This chapter presents the scenario of irrigation in India. Detailed information about SPV powered water pumping systems; various schemes announced by government are presented. Major topics appearing in present research work and literature review of corresponding topics are presented. Objectives set for research work are listed. Further, organization of the thesis is described.

1.1. Overview of Agriculture in India

History of agriculture in India dates back to Indus Valley Civilization Era and even before, in some parts of southern India. Today, India ranks second worldwide in farm output. Economic contribution of agriculture to India's GDP is steadily declining with country's broad-based economic growth. Still, agriculture is demographically broadest economic sector and plays a significant role in overall socio-economic fabric of India [1]. Further, Indian agriculture is getting enhanced with greater support from Government of India. For the 12\textsuperscript{th} Plan (2012-17), a growth target of 4 percent has been set for agriculture sector. Recent developments and issues associated with Indian agriculture systems are presented in following sections.

1.1.1. Agriculture and Irrigation – Indian Scenario

India is a country of villages, with major population depending on agriculture directly or indirectly. Farmers depend on rainfall and other water resources for irrigation. There are an estimated 21 million irrigation pumps in India contributing to 15-20\% of total national electricity consumption. India’s irrigation pumps are also believed to be far less efficient than those used in other parts of the world [2]. Source of electricity to pump water is also a big problem in developing countries like India. Further, agriculture, along with fisheries and forestry, is one of the largest contributors to Gross Domestic Product (GDP) of India.
As per estimates by Central Statistics Office (CSO), New Delhi, share of agriculture and allied sectors including livestock, forestry and fishery is 15.35% of the Gross Value Added during 2015-16[4]. Sector wise GDP of India is presented in Fig.1.1. Further, workforce employed under this sector stood at 53% of the total workforce. Fig.1.2 presents sector wise employment in Indian job market. Both Fig.1.1 and 1.2 reveal the importance of agriculture in sustained development of Indian economy.

![Sector wise split-up of Indian GDP for 2015](image1)

**Fig.1.1. Sector wise split-up of Indian GDP for 2015 [6]**

![Sector wise sector wise employment in Indian job market](image2)

**Fig.1.2. Sector wise sector wise employment in Indian job market [7]**
Recognizing the importance of agriculture sector, government of India took number of steps for sustainable development of agriculture, during the budget 2014-15 [2]. These steps include:

- Promotion of scientific warehousing infrastructure including cold storages and cold chains in the country for increasing shelf life of agricultural products
- Enhanced institutional credit to farmers
- Setting up of agritech infrastructure fund for making farming competitive and profitable
- Improved access to irrigation through Pradhan Mantri Krishi Sinchayee Yojana
- Provision of price stabilization fund to mitigate price volatility in agricultural products
- Mission mode scheme for soil health card
- Provide institutional finance to joint farming groups of Bhoomi Heen Kisan through NABARD
- Development of indigenous cattle breeds and promoting inland fisheries to supplement the income of farmers.

With all prevailing support, agriculture sector still faces issues with electricity supply for irrigation pumpsets. Indian power industry has total generation capacity of 307GW and operates with peak shortage between 10-14%. To meet peak demand, load shedding in rural areas has resulted in limited power supply of 4-6 hours/day. To overcome this, renewable energy powered irrigation systems are promoted by Government of India. Status of existing SPV based irrigation schemes and their details are presented in following section.

1.1.2. **SPV Powered Water Pumping Systems**

Most part of agriculture sector is located in rural areas. Developing electrical grid system is often too expensive, as villages are far away from existing grid lines. Use of renewable energy is an attractive solution for water pumping applications in remote areas. Transportation of renewable energy systems, such as photovoltaic (PV) pumps, is much easier, because they can be transported and assembled onsite. Therefore solar operated photovoltaic water pumping system provides better sustainable alternative option to fulfill irrigation requirement of agriculture. Solar photovoltaic (PV) water pumping has been
recognized as most suitable for grid isolated rural locations in many countries. Solar photovoltaic water pumping systems can provide irrigation water without need for any kind of fuel or extensive maintenance as required by diesel pumps. They are easy to install & operate, highly reliable, durable & modular, which enables its future expansion. Although cost of solar photovoltaic water pumping systems is initially high, they demand less maintenance, require no fuel and thus save on energy costs.

Solar Pumping Programme is first started by Ministry of New & Renewable Energy (MNRE) in the year 1992. Number of solar pumps installed between 1992 to 2014 is 13964. This number is minuscule, when compared to conventional pumps in agricultural sector. High costs of solar modules during these years resulted in low penetration of solar pumps. However, in recent times the module costs have started decreasing and are presently hovering around one fourth of the price in those days. As a result, the programme has become more viable and scalable [3, 4].

