Indian Queens power facility

Tucked away in the Cornish countryside at the southwest tip of England is a gas turbine plant that is capable of peak lopping and synchronous compensation. This is the story of Indian Queens.

The Indian Queens Power Facility, based on a Model 9E gas turbine, will provide synchronous compensation and peak power generation services at the western extremity of the UK National Grid Company's (NGC) distribution system in the county of Cornwall.

The concept of installing a gas turbine with a declutchable generator adjacent to an electrical grid system has been carried out by John Brown at 20 sites worldwide.

Above:
Construction work begins at the Indian Queens 400kV power facility on the southwest peninsula of England

For this reason, John Brown were selected to review and participate in the early stages of plant design and project feasibility.

The project was developed by Destec Energy, Inc., a Houston USA based independent power developer, who were interested in expanding into Europe. Destec identified the need for a reliable contractor to build the facility and selected John Brown from a number of international bidders. The plant design is based around the technical requirements of NGC who have contracted with Destec to buy the plant's reactive power (180MVAr lagging, 75MVAr leading). At times of peak demand the plant will generate up to 140MW.

The plant is located in an environmentally sensitive rural area, near the village of Indian Queens, and was the subject of environmental impact studies prior to planning consent. It is also subject to environmental monitoring programs before, during and after construction and has strict noise and emissions levels to meet.

The turnkey construction contract was awarded to JBE in April 1995, with commercial operation scheduled by December 1996.

Plant operation

NGC owns and operates the 400kV and 275kV 50Hz AC Transmission System

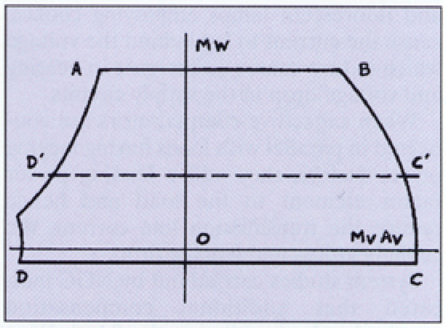
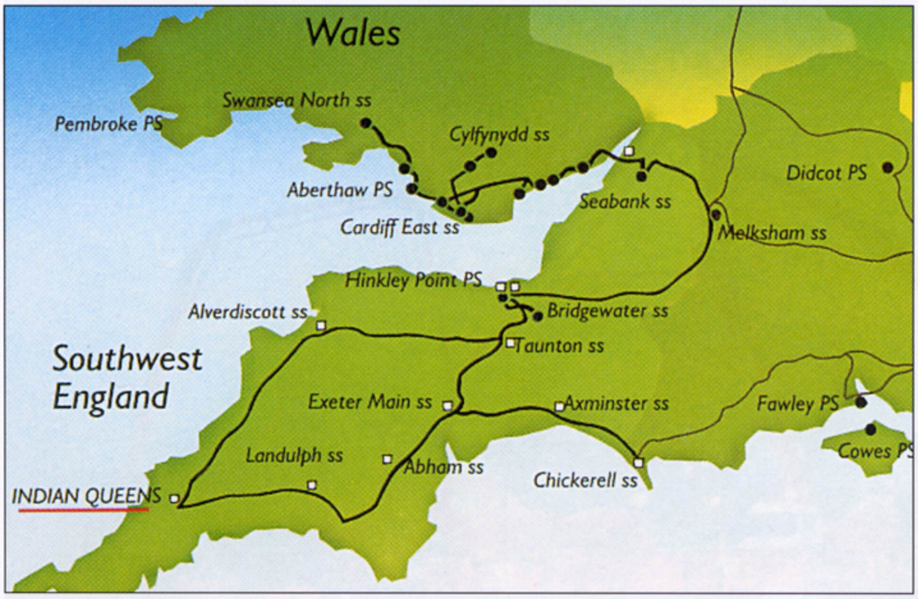


Fig 1: Generator capability diagram.
A gas-turbine generator can produce both active and reactive power.



