SPE 112226

Intelligent Wells to Intelligent Fields: Remotely Operated Smart Well Completions in Haradh-III

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This paper was prepared for presentation at the 2008 SPE Intelligent Energy Conference and Exhibition held in Amsterdam, The Netherlands, 25–27 February 2008.

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Abstract

Haradh-III, Saudi Aramco's latest developed field within Giant Ghawar Field, is regarded as one of the industry firsts in terms of its application of advanced drilling techniques, multilateral wells, smart well completions and permanent monitoring systems. This recently commissioned field, on February 2006, integrated all of the above mentioned technologies with an advanced SCADA system that enable the real time monitoring and control of the downhole and surface equipment remotely from the control room.

The design and installation of the automated surface control system to remotely monitor and control the smart completions is a multidisciplinary project integrating subject experts and tools from well completions, production engineering, facilities, instrumentation, and communication engineers. The system enables the operator in the control room to remotely operate the downhole valves in all the multilateral smart wells through the SCADA system.

The paper will present the design, installation and commissioning of the surface control system and remote monitoring capabilities and cite a field case of remote operation to flow test a well with three zones smart well completion, permanent downhole gauge and surface multiphase flow meter. The system has enabled the operator to remotely perform flow testing of the individual laterals of the multilateral wells through different settings of the downhole valves. The remote control capabilities enabled these tests to be done from the control room without the engineer spending extended periods in the well site.

The learning discussed in this paper will provide an insight into how the implementation of such control system was systematically handled to achieve a successful conclusion.

Introduction

Haradh-III field is located in the southernmost part of the Ghawar field and has been developed with 32 Maximum Reservoir Contact (MRC), multi lateral wells with intelligent completions installed on 28 wells. This setup reduces the well count required while achieves higher productivity from each well[1]. Studies have shown that field development with MRC wells and smart completion technology in Haradh-III will delay water encroachment, improve flood front conformance and recovery while lowering water production and reducing operating costs[2]. Table 1 shows the project statistics summary[3]

Production MBD	300	Multiphase flow meters	40
Injection MBD	560	RTU/ SCADA	72
Producers	32	Flow lines (10")	68 Km
Injectors	28	Injection start up	Sept 05
Evaluation/ Observation wells	12	On stream date	Feb 06
Permanent downhole gauges	40	Intelligent completions	28
Average PI	150	Average reservoir contact	5 Km

Table 1. Haradh-III Project Statistics

The concept of intelligent fields was incorporated into the design of the field to enable continuous monitoring of key reservoir performance parameters and real-time data transmission from downhole to the engineers' desktop. The surface infrastructure was designed with the communication and power facilities required to connect all the wells to the field SCADA. The field communication infrastructure was designed as an open architecture to integrate the intelligent well controls as an independent subsystem to the field control system.

System Overview

Haradh-III field communication network is based on a scattered / distributed layout linking all the wellsites to the GOSP. The field control system architecture uses a RTU (Remote Terminal Unit) at the well site connected to a central SCADA application in the GOSP, by means of a Fiber Optic communication network. In addition to intelligent completion technology, each well in the field is provided with both

downhole point pressure and temperature sensor and a multi phase flow meter at surface.

The RTU is a powerful Pentium IV based PLC whose function is to control surface choke valves as well as acquiring data from other sub-system located at the well site. The RTU PLC boosts OPC Server capability.

The fiber optic field communication infrastructure leverages TCP / IP technology thanks to the bandwidth delivered by the Fiber Optic system. This has enabled the use of a mixture of OPC DA and HDA technology.

The field SCADA application acts as single interface point for the whole field control. Data hand-off to the field historian (PI station) occurs at the GOSP. The application is also the integration point for intelligent completion systems.

Figure 1, shows the field communication network linking the wellsites to the terminal at the control room. On one end of the network are the downhole and surface equipment at every well site and the other end is the field control supervisory application in the control room. The different components of the intelligent field architecture are discussed in the sections below.

