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AFGHANISTAN

ENGINEERING SUPPORT PROGRAM

KABUL 100MW POWER PLANT HFO AUDIT

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Tetra Tech

Kabul 100MW Power Plant

HFO Audit

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EXECUTIVE SUMMARY

The Special Inspector General – Afghanistan Reconstruction (SIGAR) in its report dated January 20, 2010, reported on the delays and cost overruns that have arisen during the construction of the 100MW diesel/heavy fuel oil power plant at Tarakhil, Kabul.

SIGAR recommended as follows:

To help ensure the long term sustainability of the Kabul Power Plant, SIGAR recommends that the USAID Mission Director in Afghanistan produces a definitive study on the technical feasibility and advisability of using heavy fuel in the Kabul Power Plant and factor this information into plant completion decisions and any decisions regarding post-construction use of heavy fuel oil by the GIRoA.

POWER Engineers was asked by Tetra Tech to assess the technical feasibility and advisability of using heavy fuel oil in the Kabul Power Plant.

This report finds that the plant is technically capable of operating on heavy fuel oil: the plant used is designed for this fuel and there is a long history of similar plant operating successfully. Provided that a supply of fuel can be secured, and assuming that the plant can be run at full load, fuel cost savings of some $27 million per year can be expected when compared to the same operating duty using diesel oil.

Preliminary indications are that adequate supplies of heavy and light fuel oils can be secured.

However, using heavy fuel oil will impose a larger burden on operations and maintenance compared to similar operation on diesel oil, and there will inevitably be a penalty in terms of plant availability. Staff training will be more arduous – and personnel experienced in running this type or similar types of plant are of course not readily available in Afghanistan.

Furthermore we understand that there is insufficient load on the local electricity system to enable the plant to reach full load and this is likely to continue for several years. If the maximum plant load is only 20% of its capacity then the fuel savings will be correspondingly lower.

Recommendations

We recommend that the plant is operated on heavy fuel oil in the medium to long term in order to take advantage of the significant fuel cost savings available. However, in view of the current lack of load and the shortage of skilled staff, we recommend that in the short term the plant is completed, commissioned and operated firstly on diesel fuel. We recommend that this is facilitated by a two-phase completion and commissioning program as follows.

The first phase would be to bring the plant into full operation on diesel fuel, and equipment not required for diesel fuel operation should be sealed and preserved until the second phase of commissioning. The exception to this is the heavy fuel storage tank shells, the construction of which should be completed now.

Staff training can be focused on diesel fuel operation only, which will more quickly bring about the situation where locally employed staff can take on responsible roles in operating the station.

We then recommend that a second phase of commissioning be performed when the available load and the staff capabilities permit the plant's heavy fuel oil capability to be brought into operation.

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1. Introduction

The power station under construction at Tarakhil, Kabul, Afghanistan, comprises 18 medium-speed heavy fuel diesel engines, model 16CM32C, supplied by Caterpillar from their facility in Germany which was formerly MaK. These engines are typical for the application, and though as many as 18 units in one power plant is not common, it is not unreasonable.

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As a result, POWER Engineers was asked by Tetra Tech to assess the technical feasibility and advisability of using heavy fuel oil in the Kabul Power Plant.

POWER Engineers' scope is as follows:

a) Provide an overview describing the reasons for using heavy fuel oil and the extent of its use in plant similar to the Kabul Power Plant.

b) Describe the technical challenges and requirements for operating the plant on heavy fuel oil as opposed to operating on diesel fuel oil.

c) Review the existing design drawings and data, in order to determine what modifications would be required if a change to operate on diesel fuel only were required.

d) Describe the likely differences in staffing levels and training requirements for operating the plant on heavy fuel as opposed to operating on diesel fuel oil.

e) Report on the availability and price of both heavy fuel and diesel fuel oil in Kabul, taking into consideration the likely supply routes and security of supply.

2. Note on Terminology used in this Report.

To avoid ambiguity, the meanings of certain terms are described below. These are all consistent with normal practice in the diesel / heavy fuel engine field.

Diesel engine: any reciprocating piston engine that operates on the compression ignition cycle, whereby the heat generated by compressing air in the engine's cylinders causes liquid fuel, when injected into the hot air in a fine spray, to ignite. No spark plugs or other sources of energy are used. The term “diesel engine” does not imply any particular fuel: the diesel engine was named for its inventor, Dr. Rudolph Diesel, and diesel fuel was developed for it.

