Off-grid rural electrification in Karnataka state of India: Technology options, modeling method

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***Abstract*–Energy deficiency is one of the key enigmas impacting the livelihood of millions of poverty stricken people throughout the world. It is quite evident that electrification of rural areas can improve the standard of education, health conditions, living and empowering the youth of the nearby population. Census of India reveals that about 19706 of numbers of villages are still unelectrified in the state. Electrification of these villages/hamlets of remote hills using renewable energy resources in off-grid mode is a feasible option compared to uneconomical grid extension. The mean annual daily solar radiation of 4.5-7 kWh/m^2/day through the year,solar radiation with 300 sunny days in a year, enormous forest foliage, crop residue, and animal waste and mean annual wind speed of 4.5-5.4m/s in some places of the state. The present study comprises the utilization of single technology based system such as small hydro, biomass, biogas, solar and small wind turbines etc. and also aggregated technology, depending on the availability of the resources in the present locality. A methodological framework has been established to avail the demand and resources assessment of the area.**

***Keywords:* Single technology based system, Integrated Renewable energy system, hybrid energy system and small hydro power system.**

I.INTRODUCTION

The vast majority of global population lives in the developing countries and more than one third of developing nations comprise of rural areas with no access to commercial forms of energy. Energy access is a complex task in rural areas as most of the unelectrified villages/hamlets are located at remote and/or hilly terrain. Barriers in energy access include uneconomical grid extension and high transportation cost of fuels (diesel, petrol, kerosene, LPG, LNG). However, these remote areas are rich in availability of locally available resources such as cattle dung, waste from agricultural field, forest foliage, water streams, solar intensity, wind Utilization of these etc. resources in off-grid mode would be the most appropriate solution for energy access in rural areas.[1-10]

The Karnataka state is situated on a tableland where the Western and Eastern Ghat ranges converges into the complex,in the westernpart of the Deccan Peninsular region of India.The state is bounded by Maharashtra and Goa States in the north and northwest; by the Arabian Sea in the west byKerala and Tamil Nadu States of Andhra Pradesh and Telangana in the east.

In Karnataka state, most of the rural households have no access of electricity due to uneconomical grid extension in hilly terrains. As per the Census 2011, the total inhabited villages were 27397, as on 01/04/2015: 39 numbers of unelectrified villages are there in Karnataka. Most of the unelectrified villages are rich in the availability of renewable energy resources like solar, small hydro, biomass etc. Utilization of these resources has the potential to meet demand of rural areas including cooking, lighting, heating and cooling and employment. Energy access in rural areas can help in improving agricultural condition, per capita income and poverty level in the state.

In this paper, renewable energy based strategies for off-grid rural electrification in the state of Karnataka has been presented. Availability of renewable energy sources in the state has been discussed in the paper. Further, possible technology options have been proposed for energy conversion of available resources. A methodological framework has also been established for rural electrification in off-grid mode.

II. RENEWABLE ENERGY RESOURCES IN KARNATAKA STATE

Karnataka state has enormous potential of renewable energy resources like solar, micro hydro power, biomass, biogas etc. State is rich in natural resources especially water and forests with many rivers, water streams, dense forests. The land area of Karnataka is of 19.05 million hectares, 3.82 million hectares are the forest lands which constitute 20 percent of the geographical area of the state spread largely over the Western Ghats. The unwooded forests, shrub and dry deciduous forests cover major portion of the forest area with 70 percent and the remaining part covered with evergreen and semi-evergreen and moist deciduous forests.

Biomass collected from national parks and wildlife sanctuaries can be utilized for power generation in bio-energy projects i.e. biomass cogeneration, wood-based biomass gasifier etc.