Indian Queens 400kV substation is at the end of twin transmission circuits with the nearest generating facility Hinkley Point, 100 miles away. National Grid Company owns and operates the 400kV and 27SkV, SOHz system.

serving England and Wales. The NGC system takes in electrical power from the power station operators at discrete points on the system and distributes it, principally through interconnected overhead transmission lines to substations where ownership and responsibility for local distribution is passed on to the Regional Electricity Companies (REC's). NGC has a statutory responsibility to provide power at the substations within specific limits of voltage and frequency.

The map shows the NGC 400kV Substation at Indian Queens lies at the western extremity of NGC's network. It is supplied by two twin circuit 400kV transmission lines which approach along the North and South coasts of the SW peninsular. The nearest power station is a nuclear facility at Hinkley Point some 100 miles away on the Northern circuit. Power stations on the Southern circuit are even more remote, the nearest being Fawley (oil), Didcot (coal + future CCGT) and Dungeness (nuclear). To provide adequate voltage regulation to the South West area and to reduce transmission losses, NGC operates a number of capacitive compensators at various 400kV substations along the South Coast. Highly inductive loads, such as induction motors, transformers, and fluorescent lamps employing chokes, cause the current to lag behind the voltage which in turn causes an increase in heating and voltage drop in the supply circuits.

When capacitive compensators are connected in parallel with loads having lagging power factors, they add a leading power factor element to the load and hence reduce the transmission line current, the cable heat loss and voltage drop.

System studies carried out by NGC indicated that additional compensation required to be installed in the South West area by the end of 1996. NGC also identified that an appropriately sized generation facility in the area could serve in place of this reactive compensation.

The requirement for providing both compensation and power generation can be met by installing a declutchable gasturbine generator. When driven by the gas turbine the generator can be controlled to produce active (MOO) and reactive (MVAr) power at any point within the characteristic (Fig 1) bounded by:

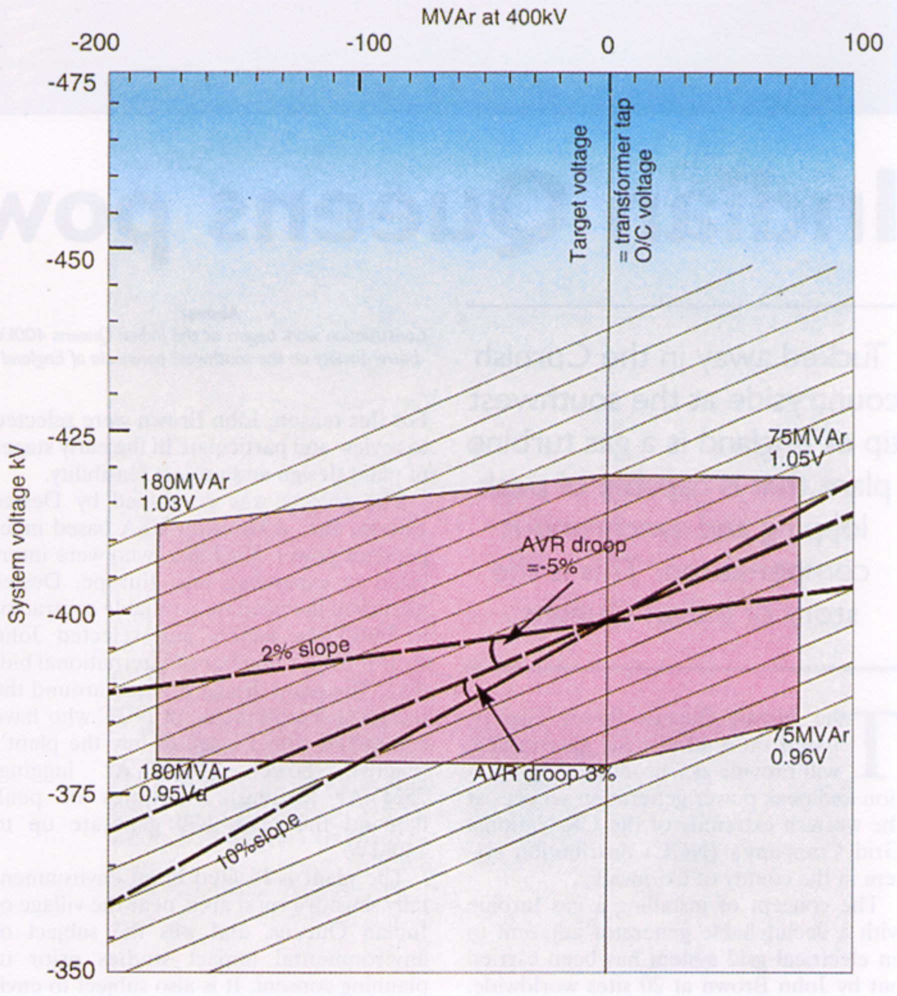
- *AB Turbine Power Limit*
- *CD Minimum Controllable GT power Limit*
- *BC Generator Thermal Limit*
- *AD System Stability Limit*