Compression ignition engine: this term is completely interchangeable with “diesel engine”.

Medium speed: this is not a tightly defined term, but refers to engines operating at speeds of between typically 400 rpm and 1000 rpm, usually using the four-stroke cycle. The engines in question for this report fall into this category. (Other categories are “high-speed”, which refers to engines operating at speeds above 1000 rpm, and “low-speed” which operate below 400 rpm and usually use the two-stroke cycle. High-speed engines are generally not suitable for HFO operation; most low-speed engines operate on HFO.)

Heavy fuel oil or HFO: this is the fuel primarily used in medium (and low) speed engines *(q.v.)* in the vast majority of marine and land-based applications.

Distillate fuel / diesel oil / light diesel oil: these terms are interchangeable.

3. Overview of HFO Usage

3.1 What is Heavy Fuel Oil?

When crude oil is refined the lighter fractions are extracted to produce petrol, diesel oil (gas oil), medium grade fuels, lubricating oils, etc., leaving a heavy, viscous, black fluid that typically does not pour at room temperature and is difficult to burn. This “residual oil” is the main constituent of commercial heavy fuel oil (HFO).

For commercial use, residual oil is blended with lighter oils in order to achieve consistent combustion qualities, viscosity, pour point and contaminant levels. It is commonly available today in several grades, broadly differentiated by viscosity at a nominal temperature, generally 50°C.

HFO tends to contain higher levels of ash, sulphur, sodium and vanadium than the more refined fuels, as well as water and sometimes solids such as catalytic fines, dust and even sand, depending on the source and refining process. All of these are undesirable and present challenges to the engine builder.

3.2 Why Use Heavy Fuel Oil?

The 1973 oil crisis prompted the oil-dependent developed countries to look at how their growth in oil consumption could be constrained, leading to improvements in the efficiency of oil consuming equipment and to maximizing the use of the lower-value products of crude oil.

In particular, the manufacturers of reciprocating compression ignition engines, i.e. diesel engines, began to develop their engines to operate on increasingly heavy fuels in order to offer lower cost operation, especially to the marine world’s merchant fleet.

Nowadays the vast majority of merchant ships operate on HFO, as does the vast majority of the larger diesel engines used for power generation on land. The requirement of the marine industry to reduce emissions of sulphur, which is always present to some degree in the HFO it uses, has pushed up the price of HFO but nevertheless HFO purchased in bulk today is typically some 30% less costly than diesel oil.

A 100MW diesel power plant operating at full load will consume some 150,000 tonnes of fuel per year. Using today’s typical market prices[1] for marine fuel available at the major world ports, this quantity of HFO would cost $70 million. To use diesel oil instead would cost $97 million. Fuel at site is likely to be more costly because of the need to transport it considerable distances by road tanker.

So essentially, HFO is used because it is cheaper than diesel oil, and nowadays the problems faced by the users have been overcome to the extent that the availability of a power plant operating on HFO is not far behind a similar plant operating on diesel.

[1] February 22, 2010. Singapore bunker fuel prices: Marine Gas Oil $647/mt; IFO380 (HFO) $468/mt

4. Technical Issues in Using HFO

4.1 Introduction

The use of HFO in diesel engines presents a number of challenges to the designers of engines and ancillary systems. These challenges have been met over the last 30 years or more to the extent that virtually all commercially available medium speed diesel engines today are essentially heavy fuel oil engines. This means that HFO engines are the normal standard design for today's diesel engines, and HFO capability is not provided by additional or non-standard features.

The fuel specifications for diesel and HFO provided by the engine manufacturer for the Kabul plant are typical of fuel specification used worldwide.

4.2 Fuel Viscosity

Light diesel oil has a viscosity of less than 10cSt at 50°C (122°F), whereas commercial HFO for applications such as the Kabul power plant is available in several standard grades with viscosities of up to 700cSt at 50°C.

Fuel is injected into the engine's combustion chambers through extremely fine spray nozzles at high pressures, and in order to achieve this with HFO its viscosity is reduced to some 10 to 20cSt by raising the temperature. The temperature of the fuel at the injection pumps is typically close to 160°C (320°F). In order to achieve and maintain this fuel temperature, not only does the fuel have to pass over heating elements – heated by electricity, steam or thermal oil – but all the storage tanks and all the HFO pipes must be heated and lagged for thermal insulation.

