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Saudi Arabian Geothermal Energy Resources - an Update

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ABSTRACT

The objective of this paper is to prepare an update on the existing, on-going, and planned sources of geothermal energy in Saudi Arabia. As per available information from the literature, there exists some lava activity in Madina Al-Munawwara and hot springs in Wadi Al-Lith, Gizan, and Al-Hassa regions. The capacity and usage of these sources have to be explored both in terms of quality and quantity. A sample of water was collected from Wadi Al-Lith and a geochemical analysis was conducted in the laboratory. The results of the same are also included here in this country update report.

1. INTRODUCTION

Recently, in May 2009, an earthquake tremors measuring between 3 and 5.4 on Richer scale were observed in various villages (Al-Qarasa, Al-Hadama and Al-Amid) in and around Yanbu, Madinah and Al-Ais region in Saudi Arabia. The epicenter of the tremors, Harrat Al-Shaqah (also known as Harrat Al-Lunayyir), is an extinct volcano, which recently showed signs of coming alive. Several rifts, some of them measuring up to 900 meters in length, have appeared on Harrat Al-Shaqah. Add further to it lava from al-Ais volcanoes has never spread out beyond 18 km and the last volcanic eruption there was observed over 700 years ago. This is an indicator that geothermal sources do exist in Saudi Arabia and it is just matter of identifying and quantifying these resources.

Exponentially growing global population, increasing pollution, changing global climate, and fast depleting sources of fossil fuels have been the matters of concern to environmentalists, engineers, scientists, and in recent years to governments, too. In order to counter all of these concerns green sources of energy like solar, wind, geothermal, tidal, etc. are being encouraged globally. Of these sources of energy, wind power has been on the top relative to others sources of energy in terms of its global installed capacity.

Saudi Arabia, though has abundance reserves of fossil fuels, has been on the forefront of the development and usage of renewable sources of energy in general and solar in particular. The measurement of global solar radiation and sunshine duration was started in 1970. A total of 41 radiation measurement stations were established. These stations were maintained by The Ministry of Agriculture, Saudi Arabia. Recently, in the year 1995, around 14 new generation solar radiation measurements stations were established to collect data on various components of solar radiation. These new generation stations are being maintained by King Abdulaziz City for Science and Technology (KACST). Another 63 stations were established between 1970 and 1985 where meteorological parameters like air temperature, surface pressure, relative humidity, wind speed, wind direction, rain fall, visibility and cloud cover are being recorded. These stations are maintained by Presidency of Environment and Meteorology previously known as Meteorology and Environment Protection Agency (MEPA). The other organizations including Saudi Aramco, Saudi Basic Industries (SABIC), Saudi Electricity Company (SEC), Royal Commission of Yanbu and Jubail, King Fahd University of Petroleum and Minerals (KFUPM), King Abdulaziz University (KAAU), Ummulqura University, King Saud University (KSU), etc. also collect data on various meteorological parameters.

Just two years back the ministry of higher education has provided large funds for the establishment of a center of research excellence in renewable energy at King Fahd University of Petroleum and Minerals. The center has started its research activities in the areas of wind, solar and geothermal power resources assessment and utilization in the Kingdom of Saudi Arabia. The government has also provided lot of funding for research and development work on various aspects of solar energy utilization. A good number of research papers and books are found in the literature on various topics including solar radiation data analysis, development of empirical model for the prediction of solar radiation, wind data analysis, electricity production and energy cost estimation, solar cookers for Mina and Arafat, etc. A comprehensive review of the work done on solar radiation was compiled by Rehman and Halawani 1998.

The objective of this paper is to prepare an update on the existing, on-going, and planned sources of geothermal energy in Saudi Arabia. Section two describes briefly the geology of Saudi Arabia while electricity present and future demands are discussed in section 3. Section four is devoted to existing sources of geothermal energy in Saudi Arabia. Section 5 sheds light on some of the existing and planned usage of solar and wind energy in Saudi Arabia.

