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Implementation of Distributed Power Generation for Non-Electrified Areas in India

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ABSTRACT*:* A vast majority of the total Indian population live in the numerous villages, scattered throughout the country. According to the 2011 Indian census, there are 638365 villages in India and about 74% of Indian population lives in these villages. Electrification of many villages is still a challenge, considering the demand-supply gap. The per capita consumption of power in India is meager compare to that of the developed countries in the world. According to the World Bank, roughly 40 percent of residences in India are without electricity. The main aim of this paper is to educate and encourage the people on adopting a dispersed generation system in their daily usage of electrical energy, provide solution to basic electrical services such as light inside their homes, fans and television and investigate the feasibility of using AC domestic load or DC domestic loads and SPV water pumping system in non-electrified areas. The cost of investment and payback for each load will be calculated separately using simulation results.

KEYWORDS*:* Distributed Generation, Storage devices, Charge controller, Power conditioning unit, AC domestic loads, DC domestic loads, SPV water pumping system, cost benefit analysis.

I. INTRODUCTION

It is extremely difficult to extend transmission lines to these remote villages resulting in technical limitations and prohibitive cost. People depend on the wood and often kerosene for their lighting needs. There exists little or no reliable access to communication systems, television, and health facilities, all of which requires more electricity. Families in the remote area use precious trees as firewood for cooking, room heating and lighting. These activities, especially indoor cooking and lighting on open fire places, consume firewood, with direct chronic impact on the health of women and children which causes environment pollution [1]. Among various renewable energy sources based technologies, the photovoltaic technology for power generation is considered well-suited technology particularly for distributed power generation in India where non-electrified areas. For many people, powering their homes or small businesses using a small renewable energy system that is not connected to the electricity grid called a stand-alone system makes economic sense and appeals to their environmental values. Now days in remote locations, stand-alone systems about 1 kW with subsidy is not cost-effective than extending a power line to the electricity grid (the cost of which can range from Rs.10 lakhs to Rs.33 lakhs per mile). But these systems are also used by people who live near the grid and wish to obtain independence from the power provider or demonstrate a commitment to non-polluting energy sources. Successful stand-alone systems generally take advantage of a combination of techniques and technologies to generate reliable power, reduce costs, and minimize inconvenience. Some of these strategies include using fossil fuel or renewable hybrid systems and reducing the amount of electricity required to meet your needs [2].

Now days the utilization of the DC supply in the building home/ industrial is increases day by day. Most off the appliances in the homes like LED, CFL, Fans, TV, etc are only DC compatible. As most of the state governments are given subsidy 20% from state and 30% from central government for 1 kW SPV, promoting the renewable energy sources in non-electrified area where the grid is not available and most of the renewable sources like solar photovoltaic and storage battery bank are DC source. So we can use electricity directly in DC form. The use of renewable sources especially photovoltaic cells and availability of energy storage devices like batteries, fuel cells and power conditioning unit in domestic level and use of electronic devices that run on AC power. Sunlight can be converted directly into electricity using photo-voltaic (PV). The photovoltaic generation is a technique of converting solar radiation or photon energy into direct current electricity using a semiconductor material that exhibits photo-voltaic effect. India has adequate sunshine; there is greater opportunity for extension of solar energy system in the Indian scenario. Due to increasing demand and environment concern, the integration of renewable energy source (RES) to power system is increasing day by day. The Electricity Home Systems (EHS) small power systems are designed to power individual

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households or small buildings and provide an easily accessible, relatively inexpensive, and simple to maintain solution. In stand-alone systems, power generation is installed close to the load and there are no transmission and distribution costs. Distribution generation systems generally consist of the following:

- Small and modular generating systems (such as micro turbines, reciprocating engines, fuel cells, cogeneration of heating/power systems, and hybrid units) that use a diversity of fuels, such as natural gas and hydrogen;
- Renewable energy resources (such as PV, solar, wind, geothermal, biomass, tidal, and hydropower).

We confine our analyses in this paper to off grid because of the popularity of this type of system. With further developments in the PV technology and lower manufacturing costs, it is envisioned that the PV power will account for a higher percentage of electric power generation in the near future. PV represents superior characteristics such as pollution free and abundant alternate source of energy with minute generation costs [3]-[4].

II. POWER SYSTEM MODEL

In the power system model of this paper we consider a single user. A consumer obtains electricity from solar and local energy storage capacity (e.g. Battery). In this power system model a consumer can turn on any appliance at any instant of time.

Relation of energy consumption of an appliance over a period is given as:

$$E_a = \sum_{h=1}^{H} Z_a^h \tag{1}$$

Where, E_a -energy consumption of appliance 'a'.

Z_a^h-energy consumption of appliance'a' over 1 hour.

We consider peak hours between 6 PM to 11PM.

$$18 \le T_p \le 20,\ 1 \le T_{op} \le 17,\ 22 \le T_{op} \le 24$$

The electricity bill gives us the record to know how much electricity we consume for calculating payback of standalone system. It depend on at which time how much power is consumed. Therefore the cost function depends on time of use of electricity. Total energy consumption of appliance 'a' is the sum of energy consumption in on-peak hour and off-peak hour.

$$E_a = E_{a,p}^t + E_{a,op}^t \tag{2}$$

Similarly, energy consumption of all the appliances over a period of 24 hour is given as [5]:

$$E = \sum_{a=1}^{A} E_a \tag{3}$$

(A) Batteries for stand-alone systems

Batteries store electricity for use during times that your system is not producing electricity (the resource is not available). Batteries are most effective when used in wind and photovoltaic systems (variations in micro hydropower resources can be more seasonal in nature, so batteries may be less useful).The "deep-cycle" (generally lead-acid) batteries typically used for small systems last 5 to 10 years and reclaim about 80% of the energy channeled into them. In addition, these batteries are designed to provide electricity over long periods, and can repeatedly charge and discharge up to 80% of their capacity. Automotive batteries, which are shallow-cycle (and therefore prone to damage if they discharge more than 20% of their capacity), should not be used. The cost of deep-cycle batteries depends on the type, capacity, and climate conditions under which they will operate, frequency of maintenance, and chemicals used to store and release electricity. Wind or photovoltaic stand-alone system batteries need to be sized to store power sufficient to meet your needs during anticipated periods of cloudy weather or low wind. For safety, batteries should be located in a space that is well ventilated and isolated from living areas and electronics, as they contain dangerous chemicals and emit hydrogen and oxygen gas while being charged. In addition, the space should provide protection from temperature extremes. Be sure to locate your batteries in a space that has easy access for maintenance, repair, and replacement. Batteries can be recycled when they wear out [2]. In this paper, we have assumed that each individual customer $m \in M$ is equipped with a dedicated electricity storage device with a storage capacityB_m^{Cap}, a charging efficiency η_c and a discharging efficiency η_d off grid and grid with battery connected system. We further denote the charging behaviour of house hold m at period h as $B_{h,m}^c$ and its corresponding discharging power profile for the same

