# How Transient Analysis Facilitates Asset Optimisation

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## Abstract

Natural gas transmission networks tend to be dynamic in nature and the majority in Europe do not normally operate on a simple steady-state basis. Loads ramp up and down in response to changing demands, driven to some extent by the new emerging European market.

The packing and drafting generated by end-users, can make it difficult to understand the dynamics of a network, particularly when using steady-state analysis, as it offers only a limited view of the system.

This paper discusses how and why, a transient model of Dublin City was developed, and how the model was subsequently and successfully used to identify additional capacity within the system. There is also some theoretical information outlined within the paper which provides an outline of the engineering principle underlining this case study.

An outline is provided as to how a request for additional firm capacity in the Dublin area was technically analysed. Steadystate analysis produced insufficient evidence to support the accommodation of the request for extra capacity. In light of this, a transient model was developed which facilitated determination of a suitable network arrangement.

In summary, the paper is an example of how using transient analysis facilitates asset optimization in a gas transmission network.

## Introduction

In late 2003, Ireland's largest electrical generation company, state owned ESB, enquired about the feasibility of securing additional capacity for one of its plants in central Dublin, Poolbeg, shown above. Bord Gáis Éireann (BGE) have in recent years, made significant reinforcements to the Dublin area transmission system. In light of these infrastructural developments, it was felt that the network should be able to accommodate additional flows of gas to the relevant power stations. However preliminary steady-state modelling indicated that the request could not be accommodated because certain system capacities were exceeded. However by building a transient model a better understanding of the network was established and additional capacity was successfully identified.

## Transient Theory Overview

The majority of problems analysed by engineers involve some form of transient phenomena. Transient solutions to problems, whilst often attempted, are not always fully utilised or understood. The reasons for this may include:

- Steady-state analysis provides an adequate approximation
- Transient analysis is complicated
- Transient analysis is time consuming

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Whilst the point that steady-state analysis provides an adequate approximation may be argued, with modern software and personal computing power available the points regarding the complexity of transient analysis and the time consuming nature of transient analysis may be disregarded.

The question may then be asked: *"Why use a transient simulation?"*

Transient simulations of a pipeline support a more detailed understanding and appreciation how a pipeline will behave under operational conditions.

For example, a gas transmission system which supplies power facilities for a region: because of the likely large swing in load requirements on a diurnal delivery schedule, such a pipeline should be analysed to ensure that the swing can be maintained by the existing capacity of the pipeline without the need for storage, and that the gas can be transported along the pipeline quickly enough to replenish the depleted parts of the network when required.

Transient simulators all use the same fundemental equations to solve the problems of transient flow. The equations of transient flow are the equations for the conservation of mass, momentum and energy. Together with an equation of state these form a complete system which can be solved. Other variables may be computed from the results.

The equations which are solved in transient simulators are:

- Mass Conservation

$$(A\rho)_t + (A\rho v)_x = 0$$

Where

$0 \le x \le L \;\&\; t \ge 0$

- Momentum Conservation

$$v_t + vv_x + \frac{P_x}{\rho} + gh_x + \frac{f}{2D}v|v| = 0$$

- Energy Conservation

$$\rho c_v (T_t + vT_x) = -T\left\{\frac{\delta P}{\delta T}\right\}_\rho v_x + \rho\frac{f}{2D}|v|^3 - \frac{4U_w}{D}(T - T_g)$$

- Equation of state

$$PV = ZRT$$

Where

| | | | |
|---|---|---|---|
| A | Cross sectional pipe area | L | Length of pipe |
| ρ | Fluid density | U | Heat Transfer Coefficient |
| v | Fluid velocity | $C_v$ | Heat capacity of gas |
| x | Position along the pipe | $T_g$ | Ground Temperature |
| t | Time | Z | Compressibility |
| L | Length of pipe | R | Gas Constant |
| f | Moody friction factor | D | Internal Pipe Diameter |
| g | Acceleration due to gravity | h | Elevation of pipe |