4.3 Fuel Contaminants

The different undesirable contaminants of HFO are dealt with in different ways.

a) Water and Sludge

Water and the heaviest residual elements are removed by passing the fuel through a centrifuge plant. Though the bulk density of HFO at room temperature is often greater than that of water, as the temperature is raised the density of oil falls more quickly than that of water, and when the point is reached that the oil is lighter than water, the water can be removed in a centrifuge. As well as removing water, the heaviest one or two percent of the fuel, comprising waxy and tar-like compounds, will also be removed, thus improving the fuel's injection qualities.

All HFO diesel engine installations include centrifuge equipment to clean the fuel. This results in a cleaner and less contaminated fuel, but also a sludge waste product which must be disposed of. Sometimes the sludge is burned at site with a dedicated sludge burning furnace, and sometimes it is removed from site by a specialist contractor for disposal elsewhere.

b) Catalytic Fines

These are oxides of aluminum and silicon, used to improve the yield of lighter oils in the refining process. Traces can remain in residual oils. The fines are very fine particles but they are very hard and can lead to accelerated wear of fuel injection equipment, pistons, piston rings and cylinder liners, leading to poor fuel combustion and excessive lubricating oil consumption.

Fuel specifications usually limit the quantity of fines permitted, but it is still in the interest of the plant operator to remove as much as possible. The centrifuge plant used to remove water and sludge will also remove a large proportion of catalytic fines together with rust and sand that may also be present.

c) Sodium

HFO generally contains a small amount of sodium, originating from geological salt and sea water contamination. A high level of sodium will give rise to post-combustion deposits in the engine's turbochargers, which can normally be removed by water washing. If sodium is present at high levels, the fuel treatment process sometimes includes mixing small quantities of fresh water to the fuel to dissolve the sodium salts, prior to removal in the centrifuge plant.

d) Vanadium

Vanadium is a metal present in all crude oils in an oil-soluble form. The levels found in residual fuels depend mainly on the crude oil source, with those from Venezuela and Mexico having the highest levels. The actual level is also related to the concentrating effect of the refinery processes used in the production of the residual fuel. There is no economic process for removing vanadium from oil.

Vanadium and sodium in combination can result in high temperature corrosion damage to valve and turbocharger components. As well as minimizing the sodium in the fuel, engine designers have mitigated the corrosion problem with appropriate choices of materials on exhaust valves and exhaust valve seats.

4.4 HFO Handling

The biggest single difficulty in handling HFO is its viscosity. Commercial HFO will have a pour point of typically 30°C (86°F) or more.

This means that delivery tankers must be thermally lagged and fitted with heaters; storage tanks must also be lagged and heated. All piping must be lagged and trace heated, and each engine is arranged so that on-engine piping and the fuel injection equipment can be flushed with diesel oil before the engine is shut down and allowed to cool.

To provide adequate heating for the HFO consumes energy. In the Kabul power plant, most of the heat energy is provided via hot thermal oil, which is heated by the engines' exhaust gases. Thus, the amount of electrical energy used for fuel heating is minimized and the majority of the heat load is met from a source that would otherwise be wasted.

4.5 Operation and Maintenance

Compared with operating on diesel oil only, operations and maintenance staff at the Kabul HFO station need to manage the following.

a) The maintenance of the thermal oil system: exhaust gas boilers, oil pumping and controls.

   Exhaust gas boilers can be demanding to maintain, subject as they are to vibration and, depending on the sulphur content of the fuel, to acidic compounds in the exhaust gas.

b) Fuel treatment plant – modern centrifuge plant is very reliable and as at Kabul it is not uncommon for no redundancy to be included. Two centrifuges, operating in parallel, serve each block of six engines. In the unlikely event of a centrifuge unit being out of service for an extended period, three engines would have to be run on diesel oil or taken out of service. The diesel storage tank has a capacity of 6000m^3 which is sufficient to operate three engines at full load for over 60 days.

c) Fuel pumping and heating modules. These are fairly simple pieces of equipment that normally prove reliable.

