Gas Transmission Development Strategy – a modeling approach
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ABSTRACT
Sui Northern Gas Pipelines Limited, SNGPL, is the largest integrated gas company in Pakistan serving more than 2.5 million consumers covering 142 main towns in North Central Pakistan. The transmission system owned and operated by the Company has an annual throughput of around 640 BSCF (18.1 bscm) comprising over 3,811 miles (6135 km) of transmission system. The company operates in a region of the nation that has a rapidly growing demand for natural gas and power generation due to significant industrial development.

In view of a newly discovered gas field, cross-border import options and displacement of fuel oil in the mid country power generation, Sui Northern needed a medium to long-term infrastructure expansion planning tool to effectively cater for the projected gas demand. The company used a supply-demand model along with a pipeline hydraulic simulator to update the future development strategy. This strategic tool furnishes the information required to make critical decisions on the future strategy of infrastructure development.

The main objective of the Study was to develop a Gas Development Strategy to identify medium and long-term gas infrastructure development priorities with a focus on optimizing the flow patterns from various gas fields to the demand centers utilizing the existing infrastructure, while taking into account characteristics of the gas in individual fields; optimizing incremental expansion of the existing gas transport infrastructure; exploring the potential contribution of underground storage in Northern Pakistan to meet seasonal demands, while enabling savings on transmission investments; and identifying potential stand-alone pipeline projects from large gas fields to demand centers, especially clusters of power plants. Furthermore, the study examines the minimization of compressor fuel consumption throughout the transmission network without compromising on the demand parameters of potential consumers.

The paper analyses various ways in which the input data to the hydraulic simulator is utilized effectively in order to predict pipeline network expansion. Supply projections developed with the help of gas producers along with the seasonal demand model based on econometrics are the major inputs. The simulation methodology adopts a practical approach by applying enhancements to the existing infrastructure. The requirement is to deliver gas to the existing and known future demand centers within the customer constraints. The results of the hydraulic simulation are fed into the financial model in order to estimate the cost of development.

The approach is described and the effects of applying each method and its subsequent results are given. It is also demonstrated how effectively the hydraulic simulation tool can predict the infrastructure expansion requirements.

TRANSMISSION PIPELINE NETWORK
The Company was incorporated as a private limited company in June 1963 and became a public limited company in January 1964. Its primary objective was the transmission of natural gas to markets located in the Punjab and North-West Frontier Province (NWFP). For this, it took charge of the Sui-Multan pipeline system (217 miles of 16-inch and 80 miles of 10-inch diameter pipelines) and the Rawalpindi-Wah system (82 miles of 6-inch diameter pipeline).

Today, the company manages an extensive pipeline network that stretches all the way from Sui to Peshawar (see Figure 1). The Company is supplying gas to its potential consumers through 24 gas fields that are connected to its transmission network. 70% of the gas fields on Company’s network are located in the southern part (lower Indus basin) of the country and 30% are located in the northern part (upper Indus basin). The total length of the transmission network is 3,811 miles (6,135 km), including supply lines, as of June, 2006. For operational purposes, the pipeline network is divided into
different segments (or 'legs' as the utility terms them). The following are the major legs in the Company’s transmission system:

1. Leg A (Sui-Faisalabad)
2. Leg B (Faisalabad-Jhelum)
3. Leg C (Faisalabad-Peshawar-Mardan)
4. Leg N (Qadirpur Rawan-Lahore)

The configuration of these major sections is described below:

**Sui to Faisalabad (Leg–A)**

This segment includes the pipeline network from Sui gas field (the compressor station, AC0) to Faisalabad (AC8). Sui is the largest gas field of Pakistan which is contributing the major portion of the gas supplies. Leg – A comprises some 389 miles of pipelines, the diameters of which range from 12 inches to 36 inches. With the exception of some stretches, this segment comprises one main line accompanied by at least two loop lines.

The Guddu crossing on the Indus River comprises 1.12 miles of pipeline of 24-inch diameter and with a 36-inch loop. The Sutlej Crossing near Uch consists of three 12-inch and one 36-inch diameter pipelines. One 16-inch and one 30-inch diameter pipeline form the Sidhnai Crossing on the Ravi River.

The station AC0 compresses natural gas from the Pirkoh and Loti fields. Prior to compression it is mixed with gas from the southern area fields, Zamzama and Hassan. Gas from these fields is conveyed by pipelines that form part of the SSGCL network. Gas from the Sui field is injected downstream of AC0.

Sawan gas is transported through an 81-mile 24-inch pipeline to Qadirpur, and then independently of Qadirpur gas to Bhong compressor station (AC1X) via a 44-mile 30-inch pipeline. Its arrival pressure at Bhong is such that it is injected into the main transmission system upstream of compressor station AC1XS. Qadirpur gas is transported to Bhong via a 44-mile 36-inch pipeline and is compressed at compressor station AC1XQ before injection into the main transmission system downstream of station AC1XS. Both AC1XQ and AC1XS are installed at the same location i.e. Bhong, but compressing gases from Sui and Qadirpur separately. Provision is planned at Bhong for the transfer of additional gas from the Sui side to the Qadirpur side upstream of compressor station AC1XQ by the installation of the necessary control valves. Further compression facilities are installed in the main transmission system at AC4 (Uch), AC6 (Multan), AC7 (Shorkot) and AC8 (Faisalabad) to handle the increasing demand in the markets further north.

