The Performance of PV Electricity For Building In Four Different Locations in the Kingdom of Bahrain: Three Years Operation of BAPCO Project

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Bahrain Petroleum Company (Bapco) had decided to install a solar PV project which is 5MW of smart PV systems with micro-inverter to produce electricity connected to the national grid. These locations are at:

1. **University of Bahrain in Sakhier (middle of a desert) with 0.518 MW.**

2.Awali Town with 1.59 MW using car park canopies and light poles .

3. The refinery at Nuwaidrat (costal region) with 2.892 MW .

4. A Building Integrated Photvoltaic (BIPV) at south Awali with 8.64 kW.

Bahrain (Pilot) : 5MW Smart Grid Systems – 100% Installed and Operational

- **Helping to Make Bahrain Shine**
- 20,834 smart solar systems installed @ 240W/panel
- 400+ workers employed
- 520,000+ safe employee hours
- +$8 million direct expenditure into Bahrain economy via expenditure/procurement

Clean, Reliable & Resilient Energy:

- ~8 GWH Generated Annually
- 4,942 tons of CO_2 offset annually
- 1,470 acres of trees planted
- 56,874 MMBTU saved annually
- Area Utilized 34km^2

Types of Installations*

Site Name!	Installation Type!	Installation Size!
Awali Town	Carport Parking Shades	1.51 MW
	Solar Trees	190 kW
	Street Light Poles	46 kW
	Roof Top	8.6 kW
University of Bahrain	Ground Mount	501 kW
BAPCO Refinery	Carport Parking Shades	2.7 MW
	Total	**5.0 MW**

* Installation types distributed across 14 different sites




GCC Project Comparisons – Generation & Cost

PETRA SYSTEMS

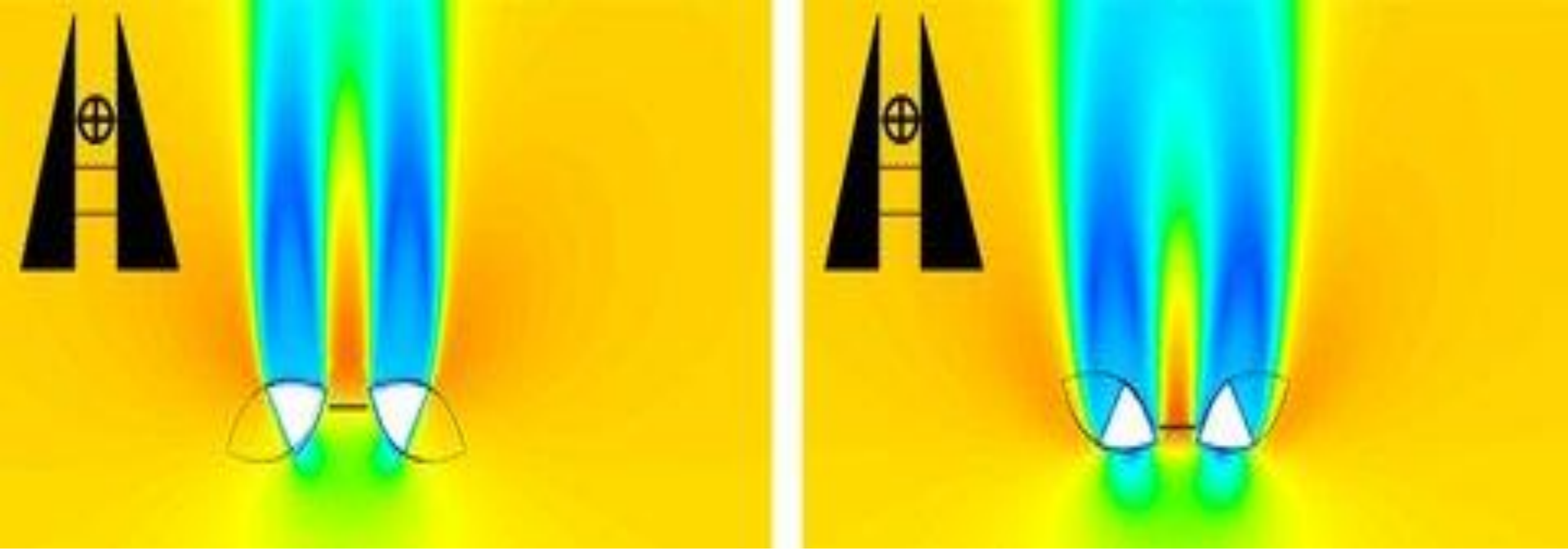
No.	Project Name	Location	Type of Installations	Capacity (Max Peak DC)	Year Built	Cost	Annual Generation	Normalized Annual Generation
1	**Masdar**	Abu Dhabi, UAE	Ground Mount	10 MWp	2009	$5/W	17.5 GWh	1.75 MWh/MW
2	**KAUST Solar Park**	KAUST Saudi Arabia	Rooftop	2 MWp	2010	$7/W	3.3 GWh	1.65 MWh/MW
3	**Saudi Aramco Solar Car Park**	Dhahran Saudi Arabia	Mixed (car park, rooftop, trees, pole mount)	10.5 MWp	2012	$10/W	17.5 GWh	1.67 MWh/MW
4	**KAPSARC Project -1**	Riyadh Saudi Arabia	Ground Mount	3.5 MWp	2013	$4.5/W	5.8 Gwh	1.66 MWh/MW
5	**KAPSARC Project -2**	Riyadh Saudi Arabia	Ground Mount	1.8 MWp	2014*	$3.5/W	2.9 Gwh	1.61 MWh/MW
6	**Kuwait Oil Company**	Umm Gudair Kuwait	Ground Mount	5 MWp	2014*	$5.6/W	-	
7	**BAPCO Pilot Project**	**BAPCO, Bahrain**	**Mixed (14 Locations)**	**5 MWp**	**2014**	**$5/W**	**8.3 GWh**	**1.66 MWh/MW**

