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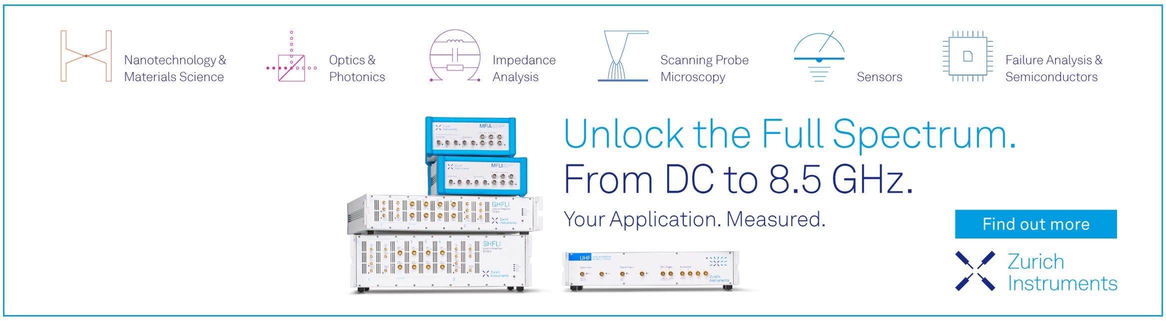

Shagaya Renewable Energy Park Project

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Abstract. The Kuwait Institute for Scientific Research (KISR) has developed Phase I of the innovative Shagaya Renewable Energy Park, which has an ambitious Master Plan to install approximately 3.2 GWe of renewable power as part of Kuwait's commitment to generate 15% renewable energy by 2030. This project, built on 84 km^2 in the desert location of Al-Shagaya, is approximately 100 km west of Kuwait City and comprises multiple renewable technologies as well as interconnection and site infrastructure. The Project objective is to enable the implementation of renewable alternatives to the use of fossil fuel resources to generate electricity in an effort to reduce emissions. The project evaluates the requirements of concentrated solar power (CSP), photovoltaic (PV) and wind energy technologies by testing how to address the challenges posed by the harsh Kuwaiti desert environment to these different technologies. WorleyParsons was appointed in 2014 as the Owner's Engineer and Project Management Consultant to support KISR with project implementation and contracting and oversight of the Design Build Operate (DBO) contractors through commissioning and the first 2 years of operation. The project has demonstrated that two of the technologies, PV and Wind, which have now been in operation over a year, have exceeded the generation predictions. The CSP plant is currently in the final stages of commissioning. This paper presents an overview of the project with a primary focus on the CSP plant, key Lessons Learned, and the concerted efforts required to meet clear HSE requirements. Also discussed more briefly are the wind farm and the PV plant given the increased trend to integrate CSP and PV technologies as synergistic generators or to offset auxiliary loads of the CSP plant.

BACKGROUND

The state of Kuwait is the 10th largest oil producer in the world with 2.792 million barrels per day (mbpd) produced in 2010, of which 1.394 mbpd were exported to rank Kuwait the 13th largest exporter of crude oil in the world (Kuwait, 2014). Kuwait is 6th in the world in terms of proven oil reserves with a total of 102 billion barrels of crude oil. Although Kuwait holds 63 trillion cubic feet of proven natural gas reserves, the country currently imports natural gas due to increased domestic consumption (EIA, 2013). Electricity is currently generated predominantly by oil and gas, and one of the objectives of the Renewable Energy program is to reduce the consumption of fossil fuels for electricity generation and the associated emissions by taking advantage of two other significant resources in the country: solar and wind energy.

The Kuwait Institute for Scientific Research (KISR) has developed the innovative Shagaya Renewable Energy Project, which constitutes the first phase (Phase I) of an ambitious Master Plan to generate approximately 3.2GW at the Shagaya Renewable Energy Park. Phase I sets the basis for future renewable energy developments in Kuwait