Guddu Thermal Power Station, Multan Power Plant, the Kot Addu Power Plant, the Muzaffargarh Thermal Power Station, Rousch Power Plant, Fauji Kabirwala Power Plant and Faisalabad Wapda power plant are the major off-takes in Leg-A. Leg–A also supplies gas to several major cities in Pakistan i.e. Bahawalpur, Multan, Faisalabad and Lahore (via Leg N and Leg B). The present flow handling capacity of the Sui-Bhong section is 770 MMscfd. However, the Bhong-Multan section is capable of transmitting 1,630 MMscfd of natural gas.

**Faisalabad to Jhelum (Leg–B)**

The pipeline system from Faisalabad to Jhelum consists of some 250 miles of pipelines, the diameters of which range from 8 inches to 24 inches. A 16-inch mainline, accompanied by a loop line of 24-inch diameter, runs from Faisalabad to Sheikhupura. From Sheikhupura, gas is transmitted to Lahore via Shahdara. Also from Sheikhupura, a 12-inch pipeline delivers gas to an industrial facility Dawood Hercules Chemicals, (D/H). The Shahdara Crossing on Ravi River consists of two 16-inch pipelines. Faisalabad to Jehlum pipeline section provides gas to major industrial and commercial consumers of the Company which are situated in Faisalabad – Gujranwala – Lahore triangle. Leg–B is interconnected with Leg–N at Bhaipheru with a 16-inch pipeline. This interconnection provides operational flexibility in providing gas to Lahore through Leg–N and Leg–B. Lahore is the largest city on Company’s transmission network in terms of gas demand which is currently being fed 60 % through Leg–N and 40% through Leg–B.

After the gas delivery point at Gujranwala, a 18- and 8-inch pipeline transmits gas for off-take at Jhelum, Gujrat, Sialkot and Wazirabad. Except for the final 62 mile 8-inch pipeline to Jhelum, much of this section is looped to meet the gas demand. To assist in fulfilling the gas demand of Faisalabad – Gujranwala – Lahore triangle, the compressor station at Mananwala, BC1, is provided.

**Faisalabad to Peshawar (Leg–C)**

Leg-C comprises the pipeline network from Faisalabad to Peshawar via Galli Jagir. It consists of some 325 miles of pipelines with diameters ranging from 6 inches to 30 inches. Leg–C supply gas to the major cities in northern areas i.e. Islamabad, Rawalpindi, Abbottobad, Peshawar and Industrial state at Wah – Hattar region. Compression requirements are met by stations at Haranpur (CC1) and at Galli Jagir (CC3). At CC3, gas from the northern fields - Moyal, Tut. Ratana, Pariwali, Dakhni and Gurgury - is also injected into the transmission system. The Ranyal pipeline is normally connected downstream of CC3, but, to save/utilize compressor power, is connected upstream of the station in winter.

The Chenab River crossing near Chiniot comprises one 12-inch line and a loop consisting of 18- and 30-inch diameter lines. Until the provision of the loops it was a major bottleneck for the transmission of gas to markets further north. A 12-inch main line, accompanied by a 30-inch loop line, is used at the Jhelum River crossing at Malakwal. At the Indus
River crossing near Attock, one 10-inch pipeline is used to transmit gas to markets in NWFP, namely Peshawar,Charsadda, Mardan, and Takht-i-Bai. A 64-mile spur line, of 10 and 8-inch diameter, supplies gas to Abbottabad from Wah.

**Qadirpur Rawan (AV29 V/A) to Lahore (Leg-N)**

This 180-mile pipeline serves as an additional loop to handle the transience of gas demand in Lahore and adjoining markets. It separates from Leg-A at the AV29 valve assembly at Qadirpur Rawan (downstream of AC6, Multan). A 24-inch pipeline is used for transmission from Qadirpur Rawan to Sahiwal and a 16-inch looped with an 18-inch pipeline transmits gas from the Sahiwal off-take to Lahore.

Lahore is thus supplied with gas via Leg-N and Leg-B. The loop line Bhaipheru on Leg-N to Dawood Hercules Chemicals (D/H) on Leg-B via Balloki provides a high-pressure connection between these legs. Currently the loop is isolated at the Leg-B end.

