Resources of Solar Radiation and Wind Energies in Uzbekistan and System of Their Combined Utilization

D.A.Abdullaev and R.I.Isaev
Scientific engineering and marketing research center
7a Djahan Abidova str. 700084 Tashkent, Uzbekistan
tel : +998 71 1375200 fax : +998 71 1375207
email: ftmtm@uzpak.uz

1. Introduction

Republic of Uzbekistan is located in central part of Eurasian continent. Its total square is 447,4 thousand km², 78,8% of them are plains, rest 21,2% - mountains, foothills and intermountain hollows. 9,7% or 43,0 mln.ha of total square are irrigable and make the base of agriculture – cotton and grain raising [1]. Annual mean harvest of raw cotton is 3,3-3,5 mln.tones considerable part of which is exported after primary processing. During independence years Republic has reached the total satisfaction of its demand for grain. The main source of water resources for Uzbekistan as well as for all Aral sea basin, is Amudarya and Syrdarya rivers with yearly average runoff volume 78,5 km³/year _ 37,9 km³/year. In mountain zone of runoff formation there is a well-developed river network with total runoff on the territory of Uzbekistan about 10% (Chirchik, Angren and other rivers). Total capacity of electrostations in 2000 was 11 GW, 1,5 GW of them is capacity of hydroelectrostations. Electric energy production ranges in (46-49).10⁹ kWh/year.

Meteorological and climatological studies are conducted in Central Asian Scientific Research Hydrometeorological Institute (CASRHI) equipped by up-to-date technical devices and software for collecting, processing and generalizing the information coming by communication channels. In 1991, 400 meteorological stations, 475 hydrological posts, 20 aktinometric stations were operating in Aral Sea basin region. During 1991-98 observation network in Aral Sea basin was reduced in total. Meteorological stations’ network was reduced for 23% in average - from 365 stations in 80s, in 1998 just 280 remained. The least reduction of meteostations was in Uzbekistan: from 91 in 80s till 75 in 1998, i.e. for 17% [2]. With the increased necessity in information for effective use of renewable energies specialists of CASRHI in collaboration with SEMRC conduct researches and create new observation stations in more energetically prospective territories.

2. Energy resources of solar radiations

Territory of the Republic of Uzbekistan belongs to the category of countries with high solar radiation intensity (Fig.1.). Gross potential of solar energy is 50973.10⁶ toe. Technically realizing potential is 176,8 10⁶ toe. Unfortunately, this powerful energy source is still non-realized. For effective transformation of solar energy into electric or thermal one, first of all it is necessary to know the solar elevation in different periods of year on given territory. On the most northern territories of Uzbekistan (45°35’ n.l.) the most height of Sun in summer solstice reaches up to 68°, and on the most southern territories (37°10’) is 76°. In winter solstice 21 _ 29°, accordingly [2]. Precising of these data on every territory during the year allows to regulate the angular regulation of PV-arrays in perpendicular to direction of sunrays and to reach an effective utilization of solar energy. Another important indicator is duration of sunshine. In the North it makes 2800 hours/year in average, and in the most South (Termez city) reaches 3050 hours/year. All these data are given in table 1.
Data of table 1 show the high energy potential of solar radiation on the whole territory of Uzbekistan and the necessity of regulation of PV-arrays inclination angle against angle of sunrays incidence. It is practically interesting to study the dependence of maximum solar radiation intensity (S) on altitude (H).

Fig. 2 shows a curve S=f(H), constructed by average data of measuring on sunny day in July. Given yearly average and monthly average data can be a base for preliminary calculation of peak capacity of PV-arrays in different geographic zones, territories of their installation. Considering data on winter and summer seasons we can conclude that in conditions of Uzbekistan solar power engineering with correct projecting can cover load demand up to 1/3 of summer and up to 1/6 in winter. Therefore utilization of solar energy only is effective for energy supply to small settlements of sheep men on desert territories and distant-pasture cattle tending in mountains.

On technical objects of permanent operation energy supply to technical equipment in periods of absence of solar radiation is realized by use of storage batteries or diesel generators. Calculations show an economical inexpedience of use of storage batteries in such conditions if consumer capacity is 10 kW and more. Forced use of diesel generators on the objects located on hard-to-reach and remote territories is connected with growth of technical difficulties and expenses for fuel delivery and servicing staff. This circumstance caused the necessity to use other kinds of renewable energies, in particular, wind energy.

