AN INTEGRATED SIMULATION STUDY OF GAS PIPELINE NETWORK IN BANGLADESH

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A Project

By

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RECOMMENDATION OF THE BOARD OF EXAMINERS

The project entitled as **"AN INTEGRATED SIMULATION STUDY OF GAS PIPELINE NETWORK IN BANGLADESH"** submitted by Md. Lutfur Rahaman, Roll No: 0412132028(F), Session April 2012, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Master of Engineering in Petroleum Engineering** on December 12, 2015.

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Declaration

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

Bangladesh is considered a natural gas rich country. Twenty six gas fields have been discovered in Bangladesh out of which 19 (nineteen) fields are producing gas at present through 92 producing wells. The natural gas transmission pipeline infrastructure in Bangladesh that delivers about 2500 MMSCF of natural gas per day, and is made up of over 2406.82 km of pipe. At present a parallel pipeline (36" × 137 km) is being commissioned for transmitting additional gas from Bibiyana to Dhanua. Another 177 km new pipeline is going to be added to the existing network after completing the river crossing operation in Padma River, to include Kushtia, Jessore and Khulna regions.

To meet the future demand, the existing pipelines are not enough to transmit large volume of gas. Before taking up construction work of new transmission lines, an extensive study of a pipeline network simulation model for this country is required. A mathematical model to simulate pipeline system operation is constructed covering this entire existing system. The model is first validated by matching with the existing network using known data. Sensitivity studies are performed to investigate the effect of supply-demand fluctuations. In this project work commercial software "PIPESIM" is used for gas pipeline network analysis and simulation.

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ACRONYMS

AGA	American Gas Association.
AGMS	Ashuganj Gas Manifold Station.
API	American Petroleum Institute.
BCF	Billion Cubic feet.
APCL	Ashuganj Power Company Limited
AFCL	Ashuganj Fertilizer Company Limited
BGFCL	Bangladesh Gas Field Company Limited.
BGSL	Bakhrabad Gas System Limited.
BOC	Burmah Oil Company.
BPDB	Bangladesh Power Development Board.
CEGIS	Center for Environment and Geographical Information Services.
CFH	Cubic Foot per Hour
CGS	City Gate Station
CNG	Compressed Natural Gas.
CS	Compressor Station.
CWC	Concrete Weight Coating.
DPP	Development Project Proposal.
EPZ	Export Processing Zone.
GIIP	Initial Gas in Place.
GPSA	Gas Processors Suppliers Association.
GPM	Gallon Per Thousand Cubic Feet.
GTDP	Gas Transmission and Development Project.
GTCL	Gas Transmission Company Limited.
GUFF	Ghorashal Urea Fertilizer Factory
GPS	Ghorashal Power Station
HDD	Horizontal Directional Drilling.
ID	Internal Diameter
IOC	International Oil Company.
JGTDSL	Jalalabad Gas Transmission and Distribution System Limited.
JFCL	Jamuna Fertilizer Company Limited
JDP	Joydebpur

KGDCL	Karnafuli Gas Distibution Company Limited.
KTL	Kailastila.
LGR	Liquid Gas Ratio.
LNG	Liquid Natural Gas.
MMscfd	Million cubic feet per day at standard condition.
NGC	National Gas Company.
NWPGCL	North-West Power Generation Company Limited.
OD	Outer Diameter.
OGDC	Oil and Gas Development Corporation.
Petrobangla	Bangladesh Oil, Gas & Mineral Corporation.
PGCL	Paschimanchal Gas Company Limited.
PPL	Pakistan Petroleum Ltd.
PSOC	Pakistan Shell Oil Company.
PUFF	Polash Urea Fertilizer Factory
QMS	Quality Management System.
RDDP	Revised Development Project Proforma/Proposal
RPCL	Roghurampur Power Company Limited
SGCL	Sundarban Gas Company Limited.
SGFCL	Sylhet Gas Field Company Limited.
STANVAC	Standard Vacuum Oil Company.
STB	Standard Stock Tank Barrel.
STP	Standard Temperature and Pressure.
TBS	Town Border Station.
TGTDCL	Titas Gas Transmission and Distribution Company Limited.
WT	Wall Thickness.

CHAPTER 1

INTRODUCTION

Bangladesh is a country of opportunities, and the petroleum industry is one of the major sectors. Countrywide well established infrastructure, advanced telecommunication facilities, growing middle-class with substantial economic capacity and fast growing need for power have attracted International Oil Companies (IOC) to invest in the petroleum sector of Bangladesh. Bangladesh constitutes the largest deltaic basins of the world with sediments deposited and has proven its ability to generate significant hydrocarbon resources. [1]

Various national and international companies used to carry out wild cat exploration in the potential areas of Bangladesh. The exploration works have so far been discovered 26 (twenty Six) gas fields including 1(one) offshore gas field and 1 (one) oil field [2]. The way of transportation of gas either by pipeline or by cylinder/vessel in the form of CNG. But the most economical, easiest and safe way of continuous transportation of large volume of gas is transportation by pipeline. In Bangladesh, National Gas Grid is operated by Gas Transmission Company Limited (GTCL), a state owned company under Petrobangla, dividing the transmission system into two operational regions such as Transmission East (Dhaka, except greater Faridpur district, Sylhet and Chittagong divisions) and Transmission West (Rajshai, Khulna and Barisal divisions including greater Faridpur district) [3].The West Zone comprises geographical area on the west side of the rivers Jamuna and lower Meghna, which means Khulna, Rajshahi, Barisal divisions and greater Faridpur district of Bangladesh [4].

All gas fields are situated in the Eastern, North-Eastern and South-Eastern side of the river Jamuna, naturally, most of the principal demand area and major gas consumers in the Transmission East area along with capital Dhaka have been brought under gas transmission and distribution network. The transmission lines, operated by the transmission and distribution companies of Petrobangla, are also situated in the eastern part of the country.

A detail study is required to know what quantity of gas at customer's required pressure would be possible to transmit through the entire network as well as to the West Zone by the present upstream pressure.

The project aims to build virtual network models for existing pipeline network along with extended pipeline by using commercial software "PIPESIM". This work is done to simulate and to analyze some sensitivity studies on the entire network from which various scenarios would come up such as pressure drop along the pipeline at different junctions/outlets when gas flow rate varies effectively, maximum gas flow rate at minimum required outlet/downstream pressure and minimum pressure at maximum required flow at demand centers under the network, the effect of compressors to the network after installation at Elenga.

CHAPTER 2

SCOPE OF THE STUDY

2.1Objectives of the study

The specific objectives are:

- To analyze the existing gas pipeline network before commissioning of Bibiyana-Dhanua pipeline in Bangladesh.

- To validate the Model with both Field data and Analytical value in terms of pressure and flow rate.

- To observe the pressure scenario along the pipeline at different junctions, District Regulating Station (DRS) and City Gate Station (CGS) when gas flow rate varies effectively.

- To observe the effect of newly constructed parallel gas transmission pipeline (36" × 137 km) from Bibiyana, Hobigonj to Dhanua, Gazipur.

- To analyze the effect of additional gas from LNG through transmission pipeline (30" × 90 km) from Moheshkhali to Chittagong Ring-Main (Fouzdarhat).

- Check bottlenecking in the whole pipeline network if any.

2.2 Methodology

The Project involves network modeling and analysis of gas transmission pipeline. The aim of the project is to analyze some sensitivity studies i.e. specify the known inlet/outlet pressure and flow rate and calculate the corresponding gas pressure and flow rate at various sets of inputs.

In this project work network models for existing gas transmission pipeline network along with extended or newly commissioned pipelines, are built by using PIPESIM software. A virtual network model comprises of physical model and fluid model. Among others, pressure drop and volume of flow depend on pipeline length, diameter, wall thickness, efficiency factor etc. which are considered to build the physical model.

For the simulation, a fluid model is defined according to the sales gas specification data of GTCL. The fluid model is the main prerequisite that should be defined first while building a simulation network model. To create a fluid model, amount of water and liquefiable hydrocarbons are also defined along with gas composition as pressure drop in pipeline largely depends on these fluid properties. Black Oil Fluid Model is defined in this simulation network. The fluid used in the model is a mixture of natural gas of several gas fields taken from Ashuganj Gas Manifold Station (AGMS) in September 2010 and the defined gas compositions are shown in Table 4.1.

Table 4.1: Used Fluid Model [5]

Element	**% Mole**
Nitrogen	0.331
CO_2	0.101
Methane	96.518
Ethane	2.091
Propane	0.458
i-Butane	0.159
n-Butane	0.086
i-Pentane	0.049
n-Pentane	0.032
Hexane	0.092
Heptane	0.074
Octane	0.011
Total	**100.00**

Specific Gravity: 0.5805 at Base Condition: 60°F & 14.696psia

Ideal Density: 0.0443 lb/ft^3

Real Density: 0.0444 lb/ft^3

Mole Weight: 16.8123 gm/mol

C5+: 0.0951 GPM (gallon per thousand cubic feet)

Effect of temperature gradient is not considered and 60ºF of gas temperature is considered all through the pipeline. The Watercut and Liquid Gas Ratio (LGR) are considered 0% and 0 STB/MMscf respectively to represent the fluid in the model as gas.

There are numbers of equations for long pipelines such as the Weymouth, Panhandle A, and Panhandle B equations to simulate compressible gas flow. These equations were developed from the fundamental energy equation for compressible flow, but each has a special representation of the friction factor. The selection of appropriate flow equation/correlation for a particular pipeline is very important and it requires detailed study on selection criteria such as flow characteristics viz. turbulent/laminar flow, flow rate, operating pressure, percentage of pressure drop etc. and length/diameter of pipeline. In these models Beggs and Brill Revised fluid flow correlation has been used for horizontal flow assuming there is no vertical flow in the network and Panhandle 'B' correlation has also been used for single phase flow considering the fluid as 100% gas. The friction factor is considered 1.

To validate the network model, pressure at different junctions, District Regulating Station (DRS) and City Gate Station (CGS) compare with both field data from the existing outlets and the simulated data obtained from existing gas transmission pipeline network analysis by PIPESIM software. The simulated data is validated with the actual data from the Gas Transmission Company Limited (GTCL) data sheet on a specific date. Once the network model is validated, it can be used to perform several sensitivity studies.

CHAPTER 3

SCENARIO OF GAS SECTOR IN BANGLADESH

3.1 A brief history of natural gas in Bangladesh

The beginning: up to 1947

The search for oil and gas in the area constituting Bangladesh began in the later part of the 19th century through some isolated geological mapping. The first serious attempt to find oil and gas was undertaken in Sitakund in 1908 by the Indian Petroleum Prospecting Company, 18 years after the first oil discovery in Digboi, Assam. During 1923-31 Burmah Oil Company (BOC) drilled two shallow wells in Patharia. The wells were abandoned though there was a reported show of oil. A total of 6 exploratory wells were drilled, the deepest being 1047 meters. There was, however, no discovery and the Second World War disrupted further activities [2]

The interim: 1948 to 1971

The promulgation of Petroleum Act in 1948 generated a lot of interest in oil and gas exploration by international oil companies. The Standard Vacuum Oil Company (STANVAC) of USA, Pakistan Petroleum Ltd. (PPL), Burmah Oil Company affiliate and Pakistan Shell Oil Company (PSOC) carried out exploration till the end of the sixties. STANVAC drilled 3 wells at Hazipur, Bogra and Kuchma in the north-western part of the country without success. PPL drilled wells in Haripur, Patharia, Chhatak, Fenchuganj, Patiya and Lalmai and made the first gas discovery in Haripur in 1955, followed by Chattak in 1959. PSOC was the most successful company and discovered 5 gas fields named Titas, Habiganj, Rashidpur, Kailashtila and Bakhrabad. They also drilled the first offshore well Cox's Bazar-1, which was dry. Oil and Gas Development Corporation (OGDC) was established in 1961 providing an institutional foundation for exploration of oil and gas in the country. OGDC carried out geological and geophysical surveys including gravity, magnetic and seismic types and drilled wells in Jaldi and Semutang, discovering gas in Semutang in 1970 [2]

The way forward: 1972 to 1979

After the independence of Bangladesh, exploration activities by both national and international companies gathered pace. Bangladesh Oil, Gas and Mineral Corporation (Petrobangla) continued its exploration efforts while the Bangladesh Petroleum Act was passed in 1974 to facilitate international participation under Production Sharing Contract (PSC). The offshore area of Bangladesh was divided into 6 blocks, which were taken up by Ashland, ARCO, BODC (Japex), Union Oil, Canadian Superior Oil and Ina Naftaplin under PSCs. These companies carried out gravity, magnetic and seismic surveys (about 32,000 km) and drilled 7 wells. Of them, only Union Oil Company discovered an offshore gas field Kutubdia in 1977. This phase of PSC ended in relinquishment of the blocks by the PSC operators in 1978. On 9 August, 1975, Government led by the Father of the Nation Bangabandhu Sheikh Mujibur Rahman purchased five gas fields, namely Titas, Habiganj, Rashidpur, Kailashtila and Bakhrabad from British company, Shell Petroleum Company Limited, for a nominal amount of 4.5 million pound sterling. This landmark decision taken by the then Government laid the foundation of energy security of the country by introducing sole ownership of the state over these major gas fields [2]

Gathering momentum: 1980 onwards

The 1980s saw accelerated exploration activities by Petrobangla. During the time, 12 exploration wells were drilled at Muladi, Begumganj, Singra, Beanibazar, Atgram, Feni, Fenchuganj, Sitakund, Bogra, Kamta, Marichakandi (Meghna) and Belabo (Narshindi); and 7 gas fields were discovered at Begumganj, Beanibazar, Feni, Fenchuganj, Kamta, Marichakandi (Meghna) and Belabo (Narshindi). Among these, Fenchuganj # 2 well remains the deepest one drilled so far in Bangladesh (4,977m). Meanwhile, a new milestone was achieved when Petrobangla discovered the first commercial oil pool in Sylhet # 7 on 23December, 1986. Since 1989, after the formation of BAPEX as the national exploration company and thereafter exploration and production company, the company has continued exploration and production activities and drilled 4 exploratory wells discovering gas at Shahbazpur, Saldanadi, Srikail and Sundalpur. In 1981 Shell Oil Company (Shell) was awarded the Chittagong Hill Tracts for petroleum exploration under PSC. Shell conducted geological and seismic survey and drilled the Sitapahar well which was dry. Subsequently Shell undertook exploration in the extreme North West of the country and drilled the first well in the area - the Salbanhat well which was also dry. In 1988 Scimitar Exploration Limited was awarded another PSC of what is now block # 13 in the Surma basin. They failed to prove the extent of the oil discovery at Sylhet structure but discovered the Jalalabad gas field. Formulation of National Energy Policy, 1996 and adoption of a model production sharing contract (PSC) document together with redefining the whole of Bangladesh territory into 23 exploration blocks ushered in a new phase of exploration and development of oil and gas in the country. In the first stage under the new arrangement, 8 blocks were awarded to 4 companies under PSC. Exploration and development activities in these blocks were rather limited and most of the blocks were moderately covered by seismic surveys. A total of 11 exploration wells were drilled and 3 gas fields were discovered in these blocks. These fields are Moulavibazar, Sangu (offshore) and Bibiyana. These 3 fields along with Jalalabad gas field discovered by Scimitar Exploration Ltd. were developed under PSC and are currently in production. The first 3D seismic survey of the country took place in Bibiyana during its appraisal. Bibiyana came under production in March, 2007. Another PSC bidding round during the late nineties culminated in awarding 4 more blocks. These were SHELL/CAIRN/BAPEX in blocks # 5 and 10, UNOCAL/BAPEX in block # 7 and TULLOW/ CHEVRON/TAXACO/BAPEX in block # 9. Exploration activity was conducted in these blocks. Substantial activities were undertaken in block # 9 only, where 5 exploration wells were drilled on the basis of seismic survey including 3D seismic. The Offshore Bidding Round 2008 being limited to newly-formed deep water blocks attracted some bids. However, the ensuing maritime boundary dispute in most of the blocks created a stalemate. In this backdrop, two blocks were negotiated with Conoco Phillips and a PSC for two blocks was signed in 2011. Conoco Phillips completed the initial seismic survey in the blocks. They relinquished these blocks in 2014 without drilling any exploratory well. After the resolution of the Maritime boundary dispute with Myanmar by virtue of the judgment awarded on 14 March, 2012 by International Tribunal for the Law of the Sea (ITLOS), the deep water blocks on the eastern part were rearranged. This is a widely acclaimed achievement of the Government led by Honorable Prime Minister Sheikh Hasina. The Bangladesh Offshore Bid Round 2012 was announced in December 2012 and substantial initial response was received. Under this Bid round, three shallow water PSCs have been signed with ONGC Videsh, Oil India & BAPEX for blocks SS-04 and SS-09. Santos, Kris Energy and BAPEX for block SS-11. Deep water bids, received in January, 2014, are now being processed. Since the signing of the PSC's, several changes in ownership and restructuring in the contracts have taken place. All of the onshore PSC's have matured from the exploration phase to the production phase and major areas of the blocks have been relinquished. As of December, 2014 PSC's are active in production areas of blocks 12, 13 and 14 (Bibiyana, Jalalabad and Maulavibazar Gas Fields) operated by Chevron. Even though exploration history of oil and gas in Bangladesh goes back almost a century, exploration density could not be enhanced as much it is required to convert domestic oil and gas resources into proven reserves. However, the exploration success ratio is high as of about 1 in 3 wells. PSC explorations were also contributing to the enhancement of gas production. As of December, 2014 out of 26 gas fields discovered, 19 were under production. Meanwhile, peak gas production per day crossed the level of 2,600 MMCFD wherein average daily gas production remained more than 2,500 MMCFD by December, 2014. Despite increase in production, the rising demand could not be met and the gap between supply and demand is widening. As such the government has taken steps to import LNG to minimize the gap. [2]

3.2 History of gas pipeline in Bangladesh

Generally natural gas fields are situated in the remote areas in Bangladesh. But the gas consumers are situated mainly in the urban areas, suburbs and industrial areas. In order to bring the gas to consumer’s premises it is essential to construct gas transmission pipe lines, stations (CGS, TBS, DRS and RMS etc.) and distribution networks. When the maximum allowable operating pressure (MAOP) of a pipeline is above 10 bars it is known as transmission and when the MAOP is below or equal to 10 bars it is known as distribution pipeline.