2. GEOLOGY OF SAUDI ARABIA

A hallmark of the land of Saudi Arabia is its enriched variety of geological features. This part of the Earth's crust is made of consolidated rock outcrops as well as unconsolidated sand dunes. The rocks display a large lithological variety of igneous, sedimentary and metamorphic types. The time period of the formation of these rocks stretches from Proterozoic to Quaternary and Recent. The western one third of Saudi Arabia is known as the Arabian Shield. The remaining eastern part is covered by the "cover rocks" of the vast Arabian Platform. The Platform region hosts most of the oil reserves of the country.

Tectonically, Saudi Arabia is situated in the southern part of the Arabian plate, one of the youngest of the 10 or more

plates that make up the present-day surface of the Earth. In this area, the plate comprises a crystalline basement of Precambrian continental crust about 40-45 km thick and mostly 870-550 million years old, an overlying sequence of younger Phanerozoic sedimentary rocks that range in age from Cambrian (540 Ma) to the Pleistocene and in thickness from zero to 10 km, surficial Cenozoic flood basalt, and Paleogene-Holocene intracontinental and, now, oceanic basins along the Red Sea and Gulf of Aden.

In its geotectonic framework, Saudi Arabia is the largest country of the Arabian Plate, occupying its 80% area; the rest being shared by UAE, Yemen, Oman, Qatar and Bahrain. The Arabian Plate exhibits a variety in its plate margins as it includes all the three major types of plate margins, i.e., the diverging margin along the Red Sea spreading axis, the converging margin along the Zargos Mountains supra-subduction zone; and the transform fault margin along the Dead Sea transform fault, as shown in Figure 1. The Red Sea mid-ocean ridge itself varies in its character from just rifting in the northern part and active spreading in the southern part. Since these plate margins are controlled by the deeper Earth processes, it is obvious that a variety of processes are operating below this part of the world.

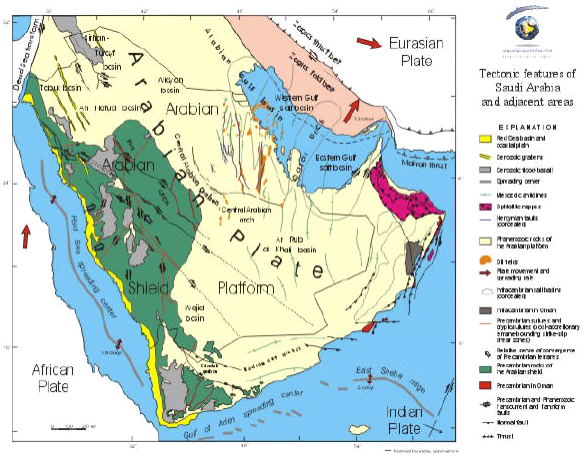

Figure 1: Map of Tectonic features of Saudi Arabia and adjacent areas, [SGS].

3. FUTURE ELECTRICITY DEMANDS

In this era of modern and materialistic life pattern, human life is increasingly depending on the energy right from powering a personal computer to cooking food. The growth in population has a direct impact on the energy requirements. With respect to Saudi Arabia, there were 3,036,000 consumers in the year 1997 and reached to 3,792,000 in the year 2001. The annual increase in number of consumer in different years is shown in Figure 2. On an average, the consumer growth rate from year to year looks linear. In fact the number of consumers increased by 3.5% to 6.5% annually with an exception of sudden jump of 11.2% in the year 2000 compared to 1999. The data presented in Figures 2 to 6 is taken from the annual report of Ministry of Water and Electricity (MOWE) [2007]. As seen from Figure 3, the energy growth reached to 165,342 GWh in the year 2007 from 75,946 GWh in 1997. On an average, the energy increased by 8.2% between 1997 and 2007 with a maximum growth of 19.6% in 2000 and a minimum of 3.9% in 2006.