3. Shortly about wind power engineering resources

Average yearly wind speed on the whole territory of Uzbekistan is 2-2.5 m/sec. This circumstance caused the opinion on non-prospectiveness of wind power engineering in the country, especially for wind turbines of middle and high power. At the same time, research of many years conducted by CASRHI specialists showed that monthly average, seasonal average and yearly average wind speeds on the territory of Republic are different [2]. Fig. 3 shows yearly average distribution of wind speed on the territory of Uzbekistan. It is easy to notice that in Aral Sea basin, Kyzylkum desert territory and foothill zones of Tashkent region (Charvaq and Bekabad) yearly average wind speed is 4-5 m/sec and more [4]. Taking into account that these territories are remote to considerable distance from grid and on hard-to-reach desert, mountain and foothill regions, utilization of wind energy in such regions looks economically expedient.

We will stop on 2 important characteristics of wind power engineering cadastre of Uzbekistan made by results of CASRHI researches of many years [4].

a) Utilizing wind energy is determined by range of working winds of wind device (Vmin≤V≤Vmax), its stable optimal speed (Vopt) and wind regime (V) of given territory. Distribution of utilizing wind speeds in different seasons is also important. Obviously, wind device operates normally in range of working speeds Vmin≤V≤Vmax. Analysis of cases where V<Vmin and V>Vmax is not practically interesting since when V>Vmax, Vmax – marginal working speed of wind device, it usually stops to avoid the damage. Fig. 3a shows the map of utilized energy for WT with Vmin=5 m/sec and Vopt=8 m/sec in January and fig. 3b in September. It is easy to notice that wind energy utilized by WT ranges on the considerable territory of Uzbekistan within 20-70%. Besides, wind speeds with 50-70% energy utilization are distributed differently on the territory. (Fig. 4.)

b) Average potential (specific) capacity of wind flow, as known, is proportional to multiplication of cube of average speed of wind flow to air density. It is follows from fig. 6 that on the most part of the territory of Uzbekistan specific wind capacity is 50-150 W/m². On the north, in Aral Sea basin and foothill zone of Tashkent region, it exceeds 150 W/m², and in Fergana valley – less than 30 W/m².
Analyzing given short information about wind energy cadastre of Uzbekistan we can conclude that considerable part of the territory of Uzbekistan is characterized by low average yearly wind speeds and, consequently, by small wind energy resource. Moreover, it can be noticed that there are quite large territories with practically efficient average wind speeds. More scrupulous analysis made by joint efforts of SEMRC and CASRHI, witnesses the presence of lots of local zones even inside of non-prospective territories where average wind speeds reach 5 m/sec and more. To utilize wind energy resources of such zones in 2003 SEMRC and CASRHI have started detailed study of wind regimes in number of local zones. Results of these researches will allow making precise the wind energy resources and will create a base for wide scale use of wind energy in Uzbekistan.

4. State of utilization of the energy of sun and wind

Opinion on wind energy non-prospectiveness of the whole territory of Uzbekistan formed in last years, caused the situation when even despite the enough study of problem, wind power engineering was not developed here. We can suppose that results of joint work of SEMRC and CASRHI on detailed study of wind energy resources of local territories will cause their utilization on local territories.

As it was mentioned above when deciding the problems of water supply to remote objects with small and middle consuming capacity, taking into account the operational mode of consumer – objects of periodical and permanent operation is the most principal. Objects of periodical operation in Uzbekistan are remote mountain settlements with just everyday energy consumption, shepherd households in desert zone where electricity is also necessary for water pumping and purification. For energy supply to such small remote objects (5-15 people) where capacity of electricity consumer is small (0.2-1.0 kW) it is enough to correctly calculate the capacity of storage battery depending on the period of year. Rational use of accumulated energy allows minimizing the expenses of fuel (petrol) with absence of sunshine during the time more than calculated.

Let’s consider the situation with energy supply to periodically operating objects. Getting independent caused the necessity of development of intellectual, cultural and everyday level of population living in remote regions. First of all, it is true for shepherd households breeding karakul sheeps on the territory of Kyzylkum. According to Center for Transfer of Technologies [5] in Republic of Uzbekistan there are 4500 sheep raising households with 5-10 people managing 400-1000 heads of mostly karakul sheep in every household. Electricity supply and water pumping in such households is still made by petrol or diesel generators. It was calculated that household with family of 5 people and 1000 heads of sheep needs 3700 m3 of water per year. To pump such quantity of water they spend 11 100 liters of benzene cost of which exceeds 2775 US dollars a year. Cost of PV-system and water pump is about 2500 US dollars. With the system’s lifetime over 10 years, economical efficiency of utilization of solar energy is obvious.