Crop residue from fields can also be used for power generation as state is rich in agricultural production. As per the year 2010-2011, State has rice production of 44.74 LakhTonne and wheat production of 3.00LakhTonne per year. Besides rice and wheat, state has paddy production of 66.66 Lakh Tonne, Ragi production of 14.99 LakhTonne, maize production of 43.35 Lakh Tonne and jowar production of 13.46Tonne. Power potential assessment of agro residue depends on surplus crop residue. Surplus crop residue is the crop residue that is left after any competing uses like cattle feed, animal bedding, heating, cooking fuel, fertilizer for agricultural system. The surplus residue can be directly utilized for power generation using biomass gasification technology.

In Karnataka, dairy farming is a promising economic activity for smallholder. As per Livestock census (2011), State has 9516 cattles, 3471 of buffalo population in the. 95384 sheep, 4796 goats, 305 pigs and 13 horse & ponies(figures in thousands). The dung from two to four cows (or 5–10 pigs) can produce enough biogas for cooking for one household and remaining can be utilized for electricity production. For cooking, 0.34 m^3 of biogas required per day per person, while to generate 1 kWh electricity, biogas engine consumes 0.46 m^3 of biogas.

Karnataka state has enormous large and small hydro power potential as it is surrounded by many rivers. The state is surrounded by many important rivers like Krishna and its tributaies, the Bhima,Ghataprabha,Vedavathi,Malaprabhaand Tungabhadra, in the north, the Kaveri, its tributaries,Hemavati,Shimsha,Arkavati,Lakhshmana Thirtha and Kabiniin the south etc. The watermills are extensively used for grinding grains and electricity generation at micro scale in remote areas of the state.

A.ADVANTAGES AND DISADVANTAGES OF PRODUCTION/CONSUMPTION OF RENEWABLE ENERGY RESOURCES

Karnataka state has enormous potential of renewable energy resources, which is significant to meet out the cooking and electricity needs of the remote villages. The utilization of renewable resources such as water streams, insolation and wind speed do not impact the environment. However, biomass and biogas based system generate marginal CO_2 emissions. The biomass gasifier-based technology generates 0.273 kg CO_2 for 1 kWh electricity, whereas biogas digester-based system generates 0.305 kg CO_2 for 1 kWh generation.[11]

Among various renewable technologies, wind and biogas based system require more land for installation. The wind and biogasbased system need land of 267.7 m^2 and 144 m^2, respectively, for 1 kW plant installation. Biomass and biogas based generating systems have a minimum capital cost in the range of Rs. 40,000– 50,000/kW, whereas SPV-based system has the highest capital cost of Rs. 80,000–100,000/kW.

The seasonal variations have a marginal impact on the overall power production of biomass and biogas based system due to marginal variation of biomass and cattle dung availability over a year. However, production from small hydro, solar and wind based system is highly dependent on the seasonal and weather conditions. The availability of small hydro potential is high during the April–September and it is low during the October– March. The monthly mean wind speed in the state also varies from 4.5 m/s in the month of March to 5.4 m/s. The monthly average solar radiation deviates from 4.5 kWh/m^2/day in the month of December to 7 kWh/m^2/day during the month of May.

III. TECHNOLOGY OPTIONS

Based on the energy need of rural areas and resources, rural electrification model can be achieved through single technology based system and/or combination of renewable energy technologies as shown in Fig. 1. Possible options for off grid rural electrification include single technology based system, Integrated Renewable Energy System (IRES) and Hybrid Energy System (HES) and shown in Fig.1.

