ALGERIAN NATURAL GAS TRANSPORTATION NETWORK:
RELIABLE MEASUREMENT SYSTEMS AND CONTROL, AND EXPERIENCE OF
ALGERIA IN THE GAS METERING STATIONS.

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1. INTRODUCTION

Natural gas is the fuel of the 21st century. Algeria, a gas country, a traditional player in gas industry, an important gas supplier, particularly to Europe, has developed close cooperation relationship with major gas countries operating in the market. The objective is to increase exports and, thus, contribute to meet the increasing demand, particularly in the European market.

Algerian natural gas pipelines are operated using sophisticated supervisory control and data acquisition (SCADA) systems. These systems are used to monitor, control and to enhance reliability and efficiency of operations, improve customer service, and minimize undesirable business practices.

Gas transportation has grown from simple local supply systems to international and pan-continental networks. Algerian transportation system is complex, so it is necessary to solve the problem of the network optimisation with the minimum of fuel conception criterion. The problem is solved by a dynamic programming procedure which is dominated by the principle of optimality of Bellman.

2. THE CONSTRUCTION OF ALGERIAN GAS SYSTEM

In 1961, gas production began at Hassi R'mel in central Algeria. Algeria is one of the major gas producing countries of Africa. In addition to its upstream strength, Algeria has a strong downstream sector which includes refining, distribution, marketing, and chemicals. Its current proven reserves are estimated at 4.52 tcm (trillion cubic meters) of natural gas at end 2000. This represents 3.0 percent of the world's natural gas reserves [8].

Algeria is particularly rich in natural gas and has instituted a strategy of investing in facilities that exploit these resources. Algeria also ranks seventh in the world after Russia, Iran, Quatar, Saudi Arabia, the UAE and the United States in terms of gas reserves. Algeria is also promoting the use of natural gas in the domestic market especially in the industrial sector, where plants can easily be converted from fuel oil to gas [8].

Natural gas represents 56 percent of Algeria’s total proven hydrocarbon reserves. Natural gas represented 5% in 1970, 33% in 1980 of Algeria’s total hydrocarbon production and reaches today more than 65% [7].

The part of the Algerian gas in the gas balances in some European countries is significant. 86% for Portugal, 61% for Spain, 49% for Italy, 26% for Belgium, 25% for France and 21% for Turkey. Today about 97% of Algerian gas exports supply the European market next to Russia, and Norway, one of the main suppliers of the Europe. Algeria accounts for 29 percent of European Union gas imports and 15% of gas consumption [7].
Two-thirds of known reserves are contained at Hassi R’mel. Others gas deposit at In Salah, Tin Fouye, Tabenkort, Rhourd Nous, Hamra and Alrar. Four plants 3 in Arzew and 1 in Skikda, liquefy gas for export.

The revamping and upgrading of the Arzew and Skikda liquefaction plants was completed in 2000. Revamping and expansion of Arzew and Skikda bring their production to around 30.5 bcm (billions cubic meters) a year.

A network of export pipelines link the gas fields to terminals for the export of Algerian natural gas. Algeria became the world’s third biggest natural gas exporter and second world largest exporter of LNG. Algeria has built two major gas pipelines to facilitate exports to Europe. The Pedro Duran Farell gasline (GPDF) was completed in November 1996, allowing the transportation of 7.9 bcm per year to Spain, Portugal, and Morocco. The existing 2,100-km Enrico Mattei gasline (GEM) to Italy via sicily has been expanded, providing throughput capacity of 24 bcm per year to Italy and neighbouring markets. Both pipelines run from Hassi R’mel through neighbouring countries-the GEM through Tunisia and the GPDF through Morocco-before crossing the Mediterranean seabed [6,7] (see figure 1).