As shown in Figure 4, the actual generation capacity of Saudi Electricity Company (SEC) was 18,805 MW in the year 1997 which increased to 32,957 MW in the year 2007, an increase of about 75% in ten years. The generation capacity increased by 2.9% in 1998 compared to 1997 while it increased by 4.7% in 1999 compared to 1998. From 1999 to 2000 the generation capacity increased by another 8.9% and by 5.3% in 2001 compared to 2000. This trend shows that with time the generation requirements will be more and more.

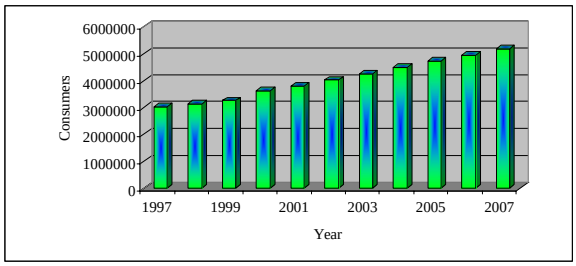

Figure 2: Annual consumer growth.

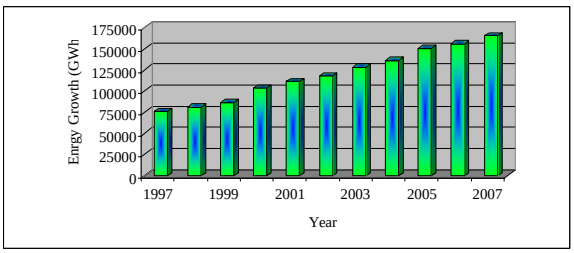

Figure 3: Annual energy growth (GWh).

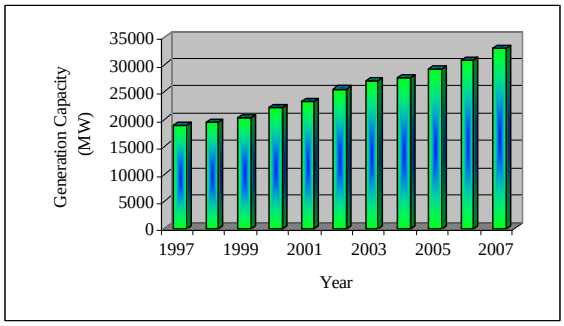

Figure 4: Annual actual generation capacity.

Figure 5 shows the total forecast demand in MW for the Kingdom of Saudi Arabia as per the details given in report SEC [1996]. As per the demand forecast, it is expected that the demand will increase to 31,936 MW in the year 2005 compared to 27,933 MW in 2000 i.e. an increase of approximately 14.3%. The demand forecast is expected to increase by 22.9%, 18.7%, 17% and 8.7% by 2010, 2015, 2020 and 2023, respectively. As given in Figure 6, the net generation is expected to increase by almost 20% i.e. from 37,808 MW to 45,522 MW corresponding to years 2005 and 2010. From 2010 to 2015 it is expected that net generation will increase by 17.6% and 16.8% by the year 2020. As per future projection, the net generation will reach 62,460 MW in the year 2023 i.e. an increase of 8.7% compared to year 2023, as shown in Figure 6.

The investment requirement for generation and bulk transmission system additions in millions of Saudi Riyals (SR million) is shown in Figure 7. As seen from this figure a huge sum of 138,551 million SR (US $36,950 millions) was spent on the electricity generation and facilitation in

the Kingdom of Saudi Arabia during the years 1995 and 2000. During next five year plan i.e. from 2001 to 2005 a sum of 79,797 million SR (US $21,378 millions) was planned to be invested into electricity sector. As per forecast figures, an amount of 77,698 million SR (US $20,720 millions) will have to be invested during the period 2006 to 2010.

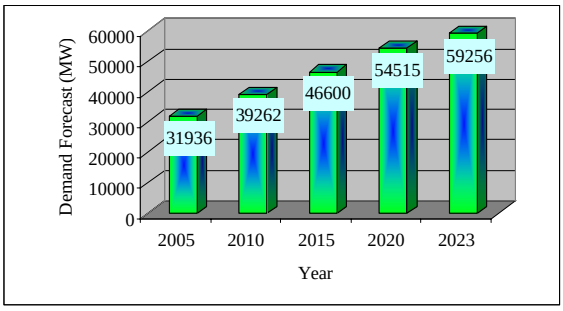

Figure 5: Future load demand forecast.

