Technical and Economic Options for Power Transit Operations through Afghanistan

Executive Summary

Draft: 27 August 2013

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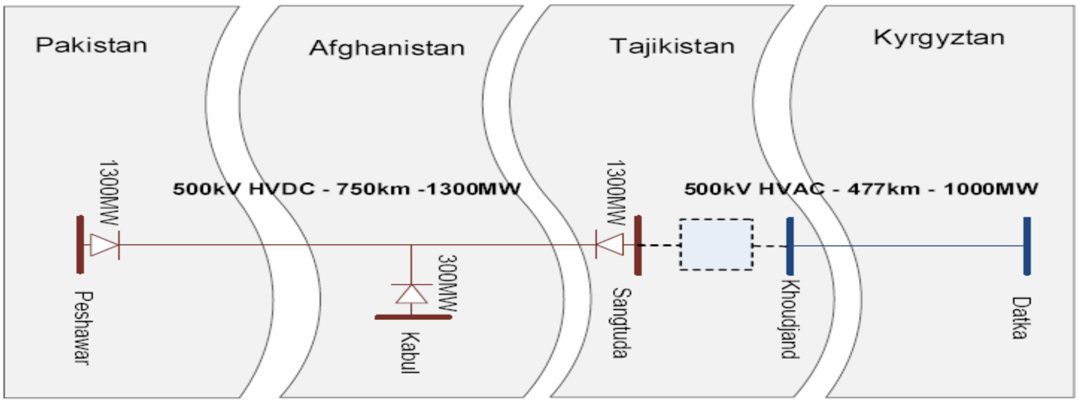
Executive Summary

Background and purpose of the report

1. The proposed CASA-1000 project would build a cross-border power trade facility, comprising 477km of 500kV HVAC transmission lines from Kyrgyzstan to a 1,300 MW HVDC converter in Tajikistan and thereafter 750km ±500kV HVDC transmission, via a 300 MW HVDC converter in Kabul, to a 1,300 MW terminal with HVDC converter facilities in Pakistan. It can be viewed as a combination of the following elements:



2. The concept of the CASA 1000 project was developed after a comprehensive Phase I pre-feasibility study (2007) of the viability of extending 500kV networks from Tajikistan through Afghanistan to Pakistan. By the time of the Phase II study (2009), that option was rejected in favour of a combined HVAC/HVDC[2] configuration. The final feasibility study was updated in December 2011 and is the basis of the currently proposed investment project.[3]

3. The use of dedicated HVDC transmission for long distance power transit interconnections is generally the optimum techno-economic option for the parties involved in the various proposed power trading operation. Moreover the use of an HVDC transmission line that overlays the HVAC domestic networks should be recognised by Afghanistan planners as an integral part of the optimal power sector development plan that will enable the country to rationally expand its own power system at least cost.

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2 HVAC = conventional high voltage alternating current power systems used throughout the world; HVDC special application high voltage direct current mostly used to transmit power over long distances, to stabilize underlying HVAC power systems or to enable synchronisation of two distant HVAC systems; but can also be used in a HVDC back-to-back configuration to interconnect cross border asynchronous systems.

3 SNC Lavalin "Central Asia-South Asia Electricity Transmission and Trade (CASA1000): Project Feasibility Study Update, February 2011 (funded by World bank on behalf of the four contries). This report updated the findings of the Phase I Pre-Feasibility study 2007 and of the Phase II study in 2009, which were funded by ADB.

4. There are differing views about the viability of this project. A recent paper by USAID[4] in support of the project has suggested ways in which the project's viability can be enhanced by making new transmission investments to facilitate additional generation being supplied to the CASA 1000 terminals during the winter period from Turkmenistan. The paper has also pointed out there have been a number of recent developments worldwide in relation to HVDC grid development that support the concept of HVDC multi-terminal converters being very relevant to the unique situation that exists in Afghanistan.