The first commercial use of gas in Bangladesh began in 1960 with the construction and commissioning of Chattak Cement Factory (Ex-Assam-Bengal Cement Factory). The gas was supplied from Chattak (Tengratilla) gas field through 4 inch diameter 19 kilometer transmission pipeline which is known as the first transmission pipeline in Bangladesh. The second transmission pipeline (psig) was constructed & commissioned in 1961 from Sylhet (haripur) gas field to Natural Gas Fertilizer Factory (NGFF), fenchuganj, Sylhet.

Gas Transmission & Distribution widely started in 1968 when Titas Gas Transmission & Distribution Company Ltd. (TGTDCL) completed its 14 inch diameter 821 kilometer Transmission pipeline from Titas Gas Field (B'Baria) to Demra with a spun line (Transmission pipeline) from Narshingdi to Ghorashal Industrial Area.

Gas fields have different wellhead pressure and after processing the raw gas to pipeline quality the gas is supplied to Transmission pipelines usually at 1000 psig (about 70 bar) in Bangladesh. But sometimes this pressure may be above 1150 psig and less than 500 psig as per requirement. [3]

3.3 Natural gas transmission system of Bangladesh

Gas Transmission Company Limited (GTCL) is now responsible for maintenance and operation of the gas transmission pipeline across the country. At present Gas is Produced by state owned enterprises i.e. companies of Petrobangla and International Oil Companies (IOC). Among them Bangladesh Gas Field Company Ltd (BGFCL), Sylhet Gas Field Company Limited (SGFCL), Bangladesh Petroleum Exploration and Production Company Limited (BAPEX) are the state owned companies of Petrobangla. The IOC's are Chevron Bangladesh, Tullow Bangladesh Limited and Santos.

Currently Six companies of Petrobangla are responsible for distributing gas in their franchise areas. The marketing companies are:

- Titas Gas Transmission and Distribution Company Limited (TGTDCL)
- Bakhrabad Gas System Limited (BGSL)
- Jalalabad Gas Transmission and Distribution System Limited (JGTDSL)
- Karnafuli Gas Distribution Company Limited (KGDCL)
- Paschimanchal Gas Company Limited (PGCL)
- Sundarban Gas Company Limited (SGCL)

Before the formation of Gas Transmission Company Limited (GTCL) in 1993 there were three gas transmission companies in Bangladesh who were also distribution companies i.e. sell gas to end customers. These were Titas Gas Transmission and Distribution

Company Limited (TGTDCL), Bakhrabad Gas System Limited (BGSL) and Jalalabad Gas Transmission and Distribution System Limited (JGTDSL). But after formation of GTCL they are not permitted to expand their transmission facilities.

3.4 Present gas reserve

26 gas fields and an oil field have been discovered in Bangladesh up to March2015 out of which 19 (nineteen) fields are producing gas at present through 92 producing wells[6] Though average daily gas production is 2490-2550 MMscfd, Bangladesh is currently a gas deficit country due to an average shortfall of 550-600 MMscfd. The overall gas sector scenario is shown in Table 3.1.

Table 3.1: Gas sector at a glance [6, 7]

*Total Gas Fields	26
Producing Gas Fields	19
Producing Gas Wells	92
Daily Gas Production Capacity	2312MMscfd
Daily Gas Production (Daily gas production and supply statics, GTCL, as on 03February 2015)	2490MMscfd
GIIP (Proven + Probable)	37.7Tcf
Total Recoverable Gas Reserve (Proven + Probable)	27.12Tcf
Gas Production up to December 2014	12.57Tcf
Remaining Reserve (Proven + Probable)	14.55Tcf
Current Gas Demand	3100MMscfd
Daily Gas Shortfall	550-600MMscfd

* Including newly (in 2014) discovered gas field named “Rupganj Gas Field”, Dhaka.

.3.5 Present gas production

Currently average gas production is around 2490-2550MMscfd. Table 3.2 shows gas production of a particular day (02-03 February 2015) only.

Table 3.2 Daily Gas Production Statistics [6]

Company	Gas Fields	No. of Producing well.	Production capacity (MMscfd)	Gas production (MMscfd)	Production as a % of Total production
1. National Gas Companies (NGCs)					
1.1 BGFCL	Titas Bakgrabad Habigonj Narsigdi Meghna	21 6 7 2 1	518 43 225 30 11	513 40 225 28 8	21.82 1.61 9.52 1.19 0.4
	Sub-total	37	827	814	34.62
1.2 SGFL	Sylhet Kailashtila#1 Kailashtila#2 Rashidpur Beanibazar	2 2 3 4 1	11 15 65 64 14	9 14 57 60 10	0.38 0.76 2.59 1.99 0.42
	Sub-Total	12	169	150	6.16
1.3 Bapex	Salda Fenchugonj Shahbazpur Semutung Sundalpur Srikail	1 3 2 2 1 2	20 40 30 12 10 44	9 38 7 5 5 4	0.59 1.61 0.29 0.42 0.21 1.78
	Sub-Total	11	156	102	4.93
Total (NGCs)		**62**	**1152**	**1066**	**45.72**
2. IOCs					
2.1 Chevron	Jalalabad Maulavibazar Bibiyana	4 6 18	230 60 770	221 51 1041	10. 67 3.19 35.68
	Sub-Total	28	1060	1313	49.55
2.2 Santos	Sangu	-	-	-	-
2.3 NIKO	Feni	-	-	-	-
2.4 Tullow	Bangora	4	100	112	4.72
Total (IOCs)		**32**	**1160**	**1425**	**54.27**
Grand Total (NGCs+IOCs)		**92**	**2312**	**2490**	**100**

From Table 2.2, it is seen that about 45% gas is produced by NGCs and 55% gas is produced by IOCs. Chevron alone is producing near about 50% of total national production.

3.6 Sector wise natural gas consumption in last 30 years

In keeping with the increased production, gas sales also showed an upward trend. By the end of 2013-14 financial year, total sales was 828.1 BCF of which power sector again consumed the largest part worth 480.93BCF followed by fertilizer sector 53.8 BCF, industry sector 141.8 BCF, domestic sector 101.5 BCF and others non-bulk 49.7 BCF.

Table 3.3 Natural gas consumption [7]

Year	Gas Production BCF	Bulk Sales BCF		Non Bulk Sales BCF					Total Sales BCF
		Power	Fertilizer	Industry	Domestic	Comm-ercial	Tea / Estate	Bricks Field	
1981-82	64.85	18	26.6	9.1	4.2	1.7	0	0	59.6
1982-83	72.16	22	25.8	9.8	5.2	1.9	0	0	64.7
1983-84	83.29	22.9	29.4	10.4	5.8	2.1	0	0	70.6
1984-85	94.59	38.3	27.2	12.6	6.3	2.2	0	0	86.6
1985-86	106.66	39.8	33.7	16.4	6.8	2.7	0	0	99.4
1986-87	125.32	51.8	34.9	18.7	6.8	3.4	0	0	115.6
1987-88	147.5	62.1	51	16.7	7.6	3.6	0	0	141
1988-89	155.93	65.5	53.4	15	9.3	3.2	0	0	146.4
1989-90	167.83	75.6	55.9	14.3	10.2	3.1	0	0	159.1
1990-91	172.84	82.6	54.2	13.2	10.5	2.9	0.7	0	164.1
1991-92	188.48	88.1	61.6	13.4	11.6	2.9	0.7	0.2	178.5
1992-93	210.98	93.3	69.2	15.2	13.5	2.4	0.7	0.2	194.5
1993-94	223.76	97.3	74.5	20.26	15.4	2.87	0.7	1.1	212.13
1994-95	247.38	107.4	80.5	24.24	18.86	2.88	0.6	1.1	235.58
1995-96	265.51	110.9	90.98	27.31	20.71	3	0.72	0.99	254.61
1996-97	260.99	110.82	77.83	28.62	22.84	4.49	0.71	0.48	245.79
1997-98	282.02	123.55	80.07	32.32	24.89	4.61	0.74	0.39	266.57
1998-99	307.48	140.82	82.71	35.79	27.02	4.71	0.71	0.35	292.11
1999-00	332.35	147.62	83.31	41.52	29.56	3.85	0.64	0.35	306.85
2000-01	372.16	175.27	88.43	47.99	31.85	4.06	0.65	0.44	348.69
2001-02	391.53	190.03	78.78	53.56	36.74	4.25	0.726	0.53	364.616
2002-03	421.15	190.54	95.89	63.75	44.8	4.56	0.744	0.527	400.811
2003-04	452.77	231.43	92.8	46.48	49.22	4.84	2.75	0.12	427.64
2004-05	486.64	249.42	93.97	52.28	52.6	4.84	4.49	0	457.6
2005-06	532.86	273.25	89.08	63.26	56.74	5.2	17.6	0	505.13
2006-07	562.7	283.28	93.46	77.41	63.13	5.64	12.73	0	535.65
2007-08	600.86	314.5	78.66	92.19	69.02	6.59	23.51	0	584.47
2008-09	653.57	351.84	74.83	104.6	73.38	7.48	31.8	0	643.93
2009-10	700	395.73	64.71	118.8	80.2	8.11	38.91	0	706.46
2010-11	708.9	395	62.8	121.5	87.4	8.5	39.3	0	714.5
2011-12	743.57	427.86	58.39	128.45	89.29	8.55	39.3	0	751.84
2012-13	800.57	463	59.95	135.74	89.74	8.81	38.56	0	795.8
2013-14	820.09	480.93	53.75	141.82	101.50	8.89	40.91	0.00	828.1