Ministry of New and Renewable Energy (MNRE) is the coordinating ministry to implement solar water pumping systems in India. Under this scheme MNRE is planning to implement yearly 10,000 solar water pumping systems for irrigating agriculture land. This programme is managed and coordinated with the support of NABARD (National Bank for Agricultural and Rural Development). Highlight of the scheme is, 40% subsidy is given to the borrower (farmer, group of individuals, NGOs, farmers’ club). Subsidy will be same for all categories of borrowers throughout the country. Capital subsidy is applicable on the system cost inclusive of installation, commissioning, transportation, insurance, 5 year maintenance and tax wherever applicable. Solar photovoltaic water pumping system is more cost-competitive when used for powering micro irrigation system as compared to an overhead sprinkler system, or traditional flood irrigation system. In future, as prices of fossil fuels will rise; photovoltaic generated power will become more cost-competitive option to irrigate agriculture crops. MNRE, Government of India has planned for installation of 10,000 solar photovoltaic water pumping systems for irrigation purpose, through National Bank for Agriculture and Rural development (NABARD) with target for 2016 [3]. List of SPV water pumps proposed for each state is listed in Table-1.1.
Table-1.1: SPV Water Pumps Proposed to each State by NABARD [3]

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>State</th>
<th>No. of Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Delhi</td>
<td>50</td>
</tr>
<tr>
<td>2.</td>
<td>Jammu &amp; Kashmir</td>
<td>30</td>
</tr>
<tr>
<td>3.</td>
<td>Mizoram</td>
<td>10</td>
</tr>
<tr>
<td>4.</td>
<td>Meghalaya</td>
<td>10</td>
</tr>
<tr>
<td>5.</td>
<td>Manipur</td>
<td>15</td>
</tr>
<tr>
<td>6.</td>
<td>Arunachal Pradesh</td>
<td>10</td>
</tr>
<tr>
<td>7.</td>
<td>West Bengal</td>
<td>500</td>
</tr>
<tr>
<td>8.</td>
<td>Sikkim</td>
<td>10</td>
</tr>
<tr>
<td>9.</td>
<td>Nagaland</td>
<td>10</td>
</tr>
<tr>
<td>10.</td>
<td>Uttar Pradesh</td>
<td>2200</td>
</tr>
<tr>
<td>11.</td>
<td>Rajasthan</td>
<td>1600</td>
</tr>
<tr>
<td>12.</td>
<td>Tamil Nadu</td>
<td>800</td>
</tr>
<tr>
<td>13.</td>
<td>Tripura</td>
<td>50</td>
</tr>
<tr>
<td>14.</td>
<td>Uttarakhand</td>
<td>250</td>
</tr>
<tr>
<td>15.</td>
<td>Madhya Pradesh</td>
<td>250</td>
</tr>
<tr>
<td>16.</td>
<td>Maharashtra</td>
<td>200</td>
</tr>
<tr>
<td>17.</td>
<td>Jharkhand</td>
<td>50</td>
</tr>
<tr>
<td>18.</td>
<td>Karnataka</td>
<td>400</td>
</tr>
<tr>
<td>19.</td>
<td>Himachal Pradesh</td>
<td>25</td>
</tr>
<tr>
<td>20.</td>
<td>Odisha</td>
<td>400</td>
</tr>
<tr>
<td>21.</td>
<td>Punjab</td>
<td>500</td>
</tr>
<tr>
<td>22.</td>
<td>Kerala</td>
<td>200</td>
</tr>
<tr>
<td>23.</td>
<td>Bihar</td>
<td>450</td>
</tr>
<tr>
<td>24.</td>
<td>Chhattisgarh</td>
<td>200</td>
</tr>
<tr>
<td>25.</td>
<td>Assam</td>
<td>250</td>
</tr>
<tr>
<td>26.</td>
<td>Andaman &amp; Nicobar</td>
<td>20</td>
</tr>
<tr>
<td>27.</td>
<td>Andhra Pradesh</td>
<td>1000</td>
</tr>
<tr>
<td>28.</td>
<td>Gujarat</td>
<td>200</td>
</tr>
<tr>
<td>29.</td>
<td>Haryana</td>
<td>300</td>
</tr>
<tr>
<td>30.</td>
<td>Goa</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>10,000</strong></td>
</tr>
</tbody>
</table>

1.1.3. Operation of SPV Water Pumping Systems

Solar photovoltaic array directly generates electricity from sun light with no moving or wearing parts. Solar radiations are converted into direct current and generated electricity is used to pump water. Size of the pump is designed based on requirement of water for irrigation. Size of solar array is designed considering availability of solar radiations on location and power required to operate water pump.