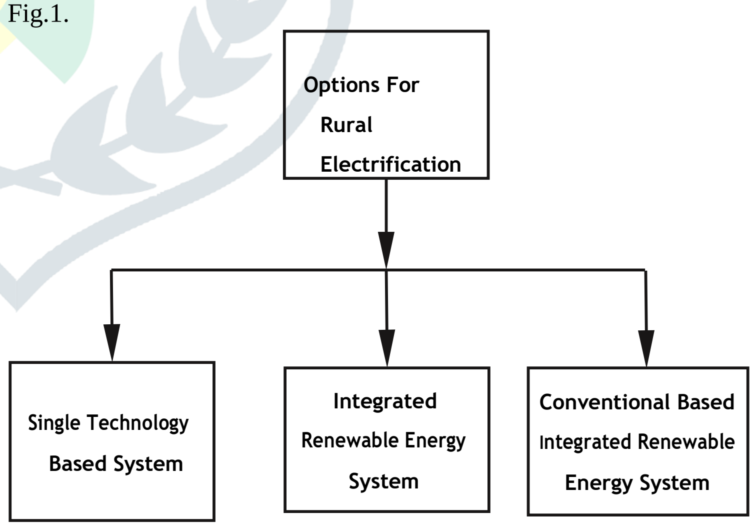

Fig.1. Possible options for off-grid rural electrification in Karnataka state

A.SINGLE TECHNOLOGY BASED SYSTEM

Single technology based system is best suitable option for electrification of single village or hamlet. As single village/hamlet has low energy requirement, it, therefore, can be easily fulfilled by single renewable energy technology. Possible renewable energy source options under single technology based system comprised of micro hydro power, biomass, biogas, solar, wind etc. Single technology based options in the state are discussed in the following subsection.

1). HYDRO ENERGY

In small hydro power (SHP) system,stored potential energy of water is converted into kinetic energy by realizing water from higher to lower elevation.This kinetic energy is used to rotate the turbine blades that in turn drive the coupled generator to produce electricity. The quality of electricity generated is determined by the volume of water flow (discharge) and the amount of head (difference between upstream and downstream level).The greater the discharge and head, the more electricity can be generated. Hydropower mainly classified as per the installed capacity of the power plant. In India, the power plants up to 25 MW installed capacity are considered as small hydro power (SHP) [12]. Further, SHP plants can be classified on the basis of installed capacity as given in Table 1.

Table1: Classification of small hydro schemes in India. [12]

SR.No.	Type	Station capacity(kW)	Unit capacity(kW)
1.	Micro Hydro	Upto 100	Upto 100
2.	Mini Hydro	101-2000	101-1000
3.	Small Hydro	2001-25,000	10001-5000

Among three SHP schemes, micro hydro is an excellent option for rural electrification in the remote, hilly and un-electrified areas where potential exists. A rural population is scattered and unaware of the technological developments. For such areas, the isolated micro-hydro power plants are the least cost options for electricity supply. A MHP system can produce enough electricity for a home/community for various end user applications. It is an efficient and reliable form of energy technology that can produce electrical power continuously compared to other renewable energy sources. Also it operates under run of river system without construction of dams and has relatively little impact on the surrounding ecology. [13]

2).BIOMASS GASIFIER

The energy obtained from the available resources such as trees, grasses, animal dung, sewage, agricultural wastes, forest foliage, garbage, wood chips and municipal wastes is collectively known as bio energy. The use of bio energy in generation point of view plays a vital role to subdue greenhouse emissions effectively.Karnataka is rich in bio-resources and ideally suited for biomass-based technologies. Based on availability in natural form, biomass is classified into woody and fine biomass. The woody biomass has high average density of 200 kg/m^3 and ash content limited to about 2%. Typical examples are firewood, cotton stalk, corn cobs, mulberry stalk and weeds like eupatorium, lantana and other similar materials. The fine biomass includes agricultural residues like sawdust, rice husk, straw, bagasse, sugarcane trash, groundnut shells, coir pith, prunes from tea/coffee plantations etc. The densities of such biomass are in the range 50–150 kg/m^3 and ash content up to 2%. The calorific value for considered biomass materials varies in the range of 12–16 MJ/kg. Rice husk and straw belongs to lower, while the wood/bagasse is higher calorific value materials. [14]