**Supply/Demand Scenarios**

**Gas Demand**

From a group of past studies [Ref. 1-5], the HBP 2002 report, *Pakistan Natural Gas Supply and Demand Analysis* prepared for ISGSL, was selected as a baseline study, i.e. a primary reference, for updating the supply and demand projections since it provided a complete set of assumptions for the development of the forecasts, and also included a seasonality analysis for residential, commercial, and power sectors in the country. Gas demand projections for the FY2005-FY2025 period were then analyzed and updated for the following sectors:

- Residential
- Commercial
- Fertilizer
- Cement
- General Industry
- Power
- Transport

A key assumption for this study was that gas demand would be met in full - there would be no planning for shortages. The following were other fundamental assumptions:

- FY2004 is the base year in the Study
- Indicated GDP growth rates were applied
- Figures for FY2005 and beyond, showing projected demand, include the unmet demand in industry and power sectors
- For purposes of this Study, WAPDA’s current expansion plans and plant-wise generation patterns were used as a key basis for the scenario modeling.
- Adjustments were made with respect to timing and capacity of new projects that could have a major impact on demand, including thermal and hydel power plants in the WAPDA system, as well as capacity additions in the fertilizer and cement sectors.

**Seasonality Analysis**

Seasonal variation in gas demand was considered for the power, residential, and commercial sectors. Gas demand for the industry sector was assumed to remain constant throughout the year, including fertilizer and cement units.

Variations in gas demand in the residential and commercial sectors occur mainly as a result of the use of natural gas to heat space and water in the peak winter months. In the case of the power sector, gas demand fluctuates because of the variations in the generation of electricity from hydroelectric plants, as well as seasonal variations in demand for electricity. Historically, gas supply has remained below demand, and supply to industry and the power sector has been curtailed in the winter months to meet the demand in the residential and commercial sectors. For the purpose of this study, however, it was assumed that gas would be available to meet the demand of the industrial consumers all year-round, and seasonal variations in demand were thus assessed assuming unconstrained supply.

To meet the seasonal swings, forecasts of demand on a monthly basis for the Company’s system were developed for the FY2010, FY2015 and FY2020 periods. The average annual gross demand was translated into monthly demand, based upon the monthly demand factors for the domestic, commercial, and power sectors, as obtained from the 2002 ISGSL primary reference report. The monthly demand projections for the Company’s system during FY2010, FY2015 and FY2020 under the ‘High’ and ‘Moderate’ demand scenarios were presented in the PPIAF January/05 *Long Term Gas Demand Projections Report* [Ref 6].

**Gas Supply**

In addition to the gas demands, it is necessary to identify all gas supplies to the network before building any hydraulic model. The list of currently producing fields identified the gas destination by pipeline operator (regional) and gas calorific value as well as the P-90 (Expected) and P-50 (anticipated) production profiles, on the basis of 950 Btu/scf, through to 2025.

From this information, further sheets were constructed to identify the supplies available to each network. A number of fields supply to one or more networks:
• Sui (to Northern and Southern networks)
• Sawan (to Northern and Southern networks)
• Zamzama (to Northern and Southern networks)
• Kandhkot (to Independent and Southern networks)

With the identification of the supply sources to each network, the supply rates were made available immediate transfer to the pipeline modeling software. Supply rates use the P-50 production profiles and are in standard volumetric volumes at field conditions, i.e., flows in MMscfd on the basis of the field’s calorific value.

**Supply/Demand Balance**

An overall gas balance can be determined based upon the average annual supply and demand rates for both the national grid and the individual sections within the Company’s and Sui Southern control. These reveal that there is a surplus of supply over demand up to, and including, 2009 for both the ‘Moderate’ and ‘High’ demand scenarios over the entire national grid. This is also true for both the Company’s and southern networks. However, using the supply allocations shows Company’s surplus would continue to 2010 for the ‘Moderate’ case, while, for the ‘High’ demand case, a shortfall would exist for the southern network in 2009. Hence, some reallocation of supply would be required to achieve a satisfactory balance in 2009. After 2009, demand is expected to rise rapidly, with the imbalance exceeding 1000 MMscfd by 2012 for the ‘Moderate’ demand scenario, and between 2011 and 2012 for the ‘High’ demand scenario. By 2014 for the ‘Moderate’ demand scenario and 2013 for the ‘High’ demand scenario, the shortfall over the national grid is anticipated to have reached 2000 MMscfd. Figure - 2 and Table - 1 illustrate the surplus/deficit, based upon average annual flows for the national grid. Equivalent figures for the Company’s network are presented in Figure - 3 and Table - 2.

When winter demand is considered, and assuming that no increase in the average annual supply rate is possible, an overall shortfall would exist from 2009 for the ‘High’ demand scenario, and from 2010 for the ‘Moderate’ demand scenario. A small shortfall of 18 MMscfd would exist over the two networks in 2007 and 95 MMscfd in 2008 for the ‘High’ demand scenario. It is possible that this might be covered from the Independents, assuming that the necessary connections were in place. However, only a full energy requirements balance would determine if such a shortfall actually existed. The hydraulic analysis would determine if supply re-allocation were required.

With the provision of storage of 300 MMscfd from 2009, and a further 400 MMscfd from 2011 within the Company’s network, no continuing shortfall would exist in this network until 2012 for both the ‘Moderate’ and ‘High’ demand scenarios. However, periodic shortfalls would exist in 2007, 2008 and 2010. For the ‘High’ demand scenario, small shortfalls of 1 and 8 MMscfd would exist in the Southern network in 2007 and 2008 respectively, though it is possible that this could be met by re-allocation of supply from the Company or the Independents. From 2009 onwards, the Southern network would require a further source, or sources, of gas to meet the projected demand growth. This illustrates that, while storage satisfies much of the growth in demand from 2009 to 2012, it cannot continue to meet the increase in demand as indigenous supplies decline. Winter demand projections show deficits of 2000 MMscfd occurring in years 2013 for the ‘High’ demand scenario, and 2014 for the ‘Medium’ demand scenario.