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through the installation of a 50 mega-watt (MW) Concentrated Solar Power (CSP) plant, a 10 MW Photovoltaic (PV) plant, and a 10 MW Wind Farm. The Kuwait Petroleum Corporation and its subsidiaries will contribute to achieving Kuwait's renewable energy goal by building Al-Dibdibah Project (Phase II of Al-Shagaya Park), which involves the construction of a PV plant that is expected to generate 3150 GWh/year through the full 25-year project lifetime. Phase III of the Shagaya Park is expected to combine CSP, PV and Wind projects, leading to an installed capacity of up to 3.2 GWe by 2030. The undertaking of Phase III is foreseen to be accomplished through a public-private partnership between the Kuwait Authority for Partnership Projects (KAPP) and successful bidders. In Table 2, Phases I and III are provided in the actual and estimated capacity, and Phase II as the stated objective that it generates 3150 GWh/year of energy in year 25 of the contract. The corresponding capacity will depend on the actual technology chosen for the park.

TABLE 1. Three Phases of the Shagaya Renewable Energy Park

Attribute	**Phase I**	**Phase II (Al-Dibdibah Project)**	**Phase III**
Technology	CSP + Wind + PV	PV	TBD
Power/Energy	50 MWe + 10 MWe + 10 MWe	3150 GWh/year	up to 3.2 GWe

The Phase I Engineering, Procurement and Construction (EPC) services and the first 6 years of the CSP and PV plant operation and maintenance (O&M) were awarded to the Spanish company TSK Electrónica y Electricidad under a Design, Build and Operate (DBO) contract. The EPC services and 6 years of O&M of the Wind Farm were awarded to a consortium between the Spanish company Elecnor and the Kuwaiti company AlGhanim. WorleyParsons was awarded the OE/PMC contract, executing the Owner's Engineering and Project Management role from the Madrid New Energy Center of Excellence and the PMC/Site Services role from WorleyParsons Kuwait.

The location of Phase I of the Shagaya Park shares an area of approximately 40 km^2 with Phase II, outlined in blue in FIGURE 1 The remainder of the site, outlined in red, will be occupied by future developments up to the total 84-km^2 surface area.

FIGURE 1. Shagaya Renewable Energy Park Phases I and II (blue) and Phase III (red)

Solar Resource Assessment in Kuwait

The solar resource inputs and the Typical Meteorological Year (TMY) file utilized in the solar generation model were based on the work reported in the Solar Resource Site Assessment report (Fichtner and GeoModel, 2013). The TMY data are P50 probability data, which indicate that for any given year there is a 50% probability that the solar resource meets or exceeds the expected value, and therefore represents the average or expected resource. More conservative estimates use P90 TMY data, for which during any given year there is a 90% chance that the solar resources will coincide with that of the TMY or better.

A SolarGIS solar time series of satellite-derived data covering a data period of 14 years (1994-2012) was used for the study. This time series was validated for representative sites in arid and semi-arid regions to determine data consistency with similar latitudes and geographical conditions. The estimated solar radiation uncertainty was supported by an analysis of aerosols, dust and humidity as the main controlling factors of solar radiation in the region. The solar resource data were used to estimate long-term monthly and annual statistics of Direct Normal Irradiation (DNI), the primary parameter of interest for designing and developing a generation model that provides the expected energy to be produced by a CSP plant, as listed in TABLE 2 and graphed in FIGURE 2. The Global Horizontal Irradiation (GHI) is the primary parameter for designing and estimating the energy generation of a PV plant. Long-term annual averages (P50 values) of these key parameters at the site are summarized as follows:

- Direct Normal Irradiation (DNI): 1982 kWh/m^2
- Global Horizontal Irradiation (GHI): 2089 kWh/m^2

TABLE 2. Monthly Statistics of DNI (reproduced from Fichtner and GeoModel, 2013)

	Daily DNI	Monthly DNI					
	Average (kWh/m^2)	Average (kWh/m^2)	Yearly share (%)	Minimum		Maximum	
				(kWh/m^2)	(%)	(kWh/m^2)	(%)
Jan	4.07	126	6.4	83	-34.1	167	32.4
Feb	4.43	125	6.3	90	-28.5	157	25.3
Mar	5.27	163	8.2	113	-30.5	201	22.9
Apr	4.39	132	6.6	98	-25.3	159	20.5
May	4.96	154	7.8	70	-54.4	191	24.1
Jun	7.06	212	10.7	155	-26.9	241	13.7
Jul	7.80	242	12.2	173	-28.5	275	13.6
Aug	7.39	229	11.6	162	-29.3	282	22.9
Sep	6.62	199	10.0	137	-30.8	229	15.5
Oct	5.28	164	8.3	116	-29.3	186	13.6
Nov	4.09	132	6.2	83	-32.8	188	53.0
Dec	3.67	114	5.7	68	-40.6	196	72.6
YEAR	**5.43**	**1982**	**100.0**	**1813**	**-8.5**	**2090**	**5.5**

