

**INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH  
TECHNOLOGY****RURAL ELECTRIFICATION IN INDIA: CHALLENGES AND STRATEGIES****I. Nawaz\***Department of Mechanical Engineering Faculty of Engineering & Technology  
Jamia Millia Islamia New Delhi-110025 (INDIA).**ABSTRACT**

Rural electrification is a critical ingredient for rural development process. Efficient provision of electricity contributes to poverty reduction by acting as a catalyst for industrial growth and enhancing agricultural productivity. Being central to basic human needs of health and education; it has significant impact on quality of life in the rural areas. Despite this strong and well established link between development and electricity provision, it is ironic that India's track record with regard to rural electrification has been far from impressive. After nearly seven decades of Independence, 68.84% of the country's population which lives in rural areas still does not have adequate access to electricity. Recent policy initiatives have however given the much needed thrust to electrification process in rural India. A significant attempt has been made to place electricity in the holistic picture of rural development. Rapid expansion of rural electrical power distribution network in India has presented several financial and technical problems. Due to low tariff, the revenue realization is not commensurate with heavy investments made on infrastructure. The system efficiency is also poor, resulting in high power losses and poor reliability of supply. The system deficiencies are largely the result of poor planning and use of inappropriate distribution practices. This study has highlighted the need to confront these challenges by adopting innovative strategies to upgrade system efficiency and to optimise future investment in this important development programme.

**KEYWORDS**— Challenges, strategies, rural electrification, rural development, electrical power distribution network, investment, infrastructure.

**INTRODUCTION**

Rural electricity is an essential requirement for all facets of life and has been established as a basic human need. It is the key to accelerating economic growth, generation of employment, human development and elimination of poverty, especially in rural areas. It is also the main infrastructure for ensuring speedy growth of agriculture sector and agro based industrial structure in rural areas. But the main challenge of the electricity sector is development of rural electrification and it has become a global concern. Even today, vast majorities of people in rural areas in developing and under developed countries do not have access to commercial forms of energy. Most of these people are dependent on traditional fuels like wood, dung and crop residue thus often resorting to using primitive and inefficient technologies. For many, this combination barely allows fulfilment of the basic human needs of nutrition, warmth and light, let alone the possibility of harnessing energy for productive uses and socio-economic development, which might initiate the escape from the cycle of poverty.

Evidently, socio-economic development of a country is inherently linked to the availability of electricity to the people for productive use. Recognizing the social and economic benefits of electricity in rural India, the programme of rural electrification has been given high priority by Government of India. Massive investment has gone into this programme and according to India's Central Electricity Authority, a total of 576,554 villages have been electrified as part of the ongoing rural electrification programme in the country. The number of un-electrified villages stands at 19,760 out of the total of 597,464 villages identified for electrification, across 29 states and 7 union territories. These figures relate to the end of XIth Plan, under the power ministry's flagship rural electrification programme, Rajiv Gandhi Grameen Vidyutikaran Yojana [1]. Out of more than 214, 25,000 the estimated ultimate potential of electrical pump sets, 92.8% of pump sets have been energized so far. Out of 1,95,94,000 pump sets, providing assured means of irrigation to the

farmers spread over the vast country side, the balance potential to be exploited later on amounts to 18,31,000 [1]. This has emerged as the major single factor in making the country self sufficient in the production of food grains. While the countrywide village electrification and pump set energisation programme has had beneficial effects on the life style of the rural population and on food production, there is also a downside. The rural electrification programme has put severe strains on the economy of the State Electricity Boards (SEBs). The pump load, accounting for more than one-fourth of the total electricity power consumption in the country, is supplied at a highly subsidised tariff. This has saddled the SEBs with heavy financial burden.