**Changes in Supply**

With the decline in indigenous production from 2010 and the increasing demand, gas imports will become necessary. At present demands are met from several large gas fields in Central Pakistan with a number of medium and smaller fields connected to the network and distributed throughout the region. Thus, the current network has been developed to distribute this production. Initially, imported gas will arrive by pipeline with a single point of unloading to the Company’s network. This, in itself, imposes different expansion criteria on the network than hitherto as gas will have to be moved away from the unloading point. Unloading will occur in the Multan area towards the southern end of the Company’s network as this is an area of high demand. The infrastructure to handle the initial imported gas flows is also present as the major producing gas fields lie relatively close. However, as demand grows and more gas is imported, it will have to be moved northwards so requiring infrastructure enhancements.

**Hydraulic Model**

**Overall Methodology**

The supply/demand projections were developed for two demand scenarios:

- ‘High’ demand scenario
  - GDP growth rate assumed at 6.5% for projection period
- Base or ‘Moderate’ demand scenario
  - GDP growth rate assumed at 5.5% for projection period

From these were developed the gas balances that defined all inflows and outflows to the Northern and Southern pipeline networks. These balances incorporated the factors to predict the gas flows required to meet the seasonal peak demands. The balances also accounted for:

- Flows from possible future gas storage,
- Flow from new discoveries, one in each of the Northern and Southern regions of Pakistan; and
Additional flow as required to balance supply and demand throughout the projection period. An optimal point for the injection of this gas into either or both networks was also determined.

The demand projections were developed on a region, sector and node basis. In such extensive networks, such as those in Pakistan, there are a large number of demand points distributed over the entire network. For example, the Company’s network has upwards of 250 such demand points. These range from large delivery quantities to power generation facilities, to small quantities delivered to towns. To adequately model the hydraulics of the networks, such distribution of demand had to be accounted for. However, it was unnecessary to model each individual take-off. An initial part of developing the gas balance involved defining how the loads were best distributed to adequately model the hydraulics of the two networks.

A gas balance was also developed for the movement of low or medium calorific value gas. The segregation of this gas into a separate network was reviewed from its impact on the main networks’ gas balances.

Using the gas balances, steady state simulations were run for the pipeline simulation model, commencing with the expected demands for 2004. This confirmed the viability of the current network to move the projected gas demands without the need for any enhancement. By advancing the year, the simulations would demonstrate the ability, or otherwise, of the network to handle the expected demand. At each stage the results were examined for restrictions or bottlenecks in the network. Restrictions examined were:

- compressor stations at, or approaching, their maximum installed power;
- high gas velocity (> 10 m/s) leading to high pressure losses in the pipeline and/or excessive compressor power consumption;
- inability to meet minimum pressure requirements to customers; and
- low pressure at compressor suctions, again causing excessive compressor power consumption.

The required network enhancements necessary to remove these restrictions were then developed. Such network enhancements included:

- increasing installed compression power at one or more stations;
- looping existing pipelines or sections of the pipeline; and
- a combination of both these enhancements.

The installation of each network enhancement was also reviewed for its ability to contribute to the network’s transportation capability for future years.

The outputs from the hydraulic simulation modelling were a series of network enhancements or possible options. These formed the input to the Economic/Financial Model so that each enhancement option could be evaluated. Typical outputs from the Hydraulic Model were:

- compressor incremental power or additional machines.
- pipeline lengths and diameters.
- pipe wall thicknesses for normal mechanical strength, and taking into account any increased wall thicknesses required in special locations, e.g., river crossings.
- pipeline locations.

Hydraulic Modeling Methodology

When modeling the network, the following fundamental considerations needed to be addressed:

- mass balance
- energy balance
- gas quality

The mass consideration was provided from the supply and demand scenarios that had to balance before any hydraulic calculations could be performed.

The energy balance was examined by considering heat losses and gains within the system. Typically heat is lost through the pipe walls and gained during compression. However, where the gas temperatures are similar to the surroundings, the energy balance can be ignored and the whole system can be considered to operate at a single uniform temperature. This removes a degree of complexity. Where long-term projections are being considered, the effects of ignoring temperature differences are usually small and can be ignored.

In the Company’s network, gases of widely differing qualities (calorific value) are supplied, while demands require a near constant calorific value. Such requirements must be met by blending gas within the network, or by processing the gas before it enters the network. Therefore, tracking of gas quality formed a fundamental part of the Study.

Three possible approaches to performing the hydraulic calculations were possible:
• using gas balances based on the flows normalized to 950 Btu/scf;
• using gas balances based on the un-normalized volumetric flows; or
• using gas balances based on energy demands, rather than flow.

The advantages and disadvantages of these approaches are outlined in Table 3.