5. On the other hand, the 2012 Afghanistan Power System Master Plan (APSMP) recommends a 500kV HVAC system which could be expanded for transit operations if and when necessary (as and when extra power from Turkmentistan may be available for re-export). [5].. Thus the APSMP proposes that an isolated synchronous national power system should be developed within Afghanistan capable of importing and exporting power from its five neighbouring asynchronous power systems. The approach proposed in the APSMP is to gradually develop Afghanistan's own significant gas, hydro, coal and solar generation sources along with the associated HVAC transmission and distribution networks to eventually reduce the country's dependence of power imports from neighbouring countries. Recognising however that the development of the country's potential generation resources will require significantly more investigation time and financial support, the APSMP envisages a need in the interim period to triple power imports from its CAR neighbours. Thus in order to import more power to Afghanistan, the APSMP proposes the development of technically complex HVDC b/b (back-to-back) interface facilities in a single location - Pul-e-Khumri - a substation about 300km north of the Kabul on the other side of the 3,900m high and narrow Salang Pass through the Hindu Kush.

6. The APSMP's concept of Afghanistan investing heavily to isolate its very small (and currently fragmented) power system from the neighbouring major power systems blocks may be questioned. Instead it would appear prudent to synchronise the Afghan power system, including its local generation plant with one of the significantly larger neighbouring power systems (as indeed parts of the NEPS are now in synchronism with UPS/IPS and then if necessary resynchronise the integrated NEPS/SEPS networks with one of the other neighbouring systems as the situation develops. Moreover the proposal by Fichtner to channel all import power from CAR countries through a single location, while arguably convenient for construction and maintenance of complex HVDC converter equipment, may have technical issues that will inhibit its proper operation[6] will make the Afghan power system vulnerable to national blackouts (due to terrorist activity or equipment failure). Worse still, if and when some of the

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4 USAID, *Possibilities for Turkmenistan Participation in CASA1000 as Power Supplier*, RESET April 1, 2012

5 Fichtner prepared two key reports relevant to the project: (i) Central Asia Regional Economic Cooperation: Power Sector Regional PSMP – October 2012 ADB report 43549 (excludes situation in Turkmenistan); and (ii) Islamic Republic of Afghanistan: power Sector PSMP May 2013 – ADB report 43497

6 Indian operators of co-located dual HVDC LCC b/b facilities have experienced difficult coordination problems with control systems sometimes working against each other. While this may not be such a problem for VSC converters the risk is increased by having more than one converter in one location.

CAR countries revert to an integrated operational mode, some or all of the HVDC b/b facilities at Pul-I-Khumri could well become stranded assets.

7. The objective of the assignment is to compare the technical and economic merits of different options for power transit across Afghanistan, in particular those which make use of the domestic HVAC system and those which make use of dedicated HVDC systems operating in parallel with the domestic system. It would in particular:

- Confirm that the HVDC approach proposed in the CASA 1000 feasibility study is technically sound from the perspective of the expansion of the Afghan domestic transmission system;
- Show how an optimised combination of HVAC for domestic use and dedicated HVDC lines for export will both minimize transmission costs and allow for a better allocation of risks and costs to export project participants;
- Show that CASA-1000 does not foreclose on domestic transmission system options that may be attractive in the future.

8. In this report we can confirm that HVDC is the lowest cost option for power exports from Tajikistan/Kyrgyzstan. It will also circumvent complex power system synchronisation issues while providing the respective parties with a secure long-distance economic cross-border power transfer configuration. Its implementation should enhance the capability of existing Afghan transmission assets and other developments in the HVAC projects if and when they proceed. Compared with other options for cross border power trade, the CASA-1000 project is unlikely to result in a stranded asset for Afghanistan when/if the current surpluses in hydro generation in the CIS countries are no longer available or if the CAR countries re-synchronise their power systems. Its successful implementation would however be subject to appropriate sharing of the financial costs, risks and benefits enshrined in secure PPAs between each of the four countries involved.

Power trade options

9. The two main drivers for power trade in the region is Pakistan's power shortages, particularly in summer when its loads are at a peak and the post soviet generation surpluses that currently exist in the Afghanistan's' neighbouring CAR countries Depending on domestic demand growth in the CAR regions the surpluses are expected to last until 2035. The shortages in Pakistan are likely to persist well into the 2020s. The development of Pakistan's own hydro resources, including several IPPs, will not eliminate these shortages, while little of Pakistan's remaining gas resources are likely to be available for power generation. The economic benefits of power trade to Pakistan, by whatever transmission mode, are therefore defined by the cost of generating power in Pakistan by imported LNG. Both Kyrgyzstan and Tajikistan have winter peaks, and winter power shortages (like Afghanistan). If these countries develop additional hydro projects to addrsss these winter shortages, the summer surplus would again increase.[7]

[7] The CASA 1000 economic analysis assumes the worst case, in which any additional surplus hydro from new projects planned but not yet commited is not included.

