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Inclusion of Human Power (HP) In Micro Grids Portfolio: A Solution for Indian Rural Electrification

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ABSTRACT : *This paper first discusses the importance of electricity in development of India along with its current status. It explores the gap between power requirement and power production in current and in prospective Indian power scenario. Then it suggests human power (HP) as an alternative which needs to be included in portfolio for providing electricity power to rural India through Micro Grid combinations with solar energy, wind energy and biomass energy due to its inherent advantages. Further discussion on Micro Grid layouts and implementation of layout in association with economics is carried out with a study on Jaipur, Rajasthan in a computer software HOMER.*
Keywords - *Economic comparison of alternative power sources, Grid electrification, Human power, rural electricity, Power in India.*

I. INTRODUCTION

Each year since 1990 the Human Development Report has published the Human Development Index (HDI) which was introduced as an alternative to conventional measures of national development, such as level of income and the rate of economic growth. The HDI represents a push for a broader definition of well-being and provides a composite measure of three basic dimensions of human development: health, education and income. India's HDI is 0.547, which gives the country a rank of 134 out of 187 countries with comparable data. The HDI of South Asia as a region increased from 0.356 in 1980 to 0.548 today, placing India below the regional average which shows India’s poor condition. Electricity is the crucial reason behind India’s backwardness because electricity is central to nearly all aspects of our lives, access to power is fundamental to a higher standard of living and directly related to socioeconomic development. In addition, electrotechnologies enhance public health and welfare through greater efficiency, safety and a cleaner environment.[1]

The electricity sector in India had an installed capacity of 185.5 Gigawatt (GW) as of November 2011, the world's fifth largest. Even then out of the 1.4 billion people of the world who have no access to electricity in the world, India accounts for over 300 million. Despite an ambitious rural electrification program, some 400 million Indians lose electricity access during blackouts. So it amount to around 700 million of people who does not have access to electricity or connected to unreliable electric connection only in India. The status of electricity in India is not going to improve also in near future as in 12th five year plan (from 2012-2017) capacity addition will be around only 50 GW so total installed capacity will become around 256 GW by 2017 which makes 119 Watts of capacity per capita which is again very low as per the international standards. So India has to look forward for alternative ways for providing power for rural electrification if it wants to improve standard of living of its citizens.

Micro grids have proved their certain advantages over the span of time. India's network losses exceeded 32% in 2010, compared to world average of less than 15%. So this makes micro grid highly suitable option for India. Discussion on advantage and applicability of micro grids will make this report lengthy so it can be referred from other resources.

Since inception of human life on this earth, human power has been considered as a valuable power source. Starting from BayGen radio (first human powered commercial radio) to most advanced Play and Freeze Ice Cream Maker(human powered ice maker) there have been around 211 human powered products in market since 2010. available resource oriented alternative to solve this problem. Human power has all the characteristics which are required to meet the requirements of rural off-grid India in the mean time of next at least 10 years till 2022.

We are suggesting that other human powered generators like merry go round generator, hand-crank generator and bicycle generator should be considered in portfolio for rural electrification through microgrid on the basis of economic merit of the other combinations available which can combine any of the renewable power sources like solar power, wind power and biomass energy. All these options in portfolio with these type of human powered