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period as $B^{d}_{h,m}$. If B^{max}_{c} and B^{min}_{d} represent the maximum charging rate and the minimum rate of discharge respectively,

$$B^{c}_{h,m} \geq 0, \ \forall h \in [6\text{-}18], \forall m \in M, \tag{4}$$

$$B^{d}_{h,m} \geq 0, \quad \forall h \in [1,24], \forall m \in M, \tag{5}$$

$$B^{c}_{h,m} \leq B^{max}_{c}, \quad \forall h \in [6\text{-}18], \forall m \in M, \tag{6}$$

$$B^{d}_{h,m} \geq B^{min}_{d}, \quad \forall h \in [1,24], \forall m \in M, \tag{7}$$

If B^{h}_{m} is the customer m's battery state of charge at period h, then:

$$B^{h}_{m} = B^{h-1}_{m} + \eta_{c} * B^{c}_{h,m} - B^{d}_{h,m}, \quad \eta_{c} \in [0,1] \tag{8}$$

Where $$B^{h}_{m} \leq B^{Cap}_{m} \tag{9}$$

Because of inefficiency associated with battery charging and discharging, concurrent charging and discharging operations in any given time period h, would result in power losses through the battery. Thus for optimal power management the constraint [6] is imposed:

$$B^{c}_{h,m} + B^{d}_{h,m} \leq 1 \tag{10}$$

Since the power discharged from the storage device during the total period H must be less than the initial state of charge, B^{0}_{m} and the power delivered into the battery during the same period, we have:

$$B^{0}_{m} + \sum_{h=6}^{18} \eta_{c} * B^{c}_{h,m} \geq \sum_{h=1}^{24} \eta_{d} * B^{d}_{h,m} \tag{11}$$

In our model, the customer can charge their batteries during off peak to meet their electrical appliances load demand during night time. Consider $E^{pv}_{h,m}$ to be the power stored from the PV into battery by customer m at time h,

$$E^{pv}_{h,m} = E_{h,m} + B^{c}_{h,m} \tag{12}$$

During night time, consumer utilized their battery backup power to run their appliances. The households' electricity load is therefore supported by the battery banks [7].

$$E_{h,m} = B^{Cap}_{h,m} - \eta_{d} * B^{d}_{h,m} \qquad \forall h \in [1,24], \forall m \in M, \tag{13}$$

(B) Charge controller for stand-alone systems

This device regulates rates of flow of electricity from the generation source to the battery and the load. The controller keeps the battery fully charged without over-charging it. When the load is drawing power, the controller allows the charge to flow from the generation source into the battery, the load, or both. When the controller senses that the battery is fully (or nearly fully) charged, it reduces or stops the flow of electricity from the generation source, or diverts it to an auxiliary or "shunt" load (most commonly an electric water heater).Many controllers will also sense when loads have taken too much energy from batteries and will stop the flow until sufficient charge is restored to the batteries. This last feature can greatly extend the battery's lifetime. The cost of controllers generally depends on the ampere capacity at which your renewable system will operate and the monitoring features you want [2].

(C) Power conditioning unit for stand-alone system

Most electrical appliances and equipment in India run on alternating current (AC) electricity. Virtually all the available renewable energy technologies, with the exception of some solar electric units, produce direct current (DC) electricity. To run standard AC appliances, the DC electricity must first be converted to AC electricity using inverters and related power conditioning equipment [2].

(D) Cost benefit analysis

The costs can come down by as much as 18% to 22% for solar PV and 10% for wind. The result is striking: renewable energy technology equipment costs are falling and the technologies themselves are becoming more efficient. The combination of these two factors is leading to declines, rapid ones, in the cost of energy from renewable

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technologies. To date, this transformation is most visible in the power generation sector, where dramatic cost reductions for solar photovoltaic (PV), but also, to a lesser extent, for wind power are driving high levels of investment in renewables. At the same time, where untapped economic hydropower, geothermal and biomass resources exist, these technologies can still provide the lowest-cost electricity of any source [8].

Capital cost of stand-alone domestic A.C loads is

$$C_{cc} = \sum C_{inv} + C_{battery} + C_{pv} + C_{chargcontroller} + C_{installlation} \tag{14}$$

Capital cost of stand-alone domestic D.C loads is

$$C_{cc} = \sum C_{battery} + C_{pv} + C_{chargcontroller} + C_{installlation} \tag{15}$$

Capital cost of stand-alone SPV water pumping system is

$$C_{spv} = \sum C_{pv} + C_{pumpinginverter} + C_{pump} + C_{installation} \tag{16}$$

Annual tariff is given by

$$T_{anu} = \sum_{i=1}^{12} T_i \tag{17}$$

Payback period calculated

$$P_p = \frac{C_{cc}}{\sum_{i=1}^{12} T_i} \tag{18}$$

III. CASE STUDIES

In this paper, solar off-grid systems are installed on stand-alone basis without any support from utility grid. They use batteries as storage devices of electricity that gets charged during the day and meets electricity needs during night. Consider different types of loads (i) A.C domestic loads (ii) D.C domestic loads (ii) Stand-alone SPV water pump system. This way these systems ensure a 24 hour power supply.

(i) A.C domestic loads:

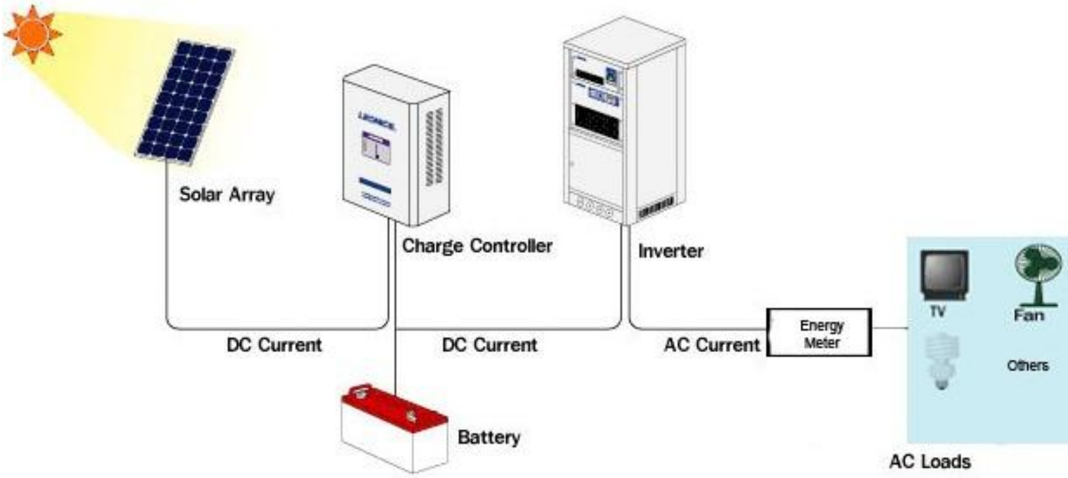

Fig.1 Off-grid (stand-alone) with battery for A.C domestic loads

The generated electricity is stored in batteries and used for the purpose of lighting, fans, television with dish and other loads, whenever required as shown in Fig. 1. These systems are most widely used in non electrified rural areas where grid is not available. The Off-grid (stand- alone) with battery system is a fixed installation designed for domestic application. The system comprises of Solar PV Module (Solar Cells), charge controller, battery, inverter and loads i.e, lighting, fans, television with dish and other loads. The solar module is installed in the open on roof/terrace- exposed to sunlight and the charge controller, battery and inverter are kept inside a protected place in the house. The solar module requires periodic dusting for effective performance [9].

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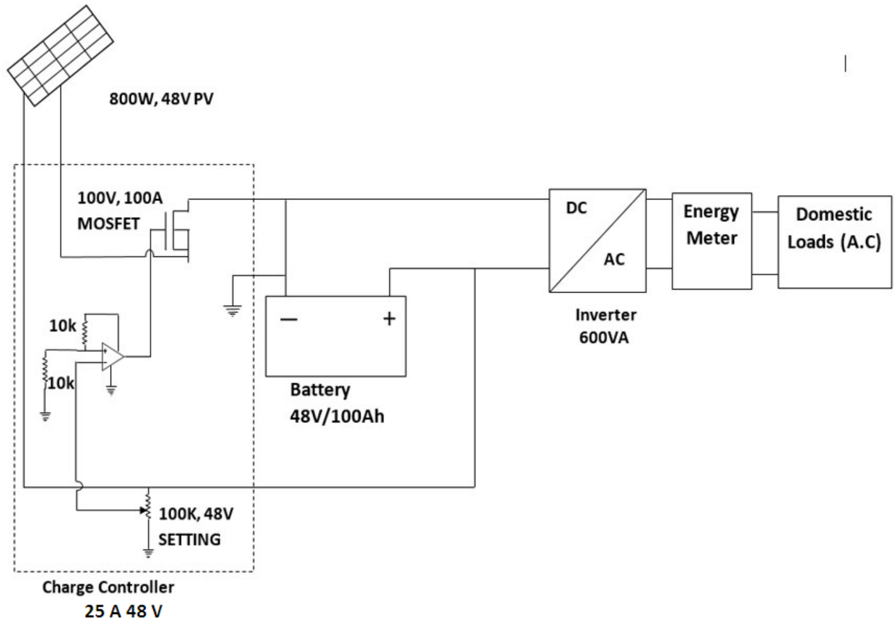

Fig.2 Schematic diagram of off grid (stand-alone) with battery system for A.C loads

The batteries will operate at a maximum depth of discharge of 85% and efficiency is 80%. The charge controller and inverters have an assumed efficiency of 98%. Fig.2 shows the solar PV output 800 W, 48 V is connected to charge controller, the charge controller will give maximum voltage of 48 V and it is fed to a battery bank output of rating 48 V, 100 Ah. The battery is connected to inverter of rating 600 VA circuit consists of four IGBT' rated 100 V, 100 A each is used, firing circuit is designed and gate pulses are generated using pulse circuit PWM technique.

(ii) D.C domestic loads

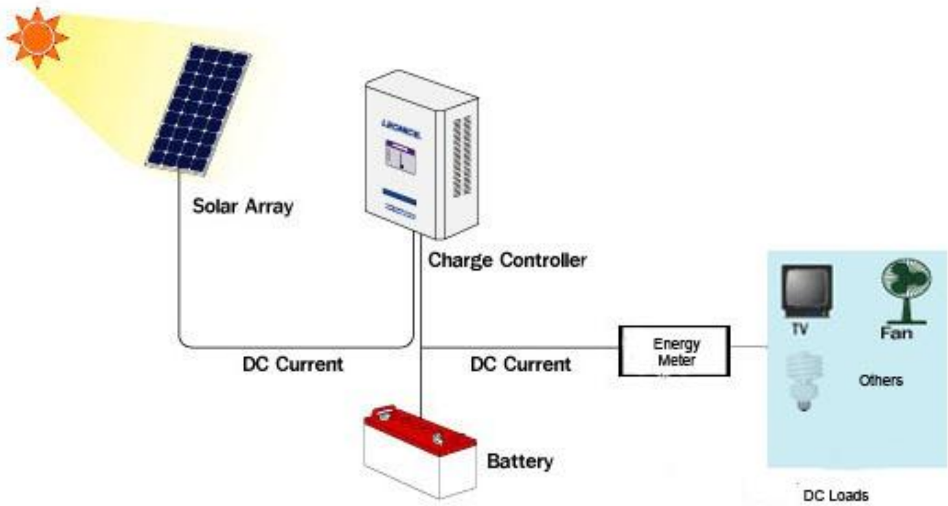

Fig.3 Off-grid (stand-alone) with battery for D.C domestic loads

The generated electricity is stored in batteries and used for the purpose of lighting, fans, television with dish and other loads, whenever required as shown in Fig. 3. These systems are most widely used in non electrified rural areas where grid is not available. The Off-grid (stand- alone) with battery system is a fixed installation designed for domestic

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application. The system comprises of Solar PV Module (Solar Cells), charge controller, battery and loads i.e, lighting, fans, television with dish and other loads.