10. All three of Afghanistan's neighbouring CAR counties purport to have proposals to export about 1,000 MW at least up until 2030 to Afghanistan and/or in transit to Pakistan. At this time the principal export opportunities are described in the 2011 CASA HVDC 1000 (Tajik/Kyrgyz) proposal, the 2012 Uzbek UAP-EST HVDC proposal (just to pre-feasibility level), [8] and in a non-specific proposal (alluded to in the 2012 APSMP) to import power from Turkmenistan to Kabul via 500kV transmission. The first two projects are the subjects of the feasibility studies by SNC Lavalin; the latter is the basis of the first stage of development of a 500kV HVAC transmission to evacuate power from 400 MW gas turbine plant being funded by ADB from Andkhoy to Sheberghan as a first stage development of the 2012 Afghan PSMP[9].

11. The CASA-1000 power trade project is fundamentally different from the other power trade opportunities as enumerated in Fichtner's APSMP because the incremental economic production cost of using surplus hydro power is zero, and even in the worst case where supply is limited to the power available at existing hydro facilities, there is no additional capital investment required for generation.[10] This is quite different to power trade options associated with gas-based power generation in Turkmenistan and Uzbekistan, which requires new generation capacity, and whose gas will inevitably be priced at international levels, currently around $300/MCM ($8.25/mmBTU) - whose net economic benefits are therefore necessarily much smaller than the HVDC transit of a large block of surplus hydro. Indeed, the economic analysis presented in the report shows that the economic returns of CASA-1000 are robust over wide ranges of uncertainties in the input assumptions, and regardless of the many uncertainties about the extent of benefits to Afghanistan.

12. One must emphasise that the proposed *financing* arrangements of CASA-1000 are independent of the *economic* costs and benefits. Afghanistan would finance the share of the CASA-1000 costs that lie in its territory, but will recover that investment from the transmission fees (even in the case that the entire 1,300 MW goes to Pakistan) – as contemplated in the Draft Master Agreement among the CASA-1000 countries.[11] It is therefore somewhat confusing to include the *total* cost of the CASA-1000 in the APSMP investment programme (that shows the cost of CASA-1000 at $US 873million).[12] The incremental *economic* cost to Afghanistan is limited to the Kabul

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8 SNC/Lavalin, *Uzbekistan-Afghanistan-Pakistan Electricity Supply and Trade Project*. Draft Report, March 2012

9 In August 2012 a draft PPA was prepared between Turkmenistan and Afghanistan to supply 300MW of power to from 2018-2028. This includes provision for a new 500kV line from Turkmenistan to Sheberghan and a 220kV line from Sheberghan to Mazar-el-Sharif funded by ADB.

10 Kyrgyztan has been able to export some of its hydro surplus to Kazakhstan, most recently at around 4UScents/kWh. But these are short-term sales, negotiated one year at a time (and may not reflect the price in a long-term PPA). Nevertheless, it serves as a yardstick of the financial price that Kyrgystan will seek in the CASA-1000 negotiations.

11 *Master Agreement in Relation to the CASA 1000 Transmission System with Standard Terms and Conditions*, Draft, February 2013. This distinguishes among *eligible project costs*, recovered by the transmission fee (i.e. the common costs are recovered from those who derive the benefits), and those expressly excluded form common costs (such as the Kabul Converter Station.

12 See, e.g., APSMP, Table 12-1.3

converter station (offset, at worst, by the potential stability benefits that will enhance the value of existing transmission assets, and the avoided cost of imports displaced by CASA-1000 delivered energy).

Dealing with uncertainty

13. There are few countries in the world where power planners face the same level of exogenous uncertainty as in Afghanistan, where layers of geopolitical and security uncertainties complicate the usual set of uncertainties over demand forecasts and the ability of Afghanistan to develop its own hydro and coal resources, to say nothing of the interrelationships with developing Afghanistan's own gas resources. Consequently the approach taken in this assessment is not: *given some set of planning assumptions, what is the least cost configuration of Afghanistan's transmission system configuration*, but rather: *given the unusually wide range of uncertainties, how do alternative investment decisions perform when risks as well as costs are taken into consideration.*

14. Indeed, the technical and economic analysis presented in this report is not designed to show that CASA-1000 is a "better" option than the power trade alternatives of the APSMP (though the economic analysis, for reasons explained above, does indeed show the unique advantages of power trade based on the exploitation surplus hydro). Rather, we show that a commitment of Afghanistan to the HVDC concept embodied in CASA-1000 involves the least risk among the various options for power trade in the region.