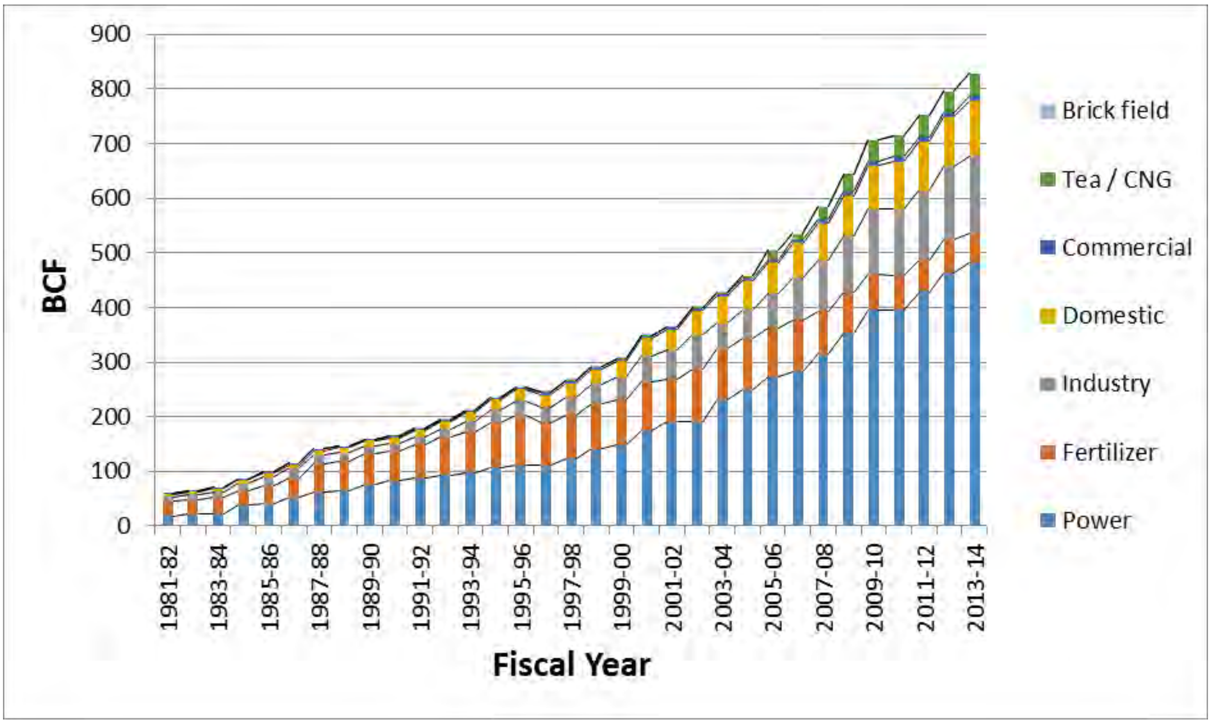


Figure 3.1: Sector-wise annual gas consumption

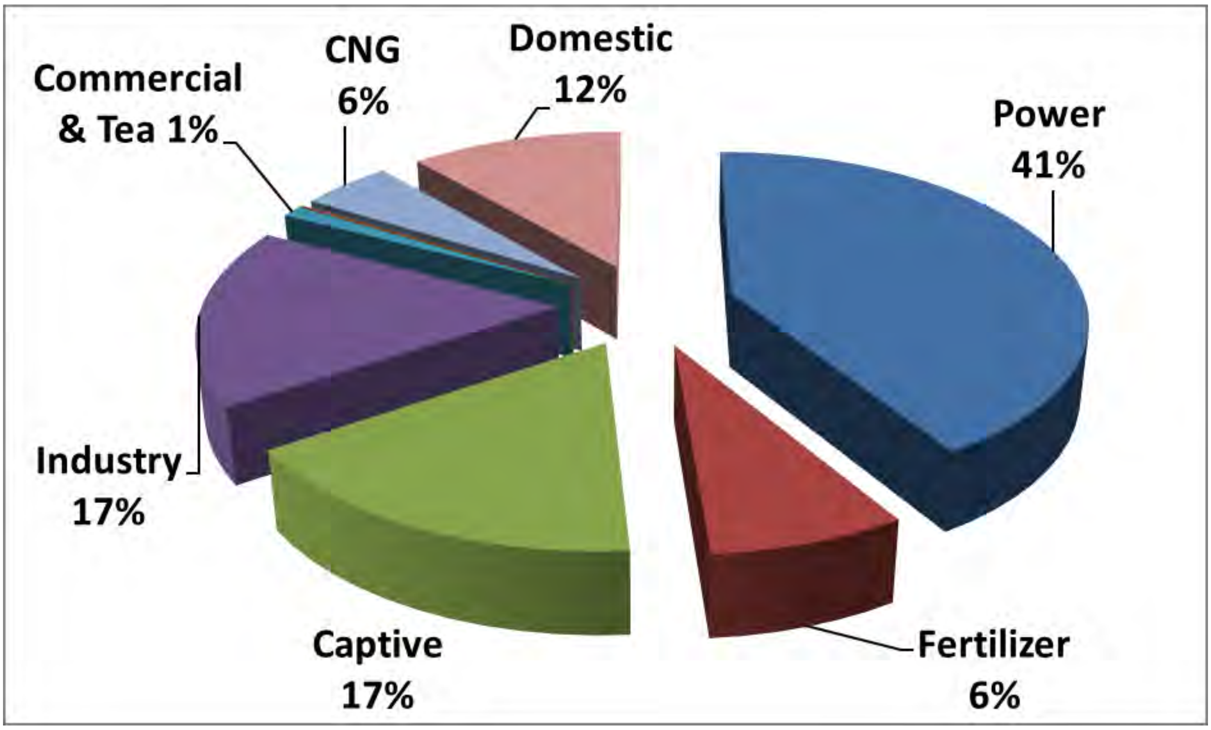


Figure 3.2: Total Consumption: 820 BCF in FY 2013-14

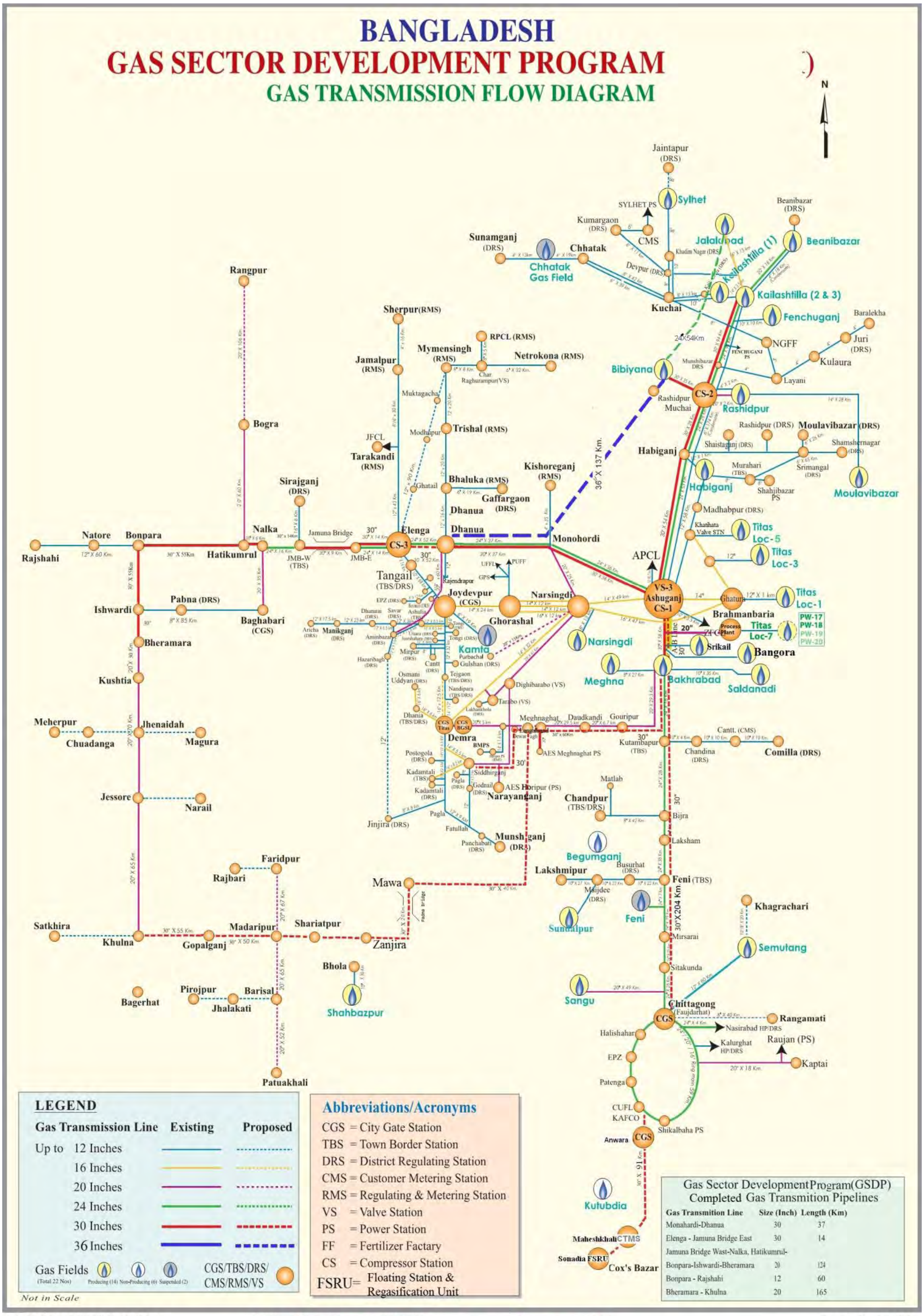
3.7 Major gas transmission pipeline and flow capacity

Before formation of Gas Transmission Company Limited (GTCL), distribution companies were transmitting gas through their transmission pipelines. GTCL is now solely responsible for augmentation, operation and maintenance of national gas grid. The name of the major transmission pipelines are mentioned in Table 3.4.

Table 3.4: Major Gas Transmission Pipeline & Flow Capacity [2]

Sl. No.	Name of pipeline	Length (Km)	OD (inch)	MAOP (psig)	Max. Flow Capacity (MMscfd)
Existing Gas Transmission Pipeline Operated by GTCL					
1.	Bakhrabad-Chittagong	175	24	960	350
2.	Bakhrabad-Demra	68	20	1000	150
3.	Ashuganj-Elenga	125	24	1000	270
4.	North-South(KTL-Ashuganj)	175	24	1135	330
5.	Ashuganj-Bakhrabad	59	30	1135	400
6.	Elenga-Baghabari	73	20/24/30	1000	200
7.	Beanibazar-Kailashtila	18	20	1090	
8.	Rashidpur-Ashuganj	82	30	1135	425
9.	Nolka-Bogra	6+54	30/20	1000	166
10.	Ashuganj-Monohordi	37	30	1000	400
11.	Dhanua-Aminbazar	60	20	1000	200
12.	Monohordi-Dhanua	51	30	1135	300-750
13.	Bonpara-Rajshahi	53	12	1000	45
14.	Titas-AB Pipeline	8	24	1000	-
15.	Bibiyana-Dhanua	137	36	1000	-
Existing Gas Transmission Pipeline Operated by TGTDCL					
16.	Titas-Narshindi-Demra	82	14	1000	175
17.	Habiganj-Ashuganj	58	12	1000	85
18.	Titas-Narshingdi-Joydevpur	84	14/16	1000	260
19.	Narshingdi-Siddirganj	43	20	1000	300
20.	Dhanua-Mymensingh	57	12	1000	55
21.	Elenga-Tarakandi	43	12	1000	80
Existing Gas Transmission Pipeline operated by other companies					
22.	Horipur-NGFF (JGTDSL)	43	-	1000	62
23.	Srimongal-Moulavibazar (JGTDSL)	26	6	1000	11
24.	ShahajiBazar-Shamsher Nagar(JGTDSL)	65	6	1000	11
25.	Kailastila-Kuchai(JGTDSL)	13	8	1000	62
26.	Meghna-Baghrabad(BGSL)	28	8	1000	20
27.	Salda-Bakhrabad(BGSL)	35	10	1000	35
28.	Jalalbad Field-Kailashtila(Chevron)	15	14	1135	
29.	Sangu-Fazdarhat(Satons)	45	20	1000	
30.	Chadpur Lateral(BGSL)	42	8	960	35
31.	Maulavibazar-Muchai(Chevron)	22	14	1135	
32.	Bibiyana-Muchai(Chevron)	42	30	1135	
33.	Semutang-Chittagong(KGDCL)	56	10	960	70

Note: These are the major transmission pipelines only. Besides these, there are other transmission pipelines of smaller diameter and shorter length which are not mentioned here.



SOURCE: PETROBANGLA Modified On 13 August'2013 By Strategic Planning Department, GTCL December-2008

Figure 3.3: Block diagram of gas transmission system in Bangladesh

CHAPTER 4
LITERATURE REVIEW

The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors/functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time. The basis for hydraulic analysis of a gas network is a simulation model. Individual, consultant and many organization simulated present and future supply situation considering existing and planned transmission and production situation by commercial software. In this study pipeline simulation network of total transmission system of Bangladesh is designed by commercial software PIPESIM, which is a steady-state, multiphase flow simulator used for the design and analysis of gas production systems [8].

Model

A model is only as good as the data that is used to build it. Analysis based on incorrect values will yield incorrect results. The analysis results should be evaluated and validated with the proper weight. In most gas distribution models, customer usage and load distribution will be the most critical parameter in the analysis.

Benefits of Modeling

- The ability to anticipate operating conditions within the system.
- The ability to identify problem areas and trouble-shoot problems before they become serious.
- The ability to efficiently size new and replacement segments of gas system.
- The ability to estimate the impact on the system of adding new customers.
- And the ability to analyze "What if" scenarios without physical manipulation of the gas system of actual operating settings.

Network

A network is any system of interconnected or interrelated components. In a network, each component to some extent, affects every other component in the network. A gas system can be considered as a network. In a gas system, the components of the network are the pipes, valves, fittings, connectors, and regulators that make up the physical configuration of the system – and the customers attached to the system. An example of how individual components of a gas network might affect the other components in the network, consider the following:

(a) The outlet pressure of a regulator supplying the system is reduced.

(b) To a certain extent, the pressure in the entire system is reduced.

(c) An additional regulator is added to the system, the flow from the other regulators will be changed.

(d) And the flow through the pipes will be redistributed to accommodate the change in flow from the regulators.

(e) A valve in the system is closed. Flow in the system must be redistributed to accommodate the changes caused by the valve closure. The flow and pressure in all the pipes will be changed, to a certain extent. Flow will decrease in the mains to which the valve was attached and increase in mains that might provide flow around the valve. When flows change in the system, so do the pressures in the system.

(f) A large load is connected to the system. The flow in the portions of the system supplying that load will be increased. The increase in flow will affect the pressures in the system and the flow required of the supplying regulators.

Simulation Model

A simulation model consists of nodes and pipes. Source, sink and storages are all represented by nodes which are interconnected by pipes.

Nodes

A node can be:

- Consumer,
- A simple node without consumption
- Producer
- Connection between one or more pipes.

Nodes are characterized by:

- Name
- Geometrical level
- Pressure
- Temperature
- Flow.

A node is placed in the model using one of the following criteria:

- Important change of dimensions;
- Branch;
- A wished position for known pressure of flow;
- Termination of a pipe without continuation;
- A large consumer.

Pipes

Pipes are connections between nodes. A pipe is characterized by-

- An upstream node;
- A downstream node;
- Length;
- Internal diameter;
- Roughness;
- Pressure;
- Pressure drops; and
- The mass flow through the pipe.

Pipes carry gas between nodes. The sum of the pipe flows going into a specific node must equal the sum of the flows leaving the node through the connected pipes plus the flow leaving the system through the node. The sum of the flow coming into the system through a node must equal the sum of the flow leaving the node through the connected pipes. In steady-state modeling, neither nodes nor pipes can store flow.

Sources

A source may be producer/supplier, intake point or others that carry in fluid into the network. It is characterized by volume, pressure, temperature etc.

Sink

A sink may be customer, off-take or other load centers that carry out fluid from the network**.** It is characterized by volume, pressure, temperature etc.

Flow

Flow in a pipe moves from the higher pressure end of the pipe to the lower pressure end. That is flow always moves in the direction of the lower pressure node. Like a ball rolling downhill, gas flows from high to low as shown in Figure 3.1

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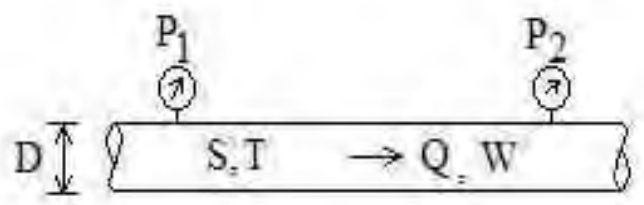

Figure 4.1: Schematic of flow in pipe.

Flow is created by a difference in pressure and consequently flow causes frictional pressure losses. As the flow increases the friction losses also increase, and tend to restrict or limit the flow. The greater the pressure difference, the greater the flow rate and the greater the frictional pressure losses.

Flow Equations.

The Weymouth, Panhandle A, and Panhandle B equations were developed to simulate compressible gas flow in long pipelines. The Weymouth is the oldest and most common of the three. It was developed in 1912. The Panhandle A was developed in the 1940s and Panhandle B in 1956[9]. The equations were developed from the fundamental energy equation for compressible flow, but each has a special representation of the friction factor to allow the equations to be solved analytically. The Weymouth equation is the most common of the three - probably because it has been around the longest. The equations were developed for turbulent flow in long pipelines. For low flows, low pressures, or short pipes, they may not be applicable.

If the pressure drop in a pipeline is less than 40% of upstream pressure (P_1) then Darcy-Weisbach incompressible flow calculation may be more accurate than the Weymouth or Panhandles for a short pipe or low flow. The Darcy-Weisbach incompressible method is valid for any flow rate, diameter, and pipe length, but does not account for gas compressibility. Crane (1988) states that if the pressure drop is less than 10% of P_1 and it is used an incompressible model, then the gas density should be based on either the upstream or the downstream conditions. If the pressure drop is between 10% and 40%, then the density used in an incompressible flow method should be based on the average of the upstream and downstream conditions. If the pressure drop exceeds 40% of P_1, then use a compressible model, like the Weymouth, Panhandle A, or Panhandle B [10].

The equations for compressible flow are shown below. The Weymouth, Panhandle A, and Panhandle B equations [9-10] are the equation beginning with Q_s=... with the constants c, n, u, x, and y defined below. All of the equations shown below use the English units indicated in the Variables section. Of course, calculation uses a variety of units with all of the unit conversions handled internally by the program.

$$Q_s = cED^n \left[\frac{T_s}{P_s}\right]^u \left[\frac{P_1^2 - P_2^2}{S^x LTZ}\right]^u$$

$$\rho_s = \frac{2.7\rho_s S}{T_s}$$

Pressure Drop (%) = $\frac{P_1 - P_2}{P_1 - P_{atm}}(100)$

$$W = \rho_s Q_s = \rho_1 Q_1 = \rho_2 Q_2$$

$$\rho_1 = \frac{2.7P_1 S}{TZ}, \rho_2 = \frac{2.7P_2 S}{TZ}$$

Variables:

The units refer to the units that must be used in the equations shown above. However, a variety of units may be used in calculation and shown in Table 4.1.

Table 4.1: Particulars of variables.

Variable	Description	Unit	Value
A	Pipeline cross sectional area	Square inch	
C	Constant	-	Weymouth: c=18.0625, Panhandle A: c=18.16125, Panhandle B: c=30.7083,
D	Pipe inside diameter	Inch	-
E	Efficiency factor	-	Typically 0.85 to 1.0
L	Pipeline length	mile	-
N	Constant		Weymouth: n=2.6667, Panhandle A: n=2.6182, Panhandle B: n=2.53
P	Absolute pressure in pipeline	psia	
Q	Volumetric flow rate	cfh	
S	Specific gravity of gas in pipeline, relative to air	-	
T	Absolute temperature (Rankin)	ºR	
U	Constant		Weymouth: u=1.0, Panhandle A: u=1.07, Panhandle B: u=1.02
V	Velocity of gas = Q/A		
W	Mass flow rate	Ib/hr	
Z	Gas compressibility		Typical value 1.0 at standard condition.
P	Density	Ib/ft^3	
x, y	Constant		X=0.96 and y=0.51 for Panhandle B

Subscripts:

1 = Upstream conditions; 2 = Downstream conditions; atm = Atmospheric conditions; and s = Standard conditions (520 ºR, 14.73 psia).

