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Lighting tunnels: Saudi Arabia



GENERAL INFORMATION

◆ **Implementing institution**

Energy Research Institute (ERI), King Abdulaziz City for Science and Technology (KACST)

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◆ **Details of institution**

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◆ **Implementation period**

Eight years.

◆ **Costs**

US\$2.7 million for tunnels 1 and 2, financed by KACST, and US\$4.1 million for 13 tunnels, financed by the Department of Roads of the Ministry of Communication.

SUMMARY

In the mountainous regions of southern and western Saudi Arabia, there are many road tunnels, which need to be lit during daylight hours to avoid accidents when drivers are suddenly plunged from bright sunlight into darkness. Since 1985, photovoltaic (PV) power systems have provided daytime lighting for two of these tunnels: tunnel 1, which is 166 metres long, and tunnel 2, which is 546 metres long. The success of this initiative led the Ministry of Communication to recommend that daytime lighting be provided to all tunnels over 100 metres in length. However, the local electricity power company found that it was unable to connect 13 of these tunnels because they are located in difficult mountainous terrain beyond the reach of the local electricity grid. The total length of these tunnels is 3,548 metres, varying from 115 to 687 metres per tunnel.

The aim of the project was to use PV systems to light the 13 problem tunnels. First, the tunnels had to be assessed to make sure that they were appropriate sites for the installation and operation of PV lighting systems. Then a suitable PV system had to be designed, which included selecting the best position and equipment to use, simulating the performance of the system, studying its life-cycle and ensuring that its battery would have sufficient capacity to allow the PV system to run autonomously during periods of continuous cloud cover. The costs of installing, operating and maintaining PV systems were estimated to be higher than for diesel systems, so it was decided that a hybrid PV system would be the best option. One reason for not choosing the diesel system alone is the worldwide need to find alternatives to fossil fuels, reserves of which are declining as the world population increases. Solar power is such an alternative.

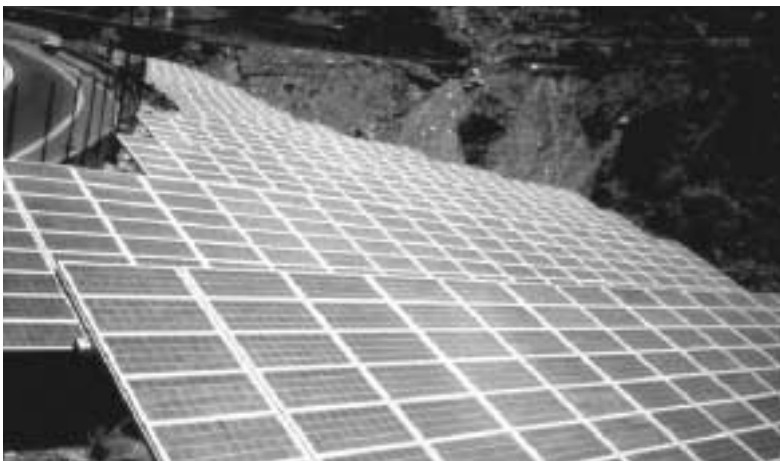


Figure 1 | PV system for tunnel no.9

BACKGROUND AND JUSTIFICATION

One of the most important applications of solar energy is the direct conversion of solar radiation into electricity using semiconductor devices that are called PV cells. For several decades, PV cells have provided reliable power to industries and other users in inaccessible locations with adequate sunshine and in areas where demand for electricity is so small that it is met more economically by stand-alone PV systems than by mains supplies. However, widespread acceptance of PV systems has been hampered by the high cost of their installation. Their use has therefore tended to be limited to isolated regions, such as mountains, which are difficult for other power sources to reach. In Saudi Arabia, lighting for road tunnels in mountainous areas has become one of the most important applications of PV energy, but little has been published on this subject.

PV energy was first used to provide daytime lighting for the mountain road tunnels of Saudi Arabia in 1985, when the King Abdulaziz City for Science and Technology (KACST), in collaboration with the Ministry of Communication, designed and implemented two systems in the southwest of the country near the city of Abha (at longitude 42° east, latitude 18° north and 2,000 metres above sea level). These systems served only two of the region's many tunnels, and the Ministry of Communication then turned its attention to providing daytime lighting for all the tunnels needing it in both the Abha and Al-baha city areas.

The first step taken by the Ministry was to ask the regional utility company to assess the possibility of connecting these tunnels to its grid. While a number of tunnels could be supplied from the grid, a total of 13 in the two areas could not be reached because of the difficult, mountainous terrain. The Ministry then went back to KACST to ask it to study the potential for using PV systems to light these tunnels. KACST assigned the project to its Energy Research Institute (ERI), which had been responsible for the success of the two existing PV tunnel-lighting systems.

DESCRIPTION

The principal aims of the project were to:

- reduce the life-cycle costs of installing, operating and maintaining tunnel lighting systems;
- find suitable sites for tunnel-lighting PV systems;
- reduce the risk of falling rocks or wild animals damaging PV systems;
- provide system autonomy that is less expensive than installing high-capacity batteries;
- vary the intensity of light provided to the tunnel so that it remains constant throughout the tunnel and between the tunnel and the daylight outside; and
- improve the economic feasibility of both life-cycle and energy costs.