Intelligent completions in Haradh-III utilize a fully hydraulic downhole control system to operate the valves and the fluid is conveyed from the surface to the downhole tool through ¼" control lines. Figure 2, shows a sketch of the downhole completion. Each downhole valve has a 10-position choke to control the inflow from each lateral. Production from each zone enters the tubing through the ICV [4]. The choke on the downhole valve is mounted on a hydraulically operated sleeve, that moves up to open and down to close. It provides full bore ID at all times. This enables the lower zones to continue producing through the tubing even when an upper ICV is closed. The lower end of the tubing is plugged with a bullnose to direct flow from the motherbore to enter the tubing through the choke on the lower ICV. The lower ICV controls flow from the motherbore. Flow from the upper lateral(s) enters the mainbore at the junction, follows an annular flow path between the tubing and casing, and enters the production tubing through the ICV for that zone. Packers provide the isolation between the laterals and as barrier for the upper annulus.

The intelligent completions utilize a closed loop hydraulic system where pressure is applied on either sides of a downhole piston to open and close the valves. Each of the downhole valves have a dedicated "open" line from the surface and a single "close" line is multiplexed to the close side of all the downhole valves. Therefore the number of hydraulic lines required is the number of downhole tools plus 1. For example, a two zone completion deploying the hydraulic logic used in this field requires only 3 control lines (3 lines = 2 tools + 1). The valves can be functioned independently by applying pressure in different sequence. Applying pressure down the open line will move the piston and the same volume is returned to the surface hydraulic panel through the remaining control line. The hydraulic control fluid is never vented to the production tubing.

A proprietary hydraulic control mechanism "AccuPulse ™"is used to function the downhole chokes to multiple positions. This is a full hydraulic module which displaces a fixed amount of fluid to the downhole valve causing it to move a predetermined distance and open to the next choke position. In Haradh-III the system was configured to incrementally open from closed to fully open through ten intermediate positions. This also allows the choke to be fully closed from any open position by applying pressure in the close line only once. The ability to close immediately from any intermediate position is useful in well control and high water cut applications. The hydraulic control lines from the downhole valves pass through the tubing hanger and exit the wellhead. The lines are connected to the smart well control panel located at the well site.

All the wells have permanent downhole gauges installed as part of the completion tubing. The gauges measure the pressure and temperature in the tubing. The gauges use resonating quartz crystal sensor technology capable of temperature and pressure resolutions greater than 1°C and 0.01psi respectively.

Fluid pressure produces compressive stress in the quartz, which changes its resonant frequency. The gauge electronics convert the resonator frequencies to a proprietary protocol prior to transmission to the surface via ¼" instrument wire that is installed outside the tubing. The gauge lines exiting the wellhead are connected to a surface gauge data logger which supplies power to the downhole gauges and records downhole data. The surface data logger is connected to the wellsite RTU via RS485 for real time data transfer to SCADA.

The IW Surface Control System is designed to monitor and control the intelligent completions and consists of

- Surface Hydraulic System placed at each intelligent wellsite
- The supervisory application server in a computer at the control room

The combined functions provide an independent and dedicated electro-hydraulic, microprocessor-based control system that controls the down-hole completion.

The intelligent completion surface hydraulic system (SHS) cabinet is installed at each wellsite and the supervisory application server at the control room operates all the downhole flow control valves in the well through the field SCADA network.

The intelligent well control unit at the wellsite comprises the hydraulic pressure generation and distribution system as well as the electronic controllers. The system contains electronic controllers to operate the directional control valves and direct fluid into the downhole control lines for operating the downhole valves. It also monitors the pressure on each control

line, controls the recirculation and pressurizing of the system via the main pump. The unit is installed non-air-conditioned covered shelter about 200 ft from the wellhead. It has a National Electric Manufacturers' Association (NEMA) rating of NEMA 4X which ensures the unit is resistant to water, dust and corrosive agents. The unit is powered by 240 V AC power supply. The unit is connected through ethernet to the SCADA multiplexer at each of the wellsites. Though designed for remote operation through SCADA, the unit can be operated in local mode by manually operating the valves on the panel or through a laptop computer connected directly to the controller at wellsite.