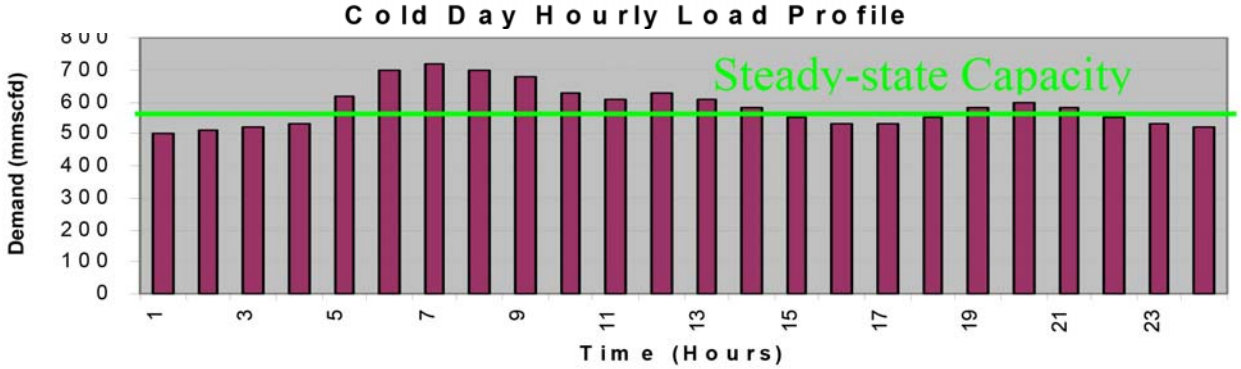


*Figure 1. Chart Illustrating How a Load May Change at a Demand on a Cold Day*

The choice of flow model depends on the use to be made of the results. Pipeline flow models may be employed in many areas such as: design and planning, scheduling/nominations, pressure monitoring,survival time and deliverability, line pack distribution, line balance, product tracking.

**A steady-state condition is a stable condition that does not change over time or in which change in one direction is continually balanced by change in another.**

A steady-state solution suggests two further questions: how the steady-state came to exist (the initial value problem) and whether is will persist (the instability problem).

**A transient is an oscillation caused by a change of conditions.**

Pipeline operations are transient. Boundary flow changes, pumps and compressors start and stop, control set points change, products move and mix as they travel through a pipeline system, temperatures vary both within the fluid and in the surrounding ambient conditions.

Mathematically the difference between steady-state and transient models is that the transient equations contain terms for rates of change with respect to time of the dynamic variables for pressure, temperature, velocity and fluid properties. By setting rates of change equal to zero the steadystate equations are obtained.

In layman's terms, the easiest way to explain the difference between these two analytical techniques is that a steady-state is comparable with a photograph of the system, whereas a transient may be considered similar to a video image.

## The Network under Consideration

The network under examination was the Dublin area Transmission System. It is a complex interconnected network with more than 10 separate transmission pipelines and over 50 offtake stations. To appreciate the analysis undertaken, it is important to have an understanding of the main features of this network.

Dublin consists of the following principle pipelines:

| Pipeline | Ø in (mm) | P psig (barg) | Year built |
|---|---|---|---|
| Canal Line | 20 (500) | 290 (19) | 1982 |
| Northern Line | 8 (200) | 290 (19) | 1984 |
| Eastwall Link | 10 (250) | 290 (19) | 1989 |
| Sandyford Line | 16 (400) | 290 (19) | 1984 |
| Southern Feeder | 18 (450) | 595 (40) | 1994 |
| Poolbeg CCGT Line | 20 (500) | 595 (40) | 1999 |

*Table 1. Principle Pipelines in Dublin Area*

There are two principle city gate stations, namely Abbotstown and Brownsbarn. Both these Above Ground Installations (AGIs) are connected to Bord Gáis's principle 1030 psig (70 Barg) Ringmain. At these points gas is reduced in pressure to 595 psig and 290 psig. Each station feeds into two pipelines. Abbotstown delivers 595 psig gas into the CCGT pipeline and 290 into the Northern Line. Brownsbarn supplies 595 psig into the Southern Feeder and 290 psig into the Canal Line.

There is an amount of interconnectivity between these pipelines. On the 595 psig CCGT pipeline there is a pressure let down station at Swords Road that injects 290 psig into the Eastwall link. Similarly there are two 290 psig injection stations on the Southern Feeder that feed into the central 290 psig system. The two stations are Sandyford and Poolbeg Feeder AGI.

Demand is approximately 40% power generation with two large CCGT plants, an open-cycle gas turbine and a Steam Plant located in the city. The remaining 60% of the demand is primarily 4 Barg distribution load supplying domestic and light industrial/ commercial customers.