Block diagram of SPV powered DC water pumping systems is shown in Fig.1.3. Main components of the system are SPV array and DC motor-pump assembly. SPV panels are made of cells, and these cells are devices which convert sunlight in to electricity. Solar
array works by allowing photons or particles of light to knock electrons free from atoms generating a flow of electricity. The generated electricity is directly connected to DC motor-pump assembly. DC pumps operate with variable DC voltage to pump water from the source. Water discharge directly depends on the amount of electricity generated from SPV module and solar radiation.

Fig.1.3. Block diagram of SPV powered DC water pumping systems

Fig.1.4. SPV Powered DC water pumps installed at BEC (A) Bagalkot
In case of AC pumps, a battery storage and inverter circuit is necessary to operate the motor. However, due to simple structure and robust operation, DC pumps are widely used than inverter connected AC pumps. Fig.1.4 shows the SPV powered 0.5 HP, 1 HP and 2 HP DC irrigation pumps installed at Energy Park, Basaveshwar Engineering College (A), Bagalkot.

1.1.4. Advantages of SPV Water Pumping Systems

Solar arrays are expected to provide about 20 years of satisfactory service under normal conditions, even though the cell itself may last much longer. Supplier provides annual maintenance contract to the beneficiary after initial guarantee period of 5 years. Only maintenance requirement is occasional washing of surface to maintain maximum optical transmission through the glass. The module has to be protected from breakage by external forces. Some manufacturers cover the cells with unbreakable glass. Motor and pump require usual periodic maintenance like cleaning, lubrication and replacement of worn parts. SPV systems have following advantages:

- **Cost effective:** Life cycle and cost to ultimate beneficiary make the SPV systems cost effective as compared to conventional systems. Farmers will have to pay the initial investment for SPV system rather than paying for capital investment for drawing lines from grid to his fields. Government may save huge resources which otherwise may be uneconomical to network every agriculture field under state electricity grid.

- **Reliable:** SPV is more reliable, consistent and predictable power option as compared to conventional power system in rural areas.

- **Free fuel:** Sunlight, fuel source of SPV system is a widely available, inexhaustible, reliable and free energy source.

- **Low maintenance:** The system operates on little servicing and no refueling, making them popular for remote rural areas, hence the operation and maintenance is very low. Suppliers provide maintenance at a very low annual maintenance contract rates.

- **Local generation of power:** SPV system makes use of local resource-sunlight. This provides greater energy security and control of access to energy.
• **Easy transportation:** As SPV systems are modular in nature they can easily be transported in pieces/components and are easily expandable to enhance the capacity.

• **Energy Conservation:** Solar energy is clearly one of the most effective energy conservation programs and provides a means for decentralized PV-generated power in rural areas. Solar pump is energy efficient and a decentralized system avoids any unnecessary expenditure.

• **Water conservation:** SPV pumping units are highly economical when combined with water conservation techniques such as drip irrigation & night time distribution of (day time pumped & stored) water. SPV system leads to optimum exploitation of scarce ground water.

• **Environmental friendly:** Use of sunlight as a source of fuel leads to clean, ecofriendly and decentralized generation of energy which saves the fossil fuel, controls deforestation and prevents environmental pollution.

### 1.2. Literature Review

Reference books and technical papers corresponding to different topics associated with research are collected and studied. Further, field visits are taken up to understand the ground reality of identified research topic. Literatures of sub-topics of research are discussed in following sections:

#### 1.2.1. Field Visits

Field visits are taken-up to survey agricultural lands at Malaprabha Riverbed, near Kittali village, Bagalkot, Karnataka. Discussions are done with farmers to collect information about installed pump specifications and availability of electricity supply. Problems faced by the farmers are listed. Visits are also made to Regional Dry Land Agriculture Research Station at Vijayapur to discuss with agricultural engineering researchers. 3 MW Solar power plant at Itanal, Chikkodi and 3 MW Solar plant at Shivasamudra, Mandya are visited to understand the working principle and issues associated with solar photovoltaic systems. Solar radiation data is collected regularly from the Automatic Weather Station installed at Energy Park, Basaveshwar Engineering College (Autonomous), Bagalkot.
Salient observations during the Field Visits

Discussions with farmers reveals that electricity supply per day to village feeders is only six hours and even less during the summer. Power supply is given during night hours, due to which farmers face inconvenience in irrigation. Further, critical observations of installed pumps and size of lands indicated the over rated installations.