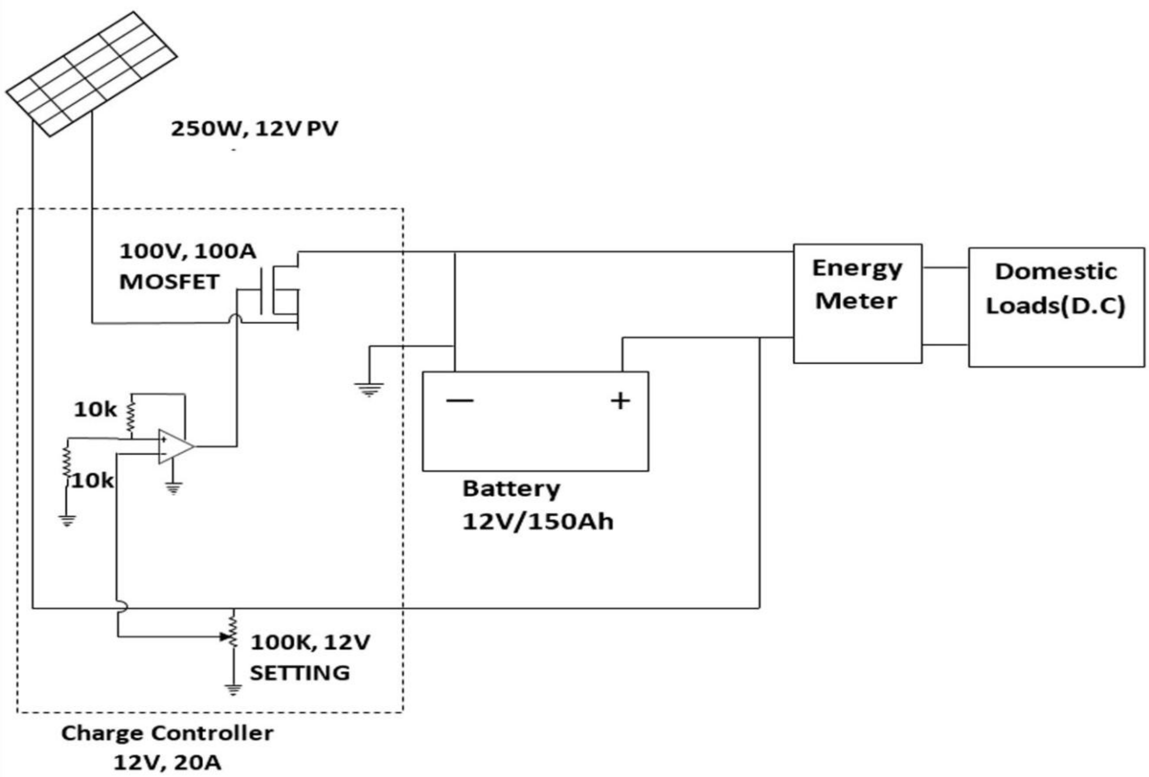

Fig.4 Schematic diagram of off grid (stand-alone) with battery system for D.C loads

Fig.4 shows Off-grid (stand-alone) with battery D.C domestic loads, the solar PV output 250 W, 12 V is connected to charge controller, the charge controller will give maximum voltage of 12 V and it is fed to a battery bank output of rating 12 V, 150 Ah. The battery is connected to D.C loads directly. The domestic loads are usually lamps, fans and T.V etc., where grid supply is not available. The people lived in remote areas are comfortably for un-interruption of power supply.

(iii) Stand-alone SPV water pump set:

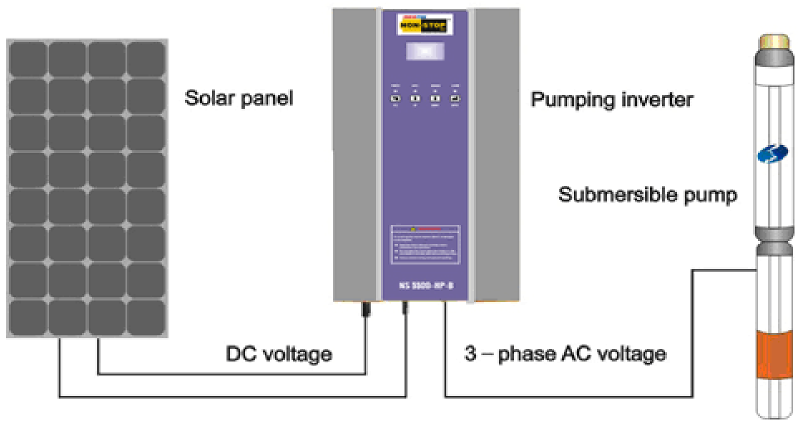

Fig.5 A typical solar-powered water pump system, which includes a solar array, controller, pump

According to the World Bank, roughly 40% of residences in India are without electricity. The main source of income in remote areas is agriculture and depends on rain only. The government encourages the formers to erect SPV

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water pump with subsidy as grid connected system as shown in Fig.5. If power is continuous, income level of people increased. In this pump set variable frequency drive is used. The speed of the drive changes according to sun light with the help of v/f control. This pump can supply water 2-3 acres of land.

TABLE-I
HOME APPLIANCES LIST USED IN REGULAR HOME FOR STAND-ALONE SYSTEM

Home appliances	Number of appliances	A.C Loads		D.C Loads		SPV water pumping	
		Rating	Home appliances average working schedule (h)	Rating	Home appliances average working schedule (h)	Rating	Working schedule (h)
LED Bulb	2	7	4-6/18-21	7	4-6/18-21	3.75 kW (5 h.p motor)	6-18
CFL Bulb	4	18	4-6/18-21	18	4-6/18-21		
Ceiling Fan	3	80	1-5/14-17/21-24	20	1-5/14-17/21-24		
TV	1	100	8-9/13-14/18-20	30	8-9/13-14/18-20		
Others	1	30	8-9/13-14/18-20	30	8-9/13-14/18-20		

TABLE-II
SYSTEM SPECIFICATIONS WITH COST

	System components	Rating	Number	Capital cost in Rs.	Total capital cost without subsidy in Rs.	Total capital cost with 30% subsidy in Rs.	Total capital cost with 50% subsidy in Rs.
A.C domestic loads	SPV	200 W, 24 V	04	32000	106000	74200	53000
	Battery	100Ah, 12 V	04	48000			
	Charge controller	25 A, 48 V	01	8000			
	Inverter	600 VA/48V	01	8000			
	Installation & cabling	--	--	10000			
DC domestic loads	SPV	250 W, 12V	01	10000	32500	22750	16250
	Battery	150 Ah,12 V	01	15000			
	Charge controller	20 A 12 V	01	6000			
	Installation & cabling	--	--	1500			
SPV water pumping	Solar pump	5 h.p, 415 V	01	490000	490000	343000	245000
	SPV	300 W, 24 V	16				
	MPPT Controller	415 V	01				

Table-I and Table-II shows list of home appliances their ratings, working schedule and stand alone system specifications, cost of each component and considering with/without subsidy.

If it is successfully implemented, people lived remote area are strengthened in all aspects. The main objectives are

- To promote distributed generation that can help in avoiding upstream network cost and contribute towards loss reduction.
- To deploy solar powered agricultural pump sets and meet power requirements of farmers during day time

The cost of a 5HP pump set is Rs 4.90 lakhs, out of which a farmer has to pay Rs 55,000 and the remaining cost would be borne jointly by the Union government and the Andhra Pradesh Power Distribution Company. The MNRE (Ministry of New and Renewable Energy), according to officials, will extend 33 per cent subsidy. The Discom will provide another 56 per cent subsidy and the beneficiary will have to bear remaining 11 percent for grid connected

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system. The cultivators may also approach the ITDA in case of tribal areas. If the same subsidy has to extend the scheme to the people who lived in remote areas, they get benefitted.