## Network Overview

Ireland's natural gas network currently has two sources of supply. The majority of gas comes from the UK, where the BGE system ties into the Transco network. Kinsale is a mature indigenous field with the ability for storage. Storage is also available on the Interconnector subsea pipelines. A 2nd indigenous field off the west coast, Corrib, is due to come on stream in 2007 and there are two major pipelines currently under construction: the Mayo-Galway pipeline & the South-North pipeline. There is an independent Transporter connected to the BGE Scottish system. This the Scotland Northern Ireland Pipeline (SNIP), operated by Premier Transmission, Ltd. (PTL).

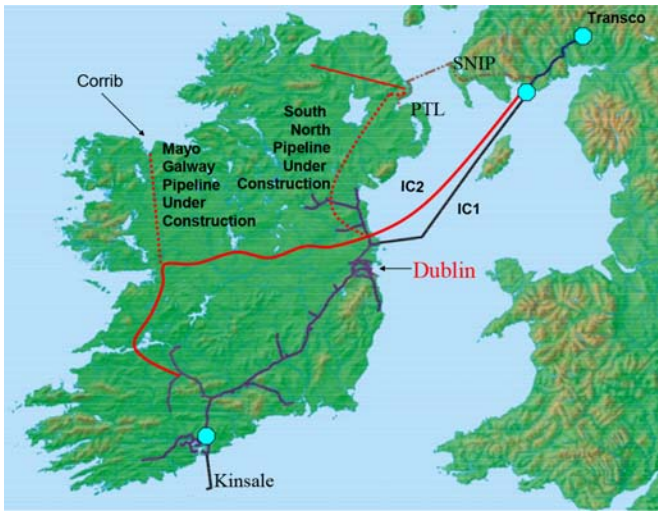


*Figure 2. BGE Network*

## Dublin Network Arrangement

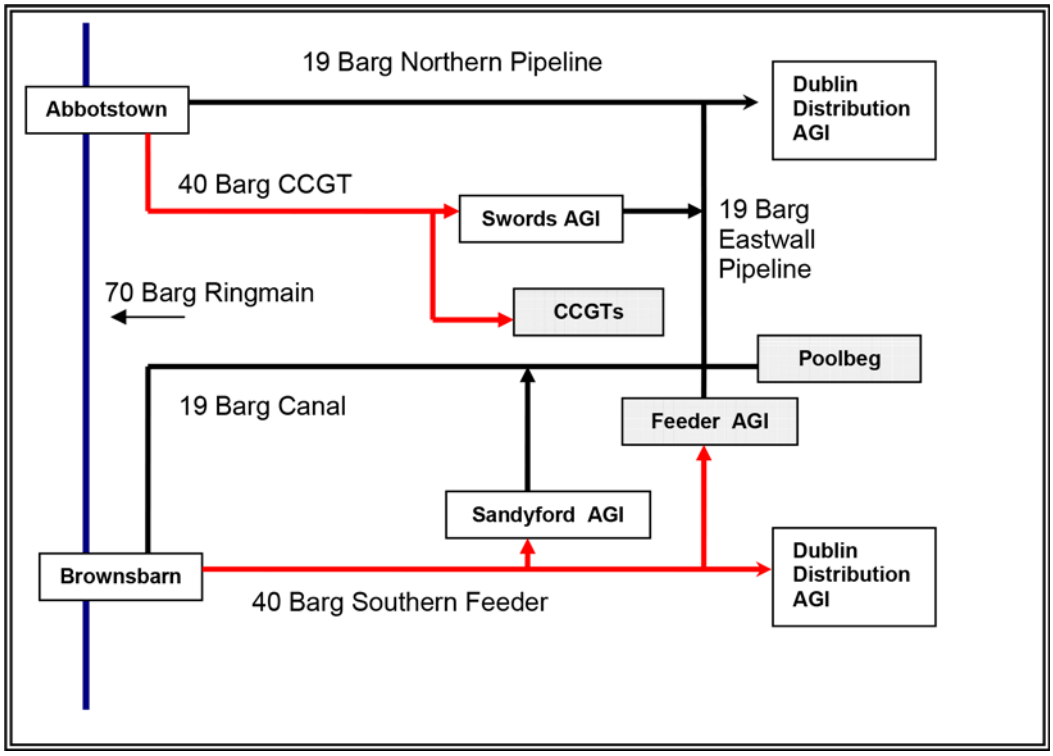


*Figure 3. Dublin Transmission System Main Components*

## Developing the Model

Up to the time of the request for additional capacity, all modelling of the Dublin network was done using steady-state analysis.

