright purchase, and others. However, comprehensive data of a high quality about this marketplace is not available for India. Not only is basic data – e.g. sales of diesel generators is not readily available, there is not much data available about the usage of these alternatives (e.g. hours of use for a typical lead acid battery). The lack of data does not imply that these alternatives do not exist. In reality, the Indian end-user demand for electricity has always been met through a combination of centralized system, and decentralized alternatives. The extent of the decentralized system is not comprehensively quantified although numerous case studies have been done([4],[9],[12]) that provide a useful qualitative picture.

From a cost-effectiveness perspective relative to the centralized system – most of the alternatives listed above are massively more expensive than the centralized system. For example, running a diesel generator is twice as expensive as even the most expensive retail tariff for electricity from the centralized system. Similarly, kerosene lanterns are among the most expensive ways of providing lighting. However, given the unreliability and often availability of the centralized system, the user is, in fact, assessing the cost effectiveness of the alternatives relative to having to forego the service (e.g. lighting) in its entirety.

It is in this context that one has to examine the role of new technologies such as distributed solar, batteries, more efficient equipment (e.g. LEDs), and others and assess the factors that influence their adoption. In India, distributed solar PV systems are fundamentally not competing with electricity from the unreliable Indian centralized system but with the substantially expensive distributed alternatives (e.g. diesel generators, etc.) that have been historically used to supplement the centralized system. Initially, solar PV was significantly more expensive than these alternatives.

The service most analogous to electricity is water. And this example, too, is telling. Unlike in western countries, most Indian cities have not been able to supply their citizens with 24-7 water through a centralized pipeline system. Consequently, almost all households and businesses have water storage tanks. Some households have multiple. Many households have private 'bore wells' that run deep underground to access subterranean aquifers; others hire companies to deliver water in private tankers. Similarly, since the quality of the water is poor, households rely on a host of purification technologies installed and operated at the point of consumption.

As the costs of decentralized systems in the electricity domain continue to decrease, i.e., rooftop PV (analogous to bore wells in the water infrastructure above) and batteries (analogous to water storage tanks in the water infrastructure above), it is quite possible that the electricity system would also evolve into a hybrid system similar to the water supply system. The problem is that the current water system (and the future potential electricity system) is not optimally designed, implemented, and operated in this hybrid form, but has simply evolved in a haphazard manner. A more thoughtful approach that actively incorporates both forms of centralized and decentralized systems in order to minimise the overall costs to society would be beneficial. For example, the distribution utilities may want to formally incorporate the decentralized systems (both spatially and temporally) while designing and operating their distribution grid infrastructure and making their wholesale level procurement decisions. Retail tariff designs could be considered that provide appropriate signals to consumers as they determine which decentralized systems to invest in. Currently, the distribution utilities have either ignored the existence of the ad hoc decentralised systems or resisted them outright.

4. BARRIERS TO DECENTRALIZATION

While the acceptance of mini-grids as a viable rural electrification technology is increasing, there are several barriers to their development such as ambiguity regarding regulations, financing constraints for developers, and lack of affordability for customers [15]. As most of the mini-grids are privately operated, their operations are likely to overlap with the central grid that is operated by country governments [9].

Many authors argue that the biggest threat to mini-grid operations is the availability of Grid Electricity. Grid electricity, while often unreliable, is often cheaper because of economies of scale and/or administrative pricing that fail to recover the full cost of generation, transmission, and distribution [9][16].

For micro-grid projects, robust resource assessment studies followed by continued reliable availability of such resources are crucial for their financial viability. This is especially true with regard to biomass gasifiers and micro-hydro projects where secure and sufficient supplies of biomass feedstock and water streams respectively, are a challenge for their effective and optimal operation [19, 20, 21, 24]. For biomass gasifier projects, the gas engine technology is also not yet fully standardized for remote village operations [22, 24]. In addition, gasifier projects have a higher scaling up/gestation time, which needs to be factored in while estimating their pay-back periods [24].

Solar PV based electrification is mainly suitable for small power requirements (lighting, mobile charging and few appliances) since its high cost prevents its use for high wattage applications. Additionally, in solar PV projects, significant attention is needed to ensure that its batteries are charged and discharged properly for longer life. The environmental impacts from production, recycling and disposal of PV components is expected to become a crucial issue in the future [20, 24].

For micro-hydro projects, robust and reliable flow data and the seasonality of flows is a major concern. Further, the absence of standardized equipment parts and designs has also been a barrier for the large uptake of this low cost resource[24].

Solar-wind-biomass hybrid systems may improve the reliability and performance of the Decentralized system, while simultaneously reducing specific costs and thereby providing improved quality of access to consumers. The suitability of such options based on hybrid technology for micro-grids which can complement each other need to be evaluated further [23, 24].

5. THE WAY FORWARD

The inevitable transition in the energy sector is mainly being driven by external technology and economic changes and hence uncertain and difficult to predict. Unless guided by conscious policy decisions, the transition will unfold chaotically, with the small and rural consumers being the likely sufferers. However, if negotiated well, it also offers an opportunity to avoid many inefficient resource lock-ins with significant economic and environmental costs. India can chart a new exemplary development path in which it can provide its citizens with modern energy services without necessarily compromising on other resources such as land, air and water, while potentially opening up employment and investment opportunities in many new sectors associated with the transition[25].

As mentioned in the earlier section, availability of Grid electricity poses a challenge to the viability of mini/micro grid projects. But case studies by authors[9, 17, 18] have shown that even though switching to or using grid electricity is very attractive due its 'limitless' supply, they are found to be

erratic and unreliable. In fact, the consumers in many studies have switched from grid electricity to off-grid sources due to its reliable supply. Though off-grid electricity tends to be expensive, they are willing to pay the price.