* Project announced

This project was inspired after the success operation of the Building Integrated Wind Turbine (BIWT) at Bahrain Trade Centre which is two towers linked via 3 sky bridges, each holding a 225 kW wind turbine, totaling to 675 kW of wind power capacity, which were turned on, for the first time, on 8 April 2008 .

The wind turbines were expected to produce 11to 15 % of the towers need of electricity.

Its two 50 Storey sale shaped office towers (240 m high) support three 29 m diameter (r =14m) horizontal axis WT. The Cost is USD 150 million .

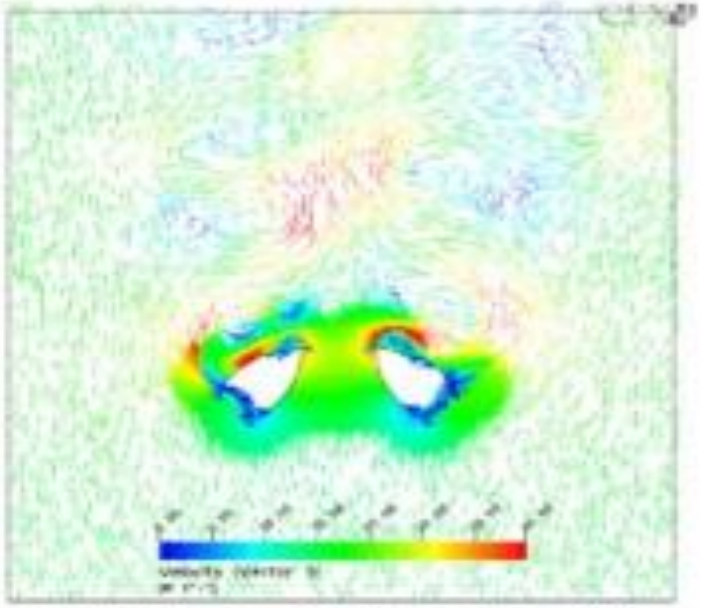


Results of computer simulations on the two configurations of the Bahrain WTC. The left picture shows the current configuration of the two towers, the right picture the situations in which the towers are built the other way round. The colors indicate the wind strength and the wind direction is up. The horizontal line between the towers indicates the position of the wind turbines. It is clear that on the right picture the area around the line is more red, indicating stronger wind flows.

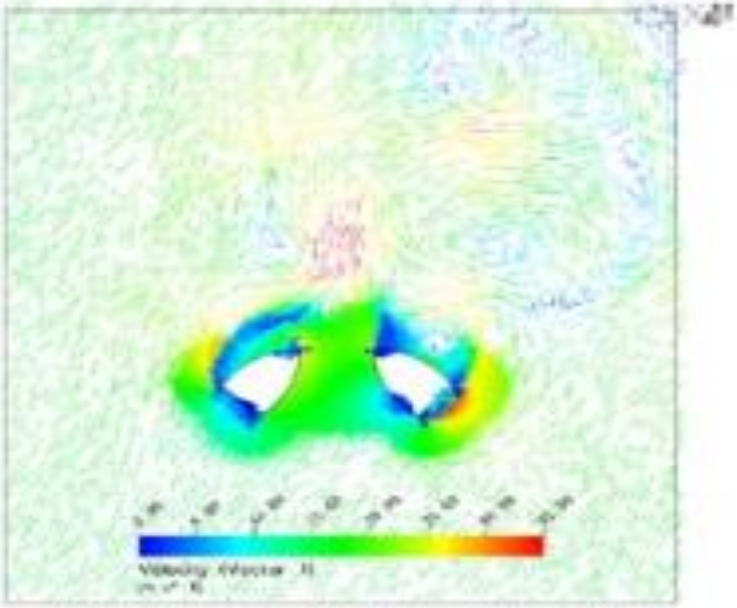
https://www.tue.nl/en/university/news-and-press/news/23-04-2014-bahrain-world-trade-center-is-exactly-the-wrong-way-round/