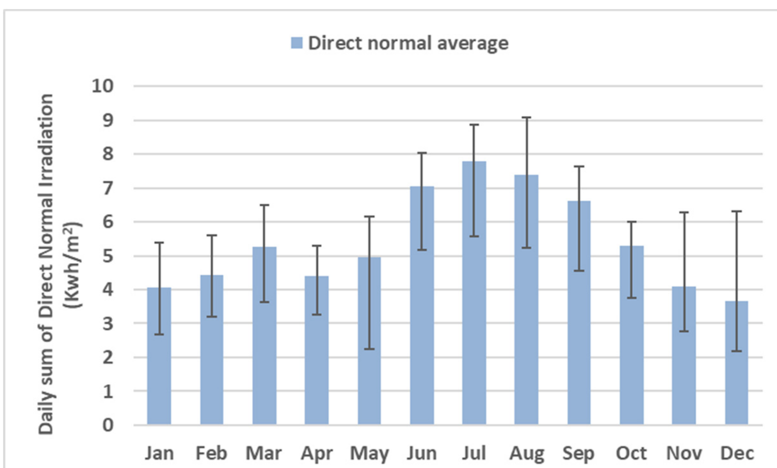

FIGURE 2. DNI**:** Monthly Statistics (reproduced from Fichtner and GeoModel, 2013). Error bars define daily minimum and maximum values calculated from monthly data.

Dust and Other Meteorological Conditions

The State of Kuwait is characterized by a desert-type environment with low and erratic precipitation, high evaporation rates and dry hot climate. Kuwait is classified as dry desert with intensely hot summers (May to September) and short, cool winters (November to March) with short transitional periods during April and October. The seasonal temperatures vary considerably, summer temperatures are extremely high, often above 45ºC in July and August, and winter temperatures during the day can be over 20ºC and fall to 3 or 4ºC during the night (Meteorological

Department, State of Kuwait). Dust and sand storms are extreme weather events that are common in Kuwait, and they frequently occur at the Shagaya Renewable Energy Park.

The park is located in a zone of high dust deposition rates, in the range of 350-500 T/km² as can be observed in FIGURE 3 (Ali M. Al-Dousari, 2014) Dust fallout characteristics within global dust storm major trajectories. Furthermore, Kuwait experiences about 128 hours of dust/sand storms per year, as well as 405 hours of suspended dust and 930 hours of haze. Dust storms can occur anytime of the year but they are most frequent during summer, and less frequently during autumn as shown in FIGURE 4 (Al-Dousari, Jassem Al-Awadhi 2012). Winds at the Shagaya site can reach a speed of 19 m/s (gust speed), which far exceeds the threshold shear velocity (~0.6 m/s) that is required to transport a particle of average size (0.4 - 2.0 mm diameter). During the spring season, the contribution of south-easterly wind increases, to match that of the north-westerly wind. This change is accompanied by a general increase in wind velocities. The maximum wind speed can reach 29.5 m/s, whilst the maximum reported gust speed has been recorded as 37.6 m/s (S. Neelamani, 2007). As has been mentioned, strong south-easterly winds can cause very severe dust storms that can impair visibility to a few metres. Sudden dust storms, common in April, are accompanied by thunderstorms, and dust from severe dust storms may create low visibilities in locations that are hundreds of kilometres distant from their point of origin. During the winter season, the main wind is north-westerly; although south-easterly winds can occur during a period of a few days in winter due to the effect of Mediterranean depressions.