Another important factor for the successful implementation of mini-grid systems in these case studies[17, 18] has been the community involvement. The design of DRE programmes and projects is a top-down activity in many cases, so that the needs of the local people are not taken into consideration [26]. Also, local people are considered to be mere 'beneficiaries'. Instead, setting up a truly participatory planning process would be able to better assess user needs through their active involvement. Use of local knowledge, social inequities and class-caste structures are often not considered [24,26]. The project should be based on the needs of the community and should use the resources available. Community involvement helps to achieve a better understanding of the local ground realities.

Case studies[17, 18] have also shown that implementation of these systems also help in job creation and overall welfare of the community. This will also help in reducing migration from villages to cities in search of work and higher. With electricity comes prosperity, which will help uplift the underserved communities.

6. AN ALTERNATE APPROACH

Existing literature and case studies on Rural Electrification using Decentralized Energy Generation is based around individuals and NGOs(Non-Government Organization) financing these projects with little to no help from the government. It is important that the policy makers recognize the benefits these systems have to offer and integrate them with overall development goals to get fruitful results[24].

A new model needs to be developed to implement such projects. Such models cannot be controlled from the center as mentioned before, as decision making from the Central Government can delay these projects and these projects need to factor in the needs of the community and systems need to be carefully designed and optimized to make use of locally available sources. In his book[28], RN Bhaskar lays out one such approach for the successful implementation of Decentralized systems.

The best approach is to have an Entrepreneur set up these systems. This will increase accountability and private entrepreneurs are more inclined toward completing projects as compared to Government entities. This entrepreneur can procure the required equipment needed after designing the system in bulk which will drive down the per unit costs viz a viz the per unit costs incurred by individual customers. The scope for power theft also reduces under the control of this entrepreneur.

A cluster of villages needs to be created such that the population is large enough to generate enough energy and cooking gas using biomass (illustrated below) and the distances to transmit the power are optimal to have minimal losses. This will also ensure that small villages are not left out from reaping the benefits. Clubbing 100-200 villages will also pave the way for building better roads for connectivity.

To produce electricity and cooking gas using biomass, sewage systems can be laid to collect human excreta and other organic wastes. Farm waste and stubble can be collected as organic waste to use in the digester. A 'centralized-yet-decentralized' system of sorts can be formed where organic waste can be collected to form biogas in huge quantities. Implementation of such sewage systems will pave the way for building of toilets, which can solve Open Defecation problems. Crop stubble is often burned as it is the cheapest way to dispose of it, even though it's illegal. Burning of corn stubble has created major pollution problems in, for example, in Delhi, the capital of India[27]. In one of the case studies[17], it was found that Husk Power Systems, a startup based in Bihar, provides electricity for six to seven hours each evening, to about 100,000 people across 125 villages, using only rice husk.

Once the methane is extracted, the slurry can be dried and distributed amongst farmers for it to be used as manure. When biogas is produced through any form of anaerobic digestion, it will be mostly polluted with hydrogen sulphide. Removal of hydrogen sulphide is often required for reasons of health, safety, environment and corrosion of equipment such as gas engines and piping. Desulphurization is also necessary when biogas is upgraded to natural gas quality and injected in the grid, for which a desulphurization plant can be set up. This also eliminates the stench of excreta. This plant can pay for itself if the volumes are large, which it is in this case. The sulphur extracted can be sold to pharmaceutical, pesticides and fertilizer industries.

Solar rooftops will not only generate electricity during the day, but can also provide a solid roof to huts in these villages. Solar companies too can be invited to set up solar on rooftops. Their investments will be much lower than those compared to setting up Solar power plants as there are no land acquisition costs.

A big system can hence be created to supply Base Loads as well as Peak Loads. Each house can have individual batteries to capture the electricity through Solar. If any extra units are generated, this can be supplied to a bigger battery placed at the center of the cluster, closer to the biomass plant, for which the user can get tariff concessions. Electricity produced through the biomass plant can be stored in this bigger battery to supply peak loads and agricultural loads. Houses requiring more units than what their roof has generated can be supplied through this big battery but for a higher tariff rate. Each private sector entrepreneur would be interested in getting his captive area to consume more electricity and would thus act as a catalyst for encouraging rural communities to start some business, which can also help in creation of jobs and improve the lifestyles of the people living in the community. Prosperity in villages will slow down the migration of people to cities in search for better jobs and higher wages.

The entrepreneur can drastically reduce his Opex (Operation and Maintenance) costs by deploying smart grids and remote sensing, which can optimize the system functions by accessing the conditions. A recent study [29] elaborated how blockchain or distributed ledger technologies can benefit energy system operations, markets and consumers by offering disintermediation, transparency and tamper-proof transactions, but most importantly, offering novel solutions for empowering consumers and small renewable generators to play a more active role in the energy market and monetize their assets.

A Committee can be formed consisting of village volunteers to look into the daily operations of the system. Community involvement helps to achieve a better understanding of the local ground realities.

7. CONCLUSION

It is important to link rural electrification programs with rural development plans. This will not only aid rural development but also increase electricity demand in Indian villages that, in turn, can improve the financial viability and thus quality of electricity services in rural areas[9].

Decentralized solutions offer much more than just being an alternative to grid electricity. They are more reliable and can be implemented to solve many other socio-economic barriers currently faced in rural communities.

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