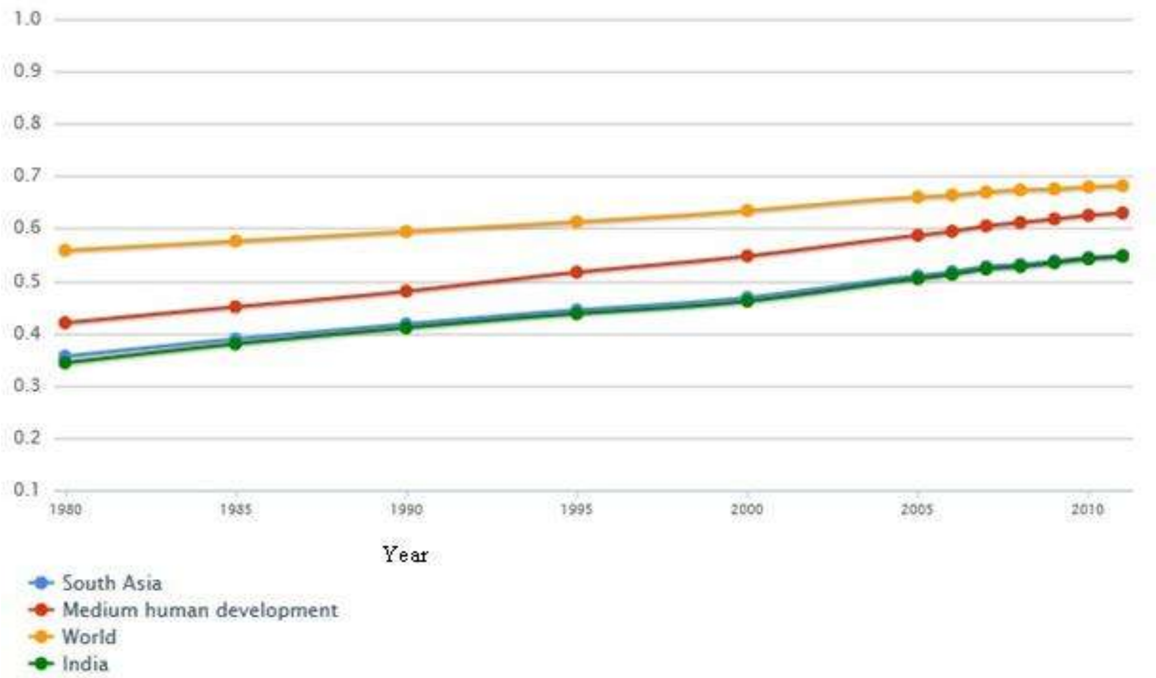

Figure 1

Human Development Index (HDI) of India from 1980 to present in comparison.

generators can be installed for small number of household in close vicinity, as this does not have any transmission and distribution losses and expenditure, only resource requirement is human hours and highly customizable in case of human powered generators, it can come out to be highly economical and resource stringent.[2][3][4]

II. STATUS OF ELECTRICITY IN INDIA

In December 2011, over 300 million Indian citizens had no access to electricity. Over one third of India's rural population lacked electricity, as did 6% of the urban population. Of those who did have access to electricity in India, the supply was intermittent and unreliable. In 2010, blackouts and power shedding interrupted irrigation and manufacturing across the country.

The per capita average annual domestic electricity consumption in India in 2009 was 96 kWh in rural areas and 288 kWh in urban areas for those with access to electricity, in contrast to the worldwide per capita annual average of 2600 kWh and 6200 kWh in the European Union.

As of January 2012, one report found the per capita total consumption in India to be 778 kWh. Electricity distribution network in India is inefficient compared to other networks in the world. India's network losses exceeded 32% in 2010, compared to world average of less than 15%. As in previous years, during the year 2010–11, demand for electricity in India far outstripped availability, both in terms of base load energy and peak availability. Base load requirement was 861,591 (MU) against availability of 788,355 MU, a 8.5% deficit. During peak loads, the demand was for 122 GW against availability of 110 GW, a 9.8% shortfall. Table 1 shows the electricity sector capacity and availability in India (excludes effect of blackouts / power-shedding). Table 1 clearly highlights the shortage of electricity in India. [5]

Despite an ambitious rural electrification program, some 400 million Indians lose electricity access during blackouts. While 80% of Indian villages have at least an electricity line, just 52.5% of rural households have access to electricity. In urban areas, the access to electricity is 93.1% in 2008. The overall electrification rate in India is 64.5% while 35.5% of the population still lives without access to electricity.