1.2.2. Assessment of Water Requirement of Crops [8-15]

Assessment of exact crop water requirements is one of objectives of the proposed research work. Concept of evapotranspiration is an effective way of indicating the crop water requirements. Further, many approaches present the assessment of evapotranspiration. Following technical papers are referred for selecting suitable method for crop water assessment for the study site.

[i]. Abhinaya Subedi and Jose L., “Crop Evapotranspiration (ET) Estimation Models: A Review and Discussion of the Applicability and Limitations of ET Methods”, Journal of Agricultural Science; Vol. 7, No. 6, ISSN 1916-9752, 2015. Authors present review of existing methodologies to assess crop evapotranspiration. They have presented all important estimation procedures available till date from simple empirical method to complex techniques. Common approach for calculating crop evapotranspiration is to estimate a reference crop evapotranspiration rate using climatic data, and multiplying it by an appropriate crop factor. There have been attempts to calculate actual crop evapotranspiration directly without using crop factors, but method is still in the developmental stage. This paper identifies and describes the needs for research in existing methods. They conclude that, full version of standard Penman-Monteith equation is considered as robust method to assess crop evapotranspiration. However, it has some limitations. Penman-Monteith equation uses aerodynamic and surface resistance, where aerodynamic resistance is relatively straight forward to calculate. However, calculation of surface resistance is not easy. The use of fixed surface resistance approach is a simplification of true diurnal dynamics of this resistance, even for a reference crop under standard conditions. Hence, modeling of surface resistance would help in estimation of crop ET with more accuracy. Based on discussion presented in the paper, it is concluded that standard Penmon method is the most effective method amongst available techniques.
Thus, Penmon method for assessment of evapotranspiration is selected as reference in the present work.


Comparisons of various methods of evapotranspiration estimation with Penman method as a reference are presented in this paper. Comparison of universally accepted methods of evapotranspiration estimation is presented with Penman Monteith as reference. Comparative analysis indicates the suitability of Christiansen method, Pan Evaporation and Hargreaves method. Improvement in estimation is carried by transformation of standard equations using single/multi parametric approach after analyzing the dependency and sensitivity of various climatic data on evapotranspiration. A proposed transformed model indicates that while estimating evapotranspiration, relative humidity during morning time plays dominant role up to 99%. Evapotranspiration assessment by combination of wind speed and bright sunshine hours exhibited better role, i.e. 98.8% than combination of wind speed and minimum temperature, i.e. 98.6%. Regression equations between reference evapotranspiration estimated through standard Penman Monteith and other techniques indicated that, most significant method of computing reference evapotranspiration is Hargreaves method. Paper presents the impact of local climatic conditions like temperature, humidity, wind speed and solar radiation intensity on evapotranspiration.

Thus it is decided to collect local climatic data of the selected agriculture land for the proposed research work.

Objective of this paper is to identify suitable relation to be used at different locations across India in estimating evapotranspiration. All India Coordinated Research Project on Agrometeorology and All India Coordinated Research Project on Dry land Agriculture have conducted research in various aspects of Agrometeorology and Dry land farming, respectively at different centers located across the country. Both the projects have some centers in common. In this paper, seven different methods are employed to evaluate evapotranspiration and results are compared with standard Penman-Monteith results for various locations across the country. It is proved that on annual basis, Turc method resulted in much errors followed by Thornthwaite and Blaney-Criddle methods. During the southwest monsoon period, estimated ET from Christiansen pan and Open pan methods resulted in more errors whilst during northeast monsoon season Christiansen pan and Hargreaves yielded more errors. During summer, Hargreaves and modified Penman methods are best methods to adopt. During the winter modified Penman and Open pan methods resulted in errors. Hargreaves method resulted in more errors during winter season compared to summer. Coefficients for calibration are evolved on seasonal and annual basis for various methods to reduce the errors in estimation. Efficiency of these said coefficients are determined through an independent data set, which showed that errors can be minimized to great extent by employing these coefficients.

Paper provided mathematical representations of different techniques available for assessment of evapotranspiration. Further, evapotranspiration data by standard Penman method for Vijayapur location is presented. This data is considered as reference in the proposed research.


Authors proposed two methods of deriving evapotranspiration by radiation and temperature methods. Comparison is carried amongst various methods for a site in Tamil Nadu. They have concluded that, methods which employ combined effect of aerodynamic variations and temperature are more promising. Further, methodologies for various techniques of crop water assessment are presented in detail. Paper strongly proposes that, combined effects of climatic data will yield better results in
comparison with methods which need only wind speed data and humidity data. Paper proved that combinational methods yield accurate results than conventional non-combinational techniques.

Thus for proposed research work, it is decided to employ the effects of various climatic conditions for assessment of evapotranspiration.