When running at synchronous speed but Jeclutched from the gas turbine, the gencrator can be controlled to produce reactive power (MVAr) along the line DC. The generator is in effect operating as an unloaded motor, drawing active power from the supply system to balance the Losses in the generator.

A decision taken early in the development was to separate the starting systems Lor power generation and compensation ,o that the high number of compensator starts envisaged did not use up operating hours on the gas turbine. This gave a distinct advantage to hot-end drive (Frame9E) technology, as separate motor starting (GT Generator start) and static start (Compensator start) could be used.

The main premise of the NGC performance requirement is that the performance and control of the synchronous

Fig 2: *The Indian Queens Synchronous Compressor*



compensator is identical, as far as practical, to the Static Compensator equipment operated by NGC.

The main features of the performance specification and their implications for system design are summarised as follows:

- *Compensator rating*

The requirement to produce/absorb 180MVAr/75MVAr at 400kV and at 30°C is slightly in excess of the 150/75MVAr rating provided by NGC's standard size of static compensator. In achieving this rating, due account was taken of the step-up transformer which effectively absorbs a proportion of the reactive power produced by the generator.

- *Extreme system conditions*

The compensator must remain in service for system voltage depressions down to 40 per cent of normal to assist system recovery. To achieve this, the compensator auxiliaries (lube oil pumps, cooling fans etc), as well as the excitation system, must remain in operation through the voltage dip. A rotary AC Uninterruptable Power Supply (UPS) is provided to supply critical loads (330kVA) for 15 minutes.

- *Control modes*

The plant can be operated and/or supervised from a number of remote locations via telephone lines. Flexibility has been built in to allow the physical locations and the remote functionality to change as the need arises.

The system is to be capable of operating in several modes other than normal active power generation. Each of the modes is selectable and controllable from a remote position, and includes:

(i) Target Voltage Mode

In this mode the compensator operates along a line characteristic as a function of Grid Voltage as shown in Fig 2, the target voltage being defined as the Grid Voltage requiring no reactive compensation. The value of the target voltage is adjusted by a combination of transformer tap-setting and AVR set-point adjustment. The slope of the line can be adjusted by the automatic voltage regulator droop setting.

(ii) Constant MVAr Mode

This brings the system back to a constant steady state MVAr output independent of Grid Voltage.

(iii) Transition between MW and MVAr operation

During the transition between reactive and active power generation and visa versa, the control logic had to be "Bumpless". For this reason, the hot end drive design of equipment was better suited to the Indian Queens application.

Above: *Part of the Delimara Power Station in Malta, built and commissioned last year byJohn Brown Engineering, which has two declutchable Frame 6 gas turbine generators allowing both for power generation and synchronous compensation.*

(iv) Target Frequency

This sets a target frequency, as determined by NGC, should the gas turbine generator be called upon in a grid frequency supporting role.

Mechanical systems

The site layout was designed to allow for the possibility of unmanned operation whilst allowing access to a local oil company for fuel deliveries. The equipment layout was largely dictated by the position of the tie-in point with the existing 400kv switchyard. The main train comprises a MS9171E gas turbine coupled through a synchronous self-shifting (SSS) clutch to a filter ventilated generator of GE Elin manufacture. The gas turbine is designed to run on distillate oil only with a projected generation time of four hours daily for four main winter months. A freestanding acoustic enclosure has been provided around both the gas turbine and the generator to meet the low noise level requirement. Additional silencing has also been incorporated into the air inlet and exhaust systems.