AGA- Turbulent

- Applicable to transmission systems with fully turbulent flow conditions.
- Accounts for relative pipe roughness using rough pipe law.
- Moderately conservative compared to other transmission style equations.

Panhandle – A

- Applicable to transmission systems.
- Yields moderate results.
- Developed in the 1940's.
- The Gas Engineers Handbook reports that the equation is applicable for large diameter transmission piping where the Reynolds number varies between 5 and 20 million. And suggests an average efficiency for steel pipelines of 0.92 for this equation.
- The Gas Process Suppliers Association (GPSA) data book reports that this equation is intended to reflect flow of gas through smooth pipes. When used with an efficiency of 0.90 the equation reasonably approximates the partially turbulent general flow equation.
- The AGA GEOP text reports that this equation is applicable to distribution systems where the Reynolds numbers range between 1,300,000 and 75,000,000 with 2% deviation from the smooth pipe and 16 inch and larger diameter pipe operating between 20 Psig and higher.
- Reynolds number dependent.

Panhandle – B

- Applicable to transmission systems.
- Revised version of Panhandle – A, published in 1956.
- Less conservative transmission equation.
- The Gas Engineers Handbook notes that the equation is applicable for large diameter transmission piping where the Reynolds number varies between 5 and 20 million. And suggests an average efficiency for steel pipelines of 0.9 for this equation.
- Efficiency factors of 0.88 to 0.94 are often used with this equation.
- Reynolds number dependent.

Weymouth

- Applicable to transmission systems, though often for both distribution and transmission.
- Yields conservative results.
- Equation published in 1912.
- The Gas Engineers Handbook reports that this equation provides a reasonable approximation of the general rough pipe equation for diameter equal to ten inch, and effective pipe wall roughness equal 0.002 inches. And suggests an average efficiency for steel pipelines of 1.10 for this equation.
- The GPSA data book reports that for short pipelines and gathering systems this equation agrees closely with metered volumes. However, the degree of error increases with pressure.
- The AGA GEOP text suggests that the equation is not applicable to calculations in distribution systems.
- Not a Reynolds number dependent equation.

Assumptions

- For the simplicity of calculation, the following assumptions are often made:
- No external work is done on the system i.e. w = 0;
- The gas flow is at constant temperature;
- The gas behaves as an ideal gas, in other words, $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
- The compressibility factor Z is taken into account;
- Differences in elevation on long pipelines are disregarded;

CHAPTER 5

NETWORK MODELING AND ANALYSIS

For transmission system analysis, it is necessary to configure the pipeline model with correct pipeline data. The transmission model is updated using all pipeline data within the software PIPESIM for steady state analysis of the main transmission grid along with interconnected transmission pipelines in the network.

The gas transmission network (existing and extended) are modeled, run and sensitivities are studied and finally analyzed. The following sensitivity studies are made and analyzed in this work:

- Volumetric flow rate and pressure scenario of the existing pipeline network before commissioning of Bibiyana- Dhanua (BD) pipeline.
- Flow rate and pressure scenario of the existing pipeline network after commissioning of (36" × 137 km) Bibiyana- Dhanua (BD) pipeline.
- Flow rate and pressure scenario of the existing pipeline network with (24" × 137 km) of Bibiyana- Dhanua (BD) pipeline.
- Prediction Case-1: Minimum pressure in Khulna at present demand considering Bibiyana- Dhanua (BD) pipeline 24 inch in diameter.
- Prediction Case-2: Maximum possible volumetric flow rate maintaining 350 psig in Khulna with boost up device.
- Prediction Case-3: Maximum demand and effect of additional gas from LNG.

5.1 Volumetric flow rate and pressure scenario of the existing network before commissioning of Bibiyana-Dhanua (BD) pipeline.

The physical model of the existing network before commissioning of BD pipeline comprises of 2406.82 km [11] gas transmission pipelines of various sizes. In this study about 2320MMscfd [12] gas is supplied through the entire network. The supplied volume is very low compare to the network supply capacity. From Bibiyana gas field 855 MMscfd gas is supplied through the network. The gas flow of different gas fields as source of the network is shown in Table 5.1 and the pressure at different sinks, obtained from the network simulation at present demand situation, are tabulated in Table 5.2.

Major junctions such as Muchai Manifold, Ashuganj MS, Bakhrabad HUB and Elenga TBS are shown in Figure 5.1. Bibiyana Gas Field is delivering gas to North South Pipeline Corridor through North South and Rashidpur –Ashuganj Pipeline at Muchai Manifold Station. The expensive gas pipeline compressor stations were set up at Muchai and Ashuganj to evacuate additional gas from Northern Gas fields including Bibiyana and Jalalabad. Gas produced from Bangora, Srikail, Salda, Meghna, Titas and Bakhrabad Gas Fields are gathered in Bakhrabad HUB and supplied through Bakhrabad-Chittagong and Bakhrabd-Demra pipeline. Gas is supplied to West Zone through Elenga TBS. The physical model of the existing network along with extended constructed pipeline which is built in PIPESIM software is shown in figure 5.2.

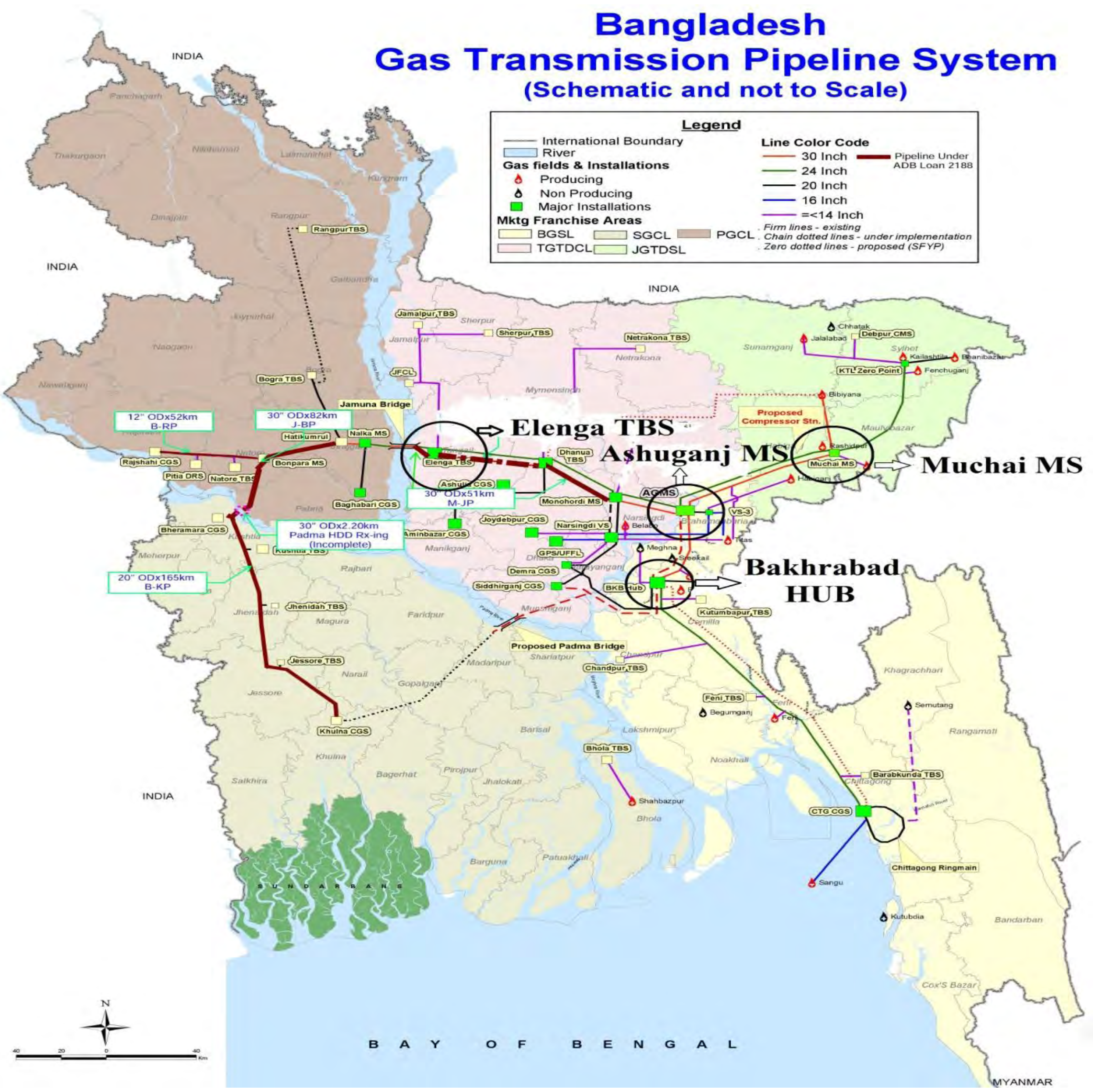

Figure 5.1: Major junction points of gas transmission network in Bangladesh (Source:GTCL)

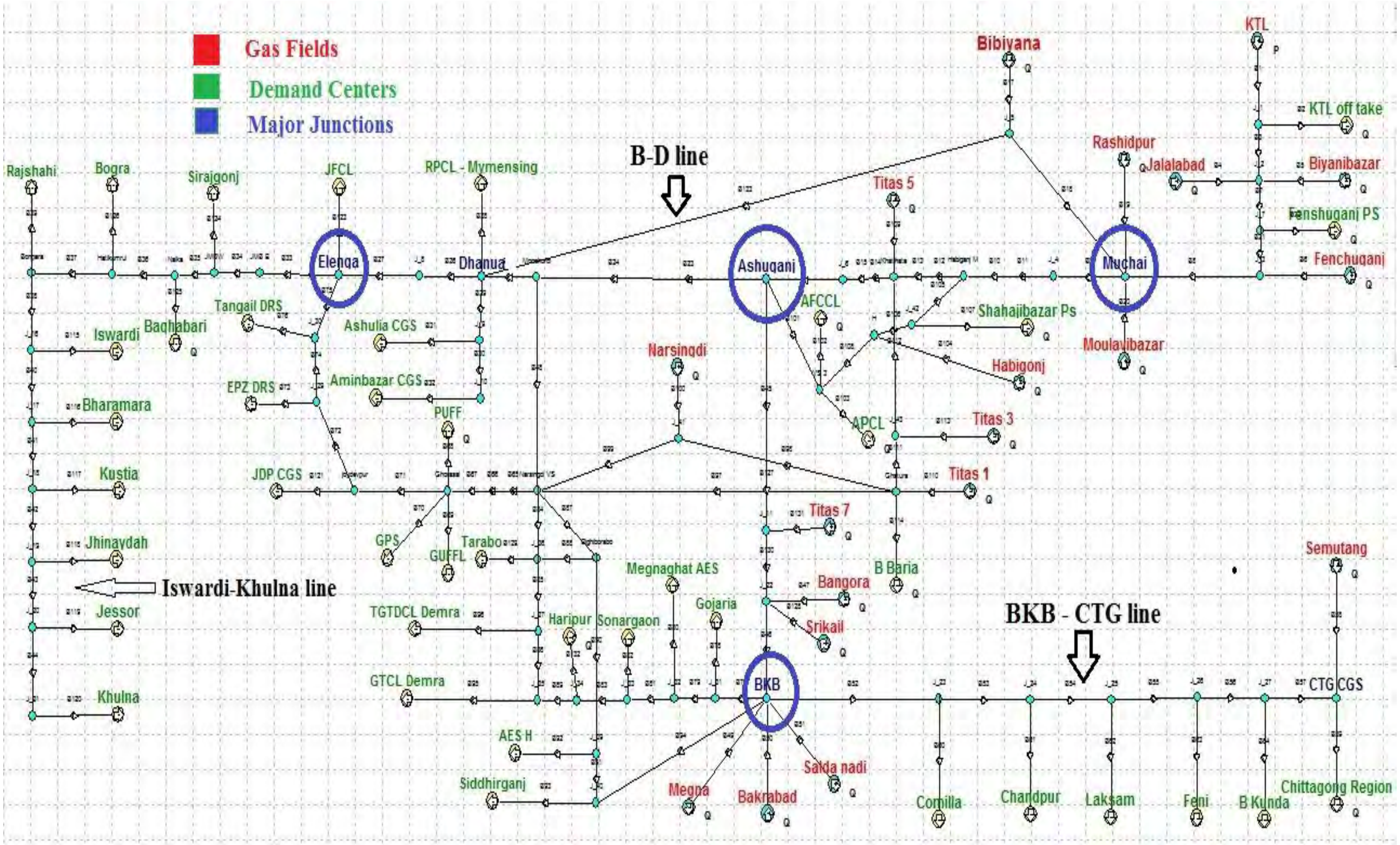

Figure 5.2: PIPESIM network modeling

Table-5.1: Input parameters (actual value) as of 17 October 2014 [12]

Name (Gas Fields)	Type	Gas Flow (MMscfd)
Bakrabad	Source	40
Bangora	Source	110
Beanibazar	Source	10
Bibiyana	**Source**	**855**
Fenchuganj	Source	38
Hobigonj	Source	225
Jalalabad	Source	210
Kailastilla	Source	60
Maulvibazar	Source	60
Meghna	Source	10
Narsingdi	Source	28
Rashidpur	Source	60
Salda	Source	12
Semutang	Source	10
Srikail	Source	40
Titas Location 1	Source	245
Titas Location 3	Source	145
Titas Location 5	Source	100
Titas Location 7	Source	55
Total		**2313**

All the gas fields are sources of this transmission network. Gas flow mentioned in Table 5.2 is the consumption rate at different District Regulating Station (DRS), City Gate Station (CGS), Town Border Station (TBS), power station, fertilizer factory etc. as of 17 October2014

Table- 5.2: Simulated pressure at different demand centers.

Name	**Type**	**Gas Flow (MMscfd)**	**Pressure (psig)**
AES Haripur	Sink	55	128.03
AES Meghnaghat	Sink	75	339.67
AFCCL	Sink	50	675.69
Aminbazar CGS	Sink	110	107.55
APCL	Sink	160	641.37
Ashulia CGS	Sink	120	157.64
Baghabari	Sink	60	325.33
Barabkunda	Sink	45	345.59
Bogra	Sink	20	345.47
Brahmanbaria	Sink	30	864.12
Chandpur	Sink	27	428.55
Comilla	Sink	10	846.58
CTG CGS	Sink	275	286.99
Fenchuganj PS	Sink	52	880.2
Feni TBS	Sink	6	690.9
Gozaria	Sink	13	410.8
GPS	Sink	140	443.41
GTCL Demra	Sink	100	187.97
Haripur	Sink	70	209.59
Iswardi EPZ	Sink	5	669.05
JDP	Sink	100	168.44
JFCL	Sink	50	552.48
KTL off take	Sink	50	933.98
Moymensing	Sink	75	301
PUFF	Sink	15	444.15
Rajshahi	Sink	5	669.27
Shahjibazar PS	Sink	45	300
Siddhirgonj	Sink	160	125
Sirajgonj	Sink	50	654.79
Sonargaon	Sink	10	287.57
Tarabo	Sink	35	205.18
TGTDCL Demra	Sink	250	280
UFFL	Sink	45	444
Total		**2313**	

Analytical Data

To validate the simulation model, pressure at different off-take/outlet points are calculated analytically using following modified Panhandle 'B' equation-most useful and fairly accurate for transmission pipeline.

$$Q_{mmscfd} = 0.00128084\left[\frac{P_1^2 - P_2^2}{L_{miles}}\right]^{0.51} d^{2.53}$$

Where,

Q= Flow in MMscfd

P_1= Upstream Pressure, psig

P_2= Downstream Pressure, psig

d= Inside pipe diameter, inch

L= Length of pipeline in Miles

Simulated, analytical and real field data of some off-take/outlet points are tabulated in Table 5.3.

Table 5.3: Simulated, actual and calculated pressure at major demand centers.