During last years Center for Transfer of Technologies has realized more than 10 demonstration projects basing on photovoltaic units produced by local factory. Positive experience of reliability, stability of operation of these systems will allow a wide scale utilization of solar energy.

Consumers of permanent operation are technical objects – regenerators of fiber-optic lines, repeating points of radio-relay and trunk communication lines, retransmitters of radio-television signals, technical objects of special purpose. Even short-time breaks in electricity supply to such telecommunication objects cause significant penalty charges, population discontent, occurring extraordinary situations in controlling systems.

Marketing research of number of telecommunication objects showed that their specific capacities range widely – from 1-5 kW to 70-80 kW. Using just solar energy in such conditions is economically inexpedient because of high price for PV-arrays and storage batteries.
5. Combined use of the energy of wind and solar radiation

Generalizing the results of given above analysis of opportunities of separate use of energy of wind and solar radiation for energy supply to remote technical objects of permanent operation is restricted. This statement is grounded on fact that in periods of absence of wind with speed \( V<3-3.5 \) m/sec or solar radiation, sustainable operation of technical objects is provided by diesel-generators with all consequent material and technical difficulties.

In mid80s authors of this paper proposed the combined utilization of energy of wind and solar radiation for increasing the stability of electricity supply to the objects of permanent operation. Operating model of such system consisting of PV-array of 260 W peak capacity, 250 kW wind turbine, 240 Ah storage battery, confirmed the high efficiency of proposed idea, and deep study of this problem has started. We called the complex of equipment for combined transformation of sun and wind energy as hybrid solar-wind system (HSWS) [6].

Topologic model of HSWS

As known capacity of PV-arrays is determined by their area \( (H) \) and efficiency \( (\eta) \) as well as insolation intensity \( (S) \)

\[
P_S = H \cdot S \cdot \eta
\]

When the sun-tracking system is absent the average value of solar radiation during insolation period \( t_S \) is used as \( S \). It is followed from equation that the capacity of PV-arrays depends on their area linearly. Therefore, the cost of PV-arrays is the linear function of their areas or, what is the same, their capacities. Consequently, the cost \( C_S \) related to the capacity of PV-arrays is \( f_S = C_s/P_s = \text{const} \) (fig.4a).

In hybrid solar-wind systems the second energy source is wind turbine. Analyzing the graphs of dependence of cost of capacity unit \( f_W \) related to wind turbine capacity that were plotted according to price-lists of companies LMW (data of 1994) and Fuhrlander (data of February 2000), we can note that these dependencies are non-linear and decrease with the increasing of wind turbine capacity (fig.5).

Analysis of the behavior of \( f_S(P_S) \) and \( f_W(P_W) \) allows to conclude that there exists some area of intersection of these functions \( f_S(P_S) \cap f_W(P_W) \), where the use of hybrid solar-wind systems is economically expedient. Topologic scheme of these dependencies is shown on fig.4b. It follows from this topology that it is expedient to use the PV-arrays when consumer capacities are low (zone A), wind turbines when demand capacities are significantly high (zone C) and in the intersection area \( f_S \cap f_W \) the use of hybrid solar-wind systems (zone B) is profitable. These conclusions are used by us for construction of economic model of HSWS [6].

It follows from topologic model that use of HSWS is effective when consumer capacity is \( 1+100 \) kW. Ratio between capacities of PV-arrays and wind turbine depends on specific customer capacity and local meteoconditions on the territory of HSWS installation. This problem is an object of further investigations.

6. Hybrid solar-wind system for TV-transmitter Charvak, Uzbekistan

Complex of HSWS equipment was constructed and put into experimental operation in 2000 under financial support of European Commission in the frame of INCO-Copernicus Program (grant ICOP-DEMO-4068-98). Executors of demonstration project were SEMRC (scientific coordinator and principal investigator), firm Armines (project coordinator, France) with the participation of specialists from Portugal (firm F.F.Lda) and Uzbekistan (Institute of power engineering and automation, firm Bakht-Ener).

Meteorological data of territory

Demonstration project of HSWS was constructed on the territory near TV-transmitter Charvak on the height 1148 meters above the sea level. For general characteristic of wind situation in zone of Charvak transmitter, yearly duration of energy-active wind speeds is given in table 3.