3. NATURAL GAS TRADE IN THE MEDITERRANEAN AREA

During the last three decades there has been an important expansion of the natural gas trade in the Mediterranean area:

1970 : About 1 bcm/y (LNG from Arzew, Algeria).
1980 : 7.7 bcm/y (5.8 bcm/y of LNG from Arzew and Skikda, Algeria and 1.9 bcm/y from Libya).
1990 : 30 bcm/y (19 bcm/y of LNG, mainly from Algeria, 11 bcm/y piped through the GEM gasline, between Algeria and Italy).
2000 : 63 bcm/y, of which 45% as LNG (mainly from Algeria, with small quantities from Qatar, Oman, the UAE and Libya) and the remaining 55% piped (27 bcm/y through the GEM gasline and about 8 bcm/y via the GPDF gasline between Algeria and Spain).
2010 : Import-export movement of Natural gas in the Mediterranean area are expected to grow further to a level estimated in the range of 90-95 bcm/y (85 bcm/y from Algeria). In this view, natural gas transport infrastructures have to be expanded, particularly the export from Algeria and Libya (project of 8 bcm/y gas pipeline from Libya to Italy).

As to proved natural gas reserves of the exporting countries in the Mediterranean area, the largest gas reserves are in Algeria (4.52 tcm), followed by Libya (1.31 tcm) and Egypt (1.0 tcm). Algeria is actually the country with the most ambitious plans of growth in gas production and export capacities [9].
4. NETWORK EXPANSION AND PROJECTED GAS EXPORT CAPACITY

One of the reasons for the expected increase in demand is that gas involves environmental advantages compared with the other fossil fuels. Increases in export pipeline capacity are necessary for a projected gas export capacity of 85 bcm a year before the year 2010. There are plans to boost the GPDF’s throughput capacity to some 12 bcm a year (in final phase it will transport 18.5 bcm/y), and to add further 6 bcm capacity to the GEM line through the construction of new compression stations.

Other projects include: Development of the In Salah gas project which is designed to move Algerian gas to existing systems in Morocco and Spain, for delivery to European markets. The seven In Salah gas fields contain at least 7.5 tcf of high quality net sales gas, as well as additional reserves in adjacent reservoirs. Total production, expected at around 9 bcm/y will be destined for southern European markets. Krechba will be the primary processing and compression centre as well as the site for removal of CO2 before drying and export via the main 48-inch export pipeline to Hassi R’Mel. The extracted CO2 will be compressed and re-injected north of Krechba field.

The project of a sub-sea gas pipeline between Algeria and Spain (direct connection), from Beni Saf, near Arzew, the transmission pipeline will cross the Mediterranean sea over a distance of nearly 200 km and reach the area of Almeria, on the Spanish coast with a capacity of 8 bcm/y to 10 bcm/y. It is scheduled to be brought into service by late 2005.

The gas pipeline project Algeria-Italy via Sardinia, is to cover a distance of nearly 1470 km with an initial capacity of 8 bcm/y. The gas pipeline will leave Hassi R’mel and join via El Kala, the South, then the North of Sardinia and finally reach Castiglione Della Pescaia, a region located North of Roma.
The project for the creation of a Trans-Saharan gas pipeline connecting Nigeria to Algeria. This pipe of 4000 km in length will convey, via the Sahara, Nigerian gas from the Abuja fields to Beni Saf, near Arzew. It will supply the whole West African region with Natural gas, and coupled with the grid existing in Algeria, it will supply Southern Europe [5,6] (see figure 1).

5. SCADA AIDS ALGERIAN SYSTEM

Pipeline simulation tools produce savings, operational improvements on the pipelines. A SCADA (supervisory control and data acquisition) system was installed to monitor and control the pipeline. Computer modelling tools were configured to supplement SCADA and to provide leak detection, predictive modelling, and operator training. These tools are intended to provide supports to the control room operator in making operational decisions and to promote safety, reliability and efficiency. The SCADA system collects pressure, flow rate and temperature measurement data from the compressor station and all metering stations and then sends that data to the on-line model approximately every 15 seconds.

The basic component of the Hassi R’mel – Skikda pipelines include steel pipes, valves, compression and processing. Pipes are 40-inch and 42-inch diameter and wall thickness of about one-half to three-quarter inch. A range of operating pressures for the transmission system is 50 to 70 bars. Powered by natural gas, compression is centrifugal type. Gas pipelines are operated with a threefold objective of ensuring safety of persons and property, reliability of service and cost effectiveness. Operations are monitored and controlled by use of SCADA systems that provide thousands of data to pipeline controllers and operators. Some data are provided at intervals of a few seconds, other data are provided at intervals of a few minutes and still others on an hourly or daily basis. Operational data include pipeline pressure, gas composition, and equipment status. Maintaining appropriate pressure in the pipeline is essential to ensure safety, maximise throughput and provide reliability of service. Flow rates are determined on the basis of energy as well as volume and are used to balance system demands and supplies. Gas composition is required to maintain appropriate combustion characteristics and balance gas transmission on a thermal basis. Equipment status, such as valve position and compressor information, is used to confirm that the system is configured to meet operational objectives.