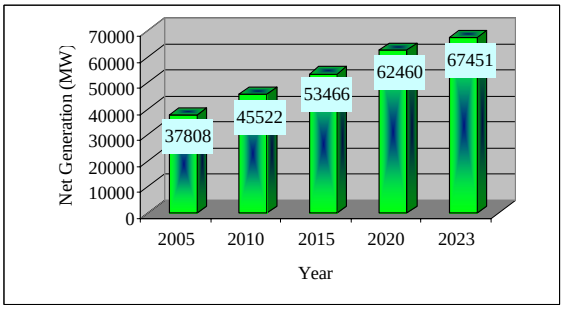

Figure 6: Future net generation requirements.

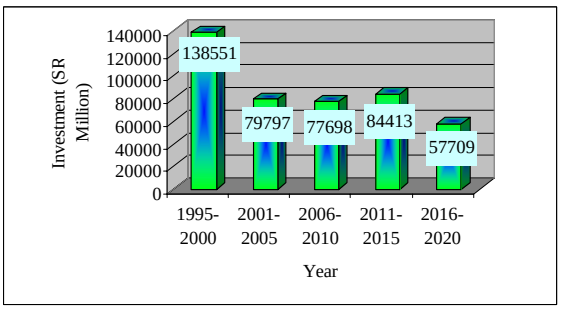

Figure 7: Total investment requirement.

4. GEOTHERMAL RESOURCES SCENARIO OF SAUDI ARABIA

Being an oil based economy, the renewable and other sources of energy, though have been paid attention whereas research and development infrastructure is concerned, but the fossil fuel based economy has dominated the previous four to five decades. In Saudi Arabia, the studies on geothermal resources exploration were started in 1980. These efforts consisted of hydro-geological reconnaissance of the hot springs in the south part of the country and a geological reconnaissance of the large volcanic areas known as harrats in the western part. The Harrats region of Saudi Arabia holds bright prospects as a source for the geothermal energy. Its geothermal potential is reviewed by Berthier et al., 1981. The hot springs and the harrats are discussed in details in sub-sections 4.1 and 4.2, respectively.

4.1 Existing Hot Water Springs

As per the available information, there are ten thermal springs in Saudi Arabia, (Al-Dayel, 1988). Of these, six are in Gizan (viz. Ain Khulab, Ain Khulab Quwa, Ain Mijara Quwa, Ain ad Damad, Ain al Wagrah and Ain al Wagrah Dam, Figure 8) and four in Al-Lith area (viz. Ain al Harra, Ain Jumah, Ain Markub, and Ain ad Darakah, Figure 9). Table 1 summarizes the geographical locations of all the thermal springs, known to date in Saudi Arabia. In Gizan area, the Ain Khulab and Ain Mijara Quwa thermal springs have very low flow-rates and flow over wadi Alluvia. According to Al-Dayel 1988, the deep temperatures are low at these location i.e. 80-100°C at Ain Khulab and 70°C at Ain Mijara Quwa. At Ain ad Damad the temperature is found to be 80-90°C. The Ain al Wagrah and Ain al Wagrah dam springs represent two fractions of a mixture of thermal water and a shallow water aquifer. At these locations, the deep temperatures calculated using chalcedony was found to be around 120°C (Al-Dayel, 1988). The thermal springs at Al Wagrah and Al Wagrah Dam are located on a major N100° striking fault which brings two very different units of the metamorphic basement inro contact (Al-Dayel, 1988). The other springs at Al Khulab and Quwa are located on the edge of the same granite unit and are controlled by faults that bring the granite into contact.