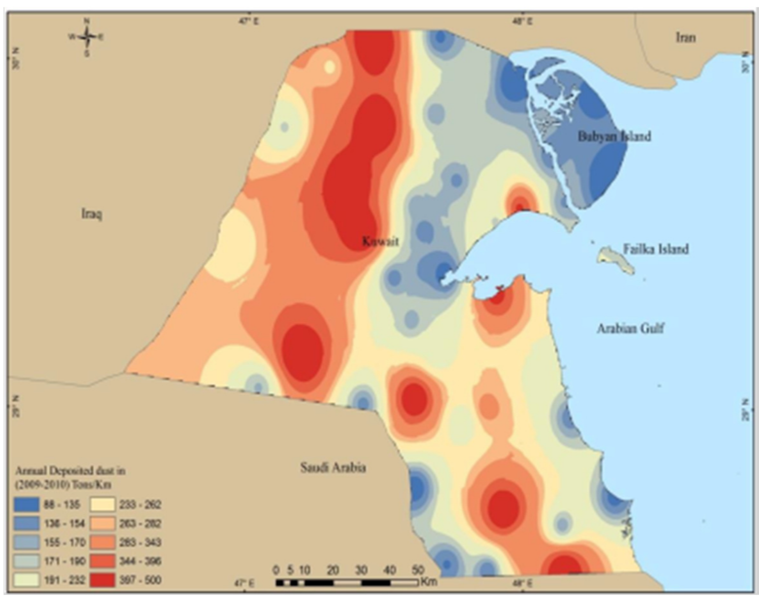

FIGURE 3. Dust Deposition rate

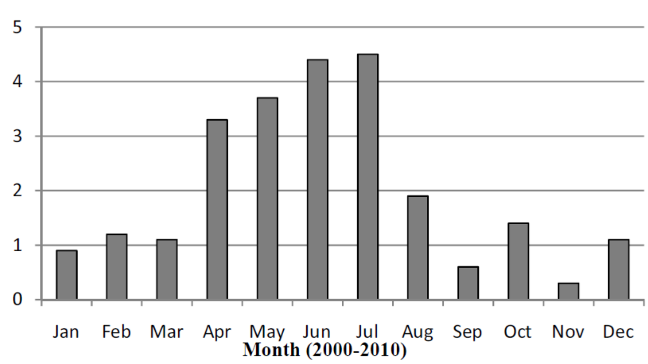

FIGURE 4. Monthly Average number of dust-storm days in Kuwait (2000-2010)

SHAGAYA RENEWABLE ENERGY PARK

KISR, owner of the project, is a governmental Research and Development (R&D) institute established in Kuwait in 1967. KISR launched its renewable energy program as a core part of its 7th strategic plan. The first phase of the Shagaya RE Park, developed by KISR, consists of six sub-projects as listed below:

- 50 MW dry-cooled CSP plant with 9 equivalent hours of TES and optional fossil-fuel backup for start-up
- 10 MW PV Plant using both thin-film and polycrystalline PV technologies
- 10 MW Wind Farm
- Shagaya substation, from which electricity is exported to the State of Kuwait national grid
- 32.5 km 132 kV overhead power transmission line to carry electricity to the national grid
- Shagaya site infrastructure and access roads

The Wind Farm and the CSP plant (see photo in FIGURE 5, below) are the first of their kind in Kuwait. The entire project serves as a technology test and regulatory benchmark in the country for these technologies, including the development of interconnection protocols and grid support for each. The outcomes from the Shagaya Project will provide the Ministry of Electricity and Water (MEW) and other authorities valuable data for the integration of renewable technologies in the Kuwait energy mix. In addition to helping reach the target of 15% of Kuwait's total expected power generation by 2030, the project will benefit Kuwait by developing specific in-country experience among Kuwaiti engineers and contractors, reducing emissions compared with existing fossil plants, and reducing liquid fossil fuel use, which can be more effectively utilized in downstream petrochemical industries.

This paper summarizes the implementation and learnings of the construction of an innovative concept that was developed by the Kuwait Institute for Scientific Research, of placing utility scale, tested technology into the quite harsh environment of the Kuwaiti desert. Part of the learnings of the project include the logistics and construction of the three different Renewable Energy technologies. The scale of the implementation allows for a representative assessment of the three technologies under high temperatures, high dust conditions, sand-storms, in the presence of variable amounts of humidity and aerosols, for later deployment of these technologies at the large scales at which plants of these technologies are currently being implemented. The project includes research and performance assessment of CSP, PV and Wind under local climate conditions, including humidity, high temperatures, and sandstorms (26 per year on average in Kuwait, which is much higher than in neighbouring states).