15. This is illustrated by a comparison of the vulnerability of the APSMP Pul-I-Khumri hub with the CASA-1000 converter station in Kabul. Provided the transmission lines can be built in proximity to the major roads, physical damage to the transmission lines can readily be repaired (and would not differ significantly between HVDC and HVAC). However, much more vulnerable are the major substations and b/b facilities. The Kabul converter station can be designed in such a way as to minimise the impact of any prolonged outage (whether by terrorist attack or by technical problem) on power transmission to Pakistan or to the domestic system (the HVDC transmission line could relatively quickly be restored, bypassing the damaged Kabul converter station). But a corresponding disruption at Pul-I-Khumri not only brings power trade to a halt, but would affect the entire NEPS system supply.

The Main Technical Issues

Synchronisation

16. The major obstacle to regional power trading, that is peculiar to the Afghanistan situation, is the inability of the various neighbouring grids in the CAR countries (i.e. those connected to the IPS/UPS grid), Iran and Pakistan to be synchronised with each other[13]. As a consequence, several domestic Afghan grids

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13 Iran and Turkmenistan have recently synchronised with each other after the latter left the IPS/UPS grid. Both Tajikistan and Kyrgyzstan have also isolated some generation from the IPS/UPS grid as required for the CASA 1000 Project

currently operate in island mode to facilitate power imports from the CAR countries. The need for islanding is also exacerbated because some of the CAR exporters do not permit Afghanistan to synchronise its domestic generation to their grids without first meeting the obligations of their respective Grid Codes[14]. This issue is of particular concern for connections through the Uzbekistan grid (currently supplying 300MW of power to Kabul) which is connected to the greater Russian IPS/UPS system. The problem is complicated by the inability of DABS' technical advisors to identify exactly what Afghanistan has to do to its protection and control systems to comply with the IPS/UPS Grid code. As a consequence Kabul is currently supplied by two different sources of generation - an intolerable operational situation for the Kabul distribution network and a significant constraint on their operator's ability to optimise generation production.

17. In the foreseeable future it will not be possible for the three large regional power systems blocks (Iran/Turkmenistan, CAR (IPS/UPS) and Pakistan/India) to be synchronized with each other, directly or indirectly through Afghanistan. If this option was to be seriously considered, its implementation would cause a great deal of disruption to the power systems in the many interconnected countries that are not involved with cross border trading. On the other hand Afghanistan could be more easily synchronised with one of the major blocks, and can feasibly be interconnected with other blocks using interfaces such as HVDC converters or VFT[15] facilities.

18. Thus for Afghanistan there are three principal connection options to facilitate power importing and transit trade:

- Synchronization of each the Afghanistan power systems with either one of the exporter's or importer's grids (subject to meeting their respective Grid Codes) and using HVDC b/b facilities for interconnection with the other domestic power system(s);
- Creating a single synchronized Afghan HVAC grid with sufficient capacity for secure 220/500kV transit operations isolated by HVDC b/b or VFT systems to the neighbouring export and import grids;
- Building the Afghan HVAC power system to meet its own needs using, where necessary smaller systems in an isolated mode, but overlaying the main synchronised NEPS/SEPS grid system, possibly synchronised with an exporter or importer, with purpose built dedicated HVDC transit lines between the exporter's HVAC grids (including intermediate converter terminals as appropriate - as in the CASA 1000 proposal)

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14 Grid Codes – An agreed set of rules for a transmission system that enables it to interconnect a variety of loads, generators and other transmission networks to enable the interconnected power system operates safely and securely under all conceivable operating conditions.