Heavy investment under Rajiv Gandhi Grameen Vidyutikaran Yojna (RGGVY) of over 51,000 crore made in the rural electrification programme has not been based on proper planning of the network and adoption of appropriate distribution practices [2]. This has resulted in high power losses about 22-25% in the high voltage (HV) and low voltage (LV) distribution network [3]. This is causing a financial burden of about 7,000 crore on the SEBs annually. Apart from high power losses, the quality of supply is also poor. Power supply to rural areas is cut off for several hours during daytime due to the need for controlling peak demand caused by simultaneous running of irrigation pumps. This has hampered economic development of rural areas as the industries are shifted to urban areas, negating an important objective of rural electrification. The system efficiency requires to be improved by adoption of modern planning techniques and use of energy efficient distribution. The new strategies should aim at removing the existing deficiencies in the supply system in a phased manner and optimising future investments in this programme. It should also be possible to implement well-conceived, commercially viable energy efficient measures by mobilizing private sector.

### **OBJECTIVES OF RURAL ELECTRIFICATION**

Rural electrification is thus a vital programme for socio-economic development of rural areas. The objectives are:

- To increase access to efficient and sustainable electricity services in rural areas
- To trigger economic development and generate employment by providing electricity as an input for productive use in agriculture and rural industries
- To improve the quality of life of the rural people by supplying electricity for lighting of homes, shops, community centres and public places in all villages

The present situation in rural sector is shown in the Appendix.

### **CHALLENGES**

One of the key challenges of the electricity sector is expansion of the coverage of electricity service and improvement of its quality in specifically rural areas. These are challenges that industrially developed as well as developing countries grapple with and must be addressed by a robust national rural electrification strategy or programme. Rural areas are characterized by low level of population density with a significant number of households that are poor. This results in low levels of household demand for electricity that generally is concentrated at evening peak times. The low population densities mean that electricity distribution costs must be spread over relatively few people resulting in high costs for each unit of electricity consumed. Demand normally matures slowly (over 2-3 years and even later) as consumers wire their houses, invest in appliances, and make the switch from other fuels for lighting and cooking. As the demand grows; the cost per customer for rural electrification declines. Unfortunately, this progression is difficult to predict, making returns to investment in grid extension to poor rural people uncertain. Thus, grid expansion costs are typically high in rural areas because loads to be served tend to be small and widely dispersed. The cost of rural electrification can however be minimized if design standards are modified appropriately, and the choice of technology is based on both financial and potential socioeconomic benefits to a community or region.

Operating and maintaining systems in rural settings poses additional difficulties. For large centralized utilities, retaining and supervising a cadre of technical staff is costly and problematic in rural setting. Larger distances make supervision difficult and expensive, resulting in, amongst other things, lower quality maintenance due to lack of technical staff. As indicated, most rural electrification programmes involve some form of subsidy to encourage rural consumers to adopt electricity. This has caused two types of problems; the first is that since governments are providing subsidies to rural electrification, politicians feel that they have a right to intervene in the operation of the distribution company to get electricity to their constituents. After connection, they also intervene on behalf of their respective

constituents to restore service that has been cut off due to lack of bill payment. This often makes the cost per consumer even higher and causes financial stress for the company providing the service. The second problem is that subsidies that are poorly designed can lead the distribution company away from a primary emphasis on serving consumers. Instead, they may maximize the amount of subsidy they can extract from the government with rural service as a secondary goal. Once such consumer orientation is lost, the quality of service is sure to suffer. Main power companies often have institutional difficulties meeting special demands of rural distribution. For integrated power companies, the rural consumers are a small part of their business. They often do not pay attention to the numerous ways that are possible to minimize costs of service to them. The result is that rural electrification becomes a tolerated loss-maker for the company, and ways are found to cut corners in terms of customer service. For instance, rural consumers more often than not are the first to be cut off when there are problems with power supply in developing countries.

Local community level problems often provide an obstacle to rural electrification. For instance, the rural poles and lines cut across the rural countryside and sometimes local elite object to installation of lines on their property or to the compensation methods that have been developed. Thus, alternatives have to be developed to involve local communities in the process of rural electrification.

The way to successful rural electrification may be paved after solving these problems. The case studies undertaken, illustrates how each country has devised solutions to the above problems.