Off take points	Pressure (psig)				
	Actual [12]	Simulated	Error (%)	Calculated	Error (%)
Ashulia CGS	161	158	1.8	160.15	0.5
Aminbazar CGS	106	108	1.8	107.78	1.7
PUFF	449	444	1.1	444.98	0.9
GUFF	449	444	1.1	444.85	0.9
GPS	451	443	1.8	444.77	1.4
Demra CGS	190	188	1.1	188.72	0.7
Meghnaghat PP	335	340	1.5	341.05	1.8
AFCCL	670	676	0.9	672.17	0.3
Ashuganj	645	641	0.6	643.02	0.3
Fouzdarhat CGS	282	287	1.8	284.57	0.9
Fenchuganj PS	873	880	0.8	878.89	0.7
Haripur PP	206	210	1.7	210.82	1.7
Siddirgonj	122	125	1.5	123.42	1.2
APCL	645	641	0.6	640.13	0.8
JFCL	557	552	0.9	555.37	0.3
TGTDCL Demra	284	280	1.4	282.34	0.7
RPCL	295	301	2.0	298.73	1.3
Feni TBS	700	691	1.3	690.05	1.4
Baghabari	322	325	0.9	320.78	0.4
Bogra	340	345	1.5	342.45	0.7

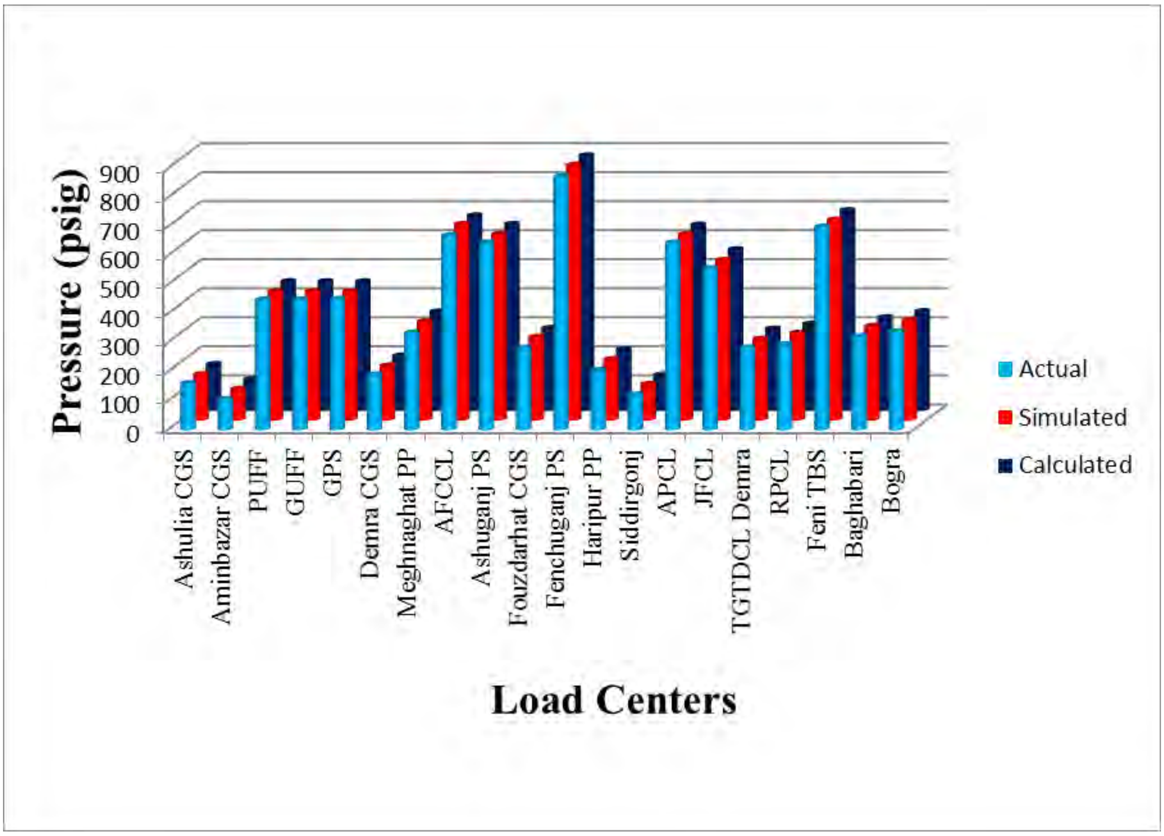

Figure 5.3: Pressure of different demand centers.

The simulated and analytical pressure data are obtained against a corresponding flow rate data, whereas the real value is recorded over the full day range. The simulated, calculated and actual pressure is plotted in the graph shown in Figure 5.3 to compare with each other at particular off-take/outlet.

Table 5.4: Actual and simulated gas flow, pressure data at major junctions

Name	Type	Gas Flow (MMscfd)			Pressure (psig)		
		Actual [12]	Simulated	Error (%)	Actual [12]	Simulated	Error (%)
Muchai Manifold	Junction	1181	1180	0.08	1132	1125	0.62
AshugonjMS	Junction	1434	1432	0.14	716	712	0.56
Bakhrabad HUB	Junction	775	774	0.13	766	760	0.78
Elenga TBS	Junction	110	107	2.73	365	362	0.82

Analysis of the study

The simulated result for different major demand centers is compared with both the real field data and the calculated value. Simulated value is quite equal to real value, though little variation (in the range of 0.3% -2% error) is observed in case of calculated value. The simulated value of gas flow and pressure for different major junctions of the transmission network is also matched with the actual data with minor variation. This variation may occur due to the variation of the value of the some factors i.e. average temperature, specific gravity, compressibility factor etc. Besides, there may have been some error with field data as, sometimes, calibration and human error being associated with it. The overall value is seemed to be very close. So, simulation network model considered as valid and can be used for further analysis.

5.2 Flow rate and pressure scenario of the existing network after commissioning of Bibiyana-Dhanua (BD) pipeline.

This case study is made for the network of additional parallel pipeline from Bibiyana to Dhanua. Gas Transmission Company Limited (GTCL), a company of Petrobangla, implemented the Bibiyana-Dhanua Gas Pipeline project aimed at supplying additional gas to greater Dhaka and western regions and for reducing lone dependency on Ashuganj hub. A 137-km gas transmission line with a 36-inch diameter has been set up over Habiganj, Kishoreganj, Mymensingh and Gazipur districts, including a 67-km Haor area in Habiganj and Kishoreganj districts as shown in Figure 5.4. The Bibiyana-Dhanua pipeline was commissioned on November 2014. Initially, it was planned to supply around 300 million cubic feet of gas through this pipeline which will gradually rise to maximum 650 million cubic feet every day [13].

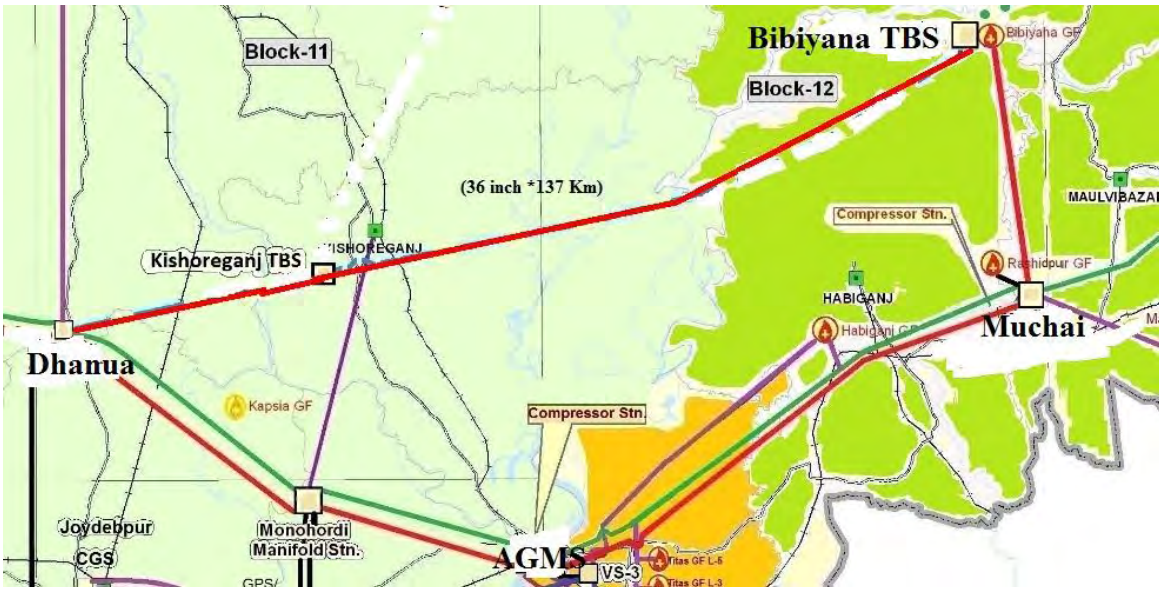

Figure 5.4: Construction route of Bibiyana-Dhanua (36" × 137 km) pipeline.

It is to be mentioned that in this study after commissioning of this line about 200 MMscfd gas is supplied through this pipeline. From Bibiyana gas field 1040MMscfd of gas is supplied through the network whereas countrywide total 2490 MMscfd gas is supplied through the entire network [6].The gas flow of different gas fields as source of the network is shown in Table 5.5. Gas consumption of different demand centers as of 2nd February 2015 and pressure at different sinks obtained from the network simulation after commissioning of this line are tabulated in Table 5.6.

Table-5.5: Input parameters (actual value) as of 2nd February 2015 [6]

Name (Gas Fields)	**Type**	**Gas Flow (MMscfd)**
Bakrabad	Source	40
Bangora	Source	110
Beanibazar	Source	10
Bibiyana	**Source**	**1040**
Fenchuganj	Source	38
Hobigonj	Source	225
Jalalabad	Source	220
Kailashtilla	Source	74
Maulvibazar	Source	50
Meghna	Source	10
Narsingdi	Source	28
Rashidpur	Source	60
Salda	Source	10
Semutang	Source	10
Srikail	Source	40
Titas Location 1	Source	240
Titas Location 3	Source	130
Titas Location 5	Source	100
Titas Location 7	Source	55
Total		**2490**

Table- 5.6: Simulated pressure at different demand centers.

Name	Type	Gas Flow (MMscfd)	Pressure (psig)
AES Haripur	Sink	55	134.01
AES Meghnaghat	Sink	75	349.86
AFCCL	Sink	50	740.35
Aminbazar CGS	Sink	120	241.82
APCL	Sink	145	733.41
Ashulia CGS	Sink	160	278.35
Baghabari	Sink	60	745.06
Barabkunda	Sink	10	537.18
Bogra	Sink	20	752.18
Brahmanbaria	Sink	30	903.88
Chandpur	Sink	27	457.93
Comilla	Sink	10	855.18
CTG CGS	Sink	300	308.25
EPZ DRS	Sink	20	631.45
Fenchuganj PS	Sink	52	924.05
Feni TBS	Sink	6	806.87
Gozaria	Sink	15	419.3
GPS	Sink	140	533.67
GTCL Demra	Sink	120	205.03
Haripur	Sink	70	225
Iswardi EPZ	Sink	5	751.81
JDP	Sink	100	440
JFCL	Sink	50	652.49
KTL off take	Sink	70	934
Moymensing	Sink	85	417
PUFF	Sink	15	534.27
Rajshahi	Sink	5	603
Shahjibazar PS	Sink	50	306
Siddhirgonj	Sink	200	425
Sirajgonj	Sink	50	739.39
Sonargaon	Sink	10	299.21
Tangail DRS	Sink	15	702.22
Tarabo	Sink	35	227.99
TGTDCL Demra	Sink	270	780
UFFL	Sink	45	534.15
Total		**2490**	

Analytical Data

To validate the simulation model, pressure at different off-take/outlet points are calculated analytically using modified Panhandle 'B' equation that describe earlier. Simulated, analytical and real field data of some major off-take/outlet points are tabulated in Table 5.7

Table 5.7: Simulated, actual and calculated pressure at major demand centers.

Off take points	Pressure (Psig)				
	Actual [6]	Simulated	Error (%)	Calculated	Error (%)
Ashulia CGS	275	278	1.1	276.34	0.5
Aminbazar CGS	241	242	0.4	245.01	1.7
PUFF	527	534	1.3	533.98	1.3
GUFF	527	534	1.3	533.87	1.3
GPS	528	534	1.1	533.42	1.0
Demra CGS	208	205	1.4	204.74	1.6
Meghnaghat PP	354	350	1.1	350.16	1.1
AFCCL	750	740	1.3	742.68	1.0
Ashuganj	725	733	1.1	733.4	1.2
Fouzdarhat CGS	304	308	1.3	305.34	0.4
Fenchuganj PS	936	924	1.3	923.95	1.3
Haripur PP	221	225	1.8	226.56	1.9
Siddirgonj	420	425	1.2	423.45	0.8
APCL	725	733	1.1	730.82	0.8
JFCL	660	653	1.1	657.46	0.4
TGTDCL Demra	775	780	0.6	781.76	0.9
RPCL	420	417	0.7	419.65	0.1
Feni TBS	820	806	1.7	812.45	0.9
Baghabari	744	745	0.1	740.12	0.5
Bogra	740	752	1.6	748.89	1.2

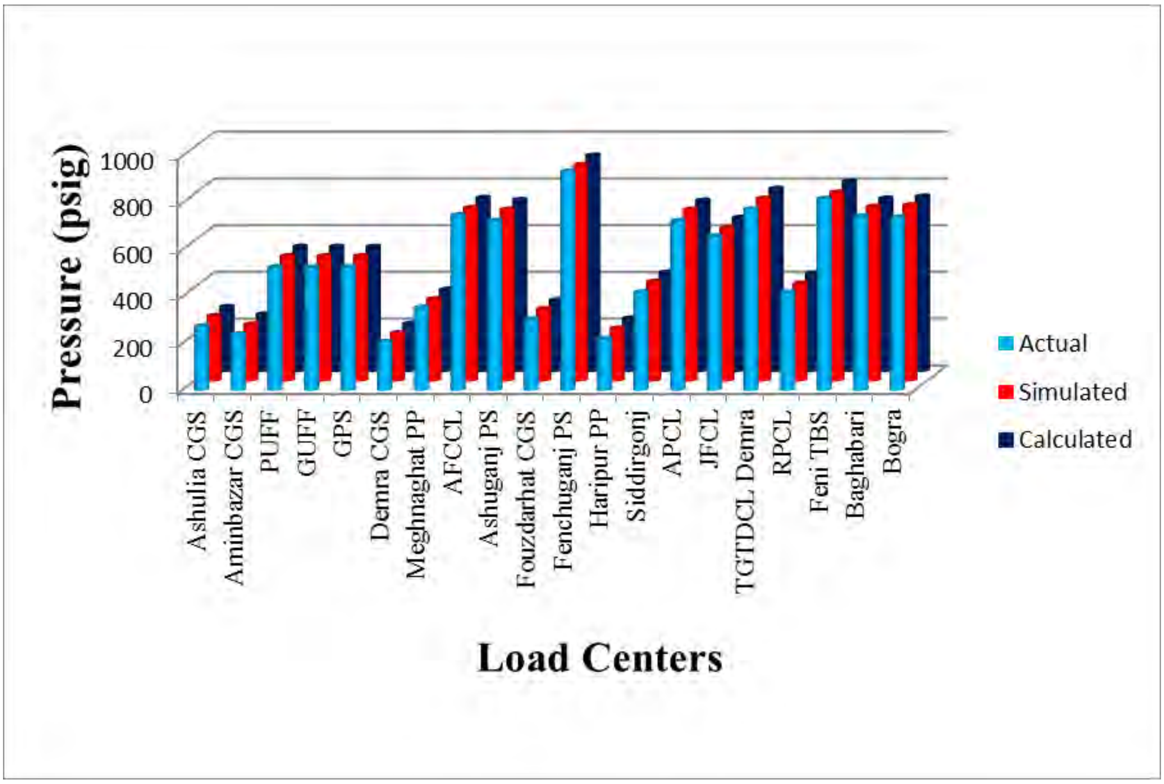

Figure 5.5: Pressure of different demand centers.

The simulated and calculated data are obtained against a particular input data whereas the actual value is recorded over the full day range. The simulated, calculated and actual pressure is plotted in the graph shown in Figure 5.5 to compare with each other at particular off-take/outlet point. The pressure and gas flow of major junction are tabulated in Table 5.8 and the pressure comparison are shown in Table 5.9.