Biomass-based cogeneration and gasifier system is mature technology for power generation. A typical schematic of biomass gasifier based system is shown in Fig.2. It consists of three main parts namely reactor, cooling and filtration arrangement and internal combustion (I.C) engine coupled with generator. The reactor consists of a vertical tubular structure with a closed top and a screw to extract the ash at the bottom. The temperature inside the reactor varies from 300 to 400 1C. The high temperature portion of the reactor, where the reactor bed temperature can reach up to 300–1400 1C, is lined with a ceramic material of low thermal conductivity. The high temperature gas must be cooled to room temperature with the help of cooling arrangement. After cooling, producer gas would have a typical composition as 20% of CO, 20% of H_2, 2% of CH_4 and the rest is N_2 with moisture. An efficient gas cleaning system with a fine filter is incorporated in between engine and cooling arrangement to remove the contaminants in gases. The I.C. engine is coupled with generator to produce electricity. [15]

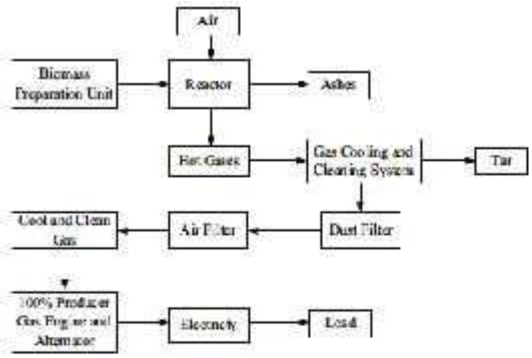

Fig.2.A Schematic showing various processes of a biomass gasifier based system [15]

II. BIOGAS ENERGY

Biogas system uses bacteria to break down wet organic biomass like animal dung, human sewage or food waste. It is generated when bacteria degrade biological material in the absence of oxygen and the process is known as anaerobic digestion. This produces biogas, which is the mixture of methane (CH_4) and carbon dioxide (CO_2). Rural families often use animal dung as the feedstock for a biogas plant. The family needs to feed the plant once each day with a mixture of dung and water. Waste food can also be utilized as the feedstock. Food waste can be easily broken down and it can produce gas more fast as compared to dung, so the slurry does not require to be held for as long; these plants are therefore smaller and more suitable for homes. A family or community using just own food waste can replace 25–50% of their cooking fuel. The slurry needs to be kept at a temperature of about 35 1C for the bacteria to work effectively and feedstock must be added regularly so that they continue to multiply [16]. The immediate effect of biogas is that it replaces other fuels for cooking, usually replaces fuel wood in rural areas. The residue from dung-based biogas can be utilized as a good fertilizer with minimum smell. Also, biogas reduces air pollution as it burns with a clean flame.

3).SOLAR PHOTOVOLTAIC SYSTEM

Solar is the abundant source of renewable energy on earth. It is also a non-polluting renewable source of energy and, therefore, helps in reducing the greenhouse gasemission. Solar energy can be utilized through two approaches such as solar photovoltaic (SPV) and solar–thermal technologies. In SPV system, solar radiations are captured from the sun and turned into electricity using SPV cells made of silicon and other materials. Utilization of solar energy in off-grid mode has the potential to meet the energy need of remote rural areas of the state. In solar thermal technology, solar radiations are collected on a surface to convert solar energy into thermal energy that can be utilized for water

heating, space heating, cooking, etc

An off grid SPV system is shown in Fig. 3 [17]. SPV system consists of components like solar panels made up of large number of solar cells, PV controller, batteries, power conditioning unit (PCU). PV controller extracts maximum power from solar panels using tracking system. PCU has inverter, charge controller and load voltage conditioning. Charge controller is essential for battery management and control for regulating and/or modifying the electrical output of PV panels. Inverter converts DC power into AC power and charge controller prevents the battery from excessive charging and discharging. Load voltage conditioning unit maintains constant voltage supply at used end.