Shagaya Wind Farm

The Shagaya Wind Farm is connected to the Shagaya Renewable Energy Substation SGRE-A. Wind Farm has a total gross installed capacity of 10 MW and consists of five (5) wind turbines placed in one (1) row and connected in three (3) strings to the Substation at a Medium voltage level of 11 kV through an underground cable (TABLE 3).

TABLE 3. Technical Characteristics of the Shagaya Wind Farm

Characteristic	Technical Value
Turbines	Siemens-Gamesa G97
Rated Power per turbine	2 MWe
Tower height	78.98 metres
Rotor diameter	97 metres
Swept area	7,390 m^2
Number of blades	3
Blades length	47.5 metres
Gearbox	1 stage planetary /2 parallel

Shagaya PV Plant

For the Shagaya PV plant a fixed structure was selected and used for 5MW of poly-crystalline panels consisting of 920 strings of Crystalline-Silicon modules, in series of 20 modules, and 5MW of thin film panels that consisted of 4320 strings of Thin Film copper-indium-selenium modules, in series of 8 modules. Key design aspects are shown in TABLE 4 below.

TABLE 4. Technical Characteristics of the Shagaya PV Plant

Characteristic	**Technical Value**
Technology Type	Crystalline-Si and Thin Film
Contracted Gross Power Capacity	10 MWe
Total PV Installed Capacity	11142 kWp
Crystalline-Si module area	110000 m^2
Thin Film module area	45000 m^2
Crystalline-Si module power	305 Wp
Thin Film module power	160 Wp
Inverters	20 units
Transformers	10 units

Shagaya CSP Plant

The Shagaya CSP Plant comprises a solar field (based on parabolic trough technology), a power block with a rated gross electric capacity of 50 MWe, and molten salt TES with a useable thermal storage capacity of 1200 MWth, and it utilises the highest number of equivalent storage hours (more than 9) in the MENA region.

FIGURE 5. Shagaya 50MW CSP Plant

All project equipment is commercially-proven in design and operation, and the most up-to-date proven technologies have been selected to test standard practice in Kuwait conditions. The key design features for the CSP plant are summarized in TABLE 5 below.

TABLE 5. Technical Characteristics of the Shagaya CSP Plant

Characteristic	**Technical Value**
Technology Type	CSP Parabolic Trough
Contracted Gross Power Capacity	50 MWe
Minimum Net Annual Energy Generation Capability	170 GWhe/year
Usable thermal capacity of TES	1200 MWth
Number of collector loops	206
Aperture/Length of Solar Collector Assemblies (SCA)	5.77 m / 148.6 m

Significant benefits from Phase I of the Shagaya Park include the lessons learned from developing, designing, constructing, commissioning and operating the multi-technology plants, the understanding gained for future phases of the Park, and the experience that is applicable globally for developments in environments similar to those in the Kuwaiti desert

Although not the main focus of this paper, it is noteworthy that the currently operational PV plant has been exceeding generation expectations, and the high temperature and dust mitigation options at the Wind Farm are being tested to determine optimal settings and implementation at the site.

The Shagaya CSP Plant converts solar energy into electrical energy using a solar field made up of 206 loops, each loop comprising 48 solar collector elements (SCEs) that collect heat from the sun into the synthetic oil heat transfer fluid (HTF). The SCEs can heat the HTF from 295ºC to 393ºC with parabolic trough collectors (approximate net aperture area of 673,620 m^2). A TES system based on molten salt with 1200 MWth of thermal storage capacity is incorporated for thermal-unloading and power generation to extend the operation of the plant during low or non-radiation hours of the day. The thermal energy is delivered through a Steam Generation System (SGS), consisting of two 50% capacity steam generation trains, where steam is produced and then sent to a 50 MWe (gross) steam turbine and generator for electric power production.