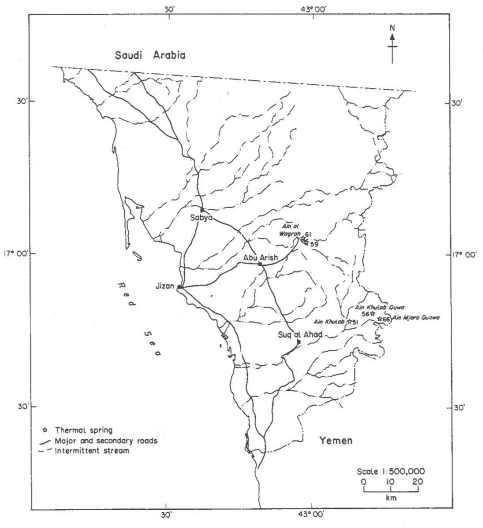

Figure 8: Map of Gizan area, showing the locations of hot water springs [Al-Dayel 1988].

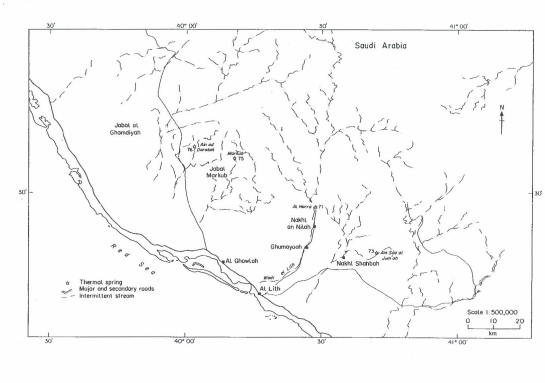

Figure 9: Map of Al-Lith area, showing the locations of hot water springs [Al-Dayel 1988].

Table 1: Physical properties of thermal springs.

Name	Latitude	Longitude	Temperature (°C)	Flow Rate (L/min)	Aquifer type
Ain Khulab (Gizan)	16°45N	43°07E	75.5	1 - 2	TS*
Wadi Khulas (Gizan)	-	-	31.4	10.0	Wadi
Ain Khulab Quwa (Gizan)	16°48N	43°12E	59.0	2.0	TS*
Ain al Wagrah (Gizan)	17°03N	42°59E	55.0	1.5	TS*
Ain al Wagrah Dam (Gizan)	17°03N	42°59E	59.0	20.0	TS*
Ain al Harra (Al Lith)	20°29N	40°28E	79.0	4 - 5	TS*
Ain al Jumah (Al Lith)	20°18N	40°42E	46.0	0.3	TS*
Ain Markus (Al Lith)	20°33N	40°09E	46.0	0.3	TS*
Ain al Darakah (Al Lith)	20°39N	40°01E	39.5	0.1	TS*

*TS - Thermal Spring

Table 2: Chemical analysis results of a hot water sample from Al-Lith (Ain Al-Harra).

Parameters	Units	Result
Physical Appreance		Colorless liquid
pH		8.38
Conductivity	ms/cm	2.94
TDS	ppm	2146
Ba	PPM	-
B	PPM	-
Ca	PPM	329.8
Sr	PPM	na
Zn	PPM	<0.5
K	PPM	24.22
Si	PPM	33.27
Fe	PPM	<1.0
Mn	PPM	0.119
Mg	PPM	0.152
Na	PPM	446.9
Chloride	PPM	813
Bromide	PPM	ND*
Sulphate	PPM	626
Bicarbonate	PPM	

*ND: not detected

In Al-Lith area, all the springs are located in the vicinity of granite boundary along a cataclastic zone. Three springs, viz. Ain Darakah, Ain Markub and Ain al Harra, represent different fractions of a mixture of thermal water with a confined aquifer. Ain al Harra, the least mixed spring contains 48% of surface water, (Al-Dayel, 1988). At these thermal springs, the estimated deep temperatures were reported to be about 100°C using Na-K geothermometer. The deep temperature at Ain Jumah spring was found to be approximately 100°C. The chemical composition of this spring was reported to be almost the same as that of the Ain al Harra. A water sample was collected from Ain al Harra in October 2008 and chemical analysis was performed. The results of the analysis are summarized in Table 2. Figure 10 shows the site of the hot water spring Ain al Harra in Al-Lith taken by the author during his visit to the site.