<table>
<thead>
<tr>
<th>&lt;3 m/sec</th>
<th>&lt;3 m/sec</th>
<th>&lt;4 m/sec</th>
<th>&lt;5 m/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>hours</td>
<td>%</td>
<td>hours</td>
<td>%</td>
</tr>
<tr>
<td>373</td>
<td>14.6</td>
<td>4165</td>
<td>47.5</td>
</tr>
<tr>
<td></td>
<td>2656</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Monthly average distribution of solar radiation intensity \( (R) \), sunshine duration \( (T_s) \) and wind speeds \( (V_{Av}) \) measured in Tashkent \( (R,T_s) \) and Charvak meteostation are given on.
These data were used for preliminary calculation of electric energy production by selected PV-arrays, wind turbine and whole HSWS (fig.6). It follows from fig.6 that demand of constant load, with use of PV-arrays only, is satisfied just in summer period and squares $S_1+S_2$ should be covered from external source, in particular, diesel-generator or storage battery.

It is seen from fig.9 that energy production by wind turbine is low if compare to PV-arrays. However, WT produces energy mostly in winter-spring time. Therefore, sum of productions $E_{SW}+E_{WT}$ is almost totally covers the demand of load. Only squares $S_3+S_4$ which can be provided by storage batteries energy are left uncovered. Therefore, combined use of energies of wind and solar radiation allow significant improving the indicators of energy device and increasing the efficiency of renewable energies utilization. Proposal on demonstration project of 5 kW HSWS approved and financed by European Commission was grounded exactly on these facts.

Short description of HSWS and exploitation results

HSWS consists of the following (fig.7a):
- Arrays of photovoltaic converters (production of company Total Energy, France) of 60 m² total square with 6 kW peak capacity;
- 3 kW wind turbine by Southwest Windpower Co. (USA);
- 1525 Ah/48 V storage battery by firm Oldham (France);
- measuring and controlling equipment;
- 4.5 kW bilateral inventor.

In normal conditions when wind speed is over 3 m/sec or sky is clear or there are both factors together, energy produced by PV-arrays and wind turbine goes to consumer and at the same time charges the storage battery (SB). If charge of SB is full controlling system turns off the chain of damp load resistance and excessive energy is transformed into thermal one.

If both sources are absent (grey day or night and also there is no wind) customer is provided by energy during the time $\Delta t$ by SB discharge. When SB is discharged till maximum allowed level, discharge controller is activated and reserve electric grid is connected. Electricity supply and SB charging is made by grid. When wind or solar radiation enough for consumer operation occurs, external chain is disconnected [7].

Measuring, scaling and remembering of values of capacity production by PV-arrays, WT and whole HSWS, temperatures, maximal wind speed and number of other parameters characterizing modes of system operation, is made by Enerpak block. Results of all measurements are fixed in special tables. Example of list of measuring values and energy at various points of Enerpak are given in table 4.

During exploitation and processing the measured values we revealed that measurement results of values of energy $E_i$ going to damp load resistance were not recorded on the blanks of daily and monthly measurements. This created uncertainty in estimation of energy balance in HSWS and efficiency of its operation. To determine by calculation the value $E_i$ there was created an equation of capacities balance in system (fig.7b)

$$E_p+E_{sw}+E_{bt} \pm \Delta E_i = E_i + E_{sw} + E_{bt}$$
where $\Delta E_S$ is difference of charge (+$E_S$) and discharge (-$E_S$) energy of storage battery. Value $E_p$ is measured in controlling device with account of all losses $E_l$ in measuring-transforming chains (1-2 kW a day). Therefore in conducted analysis we accept $E_l=0$.

As a result of study of energy transfer in HSWS chains we found that

$$E_i=E_p-E_a$$

Finding of this dependency allowed making calculations of real energy losses in damp load resistance. Energy $E_i$ produced by HSWS over consumer demand can be returned to grid or used for everyday needs of object.

### Table 4

<table>
<thead>
<tr>
<th>Synthesis-Energies (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site Name</strong></td>
</tr>
<tr>
<td>Armines, SEMRC</td>
</tr>
</tbody>
</table>

Dielectric generator: 0 kVA

<table>
<thead>
<tr>
<th>Date</th>
<th>Production</th>
<th>Battery</th>
<th>Consumption</th>
<th>Totals</th>
<th>Alarms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E_p$</td>
<td>$E_a$</td>
<td>$E_{bu}$</td>
<td>$E_{au}$</td>
<td>$E_{si}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Analysis of wind turbine operation

Wind turbine produced by Southwest Windpower Co, USA, was installed on the steel tower of $d=140$ mm on the height 10 m from earth surface. First the model Whisper-3000 was installed but in one year it was replaced by modified model Whisper-175.