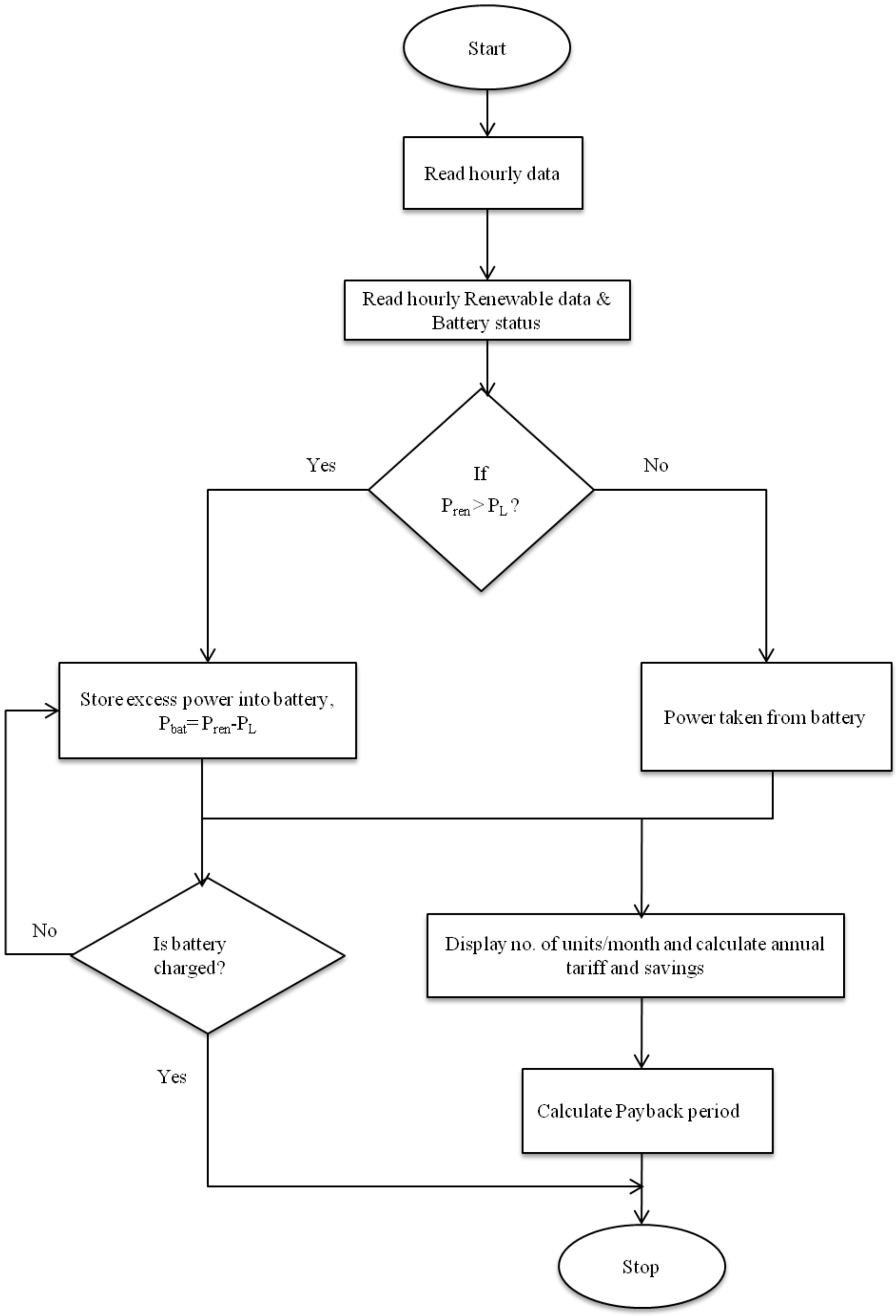

Fig.5 Flow chart for stand-alone system

Fig. 5 shows the flow of operation for stand-alone system A.C domestic loads, D.C domestic loads and SPV water pumping system.

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IV. RESULTS AND DISCUSSIONS

The following assumptions are made while simulating of results

- Solar energy produces under normal working conditions
- The batteries will operate at a maximum depth of discharge of 85%, the charge controller and inverters have an assumed efficiency of 98%.

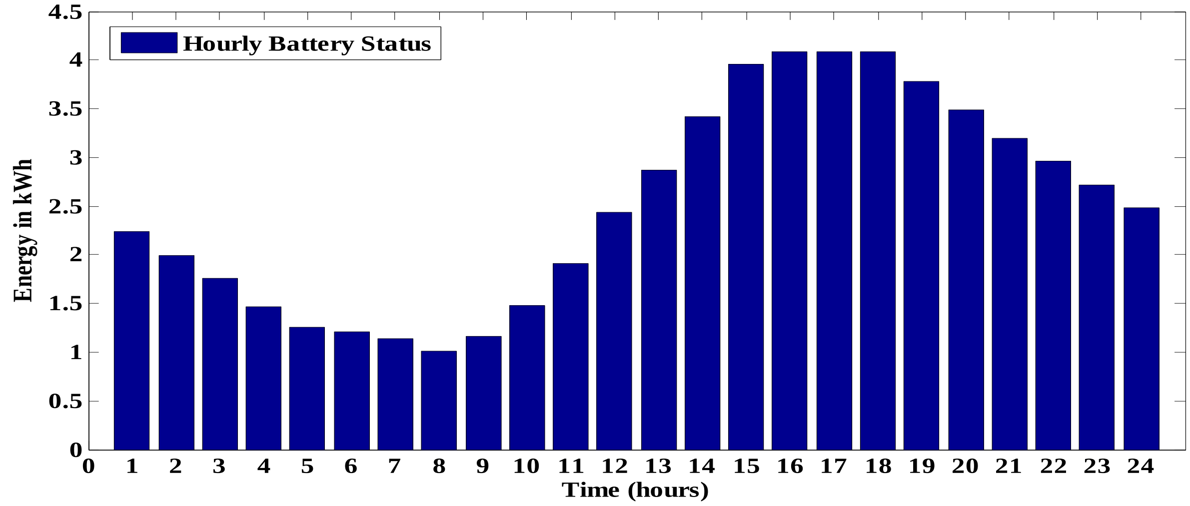

Fig.6 Energy in battery hourly status for A.C domestic loads

During sunny day solar PV is supplied to connected load of house, rest of the power charges the battery bank. At 6 a.m the battery starts charging process, assume after 10 a.m to be fully charged; both solar PV with battery supplies the total load, after 6 p.m, the battery is the only electricity, while after wards, till the next morning as shown in fig. 6.