d) Lubricating oil – heavy fuel oil combustion will produce more acidic compounds than will diesel oil combustion, mainly because of the higher levels of sulphur in the HFO. Some of these acidic compounds will accumulate in the engine's lubricating oil and when the acidity of the oil reaches a critical level the oil must be replaced. This is normally mitigated by the use of more alkali oils ("high TBN" or total base number oils) which will have a greater capacity to neutralize acids. Depending on the sulphur level in the fuel and the inherent lubricating oil consumption of the engine, it is sometimes possible to choose an oil which never becomes acidic enough to need changing – the amount of alkalinity introduced by topping up the oil to replace that burned, at least matches the acidity added by the combustion of sulphur bearing fuels.

   Nevertheless, it is most likely that the oil usage on HFO will be greater than if HFO were not being used, and the higher TBN oils are often more costly.

   In addition to acidity regulation, HFO combustion in the engine will lead to carbon deposits accumulating in the lubricating oil. These are typically removed by passing the oil through a centrifuge plant. This is very common practice and presents no significant operation issues.

e) Engine components. Under HFO operation the engines will require more frequent attention to fuel injector nozzles, and more frequent cylinder head and piston overhauls. It is difficult to quantify the difference in maintenance requirement because it is highly dependent on the characteristics of the HFO being used, the operating regime and the skills of the maintenance crews. Many HFO power plants use the manufacturer's maintenance schedule as a starting point and tailor their specific maintenance regime in the light of experience on the particular fuel and operating patterns that they experience. However, the life of the aforementioned components when operating on diesel oil is likely to be perhaps double that under HFO operation.

4.6 Plant Availability and Reliability

HFO plant in a well-run environment with structured planned maintenance and well-trained staff would be expected to operate with an overall availability (i.e. taking into account all down-time for any reason, and assuming that the engine would be dispatched 100% of the time if it were available) of 95 to 97%. This may be somewhat lower in the early days while staff become accustomed to the plant, and teething problems are overcome; and of course it will be lower when major overhauls become due after perhaps 7 to 10 years of base load operation.

Operating on diesel oil will be likely to increase overall reliability, and hence availability. Though there is little room for improvement on a well-run plant, a diesel-only operation could attain 98% or even more, as the down-time during overhauls will be shorter.

HFO plant runs most reliably when operated close to full load. Running at reduced loads will lead to carbon build-up on engine valves and turbochargers, which will reduce the engine's efficiency, require more maintenance and reduce component life. Similarly, frequent starting and stopping is not healthy for diesel engines and will reduce component life.

4.7 Converting to Operate on Diesel Fuel Only

All HFO plant use diesel fuel when starting up from cold and when shutting down, in order to flush HFO from the fuel injection system prior to the engine cooling down. Thus there are already two fuel systems in place, so fundamentally there is no need to make any changes to the power station to allow it to operate on diesel fuel only – the operators would simply need to avoid selecting HFO operation on the plant control system.

5. Review of Existing Design with Respect to a Change to Single Fuel

5.1 Overview

In its simplest form, no changes are required to operate the plant on diesel oil only, because it is already arranged to operate on diesel oil or HFO. Simply by not choosing to change the fuel over to HFO on the engines' control panels, operation on diesel oil would continue and the same maximum load can be reached.

Operations and maintenance would then be less burdensome and equipment lives would be extended, as described in the previous section.

If the engines are to be operated on diesel oil for an extended time, it is assumed that it is not the intention to take more than the minimum actions required to provide for long-term diesel oil operation without jeopardizing the facility to operate on HFO in future if required.

5.2 Thermal Oil System

5.2.1 Thermal Oil System Status

The thermal oil system comprises exhaust gas boilers, plus the tanks, pumps, valves and piping to circulate the heated thermal oil through the range of heaters and piping trace heating associated with the HFO system.

Thermal oil exhaust gas boilers have been installed on four out of every six engines (as required for adequate redundancy). The temperature of the engine exhaust gases into the boilers is, according to the Caterpillar manual, 290°C. The boilers will be able to operate dry, i.e. without being filled with thermal oil, without coming to any harm at this moderate temperature.

We understand that the thermal oil piping systems, including trace heating lines, have largely but not completely been installed, and thermal insulation has not been installed yet.