4).SMALL WIND TURBINES (AERO GENERATORS)

Wind energy is an indirect form of solar energy because the sun's differential heating of the earth's surface causes wind. Wind energy is the kinetic energy associated with the movement of atmospheric air. Wind energy converts this kinetic energy to more useful form of power. Since long time, wind energy systems are in use for irrigation and milling and in the 20th century, wind is being utilized to generate

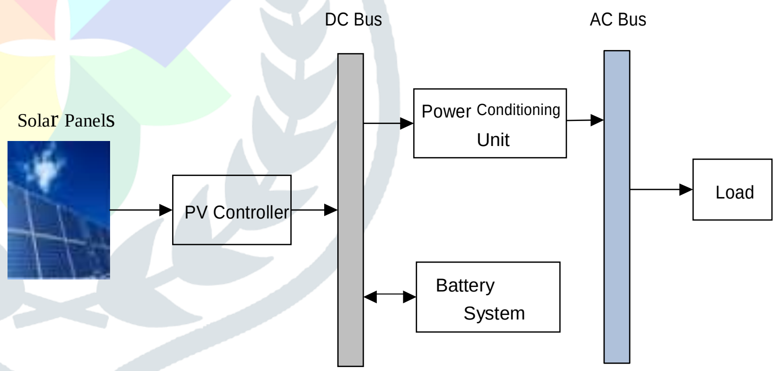

Fig.3. Solar Photovoltaic System

electric power. Wind turbines transform the energy in the wind into mechanical power, which can be utilized directly for pumping water, grinding wheel, or further converting to electric power by coupled electric generator. In India, wind turbines are designed for the wind speed of 10 m/s and above. But for small scale applications, 10 m/s speed designed aero-generators are mostly used. These types of systems are very useful for the locations where wind energy density is observed maximum for 10 m/s or nearer wind speed. Such favorable sites have been identified in some regions of Karnataka state. Small scale wind turbines are proven technologies for rural electrification and can be used singly or in clusters called 'wind farms'. Based on capacity factor and mean annual energy yield, small wind turbine model can be selected for a typical location [18]. Small scale wind turbines (aero-generators) are used to charge batteries and then power is supplied to consumer as shown in Fig.4 [19]. Small scale aero generators system consists of wind turbine rotor, charge controller, inverter and small scale capacity battery bank. Output of wind turbine generator is connected to charge controller using cables. Charge controller charges battery bank and inverter converts DC power of battery into AC power in order to serve AC loads.

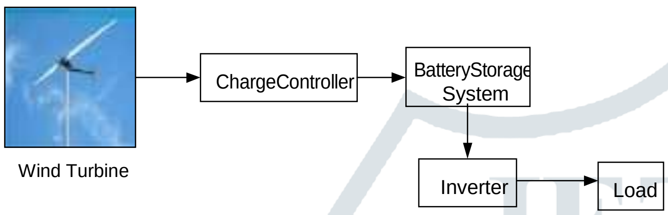

Fig.4. A schematic os small scale aero generator system for a village[19]

B.INTEGRATED RENEWABLE ENERGY SYSTEM

Electrification of cluster of villages is a better option in the state as most of the unelectrified villages/hamlets are located in same block of the district. Integrated renewable energy system (IRES) is a suitable alternative of single technology based system for the electrification of cluster of villages. This technology offers energy conservation and high energy efficiency resulting from the combination of renewable energy sources. In IRES, energy demand of an isolated area, far away from the utility grid, matches with the energy potential of locally available renewable energy resources [20–22]. In this approach, only renewable energy sources like solar, wind, MHP, biomass, biogas etc. are considered for power generation for stand-alone applications, these systems are always incorporated with storage devices in order to manage the stochastic behaviour of renewable energy sources. Integrated use of different renewable energy resources helps in minimizing the amount of energy storage, increases reliability of power supply and quality of power. To maximize benefits and end-use efficiencies, careful and strategic planning is required in IRES for matching needs and available resources. A biomass gasifier–solar–MHP based integrated system is shown in Fig.5 [20]. Control system is the heart of IRES that provides the information and communication among various components of system. Inverter converts the DC power output of solar into AC power. Charge controller is an important part for scheduling of storage subsystem and dump load. It protects the battery storage system operating storage system in prescribed limit. Whenever surplus energy is available, it is sent to battery storage subsystem to store the surplus energy and if battery if fully charged, it is wasted in dump load that can be utilized in cooking, water heating, baking etc. Under condition when demand exceeds generation, stored energy is used in order to fulfil deficit load demand. Hybrid energy system is suitable for areas having not sufficient amount of renewable energy resources to meet energy demand of rural areas. In such system, some conventional option like diesel/ petrol/gasoline based generator is used along with renewable energy resources to meet load demand of cluster of villages Analysis of green house gas emission level must be carried out on such system as use of conventional energy pollutes environment. A PV–diesel generator based integrated energy system is shown in Fig.6