Table 1

Current status of electricity in India

Item	Value	Date reported
Total installed capacity (GW)	185.5	November 2011
Available base load supply (MU)	837374	May 2011

Available peak load supply (GW)	118.7	May 2011
Demand base load (MU)	933741	May 2011
Demand peak load (GW)	136.2	May 2011

The 17th electric power survey of India report claims:

- Over 2010–11, India's industrial demand accounted for 35% of electrical power requirement, domestic household use accounted for 28%, agriculture 21%, commercial 9%, public lighting and other miscellaneous applications accounted for the rest.
- The electrical energy demand for 2016–17 is expected to be at least 1392 Tera Watt Hours, with a peak electric demand of 218 GW.
- The electrical energy demand for 2021–22 is expected to be at least 1915 Tera Watt Hours, with a peak electric demand of 298 GW.

If current average transmission and distribution average losses remain same (32%), India needs to add about 135 GW of power generation capacity, before 2017, to satisfy the projected demand after losses. But as shown in Fig. 2, India currently consumes average electricity power much below than satisfactory level of consumption. As shown in table 2, likely installed power capacity in India by 2017 will be around 256 GW in spite of the power requirement of the level 340 GW and if we consider the current transmission and distribution losses which is around 25 %, required power capacity by 2017 amounts to 420 GW, which is much higher than likely installed capacity 256GW of 2017.[6][7][8]

Table 2
Status of Electricity in India for near future

DESCRIPTION	**POWER (MW)**
Existing installed capacity as on March 2012*	199627
Installed capacity as on November 2011#	185000
Projects under construction for likely benefits during 12th plan by 2017##	58683
Power requirement by 2017**	340000
Considering the same T&D losses as today power generation capacity required by 2017	420000
Likely installed power capacity of India by 2017	256000

* Central Electricity Authority, Ministry of Power, Government of India .March 31, 2012 installed capacity status.
# Central Electricity Authority, Ministry of Power, Government of India, November 2011.
** Powering India: The Road to 2017, A report by Mckinskey & Company. Requirement calculated on the basis that by 2012, 100% villages will be connected to electric grid.
12th five year plan 2012-2017, Ministry of Power, Government of India.

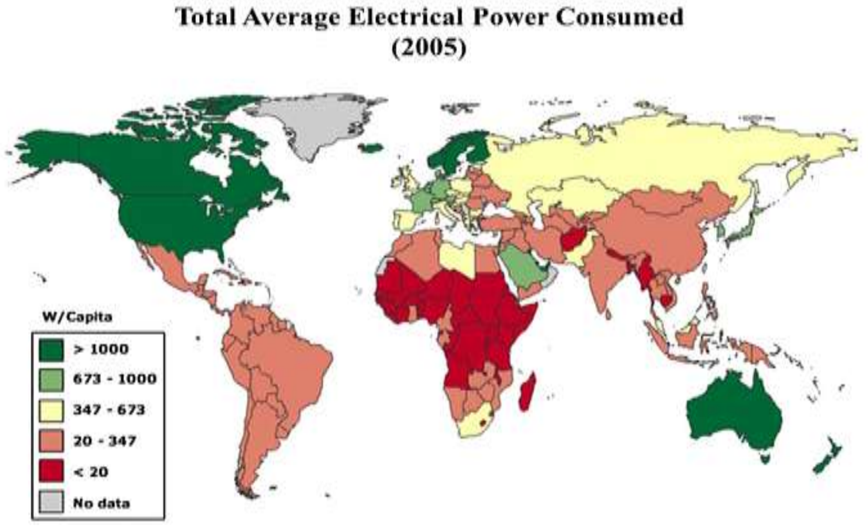

Fig.2 Country-by-country total average electrical base power used per Capita in 2005. Even today in 2011 India with 185 GW installed capacity and peak load supply of 119 GW have power around 100 W per capita which is well below than the satisfactory level.