Table 5.8: Actual and simulated gas flow, pressure data at major junctions

Name	Type	Gas Flow (MMscfd)			Pressure (psig)		
		Actual [6]	Simulated	Error (%)	Actual [6]	Simulated	Error (%)
Muchai Manifold	Junction	1123	1120	0.27	1087	1085	0.18
AshugonjMS	Junction	1486	1485	0.07	860	855	0.58
Bakhrabad HUB	Junction	850	848	0.24	850	848	0.24
Elenga TBS	Junction	85	84	1.18	770	765	0.65

Table 5.9: Pressure comparison (before and after B-D line)

Off take points	Pressure (psig)	
	Before B-D pipeline	After B-D pipeline
Ashulia CGS	161	275
Aminbazar CGS	106	241
PUFF	449	527
GUFF	449	527
GPS	451	528
Demra CGS	190	208
Meghnaghat PP	335	354
AFCCL	670	750
Ashuganj	645	725
Fouzdarhat CGS	282	304
Fenchuganj PS	873	936
Haripur PP	206	221
Siddirgonj	122	420
APCL	645	725
JFCL	557	660
TGTDCL Demra	284	775
RPCL	295	420
Feni TBS	700	820
Baghabari	322	744
Bogra	340	740

Analysis of present situation

The simulated result for both off take points and different junctions is compared with both the real field data and the calculated value. Simulated value is quite equal to real value, though little variation (in the range of 0.1% - 1.9% error) is observed. It is to be noted that the pressure of different off take points in the West Zone such as Baghabari CGS, Sirajganj DRS and Bogra as well as different District Regulating Station (DRS), City Gate Station (CGS), Town Border Station (TBS) in the entire network boosted up after commissioning of BD line.

5.3 Flow rate and pressure scenario of the existing pipeline network with (24" × 137 Km) of Bibiyana- Dhanua (BD) pipeline.

The (36" × 137 km) Bibiyana- Dhanua pipeline is designed by GTCL to carry 650 MMscfd of gas. But at present situation, Bibiyana gas field is not capable to transmit such volume of gas through this pipeline as Bibiyana gas field planned to maintain the plateau of 1200 MMscfd gas for at least next 5 years. In this study Bibiyana to Dhanua pipeline is considered 24 inch instead of 36 inch diameter to check the handling capacity of gas. It is to be mentioned here that currently about 200 MMscfd gas is supplied through this pipeline and total 2490 MMscfd [6] gas is supplied through the entire network. The gas flow of different gas fields are tabulated in Table 5.10 and pressure at different sinks obtained from the network simulation are tabulated in Table 5.11.

Table-5.10: Input parameters (actual value) as of 2nd February 2015 [6]

Name (Gas Fields)	**Type**	**Gas Flow (MMscfd)**
Bakrabad	Source	40
Bangora	Source	110
Beanibazar	Source	10
Bibiyana	**Source**	**1040**
Fenchuganj	Source	38
Hobigonj	Source	225
Jalalabad	Source	220
Kailashtilla	Source	74
Maulvibazar	Source	50
Meghna	Source	10
Narsingdi	Source	28
Rashidpur	Source	60
Salda	Source	10
Semutang	Source	10
Srikail	Source	40
Titas Location 1	Source	240
Titas Location 3	Source	130
Titas Location 5	Source	100
Titas Location 7	Source	55
Total		**2490**

Table- 5.11: Simulated pressure at different demand centers.

Name	Type	Gas Flow (MMscfd)	Pressure (psig)
AES Haripur	Sink	55	134.01
AES Meghnaghat	Sink	75	349.86
AFCCL	Sink	50	742.35
Aminbazar CGS	Sink	120	237.82
APCL	Sink	145	728.41
Ashulia CGS	Sink	160	270.35
Baghabari	Sink	60	739.06
Barabkunda	Sink	10	537.18
Bogra	Sink	20	742.18
Brahmanbaria	Sink	30	903.88
Chandpur	Sink	27	457.93
Comilla	Sink	10	855.18
CTG CGS	Sink	300	300.25
EPZ DRS	Sink	20	631.45
Fenchuganj PS	Sink	52	920.05
Feni TBS	Sink	6	800.87
Gozaria	Sink	15	419.3
GPS	Sink	140	533.67
GTCL Demra	Sink	120	200.03
Haripur	Sink	70	221
Iswardi EPZ	Sink	5	751.81
JDP	Sink	100	440
JFCL	Sink	50	648.49
KTL off take	Sink	70	934
Moymensing	Sink	85	415
PUFF	Sink	15	530.27
Rajshahi	Sink	5	603
Shahjibazar PS	Sink	50	306
Siddhirgonj	Sink	200	428
Sirajgonj	Sink	50	738.39
Sonargaon	Sink	10	299.21
Tangail DRS	Sink	15	702.22
Tarabo	Sink	35	220.99
TGTDCL Demra	Sink	270	771
UFFL	Sink	45	530.15
Total		**2490**	

The comparison between two cases, the simulated data for 24 inch BD pipeline and 36 inch BD pipeline is shown in Table 5.12 which is plotted in the graph shown in Figure 5.6.

Table 5.12: Simulated pressure data for both case at major off-take/outlet.

Off take points	**Pressure (psig)**		
	BD pipeline (36 inch)	**BD pipeline (24 inch)**	**Difference (%)**
Ashulia CGS	278	270	2.9
Aminbazar CGS	242	238	1.7
PUFF	534	530	0.7
GUFF	534	530	0.7
GPS	534	530	0.7
Demra CGS	205	200	2.4
Meghnaghat PP	350	349	0.3
AFCCL	740	742	0.3
Ashuganj	733	728	0.7
Fouzdarhat CGS	308	300	2.6
Fenchuganj PS	924	920	0.4
Haripur PP	225	221	1.8
Siddirgonj	425	428	0.7
APCL	733	728	0.7
JFCL	653	648	0.8
TGTDCL Demra	780	771	1.2
RPCL	417	415	0.5
Feni TBS	806	800	0.7
Baghabari	745	739	0.8
Bogra	752	742	1.3

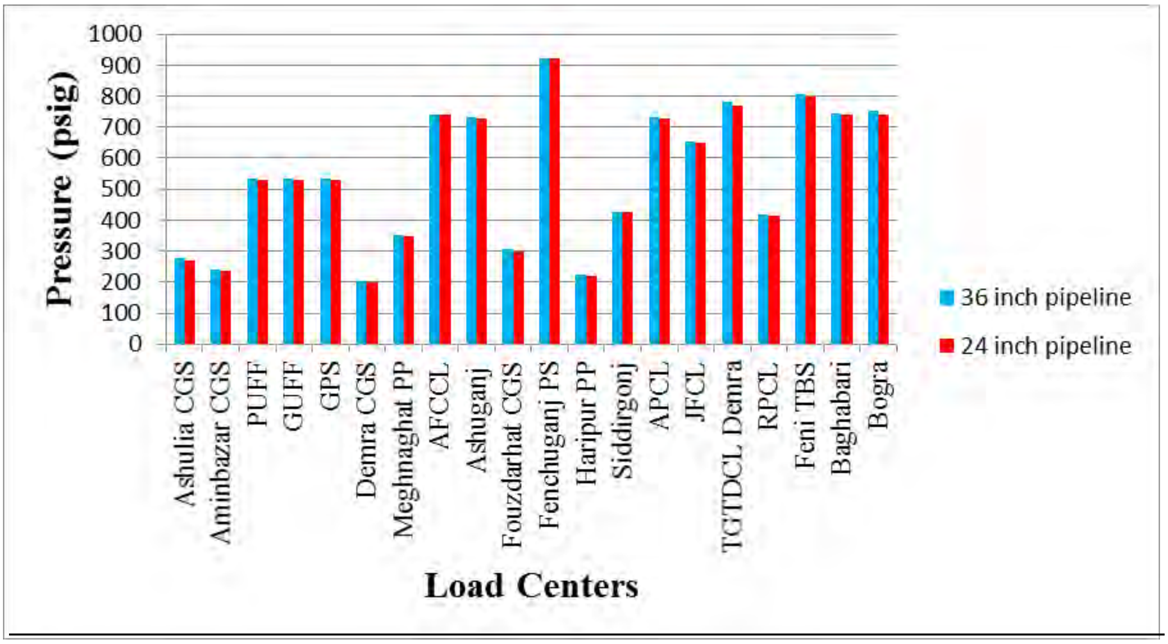

Figure 5.6: Pressure of different demand centers.

Analysis of the study

Before commissioning of BD line simulated pressure at Ashulia CGS, Aminbazar CGS, Chittagong CGS was 158 psig, 108 psig and 287 psig respectively. But after commissioning of BD line simulated pressure at Ashulia CGS, Aminbazar CGS, Chittagong CGS is 278 psig, 242 psig and 308 psig respectively. Now from the analysis it is observed that for 24 inch pipeline the simulated pressure at this particular CGS points is very close though there is little difference - maximum 8 psig (2.9%) against the simulated value for (36" × 137 km) pipeline. The overall value is seemed to be very close and the pressure data of the off take points maintain the desired pressure. So, it can be said that the existing network is capable of meeting the present demand with (24" × 137 km) BD pipeline.

5.4 Prediction Case-1: Minimum pressure in Khulna at present demand considering Bibiyana-Dhanua (BD) line 24inch in diameter.

This case study is made for additional 177 km pipeline with existing network from Iswardi to Khulna which has already been constructed except Padma River crossing [14]. After successful completion of HDD Padma River crossing, this pipeline section will be hooked-up with the existing network and will be brought under operation to supply gas to Bheramara power plant and Kushtia, Jhenaidah, Jessore and Khulna region.

At Khulna 150 MW combined cycle power plant has already been installed. The plant is producing power by high speed diesel as gas is not available there at this moment. About 35 MMscfd gas would be required to run this plant for power generation. Taking into account other industrial, commercial demand at this moment, it is anticipated that about 40 MMscfd gas might have required for Khulna at present. Around 30 MMscfd gas is considered for Bheramara as a gas based power plant (360 MW) is under installation there. Though this plant will need at least 90 MMscfd gas for its full capacity production, only 30 MMscfd is considered at this stage considering its first phase of production. For Kushtia, Jhenaidah and Jessore 5 MMscfd are set for each as there is no bulk consumer at this moment in these areas. Considering existing demand it can be assumed that around 85 MMscfd gas for Bheramara power plant and Kushtia, Jhenaidah, Jessore and Khulna region and total 210 MMscfd gas would be needed to meet the demand in West Zone right now [15]. The demand of different demand centers of West Zone at present situation is tabulated in Table 5.13 and pressure at different sinks obtained from the network simulation are tabulated in Table 5.14.

In this study the diameter of BD line is considered 24 inch for 137 km pipeline instead of 36 inch diameter to analyze the pressure drop profile and predicts the minimum pressure at Khulna. It is to be mentioned that about 300 MMscfd gas is supplied through BD line.

Inputs: The input of the network model is tabulated in Table- 5.13.

Table-5.13: Input parameters [15].

Consumption/Demand	MMscfd
Sirajgonj	50
Baghabari	50
Bogra	20
Iswardi	5
Rajshahi	2
Bheramara Power Plant	30
Kustia	3
Jhenaidah	5
Jessore	5
Khulna	40
Total	**210 MMscfd**

Table 5.14: The output of the simulated data at different off-take/outlet.

Name	**Type**	**Gas Flow (MMscfd)**	**Pressure (psig)**
AES Haripur	Sink	55	180.06
AES Megnaghat	Sink	75	336.67
AFCCL	Sink	50	711.03
Aminbazar CGS	Sink	120	264.07
APCL	Sink	150	700.08
Ashulia CGS	Sink	160	279.58
Barabkunda	Sink	15	485.82
Brahmanbaria	Sink	30	818.29
Chandpur	Sink	20	597.96
Comilla	Sink	10	825.4
CTG	Sink	300	309.98
EPZ DRS	Sink	20	541.69
Feni	Sink	5	664.01
Fenshuganj PS	Sink	50	928.01
Gojaria	Sink	15	448.22
GPS	Sink	150	595.89
GTCL Demra	Sink	100	228.96
Haripur	Sink	70	229.31
JDP CGS	Sink	110	580.87
JFCL	Sink	50	656.69
KTL off take	Sink	100	1000
Laksam	Sink	5	714.85
PUFF	Sink	15	581.42
RPCL - Mymensing	Sink	85	365.82
Shahajibazar Ps	Sink	50	303.48
Siddhirganj	Sink	200	432.27
Sonargaon	Sink	10	334.21
Tangail DRS	Sink	15	570.55
Tarabo	Sink	35	762.81
TGTDCL Demra	Sink	250	717.68
UFFL	Sink	50	573.69
Bharamara	Sink	30	350.31
Iswardi	Sink	5	333.95
Rajshahi	Sink	2	344.96
Bogra	Sink	20	358.61
Baghabari	Sink	50	350.85
Sirajgonj	Sink	50	361.95
Jessore	Sink	5	304.9
Kustia	Sink	3	343.17
Jhinaydah	Sink	5	340.3
Khulna	Sink	40	315
Total		**2578**	

Analysis of prediction case-1

This case study is made for additional 177 km pipeline from Iswardi to Khulna with existing network. The pressure situation against the present demand in west zone is predicted. From the simulated result it is observed that the minimum pressure of Khulna is 315 psig against the present demand of 210 MMscfd gas in West Zone. This minimum pressure (315 psig) of the network in Khulna, is quite enough to meet the requirement of Distribution Company's required pressure (300 psig) and also the pressure in different off take points of the West Zone is above against the desired pressure.

So, from the analysis it can be said that with (24" × 137 km) BD pipeline the network is capable of meeting the present demand in West Zone as well as countrywide demand maintaining required pressure in Khulna.

5.5 Prediction Case-2: Maximum possible volumetric flow rate maintaining 350 psig in Khulna with boost up device.

At present the overall national gas grid pressure is not well enough to maintain the distribution companies minimum required pressure. Distribution companies especially Titas Gas Transmission and Distribution Company Limited (TGTDCL) in Greater Dhaka region and Karnafuly Gas Distribution Company Limited (KGTCL) in Chittagong region are continuously facing low pressure problem so they cannot supply gas to their customers at required pressure as they received gas from the grid at pressure lower than that of required at upstream of their distribution network. To boost up the national gas grid pressure, compressor station had been installed by Chevron at Muchai, Moulavibazar and GTCL installed compressor station at Ashuganj, Brahmanbaria as well as Elenga, Tangail [16-17]. These three compressor stations are synchronized and suppose to maintain the grid pressure as shown in Figure 5.7.

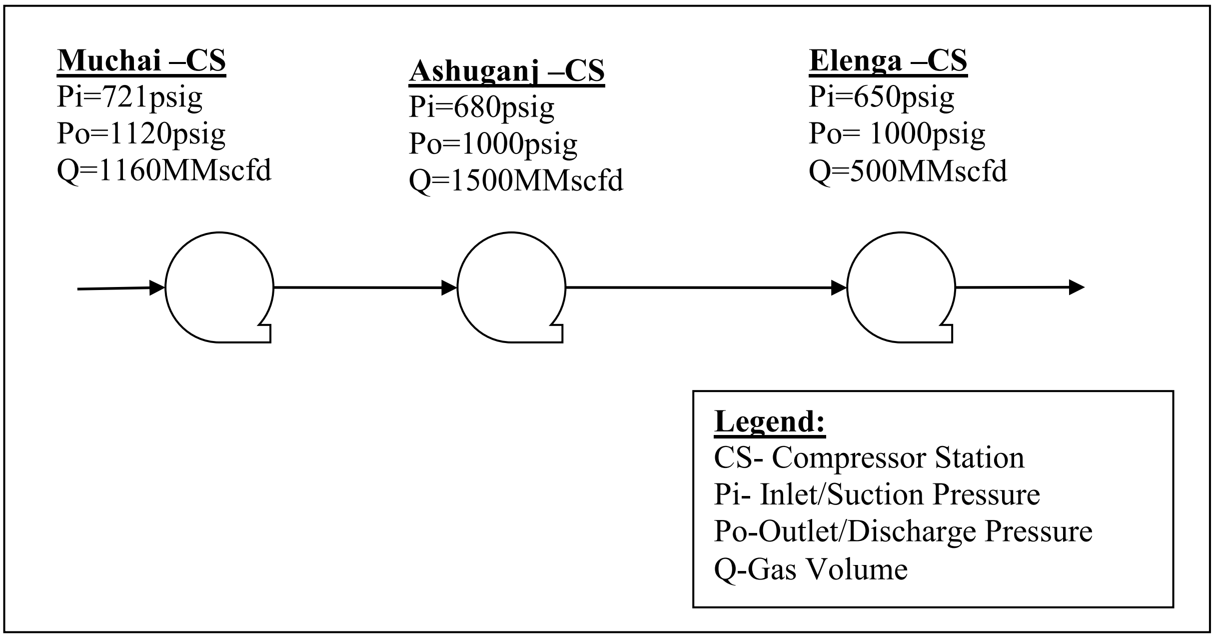

Figure 5.7: Synchronized boost up device for gas grid

The compressor station established at Muchai, Habigonj will feed gas to Ashuganj hub at pressure not less than the minimum required pressure of 680 psig at the inlet of Ashuganj compressor that will boost up pressure to 1000 psig at its outlet to feed gas to Chittagong and greater Dhaka franchise area along with West Zone.