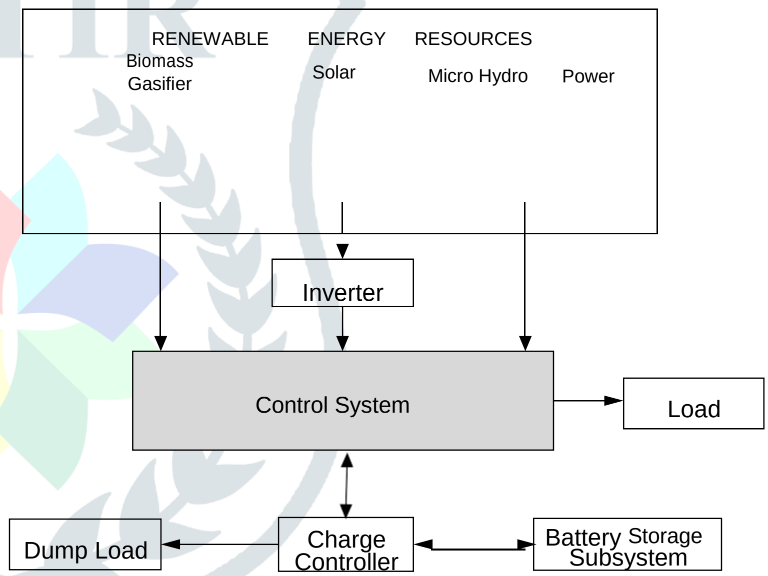

Fig.5.schematic of biomass gasifier-solar MHP Based integrated system [20]

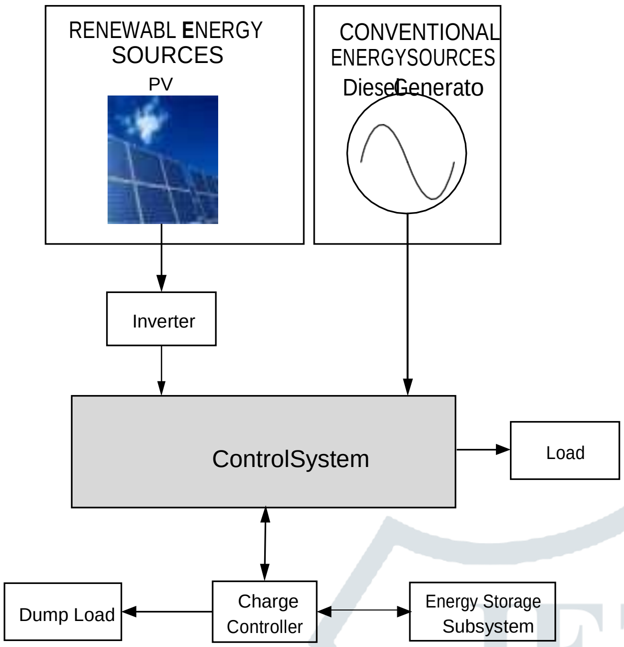

Fig.6. PV-diesel generator based integrated energy system for a rural area[22]