For the majority of the time the generator will run in synchronous compensation mode and the auxiliary systems are designed to allow for this. In particular the generator has a separate lubrication oil skid, and the gas turbine and generator

Figure 3: *Sending end and receiving end phasor diagram **without** capadtor compensator*

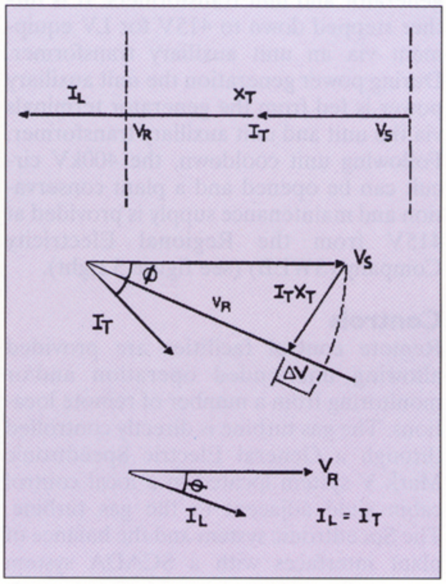
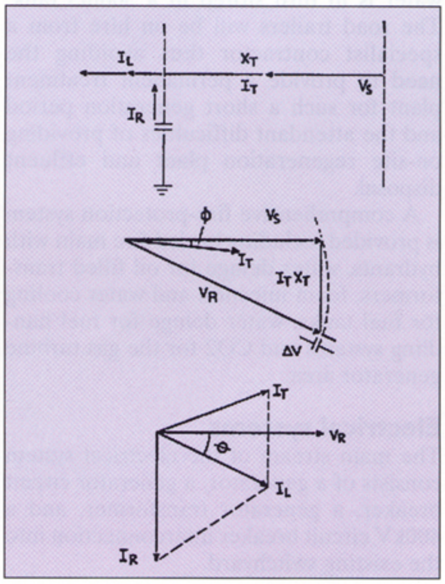
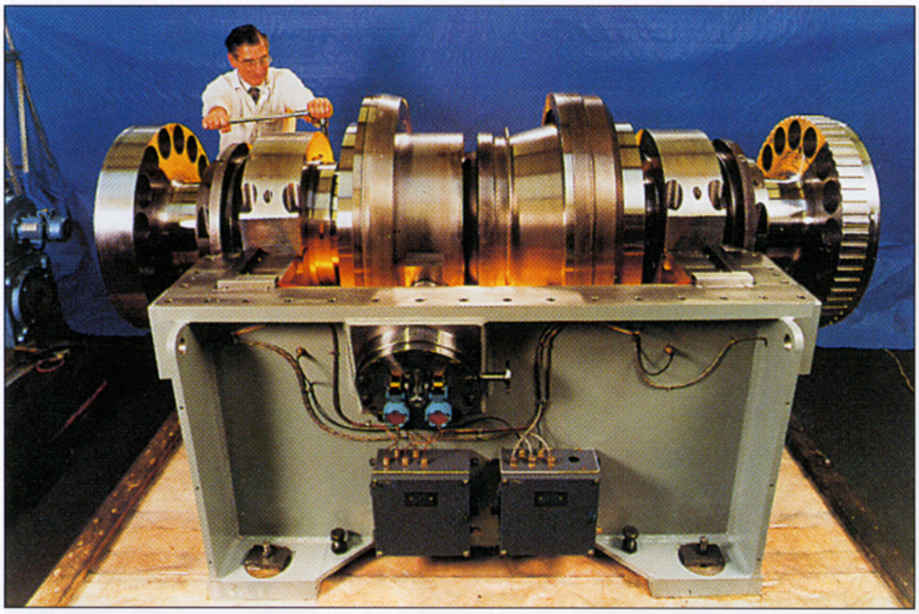