15 VFT – Variable Frequency Transformers. This is a relatively new alternative to HVDC that similarly enables asynchronous systems to be interconnected where power transfers up to 300 MW are required. See 2006 CIGRE paper: *A 100 MW Variable Frequency Transformer (VFT) on the hydro-Quebec network: - A new technology for connecting asynchronous networks.*

HVDC technology

19. Traditionally when large volumes of power are to be transmitted over long distances the use of HVDC is recommended because of the low cost of the HVDC transmission lines, typically less than half the cost of double circuit (d/c) HVAC transmission lines of equivalent capacity. For power transit between systems in excess of 600 km apart, the lower cost HVDC line makes up for the high cost of HVDC terminal facilities at each end of the line. Moreover the use of HVDC technology in the Afghanistan's situation will also enable interconnection with its neighbouring asynchronous systems; and will provide additional stabilizing functions at either end of the line (as well as in an intermediate converter location) to enhance the security of the underlying HVAC operations. If HVAC systems are considered as an alternative for wheeling power to a remote asynchronous system, the additional cost of HVDC b/b facilities at state borders to enable interconnection only adds to the transit cost without gaining many of the technical benefits as described above.

20. SNC-Lavalin recommended against a fourth terminal on the CASA line based on the lack of experience with multi-terminal DC lines and referring to the Hydro-Quebec-New England HVDC link commissioned in 1992 as the only prototype. However "greater than three" options are today considered feasible based on modern newly developed technologies such as ABB's HVDC Light, Siemens's HVDC PLUS and Alstom's HVDC MaxSine that have already reached levels of 1,200 MW and ±500 kV. In addition, the currently running project North-East Agra HVDC line in India with four terminals (albeit at three converter stations) can be used as a prototype.

21. Thus it may be possible in the near future for a fourth HVAC/HVDC converter to be built in the CASA line near Pul-e-Khumri, to which the 500 kV line from Andkhoy could be connected. If the technology allows and all technical issues of coordinated operations of the two converters (Sangtuda and Pul-e-Khumri) are resolved, they would operate simultaneously so that the Turkmen power could be used to complement supplies from Tajikistan and Kyrgyzstan in summer and serve as the only supplier in winter. In case of technical problems, or for increased reliability, the converters would be operated alternatively: Sangtuda is functioning only in summer to channel Tajik and Kyrgyz surplus energy; Pul-e-Khumri is functioning during the rest of the year, while Sangtuda is switched off.

Diversity and stability

22. The security and reliability of a transmission network is considerably enhanced if diverse transmission line alignments are used, each preferably taking shortest route between the generation sources and the main load centres. Moreover given the difficult security situation in Afghanistan it is inadvisable to create critical substation nodes in the transmission network that may be prone to terrorist activity or equipment failure (where there may be limited access to spares). In a reliable power system, for every transmission path there would normally be alternative path capable of carrying the load that would otherwise have been disrupted on a different path. Although Afghanistan does not yet aspire to an n-1 reliability criteria this will inevitably be required as the system grows. Finding suitable routes, near roads, in Afghanistan is of course very

difficult and expensive because of the difficult terrain and limited access through high mountain passes.

23. The only existing north-south transmission route is taken up by the 220kV d/c line from Pul-e-Khumri to Kabul through the Salang Pass built in 2005. This line capacity is currently limited to 250 MVA but should be able to carry up to 400 MVA if adequate reactive correction is installed along the line. The same alignment is also proposed under the CASA 1000 project for the new HVDC transmission line, although there is some doubt if the two lines can easily be accommodated in the narrow section through the Salang Pass. Although an alternative 40km deviation around the Salang pass has been considered as one solution, it is also possible that one of the two lines could be placed underground for part of the route either through the Salang Pass or through the Salang tunnel. Since the HVDC line bypasses the Pul-e-Khumri substation and can provide 300 MW capacity to Kabul from an different source, it will in fact provide 100% diversity to the city supplies.

24. The APSMP proposes to co-locate at up to three separate HVDC b/b facilities at Pul-e-Khumri thereby creating a critical node in the transmission network where at least four key transmission lines will terminate. This of course exposes the Afghan power system to severe disruption in case of terrorist activity or equipment breakdown that could result in prolonged system blackouts. Moreover when there are more than two LCC converters in one location, experience in India has shown there are likely to be serious operational problems due to the inter action of their respective control systems. This is because the HVDC b/b facilities. in response to a disturbance in the HVAC system, instead of helping the HVAC system recover may in fact counter act to worsen the situation. Simultaneous commutation failure due to AC system faults in more than one back to back system also cannot be ruled out, making recovery from HVDC commutation failures difficult..