III. FINDING ALTERNATIVES FOR RURAL ELECTRIFICATION PROBLEM

Clearly from the above discussions it is clear that India is far behind the satisfactory level of development status, India ranks a low 134 among 187 countries in terms of the human development index (HDI), which assesses long-term progress in health, education and income indicators, said a UN report released in November 2011. This very low annual electricity consumption 778 KWhr/per capita and low installed power availability of below 100 W / per capita is the crucial factor behind this very low unsatisfactory level of HDI. Considering the constraints associated with high quality coal availability, administration efficiency, high cost of imported crude oil, high cost associated with renewable energy alternatives like solar and wind energy, land acquisition and many more issues makes "100% reliable power for all" next to fantasy in near future.

As Government of India claims through Rajiv Gandhi Gramin Vidhyut Yojna (RGGVY) grid connectivity of 100% by year 2012, India does not have enough power to supply. Even going with the 12th plan by government of India estimation the expected installed capacity of 256GW and Indian population of 1.283 billion installed power capacity per capita will be around 190 W/ capita which is well below satisfactory level by year 2017.

India should go for practical and fresh approaches for solving this problem and it needs quick response from our side because implication of these approaches are enormous we cannot wait till 2050 for providing respectable life to our citizens. The important implication of electricity in rural life can be summarised as -

- Fetching water for domestic consumption from distance will be eliminated rather it will be pumped through electricity which will save lot of human energy and time which will lead to economic empowerment to women.
- Local health centres can be operated.
- Water can be treated locally which will lead to better health.
- Around 500 million who are connected to electric grid in India face unreliability issues of grid and 300 million who are not connected to electric grid both use kerosene and fuelwood for domestic lighting , if method can be replaced by some renewable energy method then this can affect environment positively and can save lots of emissions.

So considering the importance of rural electrification and its immediate requirement we need a low cost, highly efficient, fast to install, pervasive and locally available resource oriented alternative to solve this problem. And human power is an alternative which meets most of these requirements and we will discuss further in detail about this in later part of this report.[9][10]

IV. HUMAN POWER AS AN OPTION

Human power is an attractive energy source. Muscle converts food into positive mechanical work with peak efficiencies of approximately 25%, comparable to that of internal combustion engines. The work can be performed at a high rate, with 100 W mechanical easily sustainable by the average person and twice that sustainable by elite athletes. Food, the original source of the metabolic energy required by muscles, is nearly as rich an energy source as gasoline and approximately 100 fold greater than batteries of the same weight. Given these attractive properties, it is not surprising that around 250 of inventions have focused on converting human mechanical power into electrical power which includes hand crank and bicycle generators as well as windup flashlights, radios, and cell phone chargers. Even the latest applications of Human power like PavGen tiles in London Olympic 2012 and Hybrid Urban Illumination system CITYLIGHT Led Street Lamp have grasped lot of attentions from the scientific community.

Maximum sustainable power output is one of the constraints on human powered devices which determine how much power a human can output (Davies and Rennie, 1968). NASA's research on maximum sustained mechanical work (Fig. 3) shows that a 100W mechanical energy output can be sustained for about 4 h. Of course, power output will vary from person to person and depends on the health and age of the individual, but knowing the general range of power outputs possible helps to design the system. It is reasonable to assume that most healthy people in developing countries should be able to sustain an output of 100W for at least an hour a day.

Considering this 100 W for one hour of sustained power capability for an average human this amounts to 36.5 KWh (electricity units) annually for daily generation of one hour which is 37.2 % of current rural per capita electricity consumption (98 units per capita) for India. So this clearly indicates given the worrisome condition of electricity in rural India, this amount of power can bring significant improvement. Here just for making a capacity evaluation we did not consider efficiency for conversion of mechanical energy to electrical energy and other losses. Comparative range of electrical devices along with human power capacity has been shown in fig. 4.

There are 3 potential devices Bicycle generator, Merry Go Round generator and Hand-Crank generator which can be used to harvest human energy on such a scale are shown in Table 3 along with their capacity and capital cost.[11][12][13].