The Scada system is configured with a variety of instrumentation. Flow rates are measured using orifice plates. Gas quality is measured using gas chromatography. Where necessary, instrumentation is installed to sample for various contaminants including water and hydrogen sulphide. Electrical signals from measurement devices are typically converted to engineering units in computers, referred to as remote terminal units (RTU), which are located at the measurement site. Communication links are provided by radio, cell phone, private microwave or satellite. Measurements facilities, hence SCADA data, are located at points where gas is received and delivered, at compressor stations, and at other remotely actuated equipment such as valves. With so much data available at such high frequency, the effectiveness of the SCADA system hinges on appropriate data presentation, analysis and alarming. A variety of data presentation are used to transform basic data into information. Trends, schematics and other graphics are used to convey large amount of data, which vary over time, in a concise and informative format.

Many pressure measurements are combined with the physical description of the pipeline to render the inventory of gas in the pipeline as a whole and in its various segments. The result is called linepack, and this one number conveys much information about the state of the pipeline. Pipelines have hundred of locations where gas volumes are
received and delivered. Such information can be used to assess the proper level of storage field activity versus linepack utilization. Volumetric flow rates and gas qualities obtained from the SCADA system can be used to predict the gas quality of blended streams. As gas quality problems are encountered, expected blends can be calculated.

Alarms are used to indicate that operating conditions are approaching or have exceeded prescribed tolerances. Attention can be focused on problem diagnosis and appropriate actions.

The most sophisticated alarms require numerous calculations involving multiple data points. Using near real-time analyses of pipeline performance, alarms can be employed to detect abnormal pressure drops associated with flow restrictions. Compression is controlled with a combination of local and remote control. Pressure setpoints are sent from the pipeline control center to individual compressor stations via the SCADA system. The setpoints are relayed to local station automation equipment, which select units and set their speed and loading. As discharge pressures approach maximum allowable operating levels, local automation equipment slows and subtracts as necessary. Fibre optics are a potential communications link for automated meter reading and SCADA systems.

To cope with the changes, Algeria invested considerable resources into upgrading the SCADA systems. SCADA data have proven to be an important resource not only for managing pipeline operations but managing the business as well [10].

6. WIDE AREA NETWORK (WAN)

The idea of an ETHERNET network on the pipelines GK.1/GK.2 connecting the CNDG (national centre of gas dispatching), the compression stations and the arrival terminal via the optical fiber arose since the installation of the optical equipment node OTN (open transport network) at the arrival terminal in the framework of GK.2 project. The OTN node includes a network card that can be used for the implementation of a wide area network (WAN).

6.1. Network capabilities

The network is to be used in two stages:

- Implementation of a first configuration using the network capabilities with the existing means
- Implementation of a second and more complex configuration using real-time data acquisition modules

6.2. Capabilities of the existing configuration

- Files transfer, resource sharing, electronic mail, computer aided maintenance management, Intranet, repatriation of the operating parameters.

6.3. Capabilities of the future configuration

This configuration will use real-time data acquisition cards or modules and with the benefit of development tools based on Microsoft technologies, a modern, simple and efficient acquisition and parameter supervision system can be implemented. Making use of the OPC (OLE (object linking and embedding) for process control) technologies the system can:

- Acquire, display and follow up the progress of parameters in real time under EXCEL.
- Edit report under WORD.
- Record under access or SQL (structural query language) server.
Allow the consultation of real time parameters with Internet Explorer via a Web Server.
Allow the use of simulation and optimisation models of the gas pipeline network.

7. SCADA SYSTEM IMPLEMENTATION DETAILS
Our philosophy for the implementation of the SCADA system will be based on the current technologies linked to the notable development of the INTRANET and INTERNET Networks. The main object is the repatriation of the operating parameters necessary for the supervision of both pipelines from any of the seven concerned sites to the main server via the WAN. The system will be set at many levels.