**Salient observations from Literatures on Crop Water Assessment**

Literatures presented number of empirical approaches for determination of evapotranspiration. Literatures revealed the following observations:

a. Availability of meteorological data and converting that to evapotranspiration to assess water requirement is very difficult.

b. Large number of climatic data requirement will limit the application of many techniques for assessment of crop water.

c. Researchers have employed several mathematical approaches for assessment of evapotranspiration. Many of which are combination equations, with reference to measured evapotranspiration (ET) values.

d. Studies show that Kimberly Penman and Penman-Monteith are two best techniques in terms of accuracy of estimation.

e. Radiation method is best of non combination approaches. FAO-Penman method is ranked poorly due to over estimation.

f. Each method has its own limitation. Further, deciding accuracy of various methods is difficult task. However, no single method is universally acceptable under varying conditions.

**1.2.3. Sizing of Irrigation Pumps [16-25]**

Irrigation systems are very well developed in ancient India and particularly in Karnataka. Major source of irrigation water in Karnataka is rivers and riverbed irrigation through centrifugal pumps is widely employed by the farmers. In this regard, literature associated with centrifugal pumps, pipe networks and selection of pumping systems are reviewed. Selected literatures are presented in following section:

This book presents detailed analysis of water flow through pipe networks. Flow in laminar and turbulent conditions is discussed. As water flows through closed pipes, energy gets lost due to reluctance offered under high pressure. Losses depend on structure of pipeline and velocity of flow. Major loss is due to elevation of pipelines and friction with internal surface of pipe and rest losses are due to bends, fittings and pipe network configurations. Methodology for assessment of head losses is explained. Further, assessment of HP ratings of centrifugal pump is described. Methodology described in this book is employed for assessment of hydraulic head and centrifugal pump ratings in the proposed research.

However, discussions in book are carried for systems with reference to fixed velocity, which cannot be employed directly for SPV based water pumping systems. The presented method needs to be modified suitably to match SPV systems.


This paper presents water hammer effect in detail: When flowing water is subjected to sudden change in flow, shock waves are produced. This phenomenon is referred as surge pressure or water hammer. This may be caused by shock waves created due to sudden variations in the velocity of water. Flow changes and shock waves occur when valves are opened, water encounters directional changes due to pipe fittings or during ON and OFF of pump. Pressure relief valves are installed to control surge pressure, where excessive pressures are developed by operating the pump with closed valves. These valves are placed between pump discharge point and pipe network. Also, pressure relief valves are installed on discharge side of the check valve, where back flow may occur. Even air trapped in pipeline can create water hammer. Air gets compress and expands in pipeline, causing velocity to change. In order to reduce such issues, accumulation of air must be prevented in the system by installing relief valves. In this paper, it is shown that to prevent water hammer in PVC pipes, water velocities must be limited to 5 ft/s. Further, velocity of flow in
suction pipe of centrifugal pumps should be kept between 2 to 3 ft/s to prevent cavitations.

In general farmers employ PVC pipe network in agriculture lands. Thus in the proposed research work hydraulic head and sizing of irrigation pumps are carried with optimal flow of 5 ft/s velocity.


This manual is about reducing costs involved in small-scale pumped irrigation systems. It presents ways of approaching design of irrigation system and equipment selection, to take account of operating costs. Too often, irrigation systems are designed, constructed by concentrating on immediate cost of constructing and installing. Little or no attention is given to operating costs, with result that some schemes may be cheap to install but expensive to operate. In this manual examples are described to prove effectiveness of optimal design of pumping systems. Further, comparison made amongst the various designs. Guidelines are given to choose the components of new irrigation system. Manual highlighted the need for suitable sizing of irrigation systems. Key parameters to be considered for effective sizing of irrigation pump are presented in the manual.

Present research work is associated with optimally sizing SPV powered irrigation pumps. In this connection, issues discussed in manual will be considered as base for the proposed research work.

**Salient observations from Literatures on Sizing of Irrigation Pumps**

Literatures described methodology and issues associated with sizing of irrigation pumps. Sizing is carried based on discharge and head offered to pump. Detailed methodology to assess the major and minor head losses is presented. Discussions are made regarding assessment of hydraulic head and optimal irrigation pump rating. Following are the salient observations from literature review:
a. It is shown that for sustained operation, velocity of water in PVC pipes must be 5 foot/sec i.e. 1.52m/s and potential damage to pipe network due to higher velocities are discussed.

b. It is well proved that oversized pump results in excess water and undersized pump results in inadequate water output. Discussions are carried about issues associated with design of irrigation pumps.

c. Previous optimizing techniques of pumping systems, which have been the subject of numerous papers, mainly dealt with improvement of effectiveness of various system components, as well as their better mutual adjustment, with the aim of total cost reduction of pumping system. However, re-sizing the pumps based on exact crop water need for achievement of energy conservation has never been the topic of interest.

d. Current scenario in Indian agricultural lands has a great deal of energy saving opportunities.