Calculated production of WT $E_w$ is determined by characteristic $P=f(V_{av})$ ($V_{av}$ is average monthly wind speed) of attached documentation (curve $E_{wc}$, fig.8), by formula $E_{wc}=T\sum_i/P(V_{av})$, where $i$ is a number of a month in year, $T=24$ hours. According to calculations on data on $V_{av}$ by months, calculated production of WT was 3470 kW/year. On the same fig.9 it shown a curve $E_{wr}=f(T)$ constructed by averaged values of real data for 3 years of WT operation.

It follows from analysis of curves of fig.9 that in period November-March calculated $E_{wc}$ and real $E_{wr}$ are almost the same while in period April-November $E_{wc}>E_{wr}$. Average yearly production is 4150 kWh. This can be explained by the fact that statistical data characterize $V_{av}$ on the level of Charvak reservoir on the height 950 m above the sea level while WT was installed on the height 1150 m where wind speeds are higher than on the reservoir level.

Generalizing these results we can state that northern foothill territory of Tashkent region consisting of lots of hollows and valleys of mountain rivers, has quite high values of wind energy resources. They can be easily utilized thanks to well-developed transport network.

### 8. Analysis of PV-arrays operation

Aim of this analysis is to compare real energy $E_{av}$ produced by system to calculated one $E_{av,c}$ determined by calculation $E_{av,c}=RQ\cdot T\cdot \eta$, where $\eta=0.1$, $Q=60$ m$^3$, $R,T$ – according to data of meteostations. Analysis of curves $E_{av}$ and $E_{av,c}$ shows that in period November-April when ambient temperature is quite low (<25°C) $E_{av}$ and $E_{av,c}$ curves are very close. Therefore, in this period the real transformation coefficient of PV-arrays is about $\eta=0.1$. in period May-September decrease of PV-arrays productivity is observed. Such decrease of PV-arrays operation efficiency under high average daily intensity of solar radiation more than 0.7 kW/m$^2$, can be explained by high ambient temperature 35-42°C when temperature on the PV-arrays surface reaches 60°C and more. (Fig.8.) Thus, in conditions of Uzbekistan and neighboring countries, sharp decrease of PV-array operation efficiency in daytime is observed. This question, by our opinion, should be the object of research of physicists. Our organization SEMRC is ready to take part in deciding this problem.
8. Analysis of operation of hybrid solar-wind system

Curves characterizing total productivity of HSWS are given on the fig.10. Here EHc, EHr are calculated and real production of electric energy by whole HSWS, E_L is energy consumed by loading, ∆E is energy transferred to external loading. Analyzing these curves we can notice that:

- Average monthly real production of electric energy EHr=1023.4 kWh is less than calculated EHc=1198 kWh. This fact is a result of decrease of PV-arrays productivity in summer hot periods
- Average monthly real production of electric energy EHr=1023.4 kWh is less than calculated EHc=1198 kWh. This fact is a result of decrease of PV-arrays productivity in summer hot periods
- Energy produced by HSWS generally covers the demand of loading during a year. At the same time, in winter-spring periods of high cloudiness and absence of wind during 2-3 days, sustainable operation of TV-transmitter is provided by external source not exceeding 1000 kWh a year
- Average monthly overproduction by HSWS of loading demand is EHr-EL ≈ 315 kWh and 3830 kWh during a year. This energy can be transmitted to external consumer.

9. Conclusions

- Experience of creation and exploitation of HSWS completely confirmed the high efficiency of combined use of energies of wind and solar radiation when they autonomously utilized on local territories with average yearly wind speed Vav>4 m/sec.
- Principles of combined use of renewable energies, results of HSWS exploitation were discussed at International Workshop Hybrid-2002 organized by NATO grant EST-ARW-977881 (May 22-24, 2002, Tashkent). Workshop participants highly appreciated the results of made elaborations and investigations and recommended HSWS for wide scale implementation

Acknowledgements

Authors note with pleasure that this report is a result of generalized researches made in frame of European Commission grant with active participation of Project coordinator Prof.D.Mayer from Armines

References