In the first instance, the steady-state model was run, with each offtake flow rate set to the relevant maximum peak hourly rate. This preliminary analysis indicated that the additional capacity could not be accommodated, as the additional demand resulted in an unacceptably high increase in flow through Poolbeg Feeder AGI.

Given that the network had in the preceding years been significantly reinforced, there was an underlying feeling that the additional capacity could be made available. However the steady-state model indicated that there would be difficulty in doing this. Rather than carry on with the steady-state analysis on a trial and error basis, it was deemed appropriate to develop a transient model of the system, in order to get a better understanding of exactly what flows and pressures were occurring in the system.

The recent addition of the CCGT and Southern Feeder pipelines introduced a level of complexity into the network that could be more appropriately represented with a transient model. As such it was anticipated that transient analysis would make it easier to identify of any under-utilisation of the network that may exist.

Using the geometry of the steady-state model, a basic transient scenario was developed. This entailed spending considerable time and effort on determining what exactly was happening in the actual system. Large amounts of historical data were reviewed in order to establish relevant offtake demands and associated profiles.

The single biggest work function to be undertaken in the exercise was the calibration of the model. The steady-state models which had been used up to this point were principally focused on assessing capacity handling abilities in the event of peak day conditions. However those steady-state models had not been correlated with actual network conditions. It was quickly realised that it would be essential to calibrate the transient model so that an acceptable level of confidence could be associated with the results and the request for additional capacity could be accurately assessed.

The model was calibrated using actual historic data. By taking the actual flows through the Dublin network for a particular day in January of the previous year, it was possible to establish a significant level of confidence in the model. The calibration runs utilised hourly data.

Calibrating the model consisted of taking flows from SCADA and running them in the model. Model pressures were then compared with the relevant SCADA pressures and the delivered volumes in the model were comparing with actual flow data.

Considerable time was spent data cleansing. Dublin is a complex integrated network and it was important to ensure that the SCADA data under consideration was correctly interpreted. It was therefore necessary to fully understand the make-up of all the numbers being used and so considerable effort was spent ensuring that the historic information was processed appropriately.

The calibration work proved successful. Figure 4 shows pressures at Guinness AGI, which is in the center of Dublin 19 Barg network.

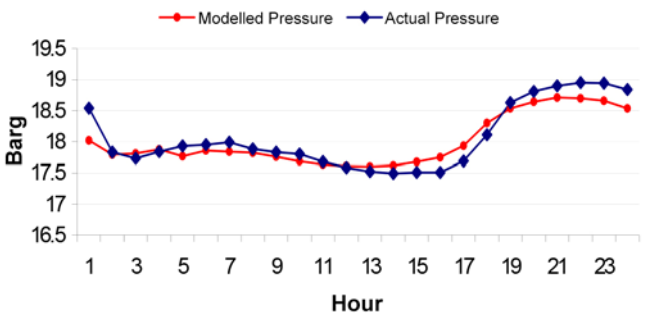


*Figure 4. Guinness AGI Pressures*

It can be seen that the after the first 3 hours of model initialization model pressures match up with the historic data. A detailed review of the pressures at all the offtake points, demonstrated that the model was functioning in manner which reflected the network to within 7.25 psi (0.5 bar). This level of accuracy provided sufficient confidence for the modeling team to proceed with the optimization runs. The outlet pressure of the regulating valves were adjusted in order to determine a network arrangement which would facilitate the request for additional firm capacity.

Once the model was calibrated the loads were set to represent 2% peak day conditions and the additional capacity was added at the Poolbeg Steam offtake.

Frictional losses in the network were determined using the AGA equation. It is assumed that certain pipeline were experiencing partially turbulent flow, as such friction factor is understood to be independent of pipe roughness. In using the AGA equation, 40μm was taken as the pipe wall roughness value for all the pipes in the model. It could be argued that it would have been more appropriate to use an alternative equation such as Colebrook-White. However given that the model had an accuracy of ±7.25 psi using AGA, this issue was deemed insignificant.

## Solving the Problem

With a calibrated model up and running, attention was focused on identifying ways in which the additional capacity request could be considered.