7.1. LEVEL 1: Real time acquisition modules
Keep the existing instrumentation:
   - Case 1: Provide the 07 sites with PC (personnel computer) fitted with acquisition cards.
   - Case 2: Equip the 07 sites with PLC (programmable logic controller).
   - Case 3: Equip the 07 sites with Ethernet modules.
Install new instrumentation:
   - Case 4: FOUNDATION fieldbus: Provide the 07 sites with FOUNDATION instrumentation and Foundation-Ethernet bridges.
   - Case 5: Ethernet fieldbus: Provide the 07 sites with Ethernet instrumentation fieldbus.

7.2. LEVEL 2: Access to real time data
The access to the real time data is based on Microsoft objects technologies basically Activex, COM/DCOM (component object model/distributed component object model) and OPC. The supplier will deliver his OPC server together with the acquisition module in conformity with the OPC Foundation standard. The OPC server distributes the data to the client in accordance with the DDO (distributed data object) model:
   - Data encapsulated in the objects.
   - Objects are of the type: Real time, Alarms, Events, Historical.
   - Objects are distributed in the network.
   - The client applications: HMI/SCADA (human men interface).
   - Real time optimisation
   - Leak detection.
Access to the (objects) data with DCOM via the OPC interface.

7.3. Level 3: Operating systems and applications
Various operating systems are now marketed namely UNIX, LINUX, SOLARIS and NT but our choice is conditioned by the technologies mentioned before. Thus we opt for the Microsoft NT technology. This is because of the implementation of these technologies especially for windows 2000 advanced server. A new technology Terminal server implemented in Windows 2000 provides new perspectives in the way of constructing client/server architecture for supervision applications. This technology based on the ICA (independent computing architecture) architecture is able to communicate via any network protocol between the server and one or many client stations.

Animating a process is the dream of the engineer. This is now possible, thanks to Activex chips and the development tools such as VB that allow the construction of a convivial graphic interface. These Activex chips facilitate the communication between
applications. Thus we anticipated the use of EXCEL as an optimisation system from the date obtained in real time.

HMI/SCADA:
- Supervision and control.
- Data base SQL server, ORACLE.
- Recording
- Reports.
- Alarms.
- Simulation- Optimisation system
- Leak detection
- SPC (statistical process control)
- ETC….

7.4. LEVEL 4: Communication of SCADA data in INTRANET/INTERNET.
We decided in favour of two client/server architecture.
Terminal server:
The technology is based on the interchange of images and the keyboard/mouse actions between the server and the client stations. Thus, the application is executed on the server. The client station includes a small executable program linked to the terminal server technology. Owing to this multi-sessions and multi-users system that requires almost nothing as for the client station technology (DOS, Windows 3.11, LINUX, etc…) the system administrator can:
- Direct the other remote acquisition servers.
- Relocate the supervision stations (HMI/SCADA).
- Allocate some client stations for displaying specific views (Trend, Alarms, etc…).
Web server/Dial-up server:
- Allows the access either through the local network or by modem via the commuted telephonic network to the supervision synoptic of the client stations fitted with a navigator.

Choice of the architecture:
Our choice relies on the integration of the new standards in the field of industrial process control.
Sites: Delivery terminal, five compression stations, and arrival terminal.
- Replace analogue instruments by instrumentation of the FOUNDATION fieldbus or ETHERNET
  - Field bus type.
  - Allocate a windows 2000 acquisition server Terminal server/Web server.
  - Save site parameters in a data base server (Allocated PC).
  - Authorise access to data according to ranking.
  - Skikda supervision centre:
    - Allocate a windows 2000 main acquisition server: terminal server/Web server.
    - Elaborate the interface HMI/SCADA for the supervision of the two pipelines GK.1/GK.2. This interface retrieves data from the acquisition server.
    - Save GK.1/GK.2 parameters on a data base server (Allocated PC).
    - Foresee some applications of assistance to an optimum management of GK.1/GK.2.
  - Provide some client stations for the management and authorize access to data according to the case (local network, commuted telephonic network).
Architecture advantages:
Cost: important reduction in maintenance cost, the FOUNDATION fieldbus instrumentation allow remote maintenance.
Flexibility: The supervision room is only conditioned by a network plug.
Safety: In case of failure of the optical fiber of the private SONATRACH/RTE network, the system can use the commuted telephonic networks. A specialised application can reconstitute the central data base by synchronisation from the data distributed in the other sites.