The Shagaya CSP Plant connects to the Kuwaiti grid through underground cables to the 132 kV Shagaya substation (SGRE-A) and from there through a double circuit over-head line (OHL) to the existing 132 kV Shagaya A substation (SHAG-A), which is located 32.5 km east of the Shagaya Site. This configuration forms part of the existing MEW transmission system, which is dispatched by the Kuwait National Control Center (NCC). Both the SGRE-A substation and the 132 kV OHL are part of the Phase I project.

Shagaya Renewable Energy Park Environmental Challenge

The work that was conducted by KISR during project development on resource assessment suggested that the site would have an adequate resource for the implementation of the three technologies, and the results after more than a year of operation of the PV and Wind farms have exceeded forecasts. The CSP plant had passed all but one tests prior to COD in December 2018, and preliminary generation results are positive. For the fixed tilt, 10MW PV plant, two different panel technologies were tested, with installation of 5MW of thin film technology and 5MW of polycrystalline panels, to understand their performance under the Kuwait desert conditions. Dust and high temperature mitigation measures were implemented in the nacelle of the wind turbines, which is also a novel test that will help improve future windfarm installations in similar environments.

For PV plants, dust can cause a drop in system efficiency due to a drop in the wiring voltage and inverter efficiency. But more than in PV plants, wind farms are quite affected by the Shagaya Park environment. Operation at extreme temperature (low and high) conditions may have an impact on drive-train losses, damping, and pitch system response. The main design difference of the wind turbine for high temperature and dusty environments compared with the standard version is the cover which involves an improvement in the nacelle's cooling systems. In extremely dusty environments, each air inlet to the inside of the nacelle must be carefully designed to prevent damage to the elements that are housed inside the nacelle. The G97 turbine units are all equipped with both dust-desert and high temperature kit so dust protection is achieved by reducing the amount of dust that enters the nacelle in the connection between the blades and the hub, the hub and the nacelle and the openings for cooling the nacelle.

The dust phenomena explained before can severely impact the CSP plants in two ways: 1) suspended dust, dust storms and haze limit the amount of solar radiation that reaches the collectors, thus reducing the output as captured in the measured solar radiation data used in the modelling; and 2) dust that accumulates on the reflective surface and collectors reduces the amount of solar radiation that can be captured and therefore reduces the amount of energy that can be generated (as well as increases the cost of cleaning). This loss of captured solar radiation is calculated using an average soiling factor, which is a combination of the assumed frequency of cleaning and the soiling rate.

CSP Plant Project Delivery and OE/PMC Control

WorleyParsons joined the Shagaya Project on 20 August 2014 to provide KISR with OE/PMC services to ensure onsite safety, compliance with safety in design, international engineering codes and standards, and reasonable and independent assurance of contract compliance by the DBO contractors.

The presence of a Project Management Team in Kuwait was crucial to help manage onsite safety to ensure that the SGRE-A and OHL sub-projects did not cause delays to other subprojects and that construction followed the engineering developed by the contractors.

WorleyParsons and KISR held alignment sessions in Kuwait to define the key safety and project objectives that were common to other projects: No harm to people and assets; and on-time and on-budget delivery and plant commissioning.

When WorleyParsons joined the project, the SGRE-A and OHL subprojects had been signed, while the PV, CSP, Wind and infrastructure projects were in the Contract Negotiation Stage with the respective preferred Bidders. WorleyParsons supported KISR by providing technical inputs for those subprojects under negotiation and incorporated lessons learned from other projects so that specific requirements, especially in the areas of HSE and Risk Management, were included in the Contracts based on WorleyParsons' project-specific experience. This early involvement of the OE during Contract Negotiation resulted in positive inputs for the project.

During the first stages of the project, some of the Contractors and subcontractors were observed during construction to have poor HSE cultures with high risk practices, and some contracts failed to specifically mention HSE requirements to the extent desired by the project. WorleyParsons and KISR developed an Action Plan that included, but was not limited to, the following:

- Held HSE alignment sessions with the KISR team and Contractors and demonstrated HSE leadership to:
- Monitored HSE closely and followed-up by requesting Contractors to increase HSE supervision.
- Submitted formal warnings by the Owner about stopping field activities if HSE of a Contractor did not significantly improve.
- Prevented Construction works from commencing until the HSE Plan was approved.
- Imposed early enforcement (contractually) to comply with minimum HSE obligations (for those projects that were in the Contract Negotiation stage).