The modeling software employed could perform the required calculations for any of the above approaches. However, it was preferred that energy demand flows be used as this represented the most common form of demand projections. [Note that a combination of energy and un-normalized volumetric demand flows could also be used.]

Modeling of compressors and the compressor stations can be performed to different levels of detail. For this study, the simplest compressor models were adopted as it was only necessary to determine the incremental power required, not the operability of the station or individual machines.

The modeling adopted the following approach:
• isothermal hydraulic modeling;
• un-normalized supply flows with gas quality or composition provided;
• energy or un-normalized delivery flows;
• tracking of gas qualities/compositions; and
• simple compressor models.

**Compressor Modeling**

The hydraulic simulations calculated the power required for compression given the gas flow, suction and discharge pressures. This was the power actually required to perform the given compression. To determine the installed driver power, assuming turbine drivers, the rated power of the driver needed to be determined. This was calculated from the required, or absorbed, power by applying the de-rating factors based on ambient temperature and elevation of the compressor station. Factors for typical inlet air and exhaust losses were also included as relevant. The rated power (ISO power) was used to determine the cost of either additional compression or a new compressor station, as cost estimates had to be based upon installed power. Typically, an installed compressor/turbine unit may have an installed ISO power rating of 6000 Hp, but will deliver only 5200 Hp of actual compression power at the installation site, due to its elevation and ambient conditions.

Calculation of ISO-power from the required compression power, and available power from the installed ISO-power, was based upon the factors outlined in the GPSA Handbook. Specifically for turbine drivers, the factors are:
• Turbine Inlet Losses
• Turbine Exhaust Losses
• Turbine de-rating due to elevation with respect to mean sea level.
• Turbine de-rating due to ambient temperature.

Installed power is determined from the above factors, and then rounding the number of units required based on a unit size. For new stations, one spare unit was included in the cost calculation.

Fuel usage was determined from the simulation. A major factor is the assumed efficiency of the compressors and drivers. For existing stations, actual compressor adiabatic efficiencies were taken as given by the company, and 78% for new stations; driver efficiency was assumed to be 25% for old stations, 30% for new.

For all operating compressor stations, suction and discharge losses, including piping, etc., were assumed to be 12 psi. These losses were accounted for in determining the compressor power requirements. For non-operating stations, the losses were assumed to be zero, i.e., the station was bypassed.

**SIMULATIONS**

All simulations were performed at steady-state. To enable a realistic assessment of the infrastructure enhancements required, pressures were not allowed to fall to their minimum values, so that an operating margin was maintained. Typically, where a minimum compressor suction pressure of 800 psig would normally be allowed, the minimum for modeling was instead maintained between 850 and 900 psig. When adding pipeline looping upstream of such stations, pressures higher than 900 psig are frequently found. This merely indicates that a short-term over-capacity would exist for this station.

Maintaining pressures above the minimum allowable also allows for upset conditions, such as the temporary loss of a compressor or other transient conditions like increase of needle peak gas demand during winter season. If the networks are subject to normal transient loads, such as diurnal swings, such loadings should be accounted for when determining precise infrastructure enhancements.

Using gas balances derived for the winter peak flow conditions, each of the existing networks was examined for its ability to meet the projected winter demands. It was assumed that all projected demands would be met, either from indigenous production, load curtailment, storage or imports.
New pipelines, looping or replacement pipes and/or new or expanded compression facilities were introduced incrementally into the network simulations, such that all necessary flow and pressure conditions were met. In general, new pipe would be of sufficient capacity that further replacement or looping of the affected section would not be required for some 5 to 10 years thereafter. Thus, following the addition of major new sections of pipe, an over-capacity might exist. Such over-capacity is usually reflected in reduced compression power requirements and compressor fuel usage.

For analysis of the expansion options, it was assumed that, once installed, compressor units would not be moved within the networks to cover shortfalls elsewhere in subsequent years. Similarly, stations that were no longer required, or whose requirements were to fall over the years, were not removed, and no credit was assumed in the economic/financial analysis if these units could be utilized elsewhere.

To examine the expansion options, hydraulic analysis was performed for each year to 2012. Thereafter, the periods 2013-2014, 2015-2016, 2017-2019, 2020-2022, and 2023-2025 were considered. This enabled realistic expansion plans to be investigated, while considering large growths in the demand. Taking too large a period span, say 5 years, could result in the introduction of too much capacity, while satisfying local pressure constraints. Such over-capacity could result in eliminating options due the high, but incorrect, cost.

In the Northern network, demand centers are widely distributed over the network, although there are some local concentrations, such as Multan and Lahore. In discussing the changes required to the network, it is convenient to consider the three main sections:

- **Leg-A**: mostly transmission line from Bhong to Faisalabad
- **Leg-B**: transmission and distribution to the Lahore area
- **Leg-C**: transmission and distribution to the Islamabad and Peshawar areas

A number of different approaches were simulated in enhancing the Company’s network:

- completion of a ring main on the northern distribution section of Leg-C; and
- addition of new transmission lines between Bhong or Multan and the northern sections of Leg-C. Routings considered were along the Indus and Jhelum Valleys, as well as paralleling the current Leg-A.