Figure 4: *Sending end and receiving end phasor diagram **with** capacitor compensator*





Above: *An SSS clutch similar to the one that will be used at Indian Queens. It will make a direct connection between the shafts of the Frame 9E gas turbine and the generator.*

each have a finfan cooler for their respective oil systems. The generator is provided with a variable speed starting-system so that it can be started and synchronised to the grid independently of the gas turbine which minimises the number of gas turbine starts. Two 1000m3 distillate fueltanks have been provided within a bunded area, to give a total of forty-eight hours generation operation without replenishment. Road tanker unloading facilities and fuel forwarding pumps are installed adjacent to the tanks.

Facilities are included to receive and hookup a trailer-mounted water demineralisation plant to provide quality water for injection into the turbine for NOx reduction. Raw water for the dual purposes of fire protection and demineralisation is stored in a further 1000m3 tank. The tank design allows a guaranteed 520m3 for fire fighting at all times. The demineralised water is in turn stored in a 300m3 tank. The road trailers will be on hire from a specialist contractor thus avoiding the need to provide a permanent treatment plant for such a short generation period and the attendant difficulties of providing on-site regeneration plant and effluent disposal.

A comprehensive fire-protection system is provided including buried fire main with hydrants, water deluge for oil filled transformers, foam injection and water cooling for fuel tanks, water deluge for fuel handling systems and CO2 for the gas turbine generator area.

Electrical systems

The main stream of the electrical system consists of a generator, a generator circuit breaker, a generator transformer, and a 400kV circuit breaker interconnection into the existing switchyard.

The generator terminal voltage is 15.75kV which is stepped up by the generator transformer to 400kV.

The connections between the generator, the generator circuit breaker and the generator step up transformer, together with associated tee-offs to the voltage transformer cubicle and a unit transformer, are made in isolated phase busducting.

The 400kV circuit comprises open terminal type switchgear including a circuit breaker, isolator, earth switch, current and voltage transformers and a lightning arrestor. The connections between the generator transformer and the connection point in the existing switchyard are made by overhead busbars.

Comprehensive protection of the unit is provided for the generator, generator transformer and the 400kV circuit.

Synchronisation of the unit takes place via the generator circuit breaker.

The unit auxiliary power is fed from the 400kV circuit during starting and synchronous condenser operation and is stepped down to 6.6kV for MV equipment via the generator and unit transformers. It is further stepped down to 415V for LV equipment via an unit auxiliary transformer. During power generation the unit auxiliary power is fed from the generator terminals via the unit and unit auxiliary transformer. Following unit cooldown, the 400kV circuit can be opened and a plant conservation and maintenance supply is provided at 415V from the Regional Electricity Company (SWEB) (see figure 5 right).

Controls

Remote control facilities are provided allowing unattended operation and/or monitoring from a number of remote locations. The gas turbine is directly controlled through a General Electric Speedtronic Mark V system located in a local control cabin sited adjacent to the gas turbine. The Speedtronic system and the balance of plant interfaces with a SCADA system within the cabin. The SCADA in turn utilises REMOTE FIX DMACS software and provides a single operator interface with the entire plant both locally and remotely.

Project implementation

The role of the Turnkey Contractor is one of overall responsibility, encompassing design and engineering, procurement, shipping, site installation and commissioning up to, and beyond, the point of handover to the client. It also includes the overall planning and coordination activities and extends to include the management of the Warranty activities in the first year of plant operation.

In the design and engineering phase, due cognisance of the operation and maintenance needs must be considered and taken into account. As Engineers and Contractors in the power industry for over 25 years, the role of the Main Contractor is well practised and understood by John Brown Engineering. The management and engineering of its projects is undertaken by a dedicated Project Team, located at the company's headquarters at Clydebank, near Glasgow, Scotland.

All systems and equipment within the plant are designed or specified, procured and managed by the Project Team, whose responsibilities encompass planning, cost control, quality control, site management, and the wide range of activities necessary on a Synchronous Compensation and Peak Power facility such as Indian Queens. □

***Fig 5:** System Line diagram*