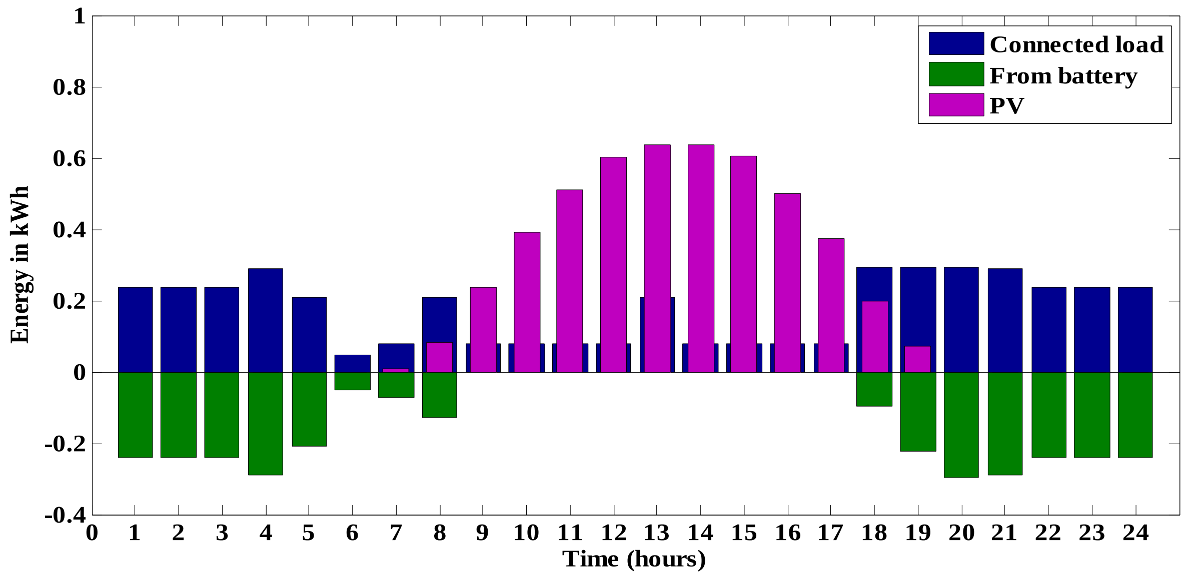

Fig.7 The annual-average daily profile of the house's electricity supply sources for SPV for A.C loads

The battery capacity is 200 Ah, 48 V. During day time 6 a.m-6 p.m entire load is connected to solar PV, after 6 p.m to while after wards, till the next morning the entire load is shifted to battery. Fig.7 shows the connected load, energy from battery, energy from SPV and the negative region shows battery discharges to load when SPV is zero.

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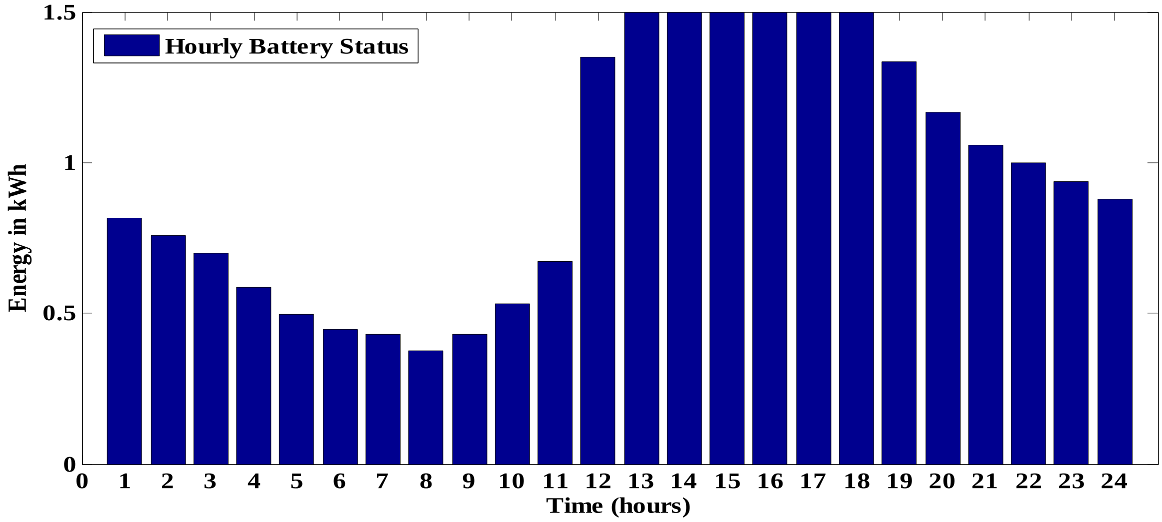

Fig.8 Energy in battery hourly status for D.C domestic loads

During sunny day solar PV is supplied to connected load of house, rest of the power charges the battery bank. At 6 a.m the battery starts charging process, assume after 10 a.m to be fully charged; both solar PV with battery supplies the total load, after 6 p.m, the battery is the only electricity, while after wards, till the next morning as shown in fig. 8.