In India the electrical demand outweighs the capacity such that there are regular electrical grid-power outages (rolling brownouts) and blackouts. The unreliability of the grid and limited rural electrification are two problems where Human Power can play a significant role; however, it is largely ignored. Many people in underdeveloped region of country accept scheduled load shedding. They may only get electricity 4 to 12 h a day or every 2 days (Sven and Peters, 2011)[10]. This load shedding case applies to India perfectly. That means the rest of the time they do not have access to electricity from the electric grid. This is a failure of the systems' electric power capacity and can be defined as unreliability. If one assumes that 50% of electricity consumers connected to the electric grid use diesel generators when the electric grid is not available this is a large amount of additional greenhouse gas emissions as a direct result of unreliable electric grids. These unreliability events should be investigated further. Back-up electricity is potentially as important as primary electricity generating devices in terms of diesel fuel consumed and the relation within the climate-poverty development nexus (Casillas and Kammen, 2010)[11].

HP is only useful for small loads in rural areas, or to act as a back-up emergency system for critical loads. This suits best for our rural population smaller load requirement for the purpose of water pumping, lighting, water cleaning and to operate small devices like radio. HP is not intended to be the only power source in places of high electricity consumption like hospitals. Many electrical devices and appliances have been produced to meet a particular need or make a particular activity more efficient. These technologies are important to the health and technological progress of a society.

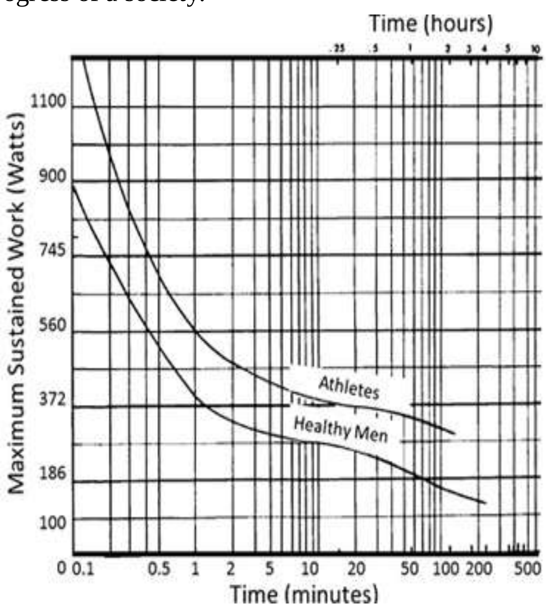

Figure 3

Reproduced from NASA experimental results on sustained maximum power for one person (Roth, 1966)[13].

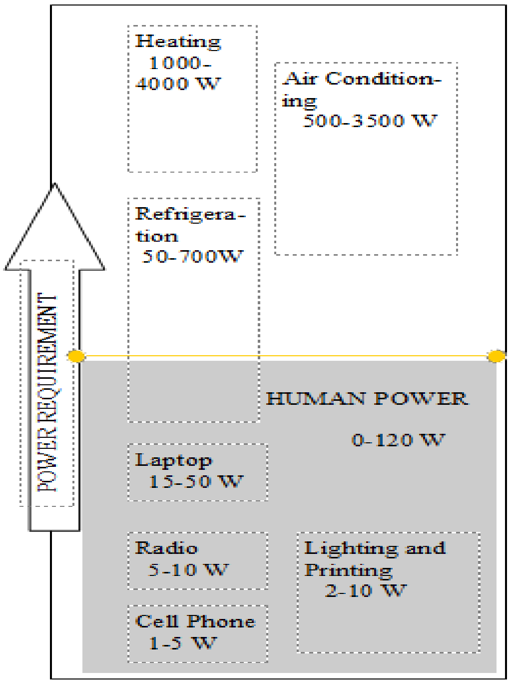

Fig. 4

Role of Human Power: What kind of Devices can be operated through it?

We propose that electricity generation in rural India can be made totally local, which can act later as platform for reliable grid connected power. This human power system can actually work as a system which can meet their lighting, pumping power and other devices like radio electric load. There are three best parts associated with this type of system –

- First this system will totally depend upon locally available renewable resources including man hours, which is quite easily available in rural India.
- Second, the system is highly customized that can be modified according to capacity requirement.
- Third, this system is highly decentralised form of power generation and distribution so it eliminates all type of administrative expenses, transmission and distribution losses from the system unlike conventional method of electricity generation, distribution and consumption.