The actual flow data used for calibration was equivalent to 64% of the estimated peak day demand for the coming winter, so load trends for the relevant offtakes were turned up, to produce appropriate peak hour demands. The load profiles associated with the calibrated data were utilised without modification. There was considerable debate over whether or not changes should be made to certain profiles, to allow for possible behavior patterns that may only exists on and around a 1 in 50 type day. In Dublin, snow on the ground for approximately 5 days could be considered representative of peak type conditions. Future work planned on this model includes the non-linear adjustment of the profiled loads to take account of the nature of the peak day in a more appropriate manner.

There are three regulating stations in the center of Dublin that act as 290 psig pressure injection points at the center of the system. Swords Road AGI is on the CCGT Pipeline. Sandyford & Poolbeg Feeder AGIS are on the Southern Feeder pipeline. In the model, these AGIs were initially set to discharge an outlet pressure of 290 psig, as they were configured in the field.

With this arrangement the transient model reflected the findings of the preliminary steady-state model. Once again the volumetric flow through the Poolbeg Feeder AGI exceeded the station's capacity. However it was also observed that the flows through Swords Road and Sandyford were less than the maximum allowable.

By adjusting the outlet pressures at these sites it was possible to control the quantity of gas passing through these Stations. Turning down the outlet pressure setting at the Feeder Station, transferred demand to Swords Road and Sandyford.

A series of model runs were carried out with various permutations of station outlet pressures until the load through each of the AGIs were less than the station volumetric limit maximum capacity.

As a result of this work it was possible to identify an operating arrangement which allowed the additional capacity to be accommodated without exceeding volumetric limit at any of the three central regulating stations.

The optimum arrangement involved setting Poolbeg Feeder to 269 psig (17.5 barg), Swords Road at 276 psig (18 barg) and Sandyford at 290 psig.

The transient analysis indicated that if the Dublin network was appropriately set up, then it would be possible to provide the additional capacity to the Electrical Generator who had made the request.

A report was prepared which described in detail the work undertaken and included a recommendation that the network be modified .Transmission Operations subsequently reset the discharge pressure at the relevant regulator stations in accordance with the findings of the transient analysis. With the system suitably biased it was possible to offer the additional capacity to the Power Generator.

It's not unreasonable to suggest that the solution could have been produced by using steady-state analysis. However such work would have involved an indefinite amount of "trial-and-error", which would undoubtedly have taken considerably longer to do. In fact it could be argued that using the transient model, forced BGE to address the key issues such as station throughputs & system biasing. In addition, the calibrated transient model provided a level of confidence in the results that would not otherwise have been present. Put simply, steady-state analysis was not the right tool for the job. Steady state studies are very useful in certain instances such as initial line sizing but such an approach was not entirely suitable in this case study.

## Further Optimisation Studies

The development of a transient model of Dublin City was a result of a specific request from a customer. The model has subsequently proved to be of considerable value in relation to other areas of the business. The accurate and robust nature of this particular software tool has enabled BGE to model numerous pipeline reroutes which have been carried out in Dublin since the time of the original work. At various locations in Dublin, relatively short sections of the existing transmission mains have had to be moved. Modelling such works in advance of construction has meant that several schemes were carried out within having to use temporary bypasses. Appropriate models developed from the original model, demonstrated the feasibility of simply shutting the particular section and thus leaving out a live by-passes. Not only does this reduce the cost of construction but it also improves the level of construction safety, by eliminating the need to have a temporary high pressure by-pass line within the construction wayleave.

The development of the transient Dublin model also proved to be very useful in dealing with an issue which developed later that year. Several questions were raised in relation to gas quality in the Dublin Area, as gas from two different supply sources feeds into the Dublin area. Both UK and Irish gas reach the Dublin 19 Barg network and these two natural gases have calorific values that differ by approximately 7%. The amount of gas from each source varies thorough the year. Using the quality tracking features in the transient model it was possible to develop a series of simulations which accurately reflected actual recorded calorific values at various offtake points. This proved to be a very interesting and worthwhile exercise. As a result of the analysis it was possible to fully answer all the questions raised in relation to gas quality in the Dublin area.

It is proposed to develop the model further and utilise the interactive functions within the software. The first study to be undertaken will examine the Dublin network in the event of an emergency. With interactive capabilities, it should be possible to easily and quickly simulate and evaluate operation responses to network difficulties.

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