**Northern Enhancements**

Currently the Company has planned a new project (Project–9) for the absorption of additional gas from the Gurguri gas field which is situated in the northern region of Pakistan. The producers have committed to supply 300 – 350 MMscfd gas to the Company from the Gurgury gas field. As the Gurgury field is located at the tail of a branch with Leg-C, major infrastructure enhancements would be required to absorb this gas. To avoid major infrastructure developments and costs, a critical analysis of Leg–C was performed for all the demand nodes. Cyclic demand patterns of all the nodes were developed in order to maximize the absorption of the additional gas from Gurgury into the region from Faisalabad to Peshawar. This will result in minimum transmission of gas from the main network (Leg-A) to Leg–C.

For the effective utilization of the Gurgury gas and to take maximum advantage of gas pressure from the producer, a 24-inch diameter pipeline is planned to be laid from the Gurgury gas field to Kohat and then from Kohat to Nowshera (near Peshawar). The selection of Nowshera termination point is based on the fact that from this point the gas can be distributed easily to the Mardan – Takht-i-Bai section or to the Peshawar region and reverse flow to the existing system through Indus crossing (10-inch and 24-inch lines), at the same time giving pressure improvement in all lines in the North-West area. Gas from Dakhni, Meyal, Tut, Ratana will be utilized for supplying gas to Islamabad through Ranial delivery node. Only a minor portion of Gurgury gas will be moved into the Kohat – Dakhni network to avoid flaring at fields and to avoid any looping or additional compression at the FC-1 compressor station. A detailed study of cyclic pattern of Islamabad demand revealed that the total gas supply from Dakhni, Tut and Meyal gas fields can be completely utilized in summer as well as in winter. Steady state simulations show that CC3 and CC1 compressor stations will not be required normally due to reverse flow of gas from Gurgury gas field. However, both these stations will still be required during transient conditions on peak days during the winter season.

**Compressor Fuel Requirements**

Project-9 also sought to minimize the compressor fuel consumption across the entire Company’s network. For this a new approach was developed to strengthen Leg-N. By strengthening Leg-N, a major portion of the gas will be shifted from Leg-A to Leg-N at point AV29 (Qadirpur Rawan). The gas for Lahore and Dawood Hercules will be diverted from Leg-A to Leg-N. This will amount to an immediate reduction of approximately 500 MMscfd in Leg-A and Leg-B. By strengthening Leg-N, the gas for Lahore and Dawood Hercules which was arriving at the respective destinations after compression and recompression at AC7, AC8 and BC1 compressor stations, will arrive at the destinations through Leg-N without any compression. This will result in fuel saving at the above mentioned compressor stations. The annual amount of fuel saving is approximately 1600 MMscf. Leg-N
will be strengthened by laying a 36-inch diameter pipeline and uplifting the current 24-inch diameter pipeline from AV29 to Sahiwal. The uplifted 24-inch diameter pipeline will be re-utilized and relayed from Sahiwal to Lahore. Further redistribution of the Lahore load to Leg-B and Leg-N will be accomplished through the Bhaipheru cross connection. By this means the pressures in Leg-A and Leg-B will significantly improve and more capacity will become available to provide gas to the potential consumers in Faisalabad – Gujranwala – Lahore triangle. Steady state simulations show significant decrease in horsepower requirements of above mentioned compressor stations. Thus no additional looping or decrease in pressure will be required for Leg-B in this scenario.

Other Mainline Routings

With the consideration of storage to meet the winter peak demands, it was determined that up to 2014 or later, depending upon the level of storage provision, only small incremental enhancements would be required in the main transmission line, Leg-A. However, as demand, and therefore, imports, increased thereafter, further looping of the existing line would not necessarily be the best solution (by 2025, the southern sections of Leg-A would consist of 7 to 8 parallel 36-inch diameter loops). Also, as demand in NWFP grew and exceeded the local supply, including storage, large northbound flows would be required in Leg-C. This would require extensive looping and/or additional compression facilities to create the necessary capacity. Hence, different routings were considered to meet these demands:

- from Bhong along the Indus Valley (west bank) to Kot Addu and Multan
  This effectively would parallel the existing Leg-A from Bhong to Multan, but on a different alignment. From Kot Addu, the new line would follow the Indus Valley to link with the proposed Kohat to Nowshera line.

- from Multan (Compressor Station AC-6) along the Jhelum Valley (west bank) to compressor station CC-3 (Galli Jagir) on Leg-C
  This would provide a parallel transmission line to the transmission part of Leg-C. However, it would not necessarily reduce the levels of enhancement required in the northern sections of Leg-C, i.e., north of Galli Jagir.

- from Bhong to Faisalabad paralleling the present Leg-A
  However, the new line has been considered as separate transmission line dropping off load at compressor stations AC-6, AC-7 and AC-8 that is then distributed using the existing system. Its alignment need not follow that of the existing Leg-A except for the noted connections. It could also provide supplies to major demand centers in its own right.