8. GAS PIPELINE OPTIMIZATION MODEL

Gas pipeline operates at relatively high pressure. The high operating costs of transmission pipelines (compared to distribution) motivate the study of these ones. For a gas pipeline of an average complexity, the fuel consumption of compressor stations represents approximately 5-10% of the gas entering the pipeline [1,2].

Wong and Larson [3] determined the steady-state optimal operating conditions of a gun barrel gas pipeline with compressors in series. Their technical solution was to use dynamic programming to find the optimal suction and discharge pressures of a fixed number of compressor stations but they do not give guidelines on how to accomplish such operation.

In our study the objective of the optimization is to minimize the fuel amount which is consumed by the gas turbine drivers.

\[
\begin{align*}
\text{Min } Z = & \sum_{i=1}^{N} \frac{C_{0i}}{\eta_{STi} LHV} \left( \left( \frac{P_{d_i}}{P_{s_i}} \right)^{\gamma} - 1 \right) \cdot Q_{p} \\
\end{align*}
\]

\( P_{d_i} \): discharge pressure
\( P_{s_i} \): suction pressure
\( LHV \): low heating value
\( \eta_{STi} \): global efficiency of station i
\( Q_{p} \): gas pipeline flow rate
\( C_{0i} \): coefficient
\( N \): number of compressor stations in the system
\( \gamma \): ratio of specific heat

Operating constraints include constraints on stations and on individual turbo compressor units. At station level constraints are imposed on suction and discharge pressures, maximum discharge temperature and horsepower of coolers. Constraints imposed on individual turbo compressor are sufficient to ensure a feasible operating profile at all times during the solution. Checks are made of surge, stonewall lines and maximum horsepower for each turbo compressor.

The problem set this way is solved by a dynamic programming procedure. The dynamic programming is dominated by the principle of optimality of Bellman according to which:
A policy is optimal if, at a stated stage, whatever the preceding decisions may have been, the decisions still to be taken constitute an optimal policy when the result of the previous decisions is included.

9. STATE RECONSTRUCTION TECHNIQUES

Every technological process is subject to the influence of disturbances that we cannot control. By disturbances, we refer to the random factors acting on the process that we cannot measure quantitatively, thus, the technical state of a gas pipeline evolves with time under the action of many factors:
- Pipe roughness.
- Accumulation of mud and condensate in the bottom.
- Atmospheric factors.

Thus, experimental works have shown that the error on the friction factor, calculated using one of the classical analytic relationships, could reach 100% [4]. Moreover, the thermal conductivity of soil could rise above 300% in case of wet soil (in the interval of a rainy period as example). Consequently, under the light of big errors susceptible to appear when taking into account given important parameters, it is rightful to ask oneself what will worth the results of an optimization model not integrating those particularities in its formulation. The availability of a SCADA system, so, of real-time measurement results and in sufficient number of main parameters enables to “reconstitute” the gas pipeline state and by this fact to obtain models reflecting in a given time, in an appropriate manner, the real state of the gas pipeline. For this, the head losses in the \( i \)th gas pipe-leg are calculated by the simple following relationship:

\[
P_{i_1}^2 - P_{i_2}^2 = K_{ri} Q_i^2
\]

Where :
- \( P_{i_1} \) : inlet pressure of the pipe-leg \( i \)
- \( P_{i_2} \) : outlet pressure of the pipe-leg \( i \)
- \( Q_i \) : flow rate in the pipe-leg \( i \).

The coefficient \( K_{ri} \) is a sort of global head losses coefficient taking into account all the disturbances. The determination of \( K_{ri} \) is done on the basis of real operating data furnished by the SCADA system. In the relationship (1) \( K_{ri} \) is linear versus head losses and the square of the flow rate. Consequently the estimation of \( K_{ri} \) may be realized by the least squares method (LSM) on the basis of a data massive collected in regular intervals on a fixed time period. To take into account of the evolution of this parameter with time, it is possible to introduce an adaptive procedure of sliding windows type, LSM with weighted criteria or other. For the same reasons, the evolution of temperature along a pipe-leg will be defined by the following relationship:

\[
T_{2i} = T_s + (T_{1i} - T_s) \exp \left( \frac{-A_i}{Q_i} \right)
\]

Where :
- \( T_{1i} \) : inlet temperature of the pipe-leg \( i \)
- \( T_{2i} \) : outlet temperature of the pipe-leg \( i \)
- \( T_s \) : soil temperature
- \( A_i \) : heat transfer exponent
10. LEAK DETECTION SOFTWARE-BASED METHODS

Software-based methods use flow, pressure, temperature and other data provided by a SCADA system.