1.2.4. Sizing the SPV Powered Irrigation Pumps [26-34]

Performance of solar powered water pumps depends on local solar radiation potential. Sizing these pumps needs special attention to local field conditions. However, many generalized approaches are available to predict performance and size the pumps. Following are some of the literatures associated with SPV based water pumping systems.


Main intent of this report is to provide technical guidance on design of small scale solar-powered water pumping systems. System design related to livestock operations and irrigation systems are presented. Review of basic elements of electricity, description of different components of solar-powered water pumps, important planning considerations and general guidance on designing a solar-powered water pump system are presented. It also provides design examples for typical scenarios of agriculture and livestock applications. Authors shown that for solar powered water pumps, DC units are more feasible than AC systems. DC motors use DC output from PV panels directly. AC motors require more complex power electronic control systems. They also result in less total energy availability due to electrical losses.
caused when an inverter is used to convert DC to AC. Because DC motors do not require an inverter, result in more total energy availability. Hence, they are most widely used in solar based pump systems.

Further, methodology proposed in the report employs performance curves of centrifugal pumps for sizing. However, sizing based on performance curves may not yield optimum results for particular sites. This necessitates the sizing of SPV powered irrigation pumps based on local field conditions of agriculture land.


This paper presents hydraulic and electrical performance of surface centrifugal pumps. Two sites in Sahara climatic conditions namely Bechar and Tamanrasset are selected for the research. Performance of the proposed solar surface pump is studied for area irrigated with four different crops, such as wheat, potatoes, tomatoes and sunflowers. Analysis of the performance concluded that, SPV based surface pump is suitable for installation in Sahara regions with lesser water heads. A computer program has been developed to simulate the irrigation performance of this system under severe Sahara climate. Program is based on mathematical models of each component of PV pumping system, PV array and pumping subsystem. In both site studies, recorded solar radiation data are used. The developed program employs solar radiation, temperature, PV array characteristics and solar surface pump characteristics versus total water head. The models calculate photovoltaic electrical power, pumped water, irrigated fields and efficiencies of complete system and individual units.

The experimental results and outcomes of simulation models concludes that for low heads, photovoltaic based surface centrifugal water pumping systems can be employed for small-scale irrigation of crops. Further, it is proved that with increased heads, efficiencies of individual units and for complete system will reduce drastically. In this work, pumps are selected and tested for performance. However,
using local climatic data sizing of pumps is not proposed. Optimally sized pumps might yield better results for the selected sites.


This paper presents results of performance optimization of a SPV powered irrigation system in Kuwait. Direct coupled SPV water pumping system employed in the study consists of DC motor and centrifugal pump, PV array, a storage tank and a maximum power point tracker to improve the efficiency of system. Pumped water is desired to satisfy domestic needs of 300 people in remote area of Kuwait. Considering need of 40 liters/person/day for water consumption, a volume of 12 m$^3$ must be pumped every day from a deep well. This needs to be carried throughout the year. A computer simulation model is developed to determine performance of proposed system in local climatic conditions. Simulation program consists of component models for, SPV panels with MPPT, DC motor and centrifugal pump. Five parameter model is employed to carry the simulations of performance of SPV units. Size of PV array, PV array orientation and pump–motor–hydraulic system characteristics are varied to achieve optimum performance for proposed system. This paper concluded that, expected reduction in prices of photovoltaic panels in future will make SPV powered water pumping systems more feasible.

Methodology proposed in this paper is employed for the water supply for domestic conditions. However, same can be extended to agriculture systems with accurate assessment of water need per day.

Salient observations from Literature on SPV based Pump Sizing

Literatures shown program assisted sizing methodologies for designing photovoltaic pumping system based on available solar potentials. Many approaches are presented. Following are some of the salient observations from the literatures:

a. Concepts of reducing SPV pump capacity with the care of local conditions are presented.
b. Optimization procedures of photovoltaic water pumping systems, which have been the interest of earlier research literatures, concentrated on sizing various system components, viz battery and inverter applications. It is evident that such sizing of SPV sources, whose price is still relatively high, doesn’t yield optimum results. Outcome is increased investment that affects possible economic justification of such systems.

c. To conquer the issues associated with sizing SPV based pumping systems methodologies are developed to opt system capacity. However, the parameters required for design are selected based on pump performance curves. This lead to uneconomic sizes of motors.

d. Further, in conventional irrigation system design motor ratings are decided based on the efficiency of pumping unit and hydraulic head. This optimization procedure is being followed since many years and suits well for conventional AC irrigation pumps, which work almost with constant efficiency and are fed from the grid. In case of solar powered units, system response keeps changing with solar radiation. This non linear behaviour makes system design difficult.

e. Thus, it necessitates to look for new sizing techniques for DC pumping systems powered by SPV based on local field conditions.