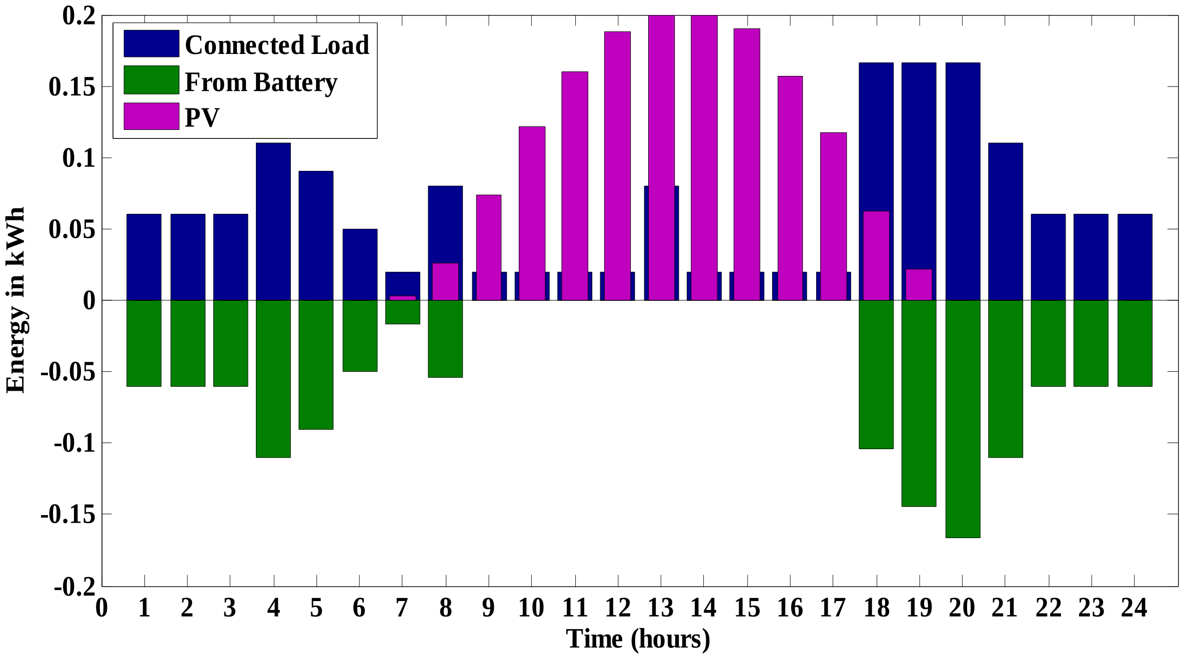

Fig.9 The annual-average daily profile of the house's electricity supply sources for SPV for D.C loads

Fig. 9 observed that the annual-average daily profile of the house and consumer will be received their daily supply from available solar power during sunny day and battery during night when D.C domestic load.

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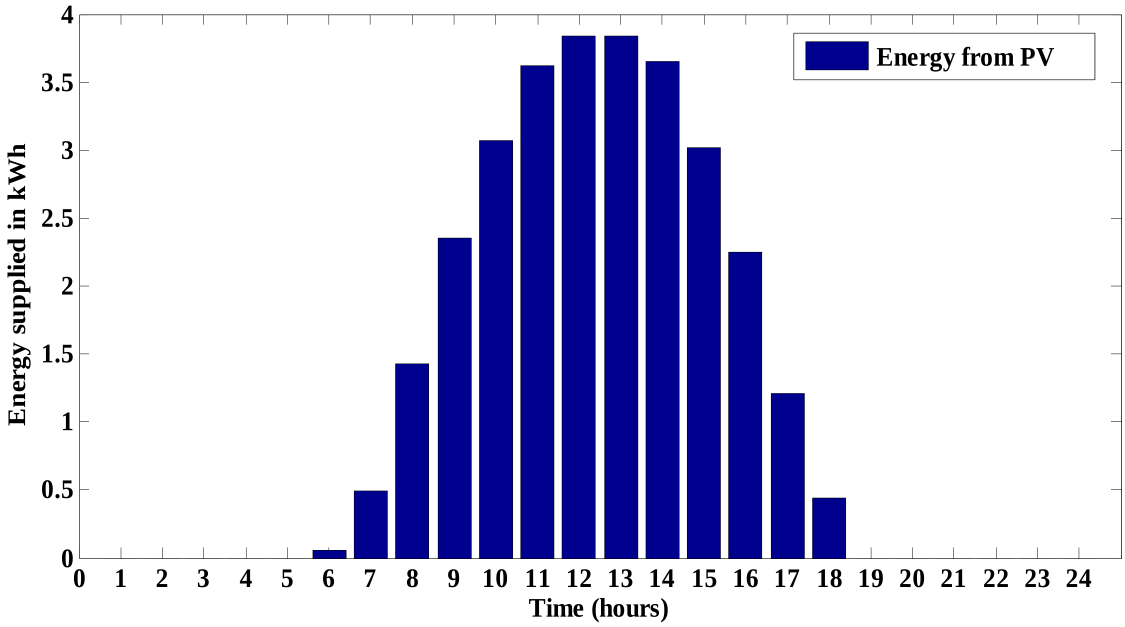

Fig.10 Energy in battery hourly status supplied to SPV water pump

Fig.10 shows the hourly energy generated through solar PV and is connected to pumping inverter. The pumping inverter coverts D.C to A.C and is fed to motor pump.

TABLE-III
COMPARISON OF ELECTRICITY CONSUMPTION AND SAVING OF STAND-ALONE SYSTEM

Off-Grid (Stand-alone)		Energy consumed in kWh/month	Tariff/ month in Rs.	Total annual saving in Rs.
A.C domestic loads	From PV	37	434	5208
	From battery	92		
DC domestic loads	From PV	17	120	1440
	From battery	30		
SPV water pumping system	From PV	878	6433	64330

Table-III shows consumption of electricity, saving of stand-alone system. The energy consumed in D.C domestic loads is less when compared to A.C domestic loads due to wattage of loads is different.

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TABLE-IV
COMPARISON OF CAPITAL COST, SAVING AND PAYBACK PERIOD WITH/WITHOUT SUBSIDY

Off-Grid (Stand-alone)		Total capital cost in Rs.	Total annual saving in Rs.	Payback period
A.C domestic loads	Without subsidy	106000	5208	20
	With 30% subsidy	74200		14
	With 50% subsidy	53000		10
DC domestic loads	Without subsidy	32500	1440	22
	With 30% subsidy	22750		16
	With 50% subsidy	16250		11
SPV water pumping system	Without Subsidy	490000	64330	8
	With 30% subsidy	343000		6
	With 50% subsidy	245000		4

Table-IV shows total capital cost, annual saving and payback period of different loads i.e A.C, D.C domestic loads and SPV water pumping system. It is observed that total capital cost, annual saving and pay back periods are different for without, with subsidy 30% and 50% subsidy for A.C, D.C domestic loads and SPV water pumping system.

