The Afghanistan Engineering Support Program assembled this deliverable. It is an approved, official USAID document. Budget information contained herein is for illustrative purposes. All policy, personal, financial, and procurement sensitive information has been removed. Additional information on the report can be obtained from Firouz Rooyani, Tetra Tech Sr. VP International Operations, (703) 387-2151.

TETRA TECH

MEMORANDUM

To: [redacted]

Fr: [redacted]

Re: **LT-0012 Pul-e-Khumri to Chimtala transmission line limiting factors**

Dt: 100905

There are a number of factors that can limit the amount of power transferred on an electrical transmission line, and all must be evaluated to determine the power transfer limit for the line. Since much of this data is not currently available to Tetra Tech, this precludes providing a quick and easy answer to the question of how to increase capacity on the Pul-e-Khumri to Chimtala line to 450-MW.

These factors are:

1. The ability of the conductors to carry the electrical current without overheating and damaging the conductor. This will be referred to as the thermal capacity of the line.
2. The ability of the conductors to carry the electrical current without sagging excessively and encroaching upon required ground clearance. This will be referred to as the ground clearance limit.
3. The ability of the existing towers to support the conductor and forces imposed on the towers, if alternate conductors are required. This is the structural limit.
4. The ability of the line to transmit the power while maintaining acceptable voltages at both ends of the line. This will be referred to as the voltage limit. In the extreme case, a voltage collapse occurs and the receiving end voltage falls to near zero.
5. The ability of the generators on either end of the line to remain in synchronism (locked together electrically). If the generators go out of synchronism they must trip off line to avoid damage. This will be referred to as the dynamic stability limit.

Any of these factors may limit the amount of power that may be transferred over a transmission line.

Each of these limitations has been assessed by Tetra Tech to the best of our ability with the data that we currently have concerning the Pul-e-Khumri to Chimtala line:

1. Thermal Capacity:

Tetra Tech has not been provided with the requested design information to allow us to identify the conductor size, type, and number of conductors per phase with confidence. This information is necessary to assess the thermal capacity of the Pul-e-Khumri Line. Conflicting data exists in some of the documents we has seen. Some of the conductors which have been mentioned in other documents (Deer, Zebra, Squab) raise the possibility that the thermal capacity of the existing conductors may prove adequate as is. See the attached spreadsheet. The Surkhan, Uzbekistan to Naibabad and Niababad to Pul-e-Khumri lines seem to be rated for only 399-MVA while the Pul-e-Khumri to Chimtala lines are rated for at least 484-MVA.

2. Ground Clearance Limit:

As the amount of power transferred on the transmission line increases the electrical current increases and the conductor heats up. As the conductor heats up, it increases slightly in length and sags toward the ground. Transmission lines are designed to operate up to a maximum conductor temperature while still maintaining the required clearance to ground. As a result, there is a maximum limit to the power that can be transferred over the line for any given set of environmental conditions (wind, ambient temperature, elevation, and a number of other less critical factors).

Tetra Tech has insufficient information to determine the ground clearance limit. To determine the ground clearance limit we will need the line design information which has been requested previously. Specifically needed, will be the plan and profile drawings (or data files), conductor information, and conductor sag-tension information.

3. Structural Limits:

The structural system (towers and foundations) that is currently being utilized to support the transmission system may not be adequate to support an alternate conductor if required. Currently we have no data to evaluate the limits for supporting the conductors and limits required for forces imposed by both conductor tension and angular forces (resulting from changes in direction). If it is determine that an alternate conductor system is required due to thermal capacity requirements, the structural system may need to modified or replaced.

4. Voltage Limit:

Voltage drop on long AC transmission lines is a relatively complex phenomenon. The major factors affecting voltage drop are:

- The length of the line. Longer lines have more voltage drop.

- The series inductive reactance of the line. Lines with larger diameter wires; bundles of multiple conductors per phase instead of a single conductor; and closer spacing between phases have lower series reactance and lower voltage drop. The use of series capacitors is another means of reducing the series inductive impedance of the line, although we understand MEW would not wish to pursue this option.
- Increasing the power transmitted on the line increases the voltage drop on the line. Voltage drop increases non-linearly with the power transmitted, becoming much more significant with increased transmitted power until voltage collapse on the receiving end of the line occurs.

Voltage drop can be compensated for by injecting reactive power (shunt reactive power compensation) into the system at the receiving end of the transmission line. This can be done through the use of switched capacitors. However, as the power transmitted increases more sophisticated equipment is needed; which could include power electronic devices such as Static VAR System (SVSs), or conventional generation units operated as synchronous condensers. There is a practical upper limit to the amount of shunt reactive power compensation that can be provided. The curve of the amount of shunt reactive compensation required on the vertical axis against power transferred on the horizontal axis has the familiar "hockey-stick" shape.