III.PROPOSED MODELING METHOD

The proposed modelling method includes area identification, field survey for load and resource assessment, system constraints, technology selection, mathematical modelling, optimization etc. At first step, geographical details of the considered area are collected. Further, energy demand of the selected rural areas needs to be estimated at second step. At third step, potential assessment of renewable energy sources in the considered area has been investigated. Furthermore, technology options need to be selected based on the demand, resource availability and constraints. After technology selection, mathematical model of system components including renewable energy sources, load demand, energy storage, converters, control system and dump load is developed. Finally, developed mathematical model is optimized using suitable technique to evolve optimal model for energy supply in rural areas Important steps to prepare rural electrification model in Karnataka state are given as

Step I—Identification of study area: In the first step, list of remote unelectrified villages/hamlets is collected from state nodel agencies viz. UREDA and UPCL. After collecting the list, unelectrified villages can be selected based on the rural electrification planning at village level, block level or district level in the state. Also, geographical details of the selected area such as longitude, latitude, mean sea level, district name, block name, access to reach villages, population can be collected from state nodel agencies. Map to road access of the selected villages can be collected from Public Works Department (PWD) office of the district

Step II—Load/demand assessment: After area identification, hourly and daily demand (kWh) of selected area has been estimated. At village level, load assessment can be done by taking the interview of local people and revenue village officers (Gram Panchayat) about energy required in various end uses viz. domestic, commercial, community, agricultural. Domestic sector includes Compact Fluorescent Lamp (CFL), fan, TV, radio, immersion road for each house. Commercial load comprised of small shops of village, saw mill, flour mill etc. and community load includes energy requirements in hospitals, schools, street lights, saw mill etc. Agricultural load in village consists of fodder cutting machine, crop thrashing machine, pumps etc. Annual and hourly demands of considered area can be calculated by the sum of annual and hourly energy demand of various end uses, respectively.

Step III—Resource assessment: After demand assessment, extensive survey needs to be carried out for the assessment of renewable energy resources like solar, wind, small hydro, biomass, biogas etc

For estimating small hydro potential at site, discharge (m^3/s) is measured using salt dilution method and net head (m) is calculated with the information of downstream level with respect to upstream level using global positioning system (GPS). Annual hourly solar radiation (kWh/m^2/day) and hourly mean wind speed (m/s) can be collected from state meteorological department for potential assessment of solar and wind resources, respectively. Information regarding forest area, agricultural land area, cultivated area, uncultivable land area, number of cattle are easily available at Economic and Statistics office of respective district headquarter of village. Biomass potential at a location depends on biomass availability such as availability of crop residues (kg) and forest foliage (kg) in a year. Biogas (m^3/day) potential depends on the cattle dung (kg/ day) available in the selected area

Step IV—Constraints: Further, system constraints like energy balance between load demand and generation units, annual electricity demand, individual capacity constraint, unit generation limit, reliability of power supply, energy storage limitations, emission, system cost, land use, employment etc. are considered. Consideration of these constraints would help in evolving a reliable and effective rural electrification model in the state.

Step V—Technology selection: Based on the load demand, resource availability and constraints, one

technology is selected out of three possible options i.e. single technology based system, IRES or HES.
Step VI—Mathematical modelling: After technology selection, mathematical model of the entire system is developed. Mathematical modelling of each renewable energy source is essential for energy conversion. Solar, wind and load data are highly random in nature and hence uncertainties associated with these parameters need to be modelled.
Step VII—Optimization: Finally, developed mathematical model is optimized with suitable techniques such as HOMER software, LINGO software, goal programming etc. Optimization process must deal with issues like electricity generation cost, employment generation benefit, land use, reduction of green house gas emission, scenario based optimum resource allocation, sizing of generators, system reliability
Based on the steps discussed above, a flow chart to represent rural electrification model has been prepared and presented in Fig.7.