Rural electric market conditions are quite distinct from those in urban areas. By definition, rural areas have significantly lower population density than urban, and they are often characterized by lower incomes; less access to primary education, health services, and clean water; and either minimal or non-existent commercial electric service. Given limited financial resources to satisfy national demand for public services, government agencies have historically allocated significantly lower levels of financial resources towards development of rural public services, including investment in electric transmission and distribution infrastructure. The financial viability of electric distribution utilities is governed by the balance of costs and revenues generated from sales of energy and the cost of providing a service. Due to lower population density, often lower income, and concurrently lower specific energy consumption for rural communities, rural distribution systems realize far lower revenue per kilometre of rural distribution line than their urban counterparts. Moreover, rural distribution service providers are also faced with higher operating expense per household or commercial consumer served, given their lower energy density. Additionally, rural electric service providers must recruit management and staff resources from communities that often have fewer trained engineers, accountants, financial specialists, and customer service specialists; due to lower levels of professional and practical skills training.

These conditions are common concerns for rural electrification programmes worldwide. Some programmes have faced greater challenges with respect to human resources, while others face challenges with respect to cost recovery from lower population densities. While the degree of the challenges vary from country to country, the nature of the technical, administrative, financial, and management problems are common.

To address these challenges, rural electrification programmes require special financing support. Similarly, design and construction standards specifically formulated to address rural power-supply characteristics are needed, while lowering capital costs associated with power systems. The programmes must define operating policies and procedures that optimize service provider operations to ensure internal cost controls, while concurrently focusing on expansion of service to the maximum number of customers and promotion to commercial and small industrial clients. Given that many programmes rely on newly formed rural service providers, the programme management agency concerned for finance and supervision of rural infrastructure is entirely responsible for establishing the guiding principles for new and expanding rural electrification programmes. This means that successful programmes will also require a programme management agency with electrification expertise; it must have the ability to adapt to the country-specific realities present in individual cases.

## **NEW STRATEGIES**

The power distribution network has already been extended to over 96.5% of total villages in India [3]. It is high time that a technical review is undertaken at this stage to work out appropriate strategies and ensure that future investments in the area are not only cost-effective but also improve the quality and reliability of supply. The new strategies should broadly aim at achieving the following objectives:

- To optimise investments by introducing computer-aided network planning and cost-effective distribution practices,
- To reduce power losses from the present high level of 22% to a reasonable level of about 10% over the next few decades,
- To improve quality and reliability of power supply, and
- To ensure suitable load management scheme of staggering pump set loads without interrupting power supply to domestic, commercial and industrial loads in the villages.

To achieve the above objectives, the following technical strategies are suggested for adoption:

- Introducing computer-aided network planning
- Setting up low-cost 33/11 KV and 66/11 KV sub-stations
- Reducing the LV/HV line ratio
- Improving the distribution power factor
- Using energy-efficient distribution transformers
- Enforcing scientific load management techniques
- Promoting Private Sector participation in the energy efficiency programme.

#### 4.1 Computer-Aided Networking

Modern Computer-aided system techniques may play a critical role in distribution of power in rural electrification development programme. The distribution network has grown at a fast pace and is becoming increasingly complex each year. Even so, extensions and reinforcements to the network are often made on ad-hoc basis and are left to the judgement of relatively junior staff. This results in haphazard growth of the system, leading to high power losses and poor reliability. In view of growing complexity of the network and heavy investment in the system, it is imperative that modern computer-aided planning techniques are adopted by the SEBs. This would ensure orderly growth of the system and optimise investments. If appropriate action is initiated without further delay, it will be possible to establish scientific planning techniques. Primarily a reliable data base including mapping of lines, sub-stations and load points is to be built. This can be achieved through modern geo-referenced satellite imaging techniques, without recourse to time consuming traditional procedures.

Once reliable data is available, it should be possible to optimise future investment on the basis of computerised network studies. These studies, for instance, can be used to establish the need and the optimum location of new substations i.e. 33/11 KV, 66/11 KV and to gauge the need for augmentation of existing lines and sub-stations. One may identify the areas of higher power losses, to study the effect of system improvement measures, like provision of capacitors and load management. In due course, the network studies need to be developed in a regular manner at the sub-divisional or divisional levels. This would be of great help in achieving the desired objectives and making network energy-efficient and reliable and make future investment more cost effective.