Figure 10: Site of Ain Al-Harra hot water spring in Al-Lith.

4.2 Existing Harrats

Geothermal energy is generated in the earth's core, about 4,000 miles below the surface. Temperatures hotter than the sun's surface are continuously produced inside the earth by the slow decay of radioactive particles, a process that happens in all rocks. The Harrats are formed by the Tertiary to Recent volcanic activity that has continued till the historical times. The volcanic eruptions of “harrat" near Madina area are recorded for the year 1256 A.D. (Camp et al., 1987). The association of "harrats" with the Red Sea rifting makes them a feature that is presently active. As the Red Sea is continuing its opening; and rifting is giving way to seafloor spreading; the volcanism of "harrats" is also in operation. This would mean the transport of hot fluids closer to the surface of Earth in this region; which can be a geothermal resource. The evidence for the occurrence of a plume under the Red Sea may provide another source for the higher geothermal gradient in the crust.

In a recent study of the Red Sea region, based on Neon isotopes, large-scale plume-lithosphere interaction has been revealed (Hopp et al., 2004). As per available resources, there are only three major areas of geothermal interest, viz.

harrat Khaybar, harrat Kishb, and harrat Rahat. The physical locations of these harrats are shown in Figure 11 which is taken from [Saudicaves]. According to Al-Dayel [1988], harrat Khaybar and harrat Rahat have potentially high heat flow. As seen from Figure 11 there are other volcanic regions like harrat ash Shamah in the north, harrat ar Raha and harrat Uwayrid near Tabuk, harrat ithnayn in the north west region, and so on.



Figure 11: Map of the Arabian plate showing locations of the Harrats Al Kishb, Ar Raha, Uwayrid, Kura, Ithnayn, Ash Shamamah and other basalt lava fields, after [Saudicaves].

The volcanoes by the side of the expressway from Jeddah/Makkah to Madinah, belong to a much younger set of basaltic lava-fields with age dates from 10 million years right up to the historic eruptions. This chain is 600 km long and is called the Makkah-Madinah-Nafud volcanic line [Saudicaves]. Between Makkah and Madinah the Harrat Rahat lava-field is spread over an area of 20,000 km^2 with 644 scoria cones, 36 shield volcanoes and 24 domes. Between Madinah and the Great Nafud are the coalesced harrats Khaybar, Ithnayn and Kura with an area of 20,560 km^2 and 327 scoria cones, 46 basaltic shield volcanoes, 20 domes, 5 tuff cones, one basaltic stratovolcano, and 39 massive and very long lava flows [Saudicaves]. According to personal communication [2004], there are live surface fumeroles in and around harrat Ithnayn which can be utilized for electricity generation. The latitude, longitude, and summit elevation of major harrat are summarized in Table 3.

Table 3: Summary of volcanic fields (Harrats) in Saudi Arabia.

Name	Lat °N	Lon °E	Summit Elevation (m)
Al Harrah, NW Saudi Arabia near the border with Jordan	31.08	38.42	1100
Harrat ar Rahah, Northernmost, Red Sea coast	27.80	36.17	1660
Harrat 'Uwayrid, NE, 110 km from the Red Sea	27.08	37.25	1900
Harrat Lunayyir, NW, east of the Red Sea port of Umm Lajj.	25.17	37.75	1370
Harrat Ithnayn, central northern, Hail province	26.58	40.20	1625
Harrat Khaybar, 66 km NE of Al Madinah in western region	25.00	39.92	2093
Harrat Rahat, Western region	23.08	39.78	1744
Harrat Kishb, Central region	22.80	41.38	1475
Harrat al Birk, Red Sea coast of SW	18.37	41.63	381
Jabal Yar, Red Sea coast of SW	17.05	42.83	305

According to Al-Mishwat and Nasir [2004], the calculated xenolith temperatures derived from two-pyroxene geothermometer of Wells [1977] vary between 800 and 900°C for group I xenoliths and between 730 and 815°C for group II xenoliths. In simpek, engineering terms, it can be said that there exists high temperatures molten materials below the earth crusts and its high energy contents can be utilized for electricity generation.