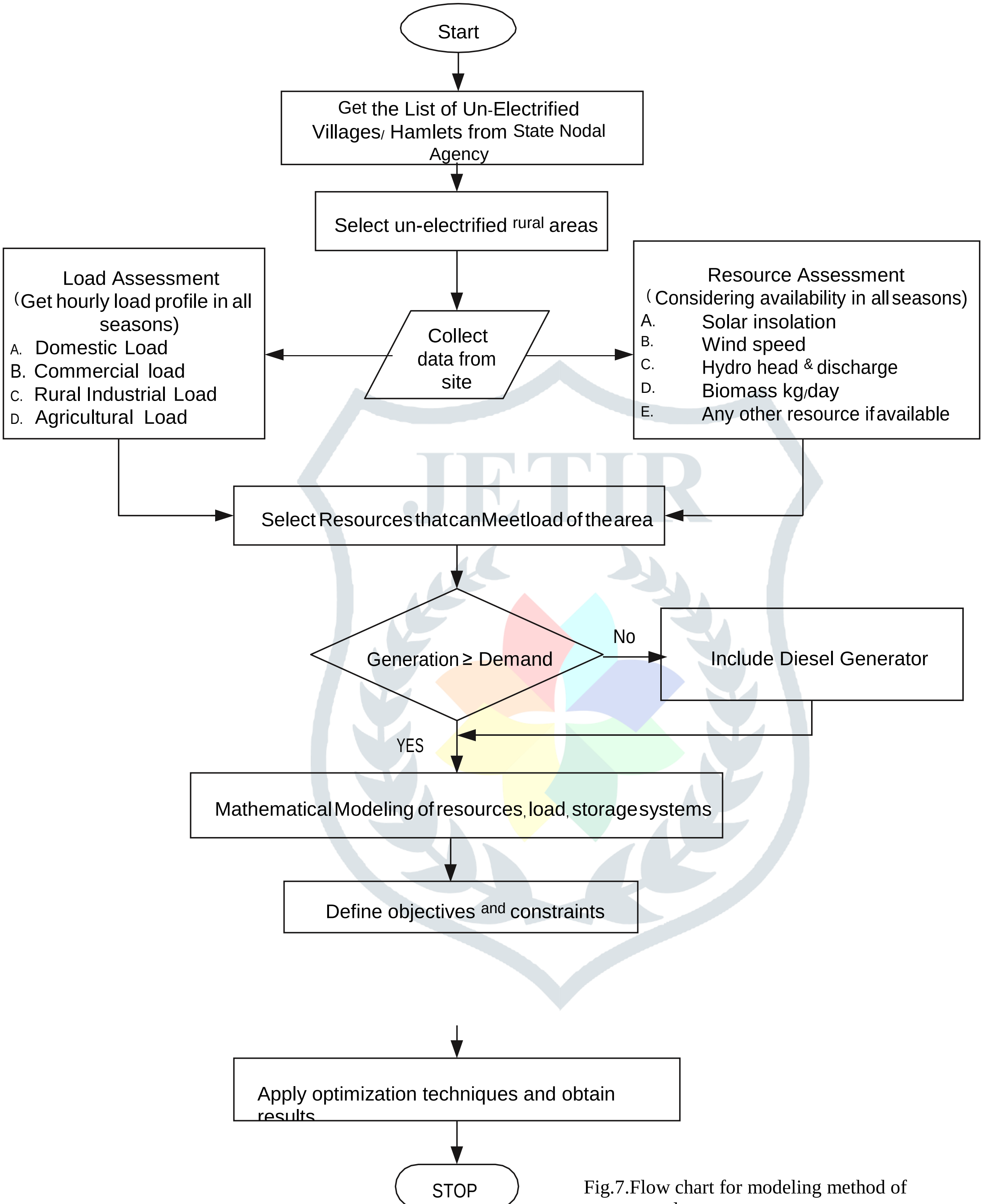

Fig.7.Flow chart for modeling method of present study.

IV. CONCLUSION:

In this paper, renewable energy based strategies for off-grid rural electrification in the state of Karnataka (India) has been presented. Availability of renewable energy sources in the state has been discussed in the paper. Further, possible technology options have been proposed for energy conversion of available resources. A methodological framework has also been established for rural electrification in off-grid mode.

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