Table 1. Wind turbine details

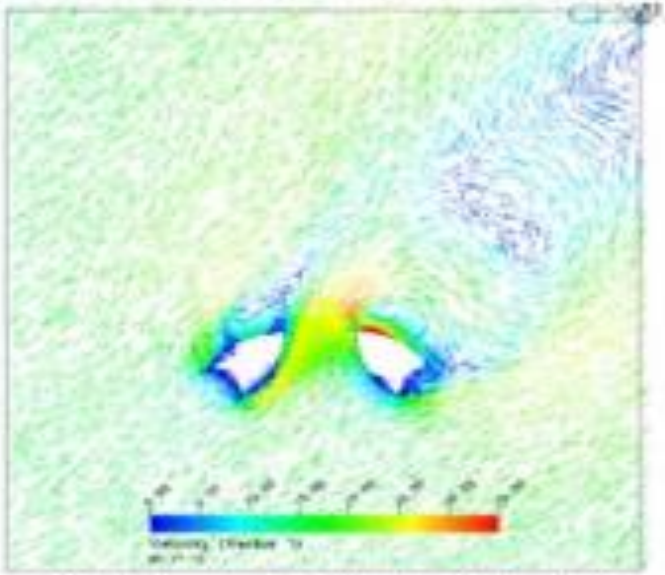
Nominal electrical power generated	225kW
Power regulation	stall
Rotor diameter	29m
Rotor speed at full load	38 rpm
Air brake	centrifugally activated feathering tips
High speed mechanical brake	fail safe type disc brake
Low speed mechanical brake	caliper type
Generator	closed, 4 pole asynchronous induction, 50Hz
Yaw system	fixed yaw
Cut in wind speed	4m/s
Cut out wind speed	20m/s (5 minute rolling average) – reduced from 25m/s for this application
Maximum wind speed for blades	80m/s (any direction) Class IV hurricane = >69m/s



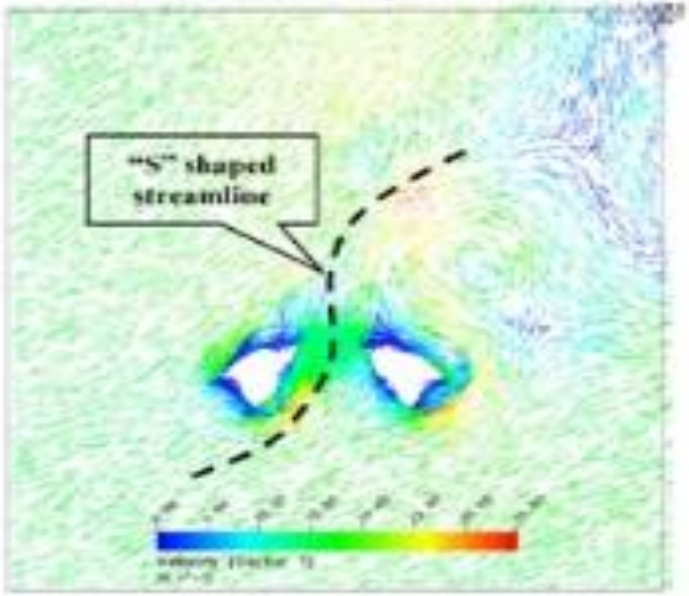
Wind direction 315° (simulation 90°)



Wind direction 345° (simulation 60°)



Wind direction 360° (simulation 45°)



Wind direction 15° (simulation 30°)