Based on the data available the maximum power transfer on the Pul-e-Khumri Line is likely to be voltage limited. This conclusion is based upon studies performed by Siemens-PTI. It is our understanding there is limited ability to provide shunt reactive power support on the receiving (Chimtala) end of the line. It is our understanding that the inability to synchronize between the Afghan electric transmission system and the Pul-e-Khumri Line leads to this limitation. Further, it is our understanding that the MEW would like to limit the shunt reactive power support to fixed capacitors to avoid potential maintenance and operation issues associated with more complex devices such as SVSs. The maximum power transfer, with shunt capacitors for voltage support, is approximately 160 MW based upon previous Siemens-PTI studies. I*t should be noted that this previous study was based upon a single circuit line between Naibabad and Pul-e-Khumri, which we understand has been upgraded to a double circuit line. The amount of power transfer before voltage collapse will increase incrementally as a result, but is still expected to fall well short of 450-MW.*

5. <u>Dynamic Stability Limit:</u>

It is our understanding that dynamic stability is less of a concern than it is typically, as the Pul-e-Khumri line will not be connected to the Afghan electric transmission system.

This issue should be discussed with Siemens-PTI, as the addition of dynamic reactive power support (such as SVSs) in the Kabul area to increase power transfer across the Pul-e-Khumri Line may introduce the opportunity for dynamic stability issues.

The data about the line is necessary to properly perform this analysis. The data is needed to determine the options available for upgrading the line, the capacity of upgrade options, and ultimately the design for any upgrades undertaken. Without it, the goal of a transmission line capable of supplying 450-MW of power that is reliable and does not compromise the safety to personnel or the equipment, cannot be evaluated short of the impractical option of gathering this information directly through very extensive field work.

Conclusion: We understand the urgency to move forward with the study. However, the replacement of the current conductors should be considered no more than one possible piece of the total effort required to achieve a 450-MW capacity of the transmission line:

1. The thermal capacity of the existing conductors may prove adequate for 450-MW. This cannot be confirmed without the line design information so that the existing conductors can be identified with certainty.

2. Upgrading to high temperature / low sag conductors of similar size and weight can still adversely impact the total electrical clearances between the conductors and ground if neither the structure heights nor original design tensions are known. We do not have the ability to specify design tensions that will maintain existing or required clearances if we are unable to obtain one of these two pieces of information.

3. Upgrading to high temperature / low sag conductors of similar size and weight may adversely impact tower loading, particularly on angle and dead-end towers. Without the design tensions of the line or the tower structural data we do not have the ability to estimate the structural costs and practicality of upgrading with any degree of confidence. The more desirable approach of using bundled conductors (which would tend to increase the amount of power that could be transferred before voltage collapse) would impact the loading on all towers and cannot be further evaluated without the detailed tower design information.

4. The ability of the line to transfer power from Pul-e-Khumri to Chimtala is not only limited by the lines thermal capacity (maximum current the conductors can carry). Instead it is limited by the amount of power that can be transported before voltage collapse occurs in the Kabul area. Studies performed under a separate contract by Siemens PTI have shown that only about 160-MW can be transferred without the

addition of dynamic reactive power support in the Kabul area. It should be noted that this previous study was based upon a single circuit line between Naibabad and Pul-e-Khumri, which we understand has been upgraded to a double circuit line. The amount of power transfer before voltage collapse will increase incrementally as a result, but is still expected to fall well short of 450-MW. Dynamic reactive power support could be provided by more advanced technologies such as Static VAR Systems or by running conventional generation units. However, there is an upper limit beyond which additional reactive power support is not practical due to expense and voltage stability concerns. **Changing from the existing conductors to a high temperature conductor of similar size will only increase the thermal capacity of the line; it will not significantly affect the amount of power that can be transferred before voltage collapse in the Kabul area.**

Recommendation:

This section of the transmission system is critical to the future electrical power needs on the North East Power System. The evaluation that is required is critical in determining the best action necessary to improve power flow to the desired level. It is our recommendation that USAID make every effort possible to obtain complete information about the line.

[redacted] at [redacted]

Attachment: Thermal capacity of conductors from Surkhan to Chimtala

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Thermal capacity of conductors from Surkhan to Chimtala

FROM	TO	LENGTH (km)	# CKTS	COND. TYPE CODE NAME	INTERNATIONAL STANDARD	COND. SIZE (mm^2)	VOLTAGE (kV)	AMPACITY (A)	FOOTNOTE	MVA PER CKT	MVA TOTAL
Uzbekistan (Surkhan)	Naibabad	95.5	2	Squab ACSR	ASTM B232/B232M	300.1	220	523	1	199.3	398.6
Naibabad	Pul-e-khumri	164	2	Squab ACSR	ASTM B232/B232M	300.1	220	523	1	199.3	398.6
Pul-e-khumri	Heavy Snow Zone	84.5	2	Zebra ACSR	BS 215, Part 2: 1970	484.5	220	635	1	242.0	483.9
Heavy Snow Zone	Heavy Snow Zone	27.1	2	Deer ACSR	BS EN 50182:2001	530	220	639	1	243.5	487.0
Heavy Snow Zone	Chimtala	90	2	Zebra ACSR	BS 215, Part 2: 1970	484.5	220	635	1	242.0	483.9

FOOTNOTES:

1. From Oman Cable Industry brochure