Shagaya CSP - Inception

The 6-year contract to Design, Build, Operate and Maintain the Shagaya 50 MW CSP Plant was officially signed between KISR and TSK on 15 September 2015 and included the provision of EPC and O&M services until 6 years after the Provisional Commercial Operations Date (PCOD). The project kick-off meeting, held amongst TSK, KISR and WorleyParsons in November 2015, defined the objectives of the project and obtained alignment on key aspects, including the scope of work, the execution plan, the schedule review, and the procurement plan. Additionally, an HSE session and a Risk Workshop were held to increase the HSE/Risk Management perception of all project stakeholders.

Shagaya CSP - Engineering

The engineering was developed according to industry practices applying methods and actions in accordance with good standards of prudence applicable to the international electricity generation industry. WorleyParsons was responsible for ensuring that the Project was designed and engineered in compliance with the specifications and other requirements specified in the DBO Contract.

KISR/WorleyParsons and TSK developed a common Master Deliverable Schedule during the KOM to register all project documentation and their submission dates. HAZOP sessions and design review meetings were held among KISR/WP and TSK for key engineering packages (e.g., P&IDs, PFDs, H&MB) that could delay further engineering efforts, resulting in positive outcomes for the project.

Another key aspect of the successful development of the engineering was the importance of common Project Plans, especially the adherence to document control protocols and tools for avoiding delays and inconsistencies in the transmittals from DBO Contractors.

Shagaya CSP - Procurement

All equipment and materials utilized in the Project were up-to-date technologies, i.e., of international quality standards and of proven design for the intended use. A list of approved subcontractors was included in the Contract to avoid extensive sub-contracting or inexperienced companies in the Country or Technology. If TSK decided to add additional suppliers, vendors and/or subcontractors, KISR had the right to confirm or deny the approval of any subcontractor. TSK also prepared a thorough Procurement Plan that was complemented with the Supplier and Subcontractor Approval Procedure developed by WorleyParsons, which described the general requirements with which any Subcontractor involved in the project must comply.

WorleyParsons monitored and ensured that inspections were undertaken by TSK according to the Contract and attended numerous shop inspections for key components of the Plant (e.g., steam turbine, heat exchangers, pumps). The results of the Factory Acceptance Tests (FAT) were satisfactory, and all manufacturers involved in the Shagaya CSP Project showed high quality standards during the procurement phase.

The main challenges faced during procurement included the lack of familiarity of the main contractor with local regulations to import material and equipment into the country and with the management of local contractors.

Shagaya CSP - Construction

The contractor for the earth works of the CSP plant was mobilised in January 2016, and several construction challenges were tackled by the Project Team for the first large-scale renewable energy project in Kuwait. Although the Shagaya Project was the first renewable energy project to be connected to the Kuwait Transmission System, a connection agreement was not in place when the project began, which led to the need for additional coordination between the utility (MEW) and the project developer (KISR), supported by its engineering representative (WorleyParsons) and the DBO Contractor (TSK).

Certain requirements were misaligned, such as the specifications and local utility standards. Essentially, the Kuwaiti interconnection codes had not yet included certain key technical requirements specifically associated with renewable energy generators.

Other challenges during construction were posed by the remoteness of the site, delays during earthworks due to the soil conditions and encountering unexploded ordnance, and meteorological conditions (high temperatures during summer and sand storms). Concrete suppliers were located at significant distances from the plant, which led to delays in the supply of concrete and some quality issues. The installation of a temporary concrete plant located near the Project was not deemed necessary by the contractor. During construction planning and the first stages of construction, it is paramount that the supplies of concrete and water to the site are guaranteed.

Important efforts were made by KISR, WorleyParsons and TSK to improve the HSE standards of the on-site subcontractors, including intensive HSE training with subcontractors and weekly HSE walk-downs on site to jointly supervise the progress. A lesson learned was that intense HSE supervision of the local subcontractors was required.