25. The APSMP has partially recognised the role of transmission diversity by proposing a new 500kV transmission line route over the Hindu Kush for a proposed new 500kV line commencing in Turkmenistan passing through Sherbergan and Mazar-el Sharif before terminating in Pul-e-Khumri. South of Pul-e-Khumri, the proposed new Hindu Kush route has an advantage of passing close to the potential new coal fired 4-600 MW generation sites at Ishputa PS and HajiGak coal mines. Notably the proposed new 500kV line from Turkmenistan passes through Sheberghan or Mazar-el-Sharif en route to the Pul-e-Khumri HVDC b/b terminal. It could have taken a shorter more direct route over the Hindu Kush mountains, and improved the diversity of transmission if the associated HVDC b/b facilities were located at Sheberghan or Mazar el Sharif.

Benefits of CASA-1000 to Afghanistan

26. The immediate problem for Afghanistan is how to continue to import about 300 MW power from Uzbekistan while at the same time being able to expand supplies to the greater NEPS Kabul/Jalalabad area using both its domestic and import sources.

There is also a political imperative to connect the southern Kandahar (SEPS) region to this NEPS system requiring even more synchronous interconnections to be made with local generation plant. This extra power required by the combined NEPS/SEPS system could be supplied in the medium term via the proposed 500kV line from Turkmenistan (300-1,000 MW), along with the injection of 300 MW from the CASA 1000 project ex Tajikistan/ Kyrgyzstan or from domestic sources at Sheberghan gas and domestic hydro power. Notably an HVDC terminal at Kabul could be designed to stabilize voltages in Kabul and thereby facilitate the connection of local generation until such time as the new 500kV line from Turkmenistan was built[16].

27. Under this scenario the imported power alone would bring the total supply capacity for Kabul to 900-1,600 MW delivered by three diverse transmission systems. The extra capacity could also be used to supply and justify the proposed expansions of both NEPS/SEPS and the Western power systems (Herat) interconnection. Moreover if the demand in the combined NEPS/SEPS/Herat system was unable to absorb all the power available, it should also possible to feed surplus power back into the CASA 1000 terminal at Kabul for onward export to Pakistan.

28. The load profile of Kabul is such that demand peaks in winter. The present imbalance in seasonal demand is accommodated by minimising summer imports from Uzbekistan, and by not using the expensive diesel sets in summer. How far into the future this flexibility remains is unclear. The main power supply benefit to Afghanistan of CASA1000 imports *in summer* would be the avoided variable cost of Uzbek imports (currently 7.5 UScents/kWh). This sets the ceiling for the financial price Afghanistan should be willing to pay for CASA1000 power (which is, in fact, the *economic* price to Afghanistan as well since this is a border price payable in US$).

29. Both the new APSMP and the previous 2004 Norconsult Plan note that construction of Afghanistan's new hydro project candidates would lead to a summer surplus that could potentially be exported. The advantage of CASA-1000 is that if and when such exportable hydro surplus becomes available, the means to export that surplus is already in place (and paid for by others). While there may be a requirement to expand the capacity of the HVDC converter in Kabul, the additional 500 kV AC line to the Pakistan border and b/b converter at Peshawar would not represent incremental costs as they would in the APSMP plan, thereby improving the economics of the Afghanistan hydro projects. Moreover, such hydro power would become available in the mid 2020s, precisely when (under worst case conditions) the hydro surplus from T&K has significantly declined, and so a market for this power would be available. Thus, notwithstanding that the seasonal profile of hydro projects such as Kunar B are largely the same as that from T&K surplus, CASA-1000 is not a *substitute* for Afghanistan's own hydro projects, but a *complement.*

30. However, in the short term, the CASA-1000 feasibility study acknowledges that because of the winter peak, off-take of power at Kabul may be limited. On the other

16 There are however significant technical issues that need to be resolved through detailed power systems studies to determine how such a combination of inputs would be controlled to maintain adequate stability.

hand during the winter with no power source available an appropriately configured Kabul HVDC terminal could help in providing the reactive support by manually energizing the filter banks/capacitor banks available in the converter station to improve the voltage profile that would enhance options to supply the NEPS system by increasing the transfer capacity of the existing 220kV line and facilitating synchronisation of local generation to the NEPS system. The extent of the network benefits at different times of the year are still under investigation by Tetratech.