Ashugonj compressor is designed in such a way that it will feed gas to Elenga at pressure not less than minimum required pressure of 650 psig at the inlet of Elenga compressor that will boost up pressure to 1000 psig to feed gas to the West zone.

By this case study, it is analyzed the effect of compressor and 24 inch diameter instead of 36 inch BD pipeline to the West Zone network, the pressure drop profile, maximum volume of flow maintaining minimum pressure 350 psig at Khulna .The input of the network model is tabulated in Table- 5.15 and the output of this case study is summarized in Table 5.16.

Table-5.15: Input Parameters [15].

Minimum required pressure at Khulna	350 psig
Consumption/Probable Demand	MMscfd
Sirajgonj	100
Baghabari	50
Bogra	100
Rajshahi	20
Iswardi EPZ	10
Bheramara	100
Kushtia	20
Jhenaidah	30
Jessore	20

Table 5.16: The output of the simulated data of different off take points

Name	Type	Gas Flow (MMscfd)	Pressure (psig)
AES Haripur	Sink	55	562.31
AES Megnaghat	Sink	75	523.9
AFCCL	Sink	50	775.4
Aminbazar CGS	Sink	120	328.27
APCL	Sink	150	723.83
Ashulia CGS	Sink	160	338.83
Barabkunda	Sink	15	466.42
Brahmanbaria	Sink	30	494.4
Chandpur	Sink	20	620.58
Comilla	Sink	10	807.98
CTG	Sink	300	309.87
EPZ DRS	Sink	20	523.51
Feni	Sink	5	587.64
Fenshuganj PS	Sink	50	905.66
Gojaria	Sink	15	433.98
GPS	Sink	150	584.72
GTCL Demra	Sink	100	516.78
Haripur	Sink	70	499.48
JDP CGS	Sink	110	676.5
JFCL	Sink	50	502.1
KTL off take	Sink	100	950
Laksam	Sink	5	724.51
PUFF	Sink	15	560.74
RPCL - Mymensing	Sink	85	558.44
Shahajibazar Ps	Sink	50	496.05
Siddhirganj	Sink	200	620.22
Sonargaon	Sink	10	421.57
Tangail DRS	Sink	15	609.71
Tarabo	Sink	35	545.98
TGTDCL Demra	Sink	250	406.74
UFFL	Sink	50	553.82
Iswardi	Sink	10	494.01
Rajshahi	Sink	20	515.67
Bogra	Sink	100	483.47
Baghabari	Sink	50	538.94
Sirajgonj	Sink	100	585.28
Bheramara	Sink	100	570.07
Kustia	Sink	20	463.07
Jhinaydah	Sink	30	426.01
Jessore	Sink	20	389.83
Khulna	**Sink**	**80**	**350**
Total		**2900**	

Analysis of prediction Case-2

This case study shows that maximum 2900 MMscfd gas is supplied through the entire network. It can supply 530 MMscfd gas to the West Zone maintaining 350 psig pressure at Khulna. Pressure at major demand centers such as Bheramara, Kustia, Jinaydah and Jessore also above the desired pressure. It can be predict that 80 MMscfd gas would be possible to transmit to Khulna with maintaining the desired pressure.

Analysis also shows that 24 inch diameter BD pipeline can carry 400 MMscfd gas maintaining 350 psig pressure at Khulna and fulfilling the future demand of West Zone.

5.6 Prediction case-3: Maximum demand and effect of additional gas from LNG.

The main source of energy of Bangladesh is indigenous natural gas. In this respect it must understand and take into consideration the demand-supply situation of the natural gas in the country. There is a widening gap between the amount of gas supplies available and the growing demand for natural gas. There are lot of industrial units exists in the country which just cannot go into operation in absence of gas. Many industries in Chittagong are already in idle condition because of non-availability of gas. There are lots of industries other than Chittagong area which cannot undertake the expansion activities of their present operations. From practical point of view, it has been observed that if infrastructures like road communication, power generation and or expansion of gas networks are established in some areas, industrial units are set up in those areas quickly. Once the Nalka-Khulna gas transmission pipeline is brought into operation, within a short span of time, the installation of industrial units in those areas will increase. As the present gas reserve is not in a position to deliver the required quantities of gas, it is must to look for alternative source of gas supply. Gas consumption will continue to increase despite the declining domestic supply and imports can help to fill the growing gap. In absence of natural gas, power generation with costly liquid fuel is being planned with lot of logistics problem. In this situation Liquefied Natural Gas (LNG) could be the alternative of natural gas to mitigate the problem.

The government took the initiative to import LNG and it has been planned to use the Floating Storage & Regasification Unit (FSRU) near Moheshkhali where required draught is available at about 5-6 km offshore of Moheshkhali coast. The mother vessel carrying LNG would be transferred to the FSRU which would be moored at about 5-6 km off-coast of Moheshkhali. An offshore pipeline would be installed from the FSRU and a delivery point will be stationed on-shore at Moheshkhali Island. From the delivery point, a gas transmission pipeline of about 85-90 km would be installed to bring the gas at the port city of Chittagong as shown in Figure 5.8. In Chittagong, it would be hooked up with Karnaphuly gas system and the gas would be supplied to the customers. Thus the supply-demand gap between production area and demand area will be solved [18].

Figure 5.8: Proposed pipeline route for additional gas from LNG

The government may take various measures in the future to cope with the gas demand/supply imbalance. However, it is forecast that the potential gas demand would increase to 4500MMscfd in near future and the gas supply would fall. According to Petrobangla, the existing gas fields are capable of produce maximum 3000 MMscfd gas. Under such circumstances to secure the gas supply for future gas demand around 1500 MMscfd gas from LNG will be supplied to the pipeline network in Bangladesh [19]. The predicted demand of the marketing companies is shown in Table 5.17

Table 5.17: Estimated Demand in 2030 [19]

Company Name	Estimated demand (MMscfd)
TGTDCL	2276
BGDCL	617
JGTDSL	510
KGDCL	800
PGCL	220
SGCL	77
Total	**4500**

This case study will show how 4500 MMscfd gas cope with the total pipeline network considering the local gas production from existing gas field remain same as case 2. This is the maximum possible gas that needs to be handled by the entire network in near future. In other words, this study analyzes the effect of additional 1500 MMscfd gas from LNG to the network. The gas flow of different gas fields along with additional gas from LNG as source of the network is shown in Table 5.18. Predicted gas consumption of different demand centers and simulated pressure at different sinks obtained from the network simulation are tabulated in Table 5.19.

Table-5.18: Input parameters

Name	**Type**	**Gas Flow (MMscfd)**
Bakrabad	Source	60
Bangora	Source	110
Beanibazar	Source	10
Bibiyana	Source	1225
Fenchuganj	Source	38
Hobigonj	Source	225
Jalalabad	Source	250
Kailastilla	Source	170
Maulvibazar	Source	60
Meghna	Source	10
Narsingdi	Source	27
Rashidpur	Source	100
Salda	Source	30
Semutang	Source	35
Srikail	Source	40
Titas Location 1	Source	245
Titas Location 3	Source	165
Titas Location 5	Source	130
Titas Location 7	Source	70
LNG	**Source**	**1500**
Total		**4500**

Table 5.19: The simulated pressure data of different off take points.

Name	Type	Gas Flow (MMscfd)	Pressure (psig)
AES Haripur	Sink	150	465.38
AES Meghnaghat	Sink	100	276.37
AFCCL	Sink	50	779.77
Aminbazar	Sink	120	339
APCL	Sink	200	732.67
Ashulia	Sink	200	396
Baghabari	Sink	80	527.46
Barabkunda	Sink	10	465.05
BGTDCL	Sink	100	673.2
Bheramara PP	Sink	100	477.84
Bogra	Sink	30	539.05
Brahmanbaria	Sink	50	864.38
Chandpur	Sink	25	404.55
Comilla	Sink	40	475.39
CTG Region	Sink	800	370
EPZ DRS	Sink	35	440
Fenchuganj PS	Sink	100	907.55
Feni TBS	Sink	40	385.58
Gozaria	Sink	30	360.33
GPS	Sink	165	450.48
GTCL Demra	Sink	300	161.18
Haripur	Sink	150	147.93
Iswardi EPZ	Sink	15	462.53
JDP	Sink	130	310
Jessore	Sink	15	294.66
JFCL	Sink	60	451.46
JGTDSL	Sink	100	911.79
Jhenaidah	Sink	15	363.06
Khulna	Sink	80	279.75
KTL off take	Sink	100	933.67
Kushtia	Sink	15	437.56
Moymensing	Sink	85	721
PUFF	Sink	40	451.38
Rajshahi	Sink	20	469.63
Shahjibazar PS	Sink	100	350.1
Siddhirgonj	Sink	300	516.29
Sirajgonj	Sink	50	556.38
Sonargaon	Sink	30	222.54
Tangail DRS	Sink	40	478.84
Tarabo	Sink	35	394.29
TGTDCL	Sink	125	516.57
TGTDCL Demra	Sink	200	490
UFFL	Sink	70	451.13
Total		**4500**	

Analysis of prediction Case-3

This case study is made for 1500 MMscfd gas from LNG. The pressure situation against the 4500 MMscfd gas demand is predicted. Around 800 MMscfd gas is consumed in Chittagong region maintaining 370 psig pressure and rest of the maximum gas is consumed to feed Dhaka region. The pressure at West Zone downstream point Khulna is 279 psig which is enough for running power plant. If additional power plant is going to install for Khulna region, a small boost up device will be needed to install for that power plant in near future to maintain desired pressure. Otherwise existing network can handle 4500 MMscfd gas.

So from the analysis it can be said that the entire network is capable to cope with 4500 MMscfd gas. Time to time analysis needed for better performance of transmission network.

5.7 Summary of case studies

In present situation 24 inch diameter Bibiyana-Dhanua pipeline is capable of meeting the present demand as the simulated pressure data matched with actual pressure data with little difference.

From the prediction case studies one thing is clear that 24 inch diameter BD pipeline meets the all required condition for future demand. It is to be noted that about 400 MMscfd gas is supplied through the BD line in all prediction cases.

Bangladesh Power Development Board (BPDB) has planned to install a new 300-450 MW Gas based Combined Cycle Power Plant (CCPP) at Bibiyana, Nabiganj, Habiganj. The natural gas for the proposed power plant will be supplied from the Bibiyana Gas Field, which is near the power plant and is also connected to the gas grid network. Bibiyana will be required to feed about 175-200 MMscfd gas to feed the power plants near the gas field [20]. Now Bibiyana gas field maintain the high production rate of about 1200 MMscfd and has planned to continue in next 5 years. After that production rate will decrease. In this situation Bibiyana gas field will not be able to feed more than 300MMscfd gas through Bibiyana-Dhanua Pipeline where (36" × 137 km) BD pipeline is designed by GTCL to carry 650 MMscfd of gas.

Upstream Pressure (psig)	**Downstream Pressure (psig)**	**Q (MMscfd)**	**Q (MMscfd)**
		(36" × 137 km)	**(24" × 137 km)**
1000	650	921	379
1000	700	864	346
1000	750	799	320

From the calculation by using modified Panhandle 'B' equation, if Upstream Pressure is 1000 psig and Downstream Pressure is 650 psig, (36" × 137 km) pipeline can handle maximum 921 MMscfd of gas and (24" × 137 km) pipeline can handle 379 MMscfd of gas. Bibiyana gas field will not able to feed more than 300 MMscfd gas through BD line in near future. So feeding Bibiyana –Dhanua pipeline with high pressure gas will not be required by Elenga Compressor station and reduce gas supply to upstream of Ashuganj Compressor station will not permit it to operate as per design.

So it can be said that (36" × 137 km) Bibiyana-Dhanua transmission pipeline was overdesigned as it can easily transmit around 400 MMscfd gas through 24 inch pipeline.

5.8 Bottleneck of the transmission network

Government has planned to install a gas transmission pipeline of about 30 inch diameter to bring the gas from LNG at the port city of Chittagong. But from the analysis, a 36 inch diameter pipeline will have to install to transmit 1500 MMscfd gas from Moheshkhali to Chittagong ring main. The diameter of transmission pipeline will must increase to 42 inch if it is needed to transmit more than 1500 MMscfd gas.

It is assumed that around 800 MMscfd gas will be consumed in Chittagong region from additional 1500 MMscfd gas and rest of the gas will supply to the network. The existing 24 inch pipeline from Bakhrabad HUB to Chittagong CGS will not able to carry additional gas from Chittagong to rest of the country. So a 30 inch parallel pipeline should be installed from Chittagong to Bakhrabad HUB for the transportation of the additional gas to rest of the country.

5.9 Costing of Bibiyana-Dhanua (BD) pipeline

The following cost categories are typically considered in pipeline costing.

□**Investment cost:** Including planning and design fees, costs of materials and equipment, transport and construction works. Some projects may also include compression stations. The length and size (i.e. the diameter) of the pipeline, the cost of steel and the type of terrain would usually be among the key determinants of the investment cost.

□**Operating and maintenance (O&M) costs:** Including personnel, gas compression cost, maintenance costs and administrative and other general costs. Note that depreciation is not to be included in the analysis, as costs are only considered on a cash-flows basis. The revised cost [21] of transmission pipeline is summarized in Table 5.20 and annual gas output of Bibiyana-Dhanua pipeline is shown in Table 5.21.

Table 5.20: Cost of Bibiyana-Dhanua pipeline

Taka in million

Component	**Cost**	
	36"OD × 137 km (BD pipeline)	**24"OD × 137 km**
Pay of Officer and Staff	85	56
Supply and service	80	96
Land acquisition	954	636
Land requisition and Compensation	382	253
Pipeline Materials (All Pipes, Valves and Fitting	5400	3600
Vehicles and Equipment’s	25	7
Pipeline Construction	1405	936
Civil Works	270	180
Regulation and Metering Station	1350	900
River Crossing	1300	850
SCADA	450	300
CD-VAT, IDC and Land Charge	2610	1740
Contingency and others	45	30
Total Cost	**14356**	**9584**
Cost per Km length/inch diameter of pipeline	**2.9**	**2.9**

Table 5.21: Annual value of output of Bibiyana - Dhanua gas transmission pipeline

year	Annual Gas Output		Transmission charge rate	Transmission charge
	MMCF	**MMCM**	**(TK/CM)**	**(In Lakh Taka)**
Year -1 (2011-2012)	0	0	0.156	0
Year -2	0	0	0.156	0
Year -3	0	0	0.156	0
Year -4	0	0	0.156	0
Year -5 (2016-2017)	160600	4551.18	0.156	7099.8408
Year -6	160600	4551.18	0.156	7099.8408
Year -7	160600	4551.18	0.156	7099.8408
Year -8	160600	4551.18	0.156	7099.8408
Year -9 (2020-2021)	233600	6619.9	0.156	10327.044
Year -10	233600	6619.9	0.156	10327.044
Year -11	233600	6619.9	0.156	10327.044
Year -12	233600	6619.9	0.156	10327.044
Year -13	233600	6619.9	0.156	10327.044
Year -14	233600	6619.9	0.156	10327.044
Year -15	233600	6619.9	0.156	10327.044
Year -16	233600	6619.9	0.156	10327.044
Year -17	233600	6619.9	0.156	10327.044
Year -18	233600	6619.9	0.156	10327.044
Year -19	233600	6619.9	0.156	10327.044
Year -20	233600	6619.9	0.156	10327.044
Year -21	233600	6619.9	0.156	10327.044
Year -22	233600	6619.9	0.156	10327.044
Year -23	233600	6619.9	0.156	10327.044
Year -24	233600	6619.9	0.156	10327.044
Year -25	233600	6619.9	0.156	10327.044

Gas Transmission Company Limited (GTCL) is mandated to operate any and all high pressure gas transmission pipelines and deliver gas to any end-users. Any section of transmission pipeline in Bangladesh remains open-access and GTCL is mandated a wheeling charge (Transmission Tariff). As a Bangladesh Energy Regulatory Commission (BERC)-regulated gas utility, GTCL has the right to ask for wheeling charge adjustment for any new transmission facility required to transport genuinely stranded gas to a potential downstream market. For this study gas price is considered 0.156 TK/CM and assumed to be constant through the whole prediction period. From Table 5.20, daily gas output through BD pipeline is 440 MMscfd which will continue for 4 years then gas output will increase to 640 MMscfd and will continue for 15 years. The investment cost for (36" × 137 km) BD pipeline is 143560 lakh taka. Using this cost discounted total cost and discounted total benefit has been evaluated (using 12% bank interest rate). The details calculations are shown in Appendix. From the calculation Net Present Value (NPV) is - 95556.56 lakh taka and Benefit Cost Ratio (BCR) is .34 for financial case. For economic case NPV is - 50239 lakh taka and BCR is .58.