Table 3

Potential of different human powered devices for power generation along with their cost

Human powered device	Power	Total capital cost
Bicycle	100-150	75-500
Hand-crank	50-100 W	50-500
Merry go round	100-600	500-2400

As shown in figure 5 there can be multiple combinations for power generation and this can be chosen based upon the power requirement, other resource availability like solar irradiance of region and wind speed of region and most importantly cost associated with these systems. Human power can be utilized through combinations of microgrid for human powered devices clubbed with other off-grid power options like biomass energy, wind energy or solar energy.

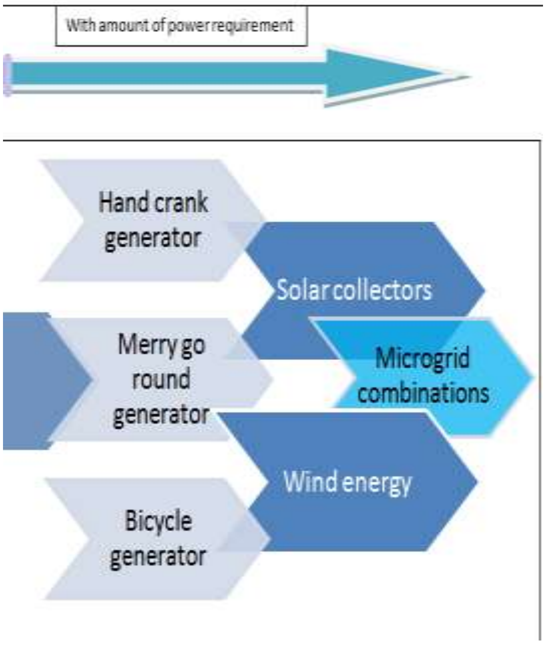

Fig. 5

Human powered electricity generation with various microgrid combination

V. A CASE STUDY ON JAIPUR

The objective of this analysis is to find scope for implementation of microgrid possibility with all the possible power sources available through HOMER in rural town near Jaipur.

The represents the ground level implementation of human powered rural electrification system proposed in earlier sections of this paper. We are now analyzing possible combinations of renewable power sources solar energy, wind energy and human power for cost and performance superiority. For this analysis we have chosen Jaipur, Rajasthan for our study area and HOMER software (Software developed by National Renewable Energy Laboratory, U.S. Department of Energy) for comparative study of all possible combinations.

5.*1. Methodology behind analysis*

1. We will consider a triplet of household in this analysis which are situated in rural part of Jaipur and not connected to any electric grid or grid does supply reliable power for their domestic usage.
2. We will assume that all the three houses are situated so nearly that there will bo negligible transmission and distribution cost and losses associated with this.
3. As per census of India 2011, average number of member in a rural household is 5 and we will go with data.
4. This HOMER model comes from the G8 Task Force recommendation of 100Wh/day/Household (HH) to 1 kWh/day/HH of electricity to meet the Millennium Development Goals (MDGs) (UN, 2008). The power load models the household (HH) electricity usage in terms of the development goals.
5. Solar irradiance and wind speed is approximated for concerned village to be same as Jaipur.
6. Home appliances taken in analysis like DC water pump, DC table fan and DC lighting is available in Jaipur. These are the specific products which have been developed for utilization of solar power worldwide.

5.2 *Load Profile considered for this microgrid for triplet of house*

Keeping Millenium Development Goal (MGD) of United Nations of providing power of amount atleast 100 Wh /HH/daily and basic requirement of a house these home appliances have been assigned to households.