5.2.2 Mothballing the Thermal Oil System

If construction of the thermal oil system is ceased, it only remains to seal open ends of pipes and ensure that the system is preserved for possible future use. Desiccant crystals are available in porous pouches and these should be inserted into pipes and vessels in sufficient numbers to prevent moisture forming and causing corrosion. All open pipes should then be sealed with suitable plugs. It should be possible to readily remove the sealing plugs in order to inspect the interior surfaces and replace when necessary the desiccant crystals.

5.3 Heavy Fuel System

5.3.1 Heavy Fuel System Status

We understand that the HFO piping is largely complete with the exception of thermal insulation, which has not yet been started. Fuel heaters and centrifuge plant have been installed but piping has not yet been completed. The centrifuge plant has not yet been prepared for commissioning – the bowls have not been installed but have been removed from their packaging.

5.3.2 Mothballing the Heavy Fuel Piping

As with the thermal oil plant, desiccant should be inserted into the piping and open ends sealed. Pipework connected to the centrifuge plant should be disconnected from it.

All of the fuel treatment equipment appears to be installed in a dry enclosed building. We would expect this building to be suitable for long-term storage of the equipment provided that open pipes are sealed. Desiccant may be required and though we would advise contacting the manufacturer for recommendations on long-term storage, this is not likely to be difficult.

Photo 1, fuel centrifuges in fuel treatment building

5.4 Fuel Storage

5.4.1 Available Storage

The fuel storage and tanker unloading facilities are not yet complete, but the site is designed to have fuel storage as follows:

1 x diesel fuel storage tank, 6000m^3
2 x HFO storage tanks, each 6000m^3
Smaller tanks for storing treated HFO.

The diesel tank is complete but the two HFO tanks are under construction. Treated HFO tanks are also under construction.

Fuel metering has been installed at each engine on the HFO system but it was not intended to be installed on the diesel system as this fuel would have only been used for short periods of time.

Photo 2, tanker unloading bay, 19 Feb 2010

Photo 3, diesel oil storage tank

Photo 4, HFO tank

5.4.2 Re-configuring Fuel Storage

6000m^3 of diesel fuel will be sufficient to run the complete 100MW plant at full load for approximately 10 days. (We note however that the load connected to the local grid is presently insufficient to demand full load from the plant.)

If 10 days' storage is considered adequate, there is no need to complete the construction of the HFO tanks. However, it would seem sensible to complete the construction of the tank shells in any case, rather than abandon part-constructed tanks to deteriorate. If the HFO system is not to be used the tanks and pipes would be better left un-insulated. It is likely that rain water will seep into the insulation and without heat to dry it out, the water is likely to corrode the underlying steelwork and damage the insulation.

If fuel storage of 20 or 30 days is preferred, the HFO tanks can be completed and used for diesel storage, though thermal insulation can be ignored. A close examination of the existing piping should quickly determine how best to connect the HFO tanks into the existing diesel fuel system.

The smaller HFO tanks, designated for the short-term storage and buffering of fuel after heating and centrifuging, may be mothballed with desiccant and sealed.

If it is required that the consumption of diesel oil be metered, the meters installed on the HFO pipework to each engine may be removed and installed in the diesel fuel pipework instead.

6. Staffing Requirements for the Use of HFO

The plant is currently in the installation and commissioning phases hence under the supervision of LBG staff. LBG have engaged local Afghan staff and other ex-pats who are expected to leave the employment of LBG and join the power plant operations organization when LBG hand over the station. These staff include some experienced people from outside Afghanistan.

LBG is just beginning their operator training program and estimate that untrained staff could be fully trained to operate the plant in 3 to 5 years. LBG are currently preparing training materials and starting to process the first group of trainees.

As previously discussed, running on HFO has a higher operation and maintenance burden than running on diesel oil because plant overhauls are more frequent and more plant is in use. Engines that have run to date have only run on diesel oil.

Operating the plant on diesel oil only will certainly make staff training easier and fewer competent staff will be required to keep the mechanical aspects of the plant in working order. From the staff training point of view, there are clear benefits to operating the plant on diesel oil and perhaps moving on to operating on HFO in future years.

We do not know how many staff LBG envisage using to run the station. Typically in the USA, a plant of this nature would have a total staff contingent of perhaps 20. In under-developed countries, a similar plant might employ three times as many, though at a much lower cost. Compared with fuel costs, it is unlikely that staffing costs in Afghanistan will have a significant impact on the economics of the plant, but staff can probably be cut by 20% if HFO is not used.