From the analysis one thing is clear that (36" × 137 km) Bibiyana – Dhanua transmission Pipeline would be a loss project as Net Present Value (NPV) for both economic and financial is negative. GTCL could minimize cost by installing 24 inch diameter pipeline instead of 36 inch diameter pipeline as it was over designed which is mentioned earlier. Because for installing (24"×137 km) pipeline cost is 95840 lakh taka where (36" × 137 km) pipeline installation cost is 143560 lakh taka.

While Bangladesh suffers investment constraints, the big investment in the largest cross-country Bibiyana-Dhanua gas transmission pipeline will become a chronic pain in the neck of the gas sector. Now this big investment of GTCL will make it bleed financially.

5.10 Gas reserve of Bibiyana gas field

At present Bibiyana gas field produces 1200 MMscfd gas and it is the highest production rate till now [22]. If this gas field continues this plateau rate it would be possible to produce gas for next 8 years from the remaining reserve as shown in Table 5.22.

Table 5.22: Life time estimation of Bibiyana gas field

Daily Production (MMscfd)	**Yearly Production (BCF)**	**Recoverable Reserve[2] (BCF)**	**Cumulative Production[22] (September 2015) (BCF)**	**Remaining Reserve (BCF)**	**Life Time (year)**
1200	438	5754	2152.65	3601.35	8.22

5.11 Cost recovery projection of Bibiyana-Dhanua pipeline

This study also cover the estimated field life of Bibiyana against different transmission rate through B-D line as shown in Table 5.23. Currently Bibiyana gas field is supplying around 400 MMscfd gas through Bibiyana-Dhanua pipeline. Considering the highest supply through B-D line as 400 MMscfd for next 8 years , the wheeling charge for B-D line should be at least Tk 0.45/ CM for break even the project as shown in Table 5.23.

Table 5.23: Cost recovery projection

Field life	**Transmission charge(TK/CM) of BD line for Break Even the project**			
	Q= 200 (MMscfd)	**Q= 300 (MMscfd)**	**Q= 400 (MMscfd)**	**Q= 500 (MMscfd)**
5 year	1.235	0.823	0.617	0.494
8 year	0.9	0.6	**0.449**	0.36
10 year	0.79	0.527	0.395	0.316
15 year	0.657	0.438	0.329	0.263

CHAPTER 6
CONCLUSION

The existing gas transmission pipeline network before and after commissioning of Bibiyana-Dhanua line of Bangladesh along with newly constructed pipeline from Iswardi to Khulna via Bheramara, Kustia, Jhenaidah and Jessore is analyzed. In this study, along with present situation, numbers of case study are done to predict the pressure and volumetric flow of the network at various flow conditions. Besides experimental results are analyzed and number of analytical calculations are done to predict how long the pipeline and boost up devices can cope up with the forecasted future demand.

Present (36" × 137 km) pipeline from Bibiyana to Dhanua is overdesigned according to local supply of gas. An economic analysis in the form of Net Present Value (NPV) and Benefit Cost Ratio (BCR) for both economic and financial has been performed for (36" × 137 km) of Bibiyana to Dhanua Gas Transmission Pipeline. The analysis shows that with current gas supply situation Bibiyana-Dhanua line is going to be uneconomical for GTCL. To reach the break even of Bibiyana-Dhanua pipeline project the wheeling charge should be at least 0.45 Tk/CM instead of 0.156 Tk/CM.

The study shows that with (24" × 137 km) pipeline from Bibiyana to Dhanua fulfill the present demand including the future demand of West Zone network maintaining 350 psig pressure at Khulna.

This study also analyzed feasibility of LNG transportation from Moheshkhali to Chittagong. A 36 inch diameter pipeline will have to install to transmit 1500 MMscfd gas from Moheshkhali to Chittagong ring main. Also a parallel pipeline of about 30 inch diameter from Chittagong to Bakhrabad HUB should be installed to transport the additional gas from LNG to greater Dhaka region prior to the import of LNG.

REFERENCES

[1] Imam, Badrul; Energy Resources of Bangladesh (2005), University Grants Commssion.

[2] Annual Report, 2014, Bangladesh Oil, Gas and Minerals Corporation (Petrobangala), Dhaka, Bangladesh.

[3] Annual Report 2012-2013 of Gas Transmission Company Limited, Dhaka, Bangladesh.

[4] "*National Energy Policy,*" Ministry of Power, Energy and Mineral Resources, Government of the People's Republic of Bangladesh, Dhaka, May 2004.

[5] "Analytical Report of Sales Line Gases of Various Gas Fields,'' of Asuganj Gas Manifold Station (AGMS), Ashuganj, Gas Transmission Company Limited, prepared by Department of Petroleum & Mineral Resources Engineering, Bangladesh University of Engineering and Technology, Dkaka, September 2010.

[6] Daily Gas Production and Supply Statistics, 02-03 February 2015, Gas Transmission Company Limited (GTCL).

[7] Management Information System (MIS) Report, January 2015, Volume 391, Bangladesh Oil Gas and Minerals Corporation (Petrobangla), Dhaka, Bangladesh.

[8] PIPESIM Fundamental: Training and Exercise Guide, Version 2007.1, Schlumberger.

[9] GPSA (Gas Processors Suppliers Association). Engineering Data Book. 11ed. 1998.

[10] Crane Co. 1988. Flow of Fluids through Valves, Fittings and Pipes.

[11] Management Information System (MIS) Report, November 2014, Volume 389, Bangladesh Oil Gas and Minerals Corporation (Petrobangla), Dhaka, Bangladesh.

[12] Daily Gas Production and Supply Statistics, 16-17 October 2014, Gas Transmission Company Limited.

[13] Monthly Progress Report, December 2014, Gas Transmission Company Limited

[14] Monthly Progress Report, December 2013, Gas Transmission Company Limited

[15] Hossain, S.M.,"Network *Modeling and Analysis: West Zone Gas Transmission Pipeline Network of Bangladesh*" M.Engineering Project, Department of Petroleum and Mineral Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka, 2014

[16] Annual Report 2013-2014 of Gas Transmission Company Limited, Dhaka.

[17] Revised Development Project Proforma/Proposal (RDPP), Compressor Station Project, Gas Transmission Company Limited.

[18] ep-bd.com/online/details.php?cid=32&id=17538 (accessed 14 November 2015)

[19] Report January 2012 of Japan International Cooperation Agency (JICA)

[20] http://www.jbic.go.jp/wp-content/upload/project (accessed 9 November 2015)

[21] Revised Development Project Proforma/Proposal (RDPP), September 2014, Bibiyana-Dhanua Gas Transmission Pipeline Project (GTCL).

[22] Management Information System (MIS) Report, September 2015, Volume 399, Bangladesh Oil Gas and Minerals Corporation (Petrobangla), Bangladesh.

APPENDIX

SAMPLE CALCULATION

Calculation of Pressure

$$Q_{mmscfd} = 0.00128084 \left[\frac{P_1^2 - P_2^2}{L_{miles}} \right]^{0.51} d^{2.53}$$

Barbkunda - Chittagong CGS pipeline:

Pressure at Barbkunda, P_1= 463 psig

Flow, Q= 300MMscfd

Inside pipe diameter, d =23.188

Length of pipeline, L = 21.35 miles

Downstream pressure at Chittagong CGS, P_2 =?

From above equation,

$$300 = 0.00128084 \left[\frac{(463)^2 - P_2^2}{21.35} \right]^{0.51} (23.188)^{2.53}$$

Or, $392.19 = \left[214369 - P_2^2 \right]^{0.51}$

Or, $121699.07 = 214369 - P_2^2$

Or, $P_2^2 = 92669.92$

Or, P = 305.4 psig

In this same way the pressure at different off take points are calculated that are summarized in below table:

Off take points	P_1	Q	L	d	P_2
Ashulia CGS	387	160	17.3	19.188	276.6622
Aminbazar CGS	325	120	19.00	19.188	244.6789
PUFF	534	15	0.061	13.376	533.986
GUFF	534	45	0.061	13.376	533.8793
GPS	534	140	0.061	15.312	533.4287
Demra CGS	205	100	0.061	19.188	204.7486
Meghnaghat PP	351	75	0.61	19.188	350.1649
AFCCL	856	50	12.81	9.5	742.6818
Ashuganj PS	856	140	1.83	9.5	733.3977
Chittagong CGS	463	300	21.35	23.188	305.344
Fenchuganj PS	927	52	0.951	11.5	923.9543
Haripur	237	70	0.9638	13.376	226.5683

ECONOMIC ANALYSIS OF BIBIYANA-DHANUA PIPELINE

Benefit (Economic)

(In lakh Taka)

Financial Year	Gas Consumption		Benefit (Financial)	SCF	Benefit (Economic)
	MMCF	MMCM			
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	160600	4551.18	7099.84	1.4	9939.78
6	160600	4551.18	7099.84	1.4	9939.78
7	160600	4551.18	7099.84	1.4	9939.78
8	160600	4551.18	7099.84	1.4	9939.78
9	233600	6619.9	10327	1.4	14457.9
10	233600	6619.9	10327	1.4	14457.9
11	233600	6619.9	10327	1.4	14457.9
12	233600	6619.9	10327	1.4	14457.9
13	233600	6619.9	10327	1.4	14457.9
14	233600	6619.9	10327	1.4	14457.9
15	233600	6619.9	10327	1.4	14457.9
16	233600	6619.9	10327	1.4	14457.9
17	233600	6619.9	10327	1.4	14457.9
18	233600	6619.9	10327	1.4	14457.9
19	233600	6619.9	10327	1.4	14457.9
20	233600	6619.9	10327	1.4	14457.9
21	233600	6619.9	10327	1.4	14457.9
22	233600	6619.9	10327	1.4	14457.9
23	233600	6619.9	10327	1.4	14457.9
24	233600	6619.9	10327	1.4	14457.9
25	233600	6619.9	10327	1.4	14457.9

Benefit Cost Ratio (Financial)

(In lakh Taka)

Year	Investment Cost (PV)	Operating Cost (PV)	Total Cost (PV)	Total Benefit (PV)	Discount Factor 12%	Discounted Total Cost	Discounted Total Benefit
1	18137.8	0	18137.75	0	1	18137.75	0
2	93664.4	0	93664.37	0	0.89	83361.29	0
3	37089.3	0	37089.31	0	0.8	29671.45	0
4	17460.1	0	17460.05	0	0.71	12396.64	0
5		101.42	101.42	7099.841	0.64	64.9088	4543.8981
6		101.42	101.42	7099.841	0.57	57.8094	4046.9093
7		101.42	101.42	7099.841	0.51	51.7242	3620.9188
8		101.42	101.42	7099.841	0.45	45.639	3194.9284
9		101.42	101.42	10327.04	0.4	40.568	4130.8176
10		101.42	101.42	10327.04	0.36	36.5112	3717.7358
11		101.42	101.42	10327.04	0.32	32.4544	3304.6541
12		101.42	101.42	10327.04	0.29	29.4118	2994.8428
13		101.42	101.42	10327.04	0.26	26.3692	2685.0314
14		101.42	101.42	10327.04	0.23	23.3266	2375.2201
15		101.42	101.42	10327.04	0.2	20.284	2065.4088
16		101.42	101.42	10327.04	0.18	18.2556	1858.8679
17		101.42	101.42	10327.04	0.16	16.2272	1652.327
18		101.42	101.42	10327.04	0.15	15.213	1549.0566
19		101.42	101.42	10327.04	0.13	13.1846	1342.5157
20		101.42	101.42	10327.04	0.12	12.1704	1239.2453
21		101.42	101.42	10327.04	0.1	10.142	1032.7044
22		101.42	101.42	10327.04	0.09	9.1278	929.43396
23		101.42	101.42	10327.04	0.08	8.1136	826.16352
24		101.42	101.42	10327.04	0.07	7.0994	722.89308
25		101.42	101.42	10327.04	0.07	7.0994	722.89308
					Total	**144112.8**	**48556.466**

NPV (Financial) = Sum of discounted benefit – Sum of discounted cost
= 48556.46 – 144112.80
= -95556.56 lakh Taka

$$\text{BCR (Financial)} = \frac{\text{Sum of discounted benefit}}{\text{Sum of discounted cost}} = \frac{48556.46}{144112.8} = .34$$

Benefit Cost Ratio (Economic)

(In lakh Taka)

Year	Investment Cost (AV)	Operating Cost (AV)	Total Cost (AV)	Total Benefit (AV)	Discount Factor 12%	Discounted Total Cost	Discounted Total Benefit
1	14873	0	14873	0	1	14873	0
2	76804.8	0	76804.8	0	0.89	68356.3	0
3	30413.2	0	30413.2	0	0.8	24330.6	0
4	14317.2	0	14317.2	0	0.71	10165.2	0
5		91.68	91.68	9939.78	0.64	58.6752	6361.46
6		91.68	91.68	9939.78	0.57	52.2576	5665.67
7		91.68	91.68	9939.78	0.51	46.7568	5069.29
8		91.68	91.68	9939.78	0.45	41.256	4472.9
9		91.68	91.68	14457.9	0.4	36.672	5783.14
10		91.68	91.68	14457.9	0.36	33.0048	5204.83
11		91.68	91.68	14457.9	0.32	29.3376	4626.52
12		91.68	91.68	14457.9	0.29	26.5872	4192.78
13		91.68	91.68	14457.9	0.26	23.8368	3759.04
14		91.68	91.68	14457.9	0.23	21.0864	3325.31
15		91.68	91.68	14457.9	0.2	18.336	2891.57
16		91.68	91.68	14457.9	0.18	16.5024	2602.41
17		91.68	91.68	14457.9	0.16	14.6688	2313.26
18		91.68	91.68	14457.9	0.15	13.752	2168.68
19		91.68	91.68	14457.9	0.13	11.9184	1879.52
20		91.68	91.68	14457.9	0.12	11.0016	1734.94
21		91.68	91.68	14457.9	0.1	9.168	1445.79
22		91.68	91.68	14457.9	0.09	8.2512	1301.21
23		91.68	91.68	14457.9	0.08	7.3344	1156.63
24		91.68	91.68	14457.9	0.07	6.4176	1012.05
25		91.68	91.68	14457.9	0.07	6.4176	1012.05
					Total	**118218**	**67979**

NPV (Economic) = Sum of discounted benefit – Sum of discounted cost
= 67979 – 118218
= - 50239 lakh Taka

$$\text{BCR (Economic)} = \frac{\text{Sum of discounted benefit}}{\text{Sum of discounted cost}} = \frac{67979}{118218} = .58$$