1.2.5. Wind-Solar Hybrid Systems for Irrigation Pumps [35-42]

In the present scenario standalone solar photovoltaic and wind systems have been promoted around the globe on a comparatively larger scale. These independent systems may not provide continuous source of energy, as they are seasonal. Solar and wind energies are complement in nature. By integrating and optimizing the solar photovoltaic and wind systems, reliability of the systems can be improved and cost of power can be minimized. Once the irrigation pump capacity is selected, energy sources are to be selected optimally based on local potential. This optimization among wind and solar system components play a major role in cost effectiveness of the system. Many techniques are presented in the literatures. However, HOMER is an effective way to get optimization amongst wind-solar system components. In this regard, some of the papers associated with wind-solar system optimization by HOMER are presented in following section.
This paper presents cost optimization analysis carried for a remote island of Bangladesh, St. Martin Island. Analysis of hybrid energy generation system is presented. Island is located 9 km away from peninsula and situated such a way that, it is impossible to connect to grid. An effort has been presented to design electricity generation system by renewable using HOMER. System is combined with diesel generator, solar PV and wind turbines. HOMER is employed to examine the cost effective combination for electricity requirement of 53 kWh/day primary load with 10 kW peak load. After many simulations, hybrid configurations with respect to net present cost and cost/kWh are listed by HOMER. Configuration, which gives lowest Cost of energy (COE) of USD 0.224/kWh and lowest total net present cost of USD 60,832.93 with a renewable energy fraction of 77% is configured with 10 kW diesel generator, 12 kW converter, 3 kW wind turbine, 10kW PV, and 104 batteries.

Paper presented the application of HOMER to a remote location with large AC loads. Various system combinations are obtained for the proposed load.

This paper presents simulation of a hybrid energy system composed of WTG together with PV, battery storage. Further, simulations of power management strategy are discussed. Paper deals with optimal cost analysis of hybrid energy system. Optimal cost analysis of hybrid energy system is carried using HOMER. In this work, real time optimal cost analysis is carried based on the wind speed, solar radiation and load profile which are collected locally in Tamil Nadu. HOMER is used to optimize the system based on Total Net Present Cost. Further, optimization of system is carried by varying sensitivity variables. Cash flow summary of the system is obtained. Paper has discussed optimization results and effective cost analysis. The cash flow summary is obtained for proposed system. Result reveals
that, combination of WTG, PV and batteries will be optimal choice for off grid system.


This literature describes the optimization of hybrid system for minimizing cost of energy and excess energy. Hybrid system of wind generators, SPV systems and batteries is the basis of analysis. System configuration of the hybrid system is derived based on theoretical domestic load at a remote location with local solar radiation and wind data. Three loads are employed in simulation. HOMER is used to find the optimum combination and sizing of components. Another set of loads are used to investigate the effect of reducing demand against maximum power provider of the system.

Results proved that, cost of energy may be reduced by 50% if the load is increased to maximum capacity. Reducing the load to capacity of dominant power generator will reduce the cost of energy by 90%. Paper explored the importance of reducing excess energy in minimizing the cost of energy for renewable energy systems. Paper discussed two suggestions to meet the objective by minimizing COE. Results from simulation shown that to reduce COE, it is important to consider amount of excess energy the system produced. Reduction of 50% excess energy would have similar effect on COE.

Salient observations from Literatures on Hybrid Systems

From the literatures it is understood that, in optimization process, HOMER simulates many possible system configurations, ranks the feasible ones according to TNPC, and presents feasible one with lowest TNPC as the optimal system configuration. In similar, many literatures discussed application of HOMER for large AC loads, which consists of PV, Wind, Battery and Converters. However, cost analysis of DC loads is not carried out. Further, optimization and analysis of irrigation systems is never been taken up.
1.2.6. Overall Outcome of Literature Review

Rigorous study of literatures revealed the following observations:

- Agriculture plays an important role in economy and development of India.
- Indian agriculture system needs a reliable and economic solution for electricity problems of the irrigation systems.
- Farmers are facing problems with power shortages due to load shedding in rural feeders.
- Most of the irrigation carried in North Karnataka region is through riverbed centrifugal pumps by surface irrigation.
- Sizing of pumps needs assessment of crop water, and head at field conditions.
- Crop water assessment can be carried locally based on climatic data and many techniques are available for the same.
- Methodologies are identified for the assessment of hydraulic head
- There is a major energy conservation opportunity identified in irrigation system, which can be achieved by sizing pumps optimally.
- There is a need for SPV based irrigation systems
- A new method of sizing SPV based irrigation pumps is necessary
- Optimizing the system components is required for economic selection of wind-solar systems based on local potential.