7. Availability and Cost of Fuel

The United States Geological Survey reports that though Afghanistan has not been thoroughly explored for oil and gas potential using the latest techniques, more than 150 million barrels of oil reserves have been identified using Soviet methods and technologies in 29 fields in the Afghan portion of the Amu Darya and Afghan-Tajik basins.

Only a very small portion of this reported resource base has been exploited, and there do not seem to be supplies of indigenous heavy fuel oil available at this time. As there are no other substantial HFO installations near Kabul, there is no established supply of HFO to the region.

The Amu Darya basin extends into Turkmenistan, Uzbekistan, and Iran, and has been exploited in these regions. It was once, but is no longer, part of the same geological feature as the Afghan-Tajik basin, and though both basins are gas dominated, small but significant reserves of liquids are also present.

HFO and diesel oil are both available in Turkmenistan, Uzbekistan, Kazakhstan and Iran, though the over-land access to Kabul is difficult, especially in winter. A better, more established source of fuel is Pakistan. Fuel oils are currently exported from Pakistan to Afghanistan by NAPCO, an Afghan company, though we understand that this is mainly diesel or furnace oils which do not need heated tankers.

Preliminary enquiries with the COO of DABS (Afghanistan's national energy utility) indicate a reasonable level of confidence that obtaining a fuel supply in the quantities required can be achieved. However Tryco International, who supply aviation fuel to Kabul, advise that a sufficient number of heated tankers to transport the required quantities of heavy fuel oil from outside Afghanistan are not available and such tankers would have to be provided by the power station or their procurement negotiated with fuel suppliers.

8. Conclusions and Recommendations

8.1 Conclusions

a) The plant as designed is perfectly capable of operating on either diesel oil or HFO, and is typical of HFO power plant operating successfully worldwide.

b) Operating on HFO at close to full load will provide fuel savings in the region of $27 million per annum, at current marine bunker prices, when compared to operating on diesel oil. We understand however that the plant is unlikely to be able to operate at full load in the near-term and perhaps 20% load would be more realistic at this time.

c) LBG have advised that staff training is likely to take 3 to 5 years before fully competent indigenous operation and maintenance staff are available. Operating on diesel oil rather than HFO will make staff training simpler and could be an effective way of introducing the power plant to the local workforce, with a view to moving to HFO operation at a later date.

d) The HFO systems are not ready for commissioning yet. Preparing HFO plant for long term storage and preservation does not present difficult challenges.

e) Indications are that adequate supplies of diesel oil or HFO can be secured.

8.2 Recommendations

We appreciate that there are significant ramifications beyond the engineering aspects to the final decisions made with regard to the completion and future support of this power plant, and consideration of these issues lies outside both the scope of this study and our area of expertise. The following are therefore based only on technical and commercial considerations, combined with experience of commissioning and operating this sort of plant in under-developed countries.

a) We recommend that the plant is run on HFO in the medium to long term. This will take advantage of the considerable fuel cost savings available to a plant that has been designed for this fuel.

b) We recommend that in the short term, the plant should be commissioned and operated on diesel fuel. This will have operational and practical benefits, including making it easier to deal with the relatively low loads available; and simplifying the training of operations and maintenance staff when starting from a very low base of skills and understanding.

c) In order to facilitate the above two recommendations, we further recommend that the completion and commissioning of the power plant is split into two parts.

   Firstly the plant should be completed and commissioned on diesel fuel only. Equipment not required for diesel fuel operation, including the fuel treatment plant and the thermal oil system, should be preserved in its present state with no further installation work done.

   We recommend that the construction of HFO storage tank shells is completed but stopped before the insulation is installed, and the tanks sealed and preserved.

   The second phase of commissioning is covered in below.

d) If the recommendations above are enacted, staff training should be focused on diesel only operation at this time, with further training on the HFO aspects of the plant in future.

e) When staff have become competent to operate the plant on diesel fuel, and when significant load growth is achieved, the second phase of commissioning should be carried out in tandem with further staff training. In this phase, the installation of the HFO equipment would be completed and the HFO systems commissioned, followed by gradually phasing in the use of HFO, engine by engine.

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