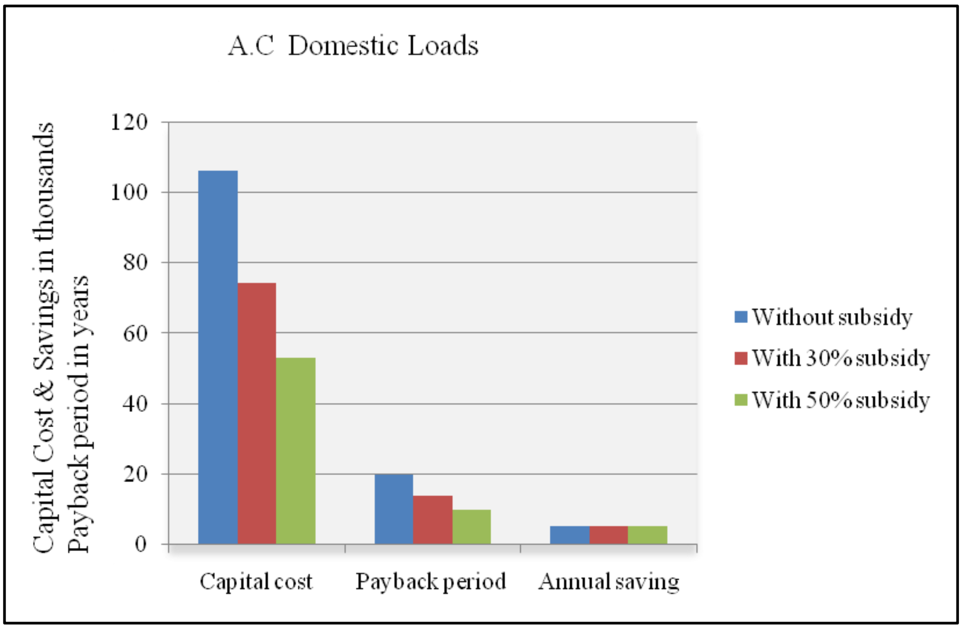

Fig.11 Comparison of capital cost, annual saving and payback periods with/without subsidy for A.C domestic loads

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Fig. 11 shows capital cost, payback and annual saving of A.C domestic loads. It is observed that the payback period is dependent on subsidy given by the government. If government has to give subsidy like grid connected systems for non-electrified areas, provide stand alone PV system to remote people with cheaper rates.

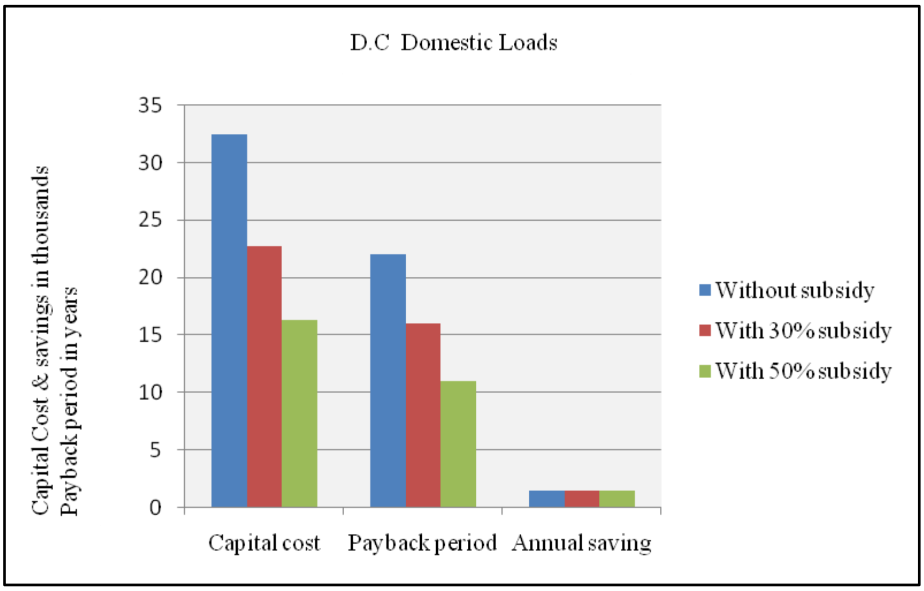

Fig.12 Comparison of capital cost, annual saving and payback periods with/without subsidy for D.C domestic loads

The capital cost, payback and annual saving of D.C domestic loads as shown in fig. 12. It is observed that the payback period is dependent on subsidy given by the government. If government has to give subsidy like grid connected systems for non-electrified areas, provide stand alone PV system to remote people with cheaper rates. As D.C loads are very few wattage of rating and the capital cost of stand-alone PV system connected to D.C loads are inexpensive when compared to A.C domestic loads.

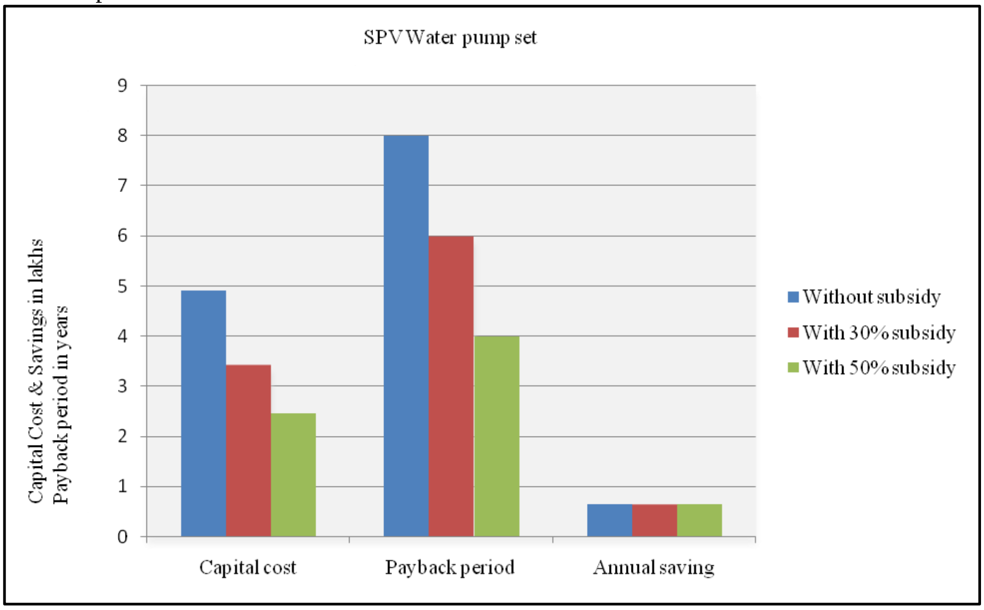

Fig.13 Comparison of capital cost, annual saving and payback periods with/without subsidy for pump load

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The capital cost, payback and annual saving of stand-alone SPV water pumping system. It is observed that the payback period is dependent on subsidy given by the government. If government has to give subsidy like grid connected systems for non-electrified areas, provide SPV water pumping system to remote people with cheaper rates. The production of crop also increased. As we know the main source of income in remote areas is agriculture.

V. CONCLUSION

The goal of this research was developed a decision support tool to help end-users identify the best usage of system for their specific applications either A.C domestic loads or D.C domestic loads and SPV water pumping system. We have developed a stand-alone PV system, the objective was to maximize saving, minimizing payback, educate and encourage the people on adopting a dispersed generation system in their daily usage of electrical energy. Either A.C domestic or D.C domestic system have chosen, but payback was very close to each other and payback period changed with/without subsidy for SPV water pumping system verified by simulation results. If power is continuous, the overall living conditions are improved who lived in non-electrified areas.

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