Parts of, or all, these proposed routings would parallel the existing main transmission section, Leg-A. For these sections, a minimum pipeline diameter of 48-inch was adopted to minimize the future looping. The line would also operate up to 1380 psig. This would enable the pipeline to retain Class 600 fittings, but might require Class 900 within the compressor stations.

It was also determined that paralleling the total length of Leg-A in one year would be unnecessary. The line was extended from station to station, northwards from Bhong, as imports grew over the period from 2014 to 2025. In particular, the provision of storage would have a major effect on when such lines would need to be introduced.

The first two of the above proposed routings would pass through areas of Pakistan where there is little or no provision of natural gas supplies, and hence no major demand centers. The provision of such supplies might provide the necessary incentives for the development of industry and other demand centers along the routes. The costing of such benefits has not been considered in this Study.

Also the alternative routings for moving gas to the northern areas would only become viable as demand in these areas were to exceed the local supply, including storage. Hence, these lines would only need to be considered from around 2020 onwards, unless storage facilities were not provided.

Simulation of the network is based on two strategies:

- Hydraulic conditions based on predicted loads such that all pressure, flow and velocity conditions are satisfied. Pressures were determined at the operational, not minimum, levels to retain realistic design conditions. All compressor stations were unlimited in power.

- Investment strategy - incremental costs were incurred as required such that investments in the network expansion were spread over the 20-year period. This provides for the optimization of the incremental network expansion.

Hydraulic simulations were performed as follows:

- Evaluate current network for peak load conditions in 2004/5 to establish expected operating conditions and to check for any network limit anomalies. None were found.

- Increment loads and gas supplies as defined by the gas supply/demand balance including storage flows as necessary. Supply/demand patterns were applied annually for 2005-2012, thereafter for 2014 and 2016
and tri-annually beyond 2016. It was assumed that any shortfall in domestic production would be met by imports through the selected injection point.

- For each supply/demand scenario, the previous network was used as the basis to provide a platform on which to develop the necessary expansions to handle the increased loads. With the increased load and corresponding supply scenario, the network was inspected for pressure and flow (velocity) failures. New pipelines (new routes) and pipeline looping was then introduced to resolve the failures. Required compressor power is calculated in all cases.

- A new pipeline routing or alignment was introduced when looping of Leg-A of the Company’s network exceeded 4 parallel lines. This was usually from 2014/2016 onwards when increases in demand required the use of pipes greater than 36 inches to transport gas away from the Bhong injection point.

- Network enhancements ignored other issues and limitations such as security of supply, environment, and geographical.

- From the incremental enhancements, tables of additional, cumulative pipe and installed compressor power were determined and extracted for each enhancement scenario. To these were applied the cost factors for pipeline (US$ per inch diameter mile) and compression (US$ per HP installed). These data formed the input to the financial analysis following the application of the base investment year. The latter accounts for investment that has already been planned and sanctioned.

**CONCLUSIONS**

With the addition of Kohat – Nowshehra Pipeline and by strengthening Leg-N, steady state results show a major cut in internal fuel consumption and operating costs. Moreover two systems, i.e., compression and pipeline based will be available to provide extra capacity from AV29 to Lahore.

The results of the hydraulic calculations in terms of the incremental infrastructure requirements (i.e. pipeline upgrading, new pipelines, additional compression, and storage) formed the basis for the economic and financial evaluation. The costs were calculated on an incremental basis, using the 2004 simulations as the Base Case.

From these routing cases, a number of conclusions were drawn.

- There is little to choose between the different Company routing options proposed. More detailed studies and cost analyses would be required to evaluate these options.

- The different routings should be actively studied for the years beyond 2014, or later depending upon the storage options implemented. Up to this time, the additional imports could be handled by upgrades / additional looping to the Company’s network. After this time, new transmission lines would be required north of Bhong / Multan.

**AUTHORS**

Saulat Rashid Lone is a Project Engineer in Sui Northern Gas Pipelines Limited, Pakistan. Currently he is working as a Pipeline Design Engineer and responsible for the design and planning of high pressure natural gas transmission pipeline network. His key experience is in project conceptualization, hydraulic designing and implementation of cross-country pipeline projects. Prior to that, Mr. Lone has worked as a Process Engineer in Engro Chemicals Pakistan Limited (Former Exxon Chemicals). Mr. Lone earned a BS and MS degree in chemical engineering from the University of Engineering and Technology, Lahore, Pakistan. He is a professional engineer and member of Pakistan Institute of Chemical Engineers.

Richard Spiers joined Energy Solutions (formerly LICEnergy, formerly SSI) in April 1984 as a Consultant after leaving BP Engineering where he provided simulation support within the Central Engineering Department. During his time with Energy Solutions he has worked on development, integration, implementation and support of many Real-Time Pipeline Modelling Systems as well as providing consultancy services. In particular, he was the senior modeling consultant for a study of the expansion of the Pakistani gas networks performed for the Ministry of Petroleum and Natural Resources (Gas) in 2004.