#### 4.2 Low-cost Sub-stations:

It may be noted that 33KV and 66KV sub-stations are the back-bone of rural power distribution network. A fairly large number of new sub-stations are set up every year to meet the load growth. These sub-stations not only require heavy investment but also involve lengthy land acquisition procedures. Considerable staff is deployed to run these sub-stations. The practice is in developed countries to set up low-cost un-manned sub-stations in rural areas even up to 132 KV level. Such sub-stations can be set up on a relatively small piece of land, of about 500 m<sup>2</sup> for a 33/11 KV sub-station. There are no civil works required for sub-station room, staff quarters and there is no indoor equipment. The 11 KV feeders are controlled by outdoor auto-closers and the power transformers are generally protected by fuses. All temporary faults in the 11KV lines, which constitute about 85% of total faults, are managed by one or two automatic operations of the auto-closers and the supply is restored. In case of permanent faults, the utility personnel in a nearby village take action immediately on receipt of complaint from the consumers. Andhra Pradesh Electricity Board has

set up a number of sub-stations, which are successfully operating. The practice needs to be adopted on a large scale in the country for 33 KV and 66 KV sub-stations both. This will result in significant saving and will cut short delays.

#### 4.3 Reduction in LV/HV line ratio:

Existing long low-voltage (LV) distribution lines in the rural power distribution system are a major source for high power losses and poor voltage conditions. At present the ratio of LV to HV lines is more than 2:1 [4]. This ratio is very high and needs to be corrected. It is little realised that, for same transfer of power, losses in LV line are 625 times and voltage drop 25 times of those in 11 KV line. Besides, LV lines have much higher incidence of faults compared to 11 KV lines due to lesser spacing of conductors in LV lines. Large spread of LV lines in the rural areas also facilitates theft of power by unauthorised tapping of naked wires. Lakhs of unauthorised pump sets are operating in the country, resulting in pilferage of power, increased number of faults and overloading of transformers. In developed countries like USA, UK, and Japan the practice is to extend HV lines as close to the loads as possible and meet the power requirement of consumers through small-length LV lines, which are mostly insulated. This results in lower power losses, better voltage and minimal system faults. Reducing faults not only improves reliability of power supply, but also increases life of distribution transformers.

To achieve the desired objective, the distribution transformers ratings should be kept as small as possible. Transformer ratings such as 63 and 100 KVA, commonly used in many states, entail long LV lines and should be avoided. A 100 KVA transformer, for example will feed 20-25 pump sets over a wide area, requiring lengthy LV lines. Realising the benefits of reducing LV lines, Punjab and Rajasthan Electricity Boards have decided to produce only smaller rating transformers like 25 KVA in future. But most of the other states use 63 and 100 KVA transformers in large numbers. From technical and economic considerations, it is far more beneficial to use small rating single-phase transformers such as 10, 16, and 25 KVA compared to 3-phase transformers. This reduces cost of transformers as also the cost of the associated single-phase HV and LV lines which require only two conductors instead of three conductors required for 3-phase lines.

However, even if some of the SEBs do not find use of single-phase system suitable for pump sets energisation due to the consumer preference for 3-phase motors, use of single-phase system with smaller transformers should find increasing application for meeting the power needs of hilly, tribal and desert areas not having much pumping load. In any case, transformer ratings above 25 KVA should be minimally used whether single-phase or 3-phase system is adopted. SEBs should endeavour to reduce the LV to HV line ratio 1:1 in a phased manner [4]. This will have a major impact on the power losses and will also reduce theft of power.

#### 4.4 Improvement in Power Factor

Normally agriculture pump motors operate at a low power factor of about 0.7. The rural power distribution network is, therefore, burdened with heavy reactive power flow, causing high power losses. The power losses will be reduced by as much as 40-50% if the power factor is improved from 0.7 to 0.9 [5]. This aspect should receive high priority in the coming decades. Studies have shown that investment on capacitors to improve the power factor is highly cost effective and will significantly improve the financial viability of the rural electrification programme.