Shagaya CSP - Commissioning, Operation and Maintenance

WorleyParsons, as OE of the Shagaya Project, developed several activities during the Commissioning phase, including review and approval of all commissioning and testing procedures, functional systems descriptions, and O&M Manuals. Key elements of WorleyParsons' role included walk-downs for each system as it was transferred from construction to the commissioning team, developing the final punch list, and attendance at all key equipment commissioning and functional tests. WorleyParsons specifically attended all mechanical, electrical and I&C tests for the commissioning of the HTF systems, the steam generation systems, and the TES systems, as well as the steam turbine and generator. WorleyParsons was also present during plant synchronization on 20 May 2018.

Tests that are standard in the industry, listed in TABLE 6 were conducted as part of the Commissioning process.

TABLE 6. Tests Completed for Shagaya CSP Plant Commissioning

Test Completed for Commissioning
Cold and Hot commissioning systems
Functional commissioning test
Exhaust gas quality at back-up firing stack outlet test
Maximum noise pressure level test
Usable thermal storage capacity of TES test
TES Charging capability at maximum charging load test
Total net power capacity of the plant at operation test (Solar only mode and TES discharge only mode)
Provisional net generation capability test of the plant
Reliability test run
Performance testing
Seasonal performance test
PAC (Provisional Acceptance Certificate)
FAC (Final Acceptance Certificate)

Commissioning challenges that were specific to the location were due to meteorological conditions (elevated temperatures, high wind speeds and associated dust and sandstorms) and reduced irradiation (combination of aerosols, dust and humidity). During high winds and dust storms, it was necessary to move the solar collectors to the stow position, which resulted in longer periods of time than expected before the plant could reach the required generation conditions to complete the tests.

CONCLUSIONS

Kuwait is a country rich in natural resources. In recent history, this primarily implied the exploration and production of abundant hydrocarbon resources. Kuwait also has tremendous wealth of renewable natural resources that include wind and solar energy, and the Shagaya project is the first focused step towards exploiting this resource for the broader benefit of Kuwait.

KISR developed the first Phase of Al Shagaya Renewable Energy Park, after completing studies of the solar and wind resources, which comprised the construction of a 50 MW CSP plant, a 10 MW PV plant and a 10 MW Wind Farm. This paper describes the project background and the approaches taken for the successful implementation of Phase 1 of Al Shagaya and the lessons learned from the perspective of the Owner's Engineer and the Project Management consultant, culminating in the following conclusions:

- What is unique about this project is the testing of proven technology under the harsh Kuwaiti desert conditions, and the transition these technologies provide the State of Kuwait from fossil resources to two ample and renewable resources in the country, wind and solar energy, enabling the utilization of fossil resources to applications with added value rather than combusting hydrocarbons for electricity generation.
- Kuwait has good wind and solar resources which have resulted in higher than expected generation from the Phase I PV and Wind plants and testing of high temperature and dust mitigation options for the Wind Farm is ongoing.

- Phase I of the Shagaya Project is a technology and regulatory benchmark for the country, has enabled the development of interconnection protocols for CSP, PV and Wind energy technologies, and produced valuable data for the integration of these technologies into the Kuwaiti energy mix.
- Lessons Learned from the grid integration of the renewable energy generators will be useful for future phases of the Shagaya Park.
- Performance of these three technologies has been tested in the harsh Kuwaiti environment, which includes dust, aerosols, high temperatures and sand and dust storms. The impact of the environmental conditions on the different technologies has been described at a high level.
- Phase 1 of the Shagaya Park sets the first material contribution toward helping reach the target of 15% of Kuwait's total expected power generation by 2030 with the additional benefit of developing in-country experience and capabilities.
- This first step contributes to and sets the path for reduced emissions compared with existing fossil fuel plants and reduced utilization of liquid fossil fuel, which can be more effectively utilized in downstream petrochemical industries.
- The CSP plant has 9 hours of Thermal Energy Storage (1200 MWth), which currently is the highest number of equivalent storage hours in the MENA region for a single plant.
- Safety alignment sessions and diligence in the implementation of HSE norms led to improvements in overall safety on site, including along the access road.
- Lessons learned from developing, designing, constructing, commissioning and operating the multiple technology plants of Phase I provide excellent input to future phases of the Shagaya Park and are applicable to other developments under similar conditions.

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