Table 4 Typical load conditions considered for Households

Load description	**Load requirement (W)**	**Load timing**	**Monthly Power consumption (Wh)**
Lighting 3 5W DC CFL 4 hours daily for each HH	45	18:00 – 22:00	5400
DC water pump a 50 W 2 hours daily	50	06:00 – 08:00	3000
Radio of 40 W 1 hour daily for each HH	120	17:00 – 18:00	3600
Table fan DC 40W 2 hour daily for each HH	120	13:00 – 15:00	7200
Total	**-**	**-**	**19200(19.2kWh)**

So solving through the software HOMER we got average electricity consumption as 640 Wh/day and peak power requirement of 213 W which has been obtained through season to season variation provided by the software.[15]

5.3 Setting up system alternatives

We have considered solar power, wind energy, hand – crank generator, Merry go round and bicycle generator in our portfolio for meeting the load requirement of triplet HH system. In our analysis each power generation option has been considered along with its capacity and all types of cost associated with the alternatives which include capital cost, maintenance cost and replacement cost. In this analysis we have considered solar irradiance profile and wind speed profile of Jaipur for throughout the year. Figure 6 represents the overall system layout.[16][17]

5.4 Results

After simulating the system shown in figure 6 in HOMER software the best system proposed by the software is

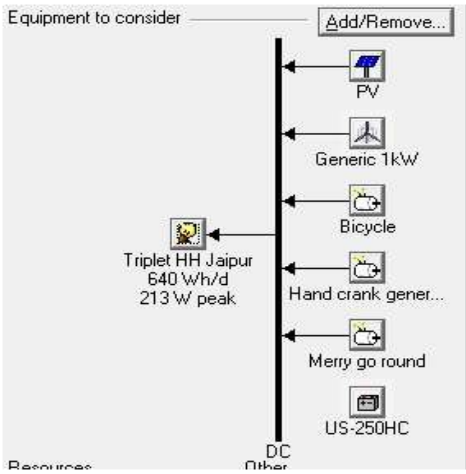

Figure. 6

Layout of power system considered for optimizing the microgrid combinations for application in triplet HH of Jaipur in HOMER.

a micro-grid combination of Hand-crank generator and bicycle generator. And the net product cost associated with this system is 734$ which includes capital cost for installation and operation and maintenance cost of this proposed micro-grid.

VI. RESULTS AND CONCLUSIONS

As India is one of the fastest growing economy and aims at double digit growth of GDP (Gross domestic product) , it still faces a rural poor India within this growing India which lives in villages lacks basic infrastructure hardly has access to education, good health, clean drinking water and electricity and all these substandard values has led India to a human development index of 0.547, which gives the country a rank of 134 out of 187 countries with comparable data. If India wants to sustain this high growth rate of GDP it has to look after the rural India and should generate equal economic opportunity in this part of India too. GOI is willing to achieve 100 % grid connectivity throughout India. But considering the constraints associated with high quality coal availability, administration efficiency, high cost of imported crude oil, high cost associated with renewable energy alternatives like solar and wind energy, land acquisition and many more issues makes “100% reliable power for all” next to fantasy in near future. So India have to choose some alternative which can serve in mean time for its rural underprivileged population, it has to think about alternatives in terms of off- grid power sources which can serve locally.

Rural electrification needs a low cost, highly efficient, fast to install, pervasive and locally available resource oriented alternative to solve this problem. Human power has all the characteristics which are required to meet the requirements of rural off-grid India in the mean time of next at least 10 years till 2022.

We in the last section of report suggested that other human powered generators like merry go round generator, hand-crank generator and bicycle generator should be considered in portfolio for rural electrification. As these type of human powered generators can be installed for small number of household in close vicinity, as this does not have any transmission and distribution losses and expenditure , only resource requirement is human hours and highly customizable , it can come out to be highly economical and resource stringent.

We have included a case study of a off-grid or connected to unreliable grid village near Jaipur considering the off-grid power alternatives available to this place including solar energy, wind power and human powered generators for a triplet of household in that village. We based on the work done by R. Mechenteg concluded that micro-grid combinations including human power generators can result into economical results and highly competitive power generation systems. This analysis was done in HOMER software v2.80.

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