![Block diagram of proposed research work](image)
Based on the outcome of literatures, block diagram of the research work is developed. Fig.1.5. shows the block diagram of proposed research work.

1.3. Motivation

In India, electrical energy consumption in agriculture is recorded highest in 2014-15 among all other countries. This indicates the need for research in energy systems for irrigation. Energy availability and distribution decides the nation’s growth very significantly. Agriculture is backbone of Indian economy, contributing major part in GDP. Irrigation alone is contributing to 15-20% of the load on electrical grid. This load has become burden and needs to be reduced by alternative options. A survey of agricultural lands revealed the excessive ratings of irrigation pumps installed. This is mainly to pump sufficient water in stipulated time. Excessive installations can be systematically addressed by re-sizing the irrigation pumps based on exact crop water and local field conditions of the agriculture land. Thus, optimal pump sizes will provide required water to crops and reduce burden on the grid. Further, SPV systems can be effectively implemented to power irrigation pumps, and reduce load on grid drastically. This necessitates the new methodology for sizing SPV powered DC water pumping systems. In view of this, research titled “Optimum Sizing of SPV Powered Irrigation Systems based on Field Conditions-A Case Study of Riverbed Pumpsets” is proposed.

1.4. Research Objectives

Based on the discussions with farmers during field visits and outcomes of literature survey, following objectives are set for the research work:

- To assess accurate water requirement for different crops under varying conditions
- To develop methodology for assessment of AC irrigation pump ratings based on water need and field conditions
- To develop methodology for sizing SPV powered DC irrigation pumps
- To conduct performance analysis of SPV DC pumps and validation of proposed methodology
- To carry out critical survey and propose optimum pump ratings for conventional AC and SPV powered DC systems
- To check feasibility of wind-solar hybrid systems for supplying irrigation loads using HOMER
1.5. Thesis Organization

The thesis is organized into five chapters, conclusions, future scope and publications from research work.

Chapter-1 presents introduction to agriculture and irrigation scenario of India. Detailed information about SPV powered water pumping systems and various schemes announced by government are discussed. The major topics appearing in research and brief literature review of corresponding topics are presented. Further, objectives set for the research are listed.

Chapter-2 presents identification of suitable method for assessment of crop water requirements in the agriculture lands at Malaprabha Riverbed, Bagalkot, India. Different methods employed for estimating the evapotranspiration are discussed in detail. Comparative analysis of resultant values from all methods with standard reference is presented. Selection of suitable method for assessment of crop water assessment for the said location is presented. Further, assessment of water requirement of various crops grown in North Karnataka region using crop factors is presented.

Chapter-3 presents achievement of energy conservation in irrigation systems by optimally sizing the pump and PVC pipe network. Assessment of diameter of pipe and flow rate based on standard velocity is presented. Evaluation of hydraulic head offered at the said agriculture locations is described. Methodology for selecting optimum pump rating is explained. Results and discussions of the survey cases are presented in details.

Chapter-4 presents a new method for estimating optimum HP rating of SPV powered DC irrigation pumps. A novel approach employed for assessment of water flowrate based on available solar potential is presented. Validation of proposed method is presented by conducting performance analysis of 1 HP water pump installed at Energy Park, Basaveshwar Engineering College (Autonomous), Bagalkot, India. Further, application of said method at survey cases and results analysis is presented.

Chapter-5 presents optimal cost analysis of wind-solar hybrid systems connected to DC and AC irrigation pumps. Simulation of HOMER software models for AC and DC
irrigation pumps are presented. Optimizing the systems components based on load profiles and wind-solar energy potentials at Bagalkot, location is discussed. Components employed for electricity generation in HOMER models are presented. Optimal configurations of wind-solar capacities are listed by considering Total Net Present Cost as objective function. Cost and electricity generation comparison is described.

Further, summary of research work and future challenges in the said research domain are listed. List of publications from the research work are given. List of references used for the work is presented. Further, the images of experimental set up at Basaveshwara Engineering College (Autonomous), Bagalkot and photos capturing during the discussions with farmers during the survey at Malaprabha Riverbed are presented.