Flow or pressure change:
This technique relies on the assumption that a high rate of change of flow or pressure at the inlet or outlet indicates the occurrence of a leak. If the flow or pressure rate of change is higher than a predefined figure within a specific time period, then a leak alarm is generated.

Mass or volume balance:
Simple line flow balances are frequently used to check for gross imbalances over hourly or daily bases. This method may identify that a leak is present but flow meters at each end of the line will not identify the leak location. A loss of product will be identified simply as the difference between the steady state inventory of the system and the instantaneous inlet and outlet flows. Mathematically this is:

\[ \text{DELTA V} = V_{\text{in}} - V_{\text{out}} - V_1 \]

Where 
\( \text{DELTA V} \) = leakage volume
\( V_{\text{in}} \) = metered inlet flow
\( V_{\text{out}} \) = metered outlet flow
\( V_1 \) = pipeline fluid inventory

Dynamic model based system:
This technique attempts to mathematically model the fluid flow within a pipeline. Leaks are detected based on discrepancies between calculated and measured values. The equation used to model the fluid flow are: Conservation of mass, conservation of momentum, conservation of energy and equation of state of the fluid. The partial differential equations are solved by a variety of computational techniques. The alternative methods include: Finite difference, finite element, method of characteristics, frequency response/spatial discretisation. The method requires flow, pressure, temperature measurement at the inlet and outlet of a pipeline, ideally also pressure/temperature measurements at several points along the pipeline.

Pressure point analysis (PPA):
This method is based on the assumption that if a leak occurs in a pipeline, the pressure in the line drops. Using simple statistics analysis of the pressure measurements, a decrease in the mean value of a pressure measurement is detected. If the decrease is more than a predefined level, then a leak alarm is generated.

11. MEASUREMENT OF GAS FLOW

The metering and control systems are located at El Aricha at the Algerian-Moroccan border for the GPDF pipeline and at Oued Saf Saf at the Algerian-Tunisian border for the GEM lines, while the departure terminals are installed at Hassi R'Mel.

11.1. System configuration (Arrival)
The metering system field equipment is comprised of parallel metering runs. Each meter run is fitted with two separate sets of flow measurement instruments (differential pressure transmitters, static pressure transmitters, and temperature sensors). Each separate set of instruments provides data to a pair of stream flow computers. The stream flow computers also receive inputs from the central computers system. The outlet header is fitted with a gas densitometer and a gas chromatograph. The outputs from this is input to the central computer system. The system has been designed to provide maximum system availability. The failure of a single sensor or instrument will have a minimum effect on the operation of the system.
11.2. System configuration (Departure)

The metering system field equipment is comprised of parallel metering runs. Each meter run is fitted with a set of flow measurement instruments (differential pressure transmitters, static pressure transmitters, and temperature sensors). These instruments provides data to a panel mounted central computer.

11.3. Stream flow computers

The measurement of gas flow is provided by flow computers. Each flow computer is provided with software specifically designed for gas orifice measurement. The following functions are provided in the stream microprocessor flow computer:

- Acquisition of all the variable input signals (differential pressure, pressure, and temperature).
- Acquisition of the outputs from the reference densimeter and the process chromatograph.
- Execution of all flow computations in conformance with standard ISO 5167 (latest revision) and specific method of computation of gas compressibility (AGA and GERG).
12. CONCLUSION

The data from SCADA systems are indispensable to monitoring and controlling operations of Algerian natural gas pipelines. Beyond these basic functions, however, the data gathered by these systems are used extensively directly and indirectly in a variety of business applications from design to invoicing.

It is necessary for the gas industry to develop the computer norms aiming to optimize solutions and to reduce costs.

Integrated and co-ordinate methods of operation and management, hardware/software technologies, automation and control systems allow gas networks to find real-time the effects of demand variations and allow to change network configuration according to target values.
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