For maximum benefits, location of capacitors should be as close to the motors as possible. Some of the SEBs have tried the experiment of providing capacitors directly on the consumers' motors but this has not proved successful as the SEBs have no control on the equipment installed at the consumer premises. Rural electrification corporation (REC) has recommended the use of automatic capacitor panels on distribution transformers which are mainly feeding pump loads. Maharashtra State Electricity Board has adopted this practice on a fairly large scale with good results. The other states should emulate this example and REC should encourage the SEBs by providing liberal financial assistance for this programme. It is to be noted that the present practice of providing capacitor banks at 33 KV or 66 KV sub-station does not serve any useful purpose as the reactive power flow in the long 11 KV lines remains unchanged. Thus there is no beneficial effect in terms of reduction of power losses in the extensive 11 KV network. Nor is the loading of 11 KV lines reduced to take up future load growth.

#### 4.5 Energy Efficient Distribution Transformers

Distribution transformer is the key equipment in rural electrification programme. About 2.25 lakh transformers are already in operation and more than 2 lakh transformers are purchased every year [6]. Poor energy efficiency of these transformers is resulting in substantial power losses, which could be minimized to a large extent. For several decades, Cold-Rolled Grain oriented steel (CRGO) has been routinely used for making transformers' cores. In recent years, several new and improved core materials such as Hi-B, amorphous alloys, etc have been introduced. This has enabled production of distribution transformers with markedly reduced core losses. Reduction in losses in amorphous metal core transformers is as high as 75% compared to the conventional CRGO core transformers hitherto used [7]. The new technology is now well established and over 15 lakh such transformers are installed in several power utility systems globally. A number of indigenous manufacturers are now producing these transformers and some of the SEBs, notably; Andhra Pradesh, Tamil Nadu, Maharashtra and Orissa have started procuring these transformers in large numbers. As energy efficient transformers have higher initial cost, it is necessary for Electricity Boards to establish their cost effectiveness before taking a decision to purchase them. REC has issued guidelines to enable the SEBs to compare the tenders quoting different losses on the basis of a national loss capitalisation formula. This is the practice now widely followed all over the world for procuring distribution transformers but is still not adopted in India; except in one or two states. REC should strictly enforce this practice through its funding programme as it will go a long way in saving valuable energy.

#### 4.6 Load Management:

Energisation of about 2.25 lakh agricultural pump sets has presented a serious problem by causing a sharp peak demand, due to simultaneous operation of pump sets. If no control is exercised to stagger the pumping load, the peak demand of pump sets will equal almost half of the total peaking capacity of the generating station. SEBs are, therefore, planned to switch off 11KV feeders by rotation, causing long interruptions of power supply even to domestic, commercial and industrial consumers in the villages. This situation not only causes hardship to the rural power consumers but hampers rural industrialization and economic development. REC has developed a load management scheme, which will enable systematic staggering of pumping loads without affecting power supply to domestic, commercial and industrial consumers in the villages. The scheme envisages remote switching of distribution transformers exclusively feeding pump loads, by rotation; using radio communication signals. If this arrangement is found feasible, it will not only provide an effective solution to the problem of pump load management but will also significantly reduce power losses in the 11 KV network due to flattening of the load curve.

#### 4.7 Private Sector Participation

Privatisation of distribution of power and commercialisation of power distribution operations of SEBs are major policy issues. They are beset with certain practical difficulties. It is felt that SEBs can easily involve private companies in implementing system improvement measures, which have good financial viability. In this connection, the initiative taken by Maharashtra and Andhra Pradesh Electricity Boards is highly commendable. These SEBs have entrusted the work of installation and maintenance of capacitors in the rural power distribution system, to private companies, based on competitive bids. The payments are spread over a period of 5-10 years and are linked to satisfactory operation of equipment. This kind of build-operate-lease-transfer (BOLT) arrangement not only reduces financial burden on SEBs but also relieves them of the responsibility of maintenance and upkeep. The SEBs have thus been able to procure capacitors worth hundreds of crore of rupees, without immediate investment. They are still able to reap the benefits of substantial energy savings.