Five of the 13 tunnels are near the city of Abha on a difficult mountain road known as the Shear descent. The other eight are near Al-baha. The tunnels in each group are extremely close to one another (distances between tunnels range from 0.35 to 4.40 kilometres) so at first, it was thought that each group of tunnels could be served from one central PV system. However, subsequent site inspection showed that there was not enough space around the tunnels for this to work, so instead, a separate stand-alone system was designed and installed for each tunnel.

The ideal position for a PV system is away from shadows and facing the sun for most daylight hours throughout the year. Such positions are difficult to find in mountainous areas, where many obstacles block the sun and cast shadows for several hours a day. When selecting suitable sites on which to install PV systems, the path of the sun throughout the year must be calculated, and the length and duration of all shadows must be predicted for each season. Once these calculations have been completed and a potential site has

been selected, the security of the site must be assessed and ensured. In mountainous areas, such considerations as avoiding areas where landslides can be caused by heavy rains and protecting the PV systems from damage by wild animals make suitable site selection difficult, increasing the costs of installing, protecting and maintaining PV systems.

The PV systems to be used for the 13 tunnels were modelled on the systems installed by the KACST project in 1985. First, the amount of power needed to light each metre of tunnel had to be calculated on the basis of the following factors:

- the light required in the approach area, which needs the most lighting;
- the light required at the entrance (transition) area, which needs less lighting than the approach area; and
- the light required inside the tunnel, which needs normal steady-state lighting.



Figure 2 | PV lighting of tunnel no. 9

TABLE 1 | Lengths and requirements of the 13 tunnels

	Tunnel no.	Length (m)	Power needed (W)	Number of PV modules needed	Area needed (m2)
AL-BAHA TUNNELS	1041	121	4,235	350	140
	1042	115	4,025	320	128
	1044	165	5,775	450	180
	1045	150	5,250	420	168
	1046	118	4,130	320	128
	1049	550	12,100	950	380
	1051	380	8,360	650	260
	1056	207	4,554	360	144
	Total	1,806	48,429	3,820	1,528
ABHA TUNNELS	1088	553	12,166	500	200
	1087	687	15,114	450	180
	1085	169	5,915	1,150	460
	1083	171	5,985	950	380
	1982	162	5,670	450	180
		Total	1,742	44,850	3,500

On the basis of these criteria and the previous experience of KACST, power consumption was calculated as follows:

- tunnels up to 200 metres long consume 22 watts per metre; and
- tunnels more than 200 metres long consume 35 watts per metre.

From this, it was possible to calculate the size of the system required for each tunnel, including: the number of PV

modules and whether they should be connected in series or parallel; the number and type of batteries and how they should be connected; and the size of the inverters (DC/AC converters). Given that an area of 0.4 square metres is needed to generate 100 watts, it is possible to calculate the total area required by multiplying the number of PV modules by 0.4. Table 1 shows the length of each tunnel and the power, number of PV modules and area that it requires.

The next step in designing the system was to calculate the size and cost of the diesel generators. Three sizes of generator were used — 5 kilowatt, 10 kilowatt and 15 kilowatt — requiring 9,000, 18,000 and 35,000 litres of diesel fuel per year, respectively. Diesel fuel costs US\$0.09 per litre, and the costs of running the different sizes of generator for 20 years are US\$171,000, \$200,000 and \$226,000, respectively. These figures include the costs for diesel fuel, filters, lubricant oil, technical transport, operation and maintenance. A comparison of the costs of installing and running PV systems and diesel generators over 20 years shows that PV systems cost about twice as much as diesel systems (table 2).

This cost difference is partly explained by the need to add 30 per cent to the costs of PV systems to compensate for the power lost as a result of mountains casting shadows on PV panels. Because of this and the unusually low cost of diesel fuel in Saudi Arabia, it was decided that hybrid PV systems would be the best option for lighting the tunnels. Such systems are supported by diesel generators when clouds obscure the sun for more than three days (the autonomy period of the PV systems designed for the

project). Use of diesel generators reduces the size and cost of the batteries that are required to maintain continuous PV system operation during such cloudy periods. For example, a battery providing five days of autonomy can represent 50 per cent of the total costs of a stand-alone PV system. In these hybrid systems, the advantages of using PV power are as follows:

- It conserves fuel.
- Diesel-only systems in remote areas are difficult and expensive to maintain.
- Diesel is expensive to transport.
- Broken-down diesel generators may take several days to repair because of the need to bring spare parts from distant cities.

LESSONS LEARNED

The main objective of the project was to improve road safety by providing daytime lighting to those tunnels that were more than 100 metres in length and out of reach of the local electricity grid so that drivers do not have to adapt too quickly to sudden darkness.

TABLE 2 | Costs of PV systems and diesel generators over 20 years

COSTS	PV SYSTEMS (US\$)	DIESEL GENERATORS (US\$)
Systems cost	4.1 million	1.4 million
Maintenance cost	1.3 million	1.3 million
Total costs	5.4 million	2.7 million

The hybrid PV-diesel system was found to be the most reliable and appropriate system for lighting the 13 tunnels. The PV systems do not have to be especially large because power is needed only during daylight hours.

KACST recommends that diesel generators be positioned between the tunnels so that power can be provided on cloudy days. It suggests that it may be advisable for the Ministry of Electricity to assume responsibility for the lighting of these 13 tunnels where system costs can be decreased and system reliability increased.

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