**REFERENCES**

2. *Utilization of Gas from New Discoveries*. Prepared by HBP for Sui Northern Gas Pipelines Ltd. (SNGPL) and Sui Southern Gas Company Ltd. (SSGCL), 2001

**ACKNOWLEDGEMENTS**

The authors gratefully acknowledge the permission of Sui Northern Gas Pipelines Limited to publish this paper.
# TABLES

<table>
<thead>
<tr>
<th>Gross Demand Country</th>
<th>FY04</th>
<th>FY05</th>
<th>FY10</th>
<th>FY15</th>
<th>FY20</th>
<th>FY25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate Demand</td>
<td>2,593</td>
<td>3,134</td>
<td>4,120</td>
<td>5,272</td>
<td>6,735</td>
<td>8,725</td>
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<tr>
<td>High Demand</td>
<td>2,593</td>
<td>3,161</td>
<td>4,383</td>
<td>5,877</td>
<td>7,865</td>
<td>10,771</td>
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</table>

<table>
<thead>
<tr>
<th>Gas Supply</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Transmission System</td>
<td>2,947</td>
<td>3,187</td>
<td>3,404</td>
<td>2,276</td>
<td>1,378</td>
<td>469</td>
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<tr>
<td>Independent Supplies</td>
<td>562</td>
<td>654</td>
<td>680</td>
<td>630</td>
<td>563</td>
<td>90</td>
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<tr>
<td>Total Supplies</td>
<td>3,509</td>
<td>3,841</td>
<td>4,084</td>
<td>2,906</td>
<td>1,914</td>
<td>559</td>
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</table>

<table>
<thead>
<tr>
<th>Surplus/(Deficit)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate Demand</td>
<td>916</td>
<td>707</td>
<td>(36)</td>
<td>(2,366)</td>
<td>(4,821)</td>
<td>(8,166)</td>
</tr>
<tr>
<td>High Demand</td>
<td>916</td>
<td>680</td>
<td>(299)</td>
<td>(2,971)</td>
<td>(5,951)</td>
<td>(10,212)</td>
</tr>
</tbody>
</table>

Note: Figures for FY2004 represent actual gas consumption.

Table 1 – Pakistan Natural Gas Supply/Demand – 2004 through 2025

<table>
<thead>
<tr>
<th>Gas Supply</th>
<th>FY04</th>
<th>FY05</th>
<th>FY10</th>
<th>FY15</th>
<th>FY20</th>
<th>FY25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td>1,789</td>
<td>1,893</td>
<td>1,763</td>
<td>1,204</td>
<td>365</td>
<td>117</td>
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<tr>
<td>Anticipated</td>
<td>5</td>
<td>26</td>
<td>350</td>
<td>278</td>
<td>418</td>
<td>208</td>
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<tr>
<td>Total Gas Supply</td>
<td>1,794</td>
<td>1,919</td>
<td>2,113</td>
<td>1,482</td>
<td>783</td>
<td>325</td>
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</table>

<table>
<thead>
<tr>
<th>Gas Demand</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>1,237</td>
<td>1,484</td>
<td>1,980</td>
<td>2,629</td>
<td>3,729</td>
<td>5,048</td>
</tr>
<tr>
<td>High</td>
<td>1,237</td>
<td>1,505</td>
<td>2,108</td>
<td>2,927</td>
<td>4,352</td>
<td>6,261</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surplus/(Deficit)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate Demand</td>
<td>557</td>
<td>435</td>
<td>133</td>
<td>(1,147)</td>
<td>(2,946)</td>
<td>(4,723)</td>
</tr>
<tr>
<td>High Demand</td>
<td>557</td>
<td>414</td>
<td>5</td>
<td>(1,445)</td>
<td>(3,569)</td>
<td>(5,936)</td>
</tr>
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</table>

Table 2 – Northern Network Gas Supply/Demand – 2004 through 2025
<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Normalized volumetric flows</strong></td>
<td>Simple to apply</td>
<td>Inaccurate hydraulic calculations where gas supply qualities differ widely.</td>
</tr>
<tr>
<td></td>
<td>Single gas quality or composition can be used in hydraulic calculations</td>
<td>Calculations of normalized flows, both supplies and demands, performed in spreadsheets</td>
</tr>
<tr>
<td><strong>Un-normalized volumetric flows</strong></td>
<td>Accurate hydraulic calculations</td>
<td>Gas quality or composition must be known for each supply.</td>
</tr>
<tr>
<td></td>
<td>Gas supplies given as flow projections</td>
<td>Gas quality at demand location is calculated. Gas balance must be applied iteratively if quality does not match that required.</td>
</tr>
<tr>
<td><strong>Energy flows</strong></td>
<td>Accurate hydraulic calculations</td>
<td>Gas quality or composition must be known for each supply.</td>
</tr>
<tr>
<td></td>
<td>Gas supplies given as flow projections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gas demands given in energy terms.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydraulic calculations performed to deliver required energy for the determined gas quality.</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 – Relative Merits of Alternative Approaches to Performing Hydraulic Calculations
Figure 1 – Sui Northern Gas Pipelines Limited transmission system network
(as on 30 – 06 – 2005)
Figure 2 – Pakistan Natural Gas Supply/Demand Outlook.

Figure 3 – Northern Network Natural Gas Supply/Demand Outlook.