The concept of private sector participation in delivery of energy saving systems is becoming popular globally. Many organisations, commonly known as Energy Service Companies (ESCOs), have emerged. Projects for energy saving are carefully conceived and their benefits are properly evaluated before awarding contracts. The ESCOs generally take the responsibility of arranging funds and take up the work on turn-key basis. They also maintain the system for a stipulated period. The payments are spread over an agreed period of time based on the savings, accruing from the project.

It is felt that the SEBs can use this concept for implementing well-conceived system improvement projects, formulated on the basis of computer-aided optimization studies, at block or a district level. The implementation can then be entrusted to private agencies based on competitive bids. Payments can be phased out over a period of time and can be

linked to the benefits accruing in terms of power saved. If the power losses in the rural power network are reduced from 22% to 12%, which should be easily possible; it would save about 12 billion units of electricity, costing more than Rs 3000 crore annually. Thus the SEBs should be able to implement a substantial part of system renovation and energy efficiency programme, by mobilising funds from private sector.

### RURAL ELECTRIFICATION APPROACH

So far the emphasis of rural electrification programs has been on the extension of the grid to reach the rural areas, so far not covered. This has certainly helped in making electricity available to a significant section. However, there are several limitations to the approach of rural electrification, being treated as a grid extension issue. Only recently, most of the planners and policy makers have realized the futility of trying to achieve 100% electrification through, grid extension. There is need for more comprehensive approach to rural electrification.

Rural load is characterized by dispersed population and low demand (resulting in low load densities). This, in turn, causes high capital costs of grid electrification. In order to cut down on the cost, often there are low voltage lines being drawn over long distances; resulting in poor supply conditions. Moreover, the high level of aggregate technical & commercial (AT&C) losses significantly increases the marginal cost, on the part of the utility, in serving rural loads. All these put together act as huge disincentives for utilities to carry out rural electrification. This needs to be seen in the light of the current environment, where the utilities are under pressure to improve performance and reduce financial losses. Evidently, this procedure is not sustainable and there is a need to explore alternatives.

### CONCLUSION

Rural electrification programmes endeavour to provide electric service to the most problematic market segment of the power sector; at affordable prices. Programmes are usually designed to extend electric service through grid electric systems, isolated conventional energy systems, and renewable remote power systems. Similar levels of service are offered in large population centres. The challenges that rural electrification programmes are facing multiple and in some cases, daunting.

Be as it may, rural electrification planners need to establish carefully defined technical standards that allow cost minimization and high quality of service and safety. If robust planning discipline is carefully followed, rural electrification programmes can be established for rural communities on a financially sustainable basis. It is also to adjust programme-implementing principles to meet the changing needs of the communities; with due regard to financial management and programme expansion. One should ensure that programmes do not fall prey to political influence that may undermine proper project selection and tariff-setting. It is important to recognize the vital role of rural electrification programmes in rural economic development. Rural communities depend on reliable power supply to remain competitive in globalized economy.

Technically, the operational efficiency of rural power distribution network is very poor. The power losses in the system are quite high (being of the order of 22-25%). The voltage levels in many areas are very low, resulting in frequent burning of pump motors. Due to the need for restoring pump loads, power supply to main feeders are cut off and domestic and industrial consumers have no power for several hours a day. All such deficiencies can be removed by adopting modern planning techniques and appropriate distribution practices. System improvement measures suggested here are commercially viable on the basis of the savings obtained, due to reduction in power losses. It should thus be possible to mobilise private sector funds for implementation of the programme on BOLT basis.

### Appendix

#### *Rural Electrification in India (As on 31.03.2015) [8]*

Total No. of villages	5,97,464
No. of villages electrified	5,76,554
No. of un-electrified villages	19,766
Percentage of villages electrified	96.5%
Total No. of households in rural area	167,826,730

No. of households have electricity connection	134,261,384
Percentage of electrified households	80.0%
Total No. of pump sets	19.76 million
No. of pump sets energised	19.0 million
Percentage of pump sets energised	96.0%

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