Economic analysis

31. As noted, different power trade options involve quite different characteristics, so the comparison of the CASA-1000 (summer peaking power based on surplus hydro) with alternative schemes based on gas-fired generation (such as EAP-EST or the Turkmen schemes) is not straightforward. Moreover, investment decisions in the Afghan power sector are closely related to the alternatives for exploiting the Sheberghan gas resource, so power and gas sector planning needs to be closely aligned. And, finally, power is not the only commodity that could be potentially traded in the region: the proposed Iran-Pakistan, and the TAPI[17] gas pipeline projects are long standing proposals.

32. The economic analysis will show that of all of these various options, the CASA-1000 project has the highest economic benefits, resting as it does on the lowest-cost technology for long-distance power transmissions, and on source of power that has zero incremental economic cost. That is not to say that other power trade options should not also be considered, or that the APSMP necessitates major revision at this time – but only to say that CASA-1000 represents the power trade option that – whatever may be the geopolitical, implementation and financing difficulties (which are obviously considerable) – also has the best prospects of success, and entails the lowest risk to Afghanistan (of stranded assets or the security of its power system).[18]

Conclusions and Recommendations

33. At the time of writing our technical and economic analysis is still incomplete. However, some preliminary conclusions can already be stated:

- The CASA 1000 project should proceed to the implementation stage as soon as possible. Regardless of the many uncertainties in input assumptions, the economic returns are robust under wide ranges of uncertainty, and under different assumptions about the valuation of economic benefits (the bulk of which arise in Pakistan) and about the future ability of Afghanistan to export its own hydro surplus. In short, CASA-1000 is robust with respect to the main uncertainties.

17 Turkmenistan-Afghanistan-Pakistan-India

18 One would in any event expect revisions of the APSMP every 3-5 years.

- Proceeding with the CASA-1000 converter station in Kabul forecloses none of the proposals in the APSMP, or indeed of the possibility of the coal-based generating stations under the Resource Corridor Development project. The economic analysis shows that the *worst* case for Afghanistan is no different to the net present value of the APSMP,[19] while under any number of (admittedly uncertain) outcomes about the development of the Afghanistan power system (coal, hydro and gas generation) the NPV improves. In short, Afghanistan's participation CASA-1000 is also robust.
- For any given level of power trade to Afghanistan, the HVDC configuration operating in parallel with domestic HVAC systems exposes all of the participants in power trade, including Afghanistan, to a lower level of risk than one centered on the APSMP-proposed Pul-I-Khumri hub. This will of course require careful consideration of the operating options to ensure the HVDC terminal interface networks are properly designed into the 220kV Kabul ring system.
- Even at worst, CASA-1000 represents for Afghanistan an inexpensive hedge against the many planning uncertainties it faces and a surplus derived from the concessionary funding for its share of the financing; at best it will derive significant economic benefits associated with lower cost power and transmission network benefits.
- Whatever may be the difficulties of implementation, among all the various power (and gas) trade opportunities in the region, CASA-1000 is likely to be the least difficult – precisely because of its unusually favourable economics - and therefore serves as an excellent demonstration of the mutual benefits of power trade and may well spur the implementation of other projects (such as UAP-EST in the future.

Our tentative recommendations include:

- The design of the Kabul terminal should take into account the possibility of being used for stabilizing voltage conditions in Kabul and the possibility of exporting surplus generation either from Turkmenistan (provided via a 500kV HVAC system) or from local Afghan generation to Pakistan..

- Need to establish exactly the conditions that are required to synchronise Afghan domestic generation to any of the neighbouring grids; and if HVDC b/b facilities or HVDC injection into the Kabul Network will be also acceptable to the IPS/UPS grid code

- Need to carry out comprehensive system studies to determine the additional requirements (e.g. FACTS etc) are needed to interconnect combination of HVAC and HVDC interconnections with the Afghan grid

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19 The APSMP does not itself present such an economic analysis, but based on the results of the proposed APSMP investment plan for both generation and transmission, and assumptions about the economic benefits of increasing power supply in Afghanistan, such a calculation can be presented

- Verify the feasibility of the UAP-EST HVDC route being deployed as a superior route for 500kV HVAC lines carrying power supplies emanating from Sheberghan, Turkmenistan or Uzbekistan that would provide access for interconnections with Ishputa and HajiGak coal fired plants.

- Confirm the status of the coal power generation projects to ensure that the proposed 220kV line could be built for 500kV but operated (initially) at 220kV.