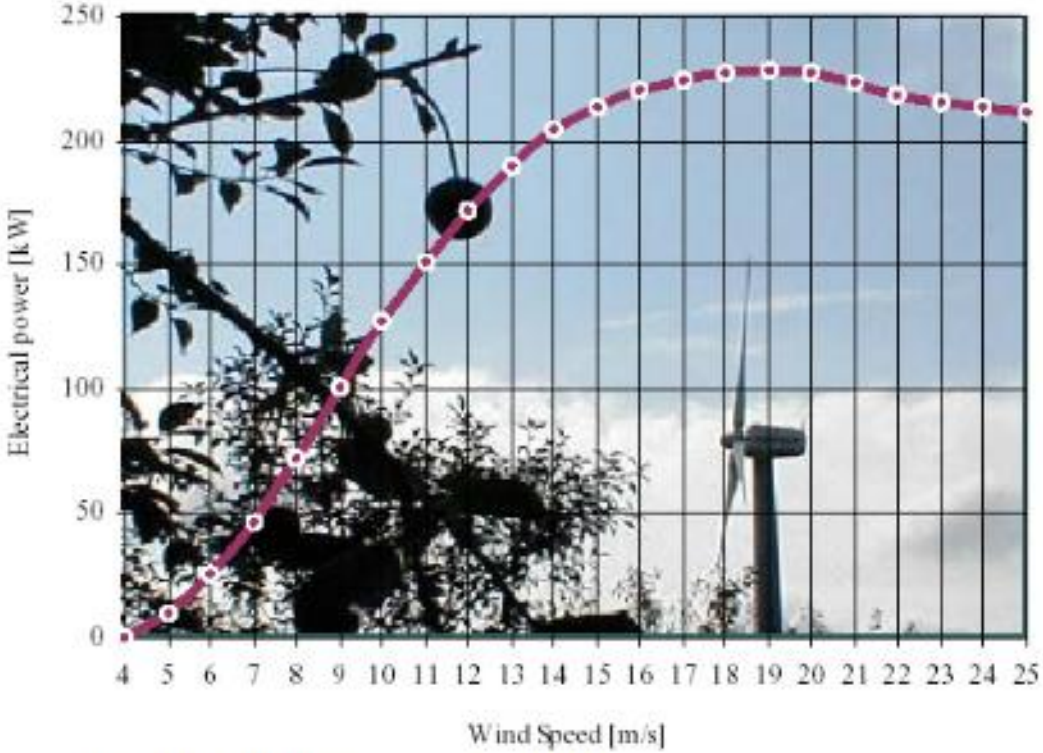


Fig. 3. Electrical power versus wind speed

Fig.7. Turbine image

Table 6. Energy yield

Turbine # 1	340 to 400 MWh/year
Turbine # 2	360 to 430 MWh/year
Turbine # 3	400 to 470 MWh/year

http://global.ctbuh.org/resources/papers/download/464-harnessing-energy-in-tall-buildings-bahrain-world-trade-center-and-beyond.pdf

Bapco 5 MW PV project was inaugurated in June 2014 and fully commissioned on 1st September 2014 and provides rich data on the performance of each smart solar panel in the array which is made available at Bapco (Bahrain) and Petra Solar Company(USA).

It was found that the actual generated solar electricity from PV systems in the four locations, in general, is less than the expected.

For, Refinery (2.892 MW) the actually produced solar electricity was 2,766 MWh and 3,563 MWh in 2015 and 2016, respectively, while the expected was 4,267 MW.

For UoB (0.518 MW) the actually produced solar electricity was 718MWh, 795 MWh and 711 MWh in 2014, 2015 and 2016, respectively, while the expected was 765 MWh.

For, Awali (1.59 MW) the actually produced solar electricity was 1,255 MWh and 1,869 MWh in 2015 and 2016 , respectively, while the expected was 2,346 MWh.

For, Sadeem house, or called the Transport building, (8.64 kW) the actually produced solar electricity is 15.6MWh and 28.1 MWh in 2015 and 2016, respectively, while the expected was 11MWh !?!

The panels' orientation are 225° from the north and have a tilt angle of 25° although the latitude of Bahrain is 26.13° N and latitude 50.8° E.

In fact, the whole project (5 MW) was expected to produce annually 8,000 MWh offsetting energy of 67,000 Mcf of natural gas and a savings of 6,900 metric tons of carbon dioxide emissions.

Reducing Bahrain Carbon Footprint

Conclusion

This 3 years operation of PV system indicates that in sizing the electricity output using PV in Bahrain lead us to conclude the following equation:

The actually obtained Solar electricity using PV system = Installed capacity of PV (in MW) x 365 (days) x 4 (hours of sunshine: minimum) to 5 (hours :maximum) in MWh

Note that the theoretical sunshine duration in Bahrain is 13.6 hrs (21 June) to 10.4 hrs (21 Dec). This means an annual average of 12 hrs! However, we have to use only 4 to 5 hrs for sizing the needed solar electricity.

It was also found that if PV panels were not cleaned regularly, the loss of solar electricity, in one year, will be from 9 to 11% while in certain dusty days will lose about 45%.