5. OTHER SOURCES OF ENERGY

Saudi Arabia observes the longest sunshine hours and highest solar radiation intensity in the world and needs to be tapped for small and big applications. According to BP Solar Company in Riyadh, Saudi Arabia the total PV installed capacity has reached 3,895 kW by the end of year 2008. The annual addition and cumulative PV installed capacity is shown in Figure 12. Of the record, in Saudi Arabia, photovoltaic panels are being used for various applications since 1981. Some of these applications include a 350 kW installed capacity electricity generation plant for a remote village in Riyadh (Solar Village), a 350 kW PV system for hydrogen production (Solar Village), another 6 kW PV system for grid connected supply (Solar Village), 4 kWp PV system for agriculture usage (Muzahmia), 10.63 kWp PV system for sea water desalination (Sadus village, approximately 70 km from Riyadh), 57.60 kWp PV lighting

system for tunnels in southern region of Saudi Arabia, etc. According to Alawaji [2001], the cumulative PV installed capacity in Saudi Arabia sums up to 4 MWp upto year 2000. At present, none of these applications are in use. The other major applications of PV systems in Saudi Arabia include the cathodic protection in oil and water pipe lines and the communication towers.

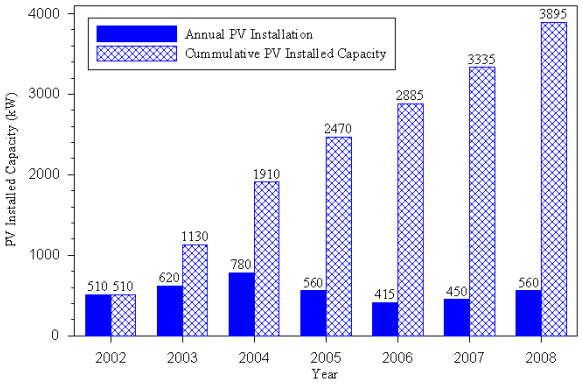

Figure 12: PV installed capacity in Saudi Arabia.

As of today, the power of the wind has not been utilized to generate electricity in Saudi Arabia but the Saudi Electricity Company has recently completed four projects through King Fahd University of Petroleum and Minerals, (i) to identify three potential locations for grid connected wind farms development, (ii) to conduct feasibility study for wind diesel hybrid system for a remote village powered by diesel only system and (iii and iv) wind speed measurements at two sites using 40 meter tall towers. So in near future, Saudi Arabia may have some MW of wind power installed capacity for the generation of electricity.

6. CONCLUDING REMARKS

The literature survey and site visit to one of the hot water spring presented in this paper can be summarized as follows:

1. The government of Saudi Arabia has embarked on the utilization of renewable sources of energy in the Kingdom and accordingly has established a Center of Research Excellence in Renewable Energy (CoRE-RE) at King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia.

2. In the present scenario, the existing geothermal resources like hot water springs and harrats are not being used for electricity generation or heating purposes. As per author's knowledge and available information, there is no existing plan to use geothermal sources for electricity generation in the near future. A private company has also started preliminary work on the exploration geothermal resources of Saudi Arabia in collaboration with KFUPM.

3. The usage of PV modules for grid connected and as well as hybrid systems is also being studied by the researchers at universities and the institutes in the Kingdom. At present, the Kingdom has 3,895 kW of PV installed capacity by the end of year 2008.

4. The Kingdom of Saudi Arabia is looking towards the utilization of power of wind to generate electricity for grid connected systems and as well as wind diesel hybrid applications for remote villages.

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