The intelligent well supervisory application running in a server in the control room remotely monitors and controls the 28 SHS that have been placed at the various well sites. It communicates to in -field controllers through a multiplexer in the GOSP communications room via a physical Ethernet connection between them. The supervisory application[5] system is based on distributed architecture technology as shown in Figure 3. The main components of the supervisory application are

- The server – central computer where the application is run
- The application – provides the Human Machine Interface (HMI), data storage, data collection and distribution (OPC Client/Modbus) functionality.
- Well Control Modules – each well contains a well control module
- Hydraulic Supply Modules – each well contains a hydraulic supply module

Network Architecture & Interface

The intelligent well supervisory application implements a distributed architecture with each wellsite controllers at the periphery. The in–field controllers contain the proprietary firmware that continuously monitors and controls the downhole intelligent completion system. The In-Field controllers are connected to the supervisory application via an Ethernet LAN utilizing TCP/IP communications. This supervisory application provides functionality for data acquisition, consolidation and distribution, system level control and specialized user interface for the intelligent wells at Haradh-III field.

All control requirements originate from the supervisory application and are communicated to the specific In-Field Controllers. Thus, the supervisory application manages the high-level commands and the In-Field controllers handle the complex logic required to carry out a tool move in the downhole intelligent completion. The request can be initiated from the supervisory application or the SCADA supervisory application from the operator console in the control room.

Integration with Field Control Supervisory Application

The control room operator monitors and controls all the field processes through the SCADA supervisory application. In order to provide complete functionality to the operator, the intelligent well control is interfaced from its own supervisory application to the field control supervisory application through peer to peer connection based on OPC DA. This system leverages the advanced functionality of intelligent well supervisory field management system while minimizing the functionality to be embedded in the field control system and achieving full operational control from the SCADA application.

The philosophy of this integration is based on the following

- The intelligent completion to be controlled from the SCADA application by clicking on a well screen. A bubble window will then appear and allow the operator to change positions of the downhole flow control valves
- Minimize the programming required by field control supervisory application to integrate the intelligent well control to SCADA. The field control application should be able to control the intelligent wells with limited number of tags through OPC DA.
- Intelligent completion valve position should be updated on the field control application throughout a valve movement operation. The SCADA system should be able to display whether the intelligent completion valve is in a confirmed or unconfirmed position as established in the intelligent well application.

An OPC data hub was created on the intelligent well supervisory application to hold the tags that will be linked to the field/SCADA application. Only the minimum number of tags required by the SCADA to control the intelligent wells was included in the OPC data hub. Based on the tags in the OPC-data hub, an OPC DA Control Module was developed to interface between SCADA and intelligent well supervisory application. The control module connects on one side to OPC data hub in the intelligent well application and on the other side offers a simplified interface to the field control/SCADA application. The Control Module gathers the appropriate information from OPC data hub, conducts validations for the tool move operations, and sets the necessary OPC tags to send a tool move command to the in-field controller. Moreover, the Control Module also provides the necessary feedback on system availability and operation status to enable the SCADA to monitor the status of each individual intelligent completion.

The interface between the field supervisory application and the intelligent well control application was documented during the system design phase and it was tested before field installation. The test equipment set up is shown in Figure 4.

Field Installation and Commissioning

The complete installation of the system consisted of the below three phases

1. Installations at wellsite
2. Configurations of intelligent well supervisory application

3. Interfacing intelligent well supervisory application to field control/SCADA application

The activities at the wellsite started with the successful installation of the intelligent completions. The requirements for implementing the I-Field were incorporated into the design of the surface communication and civil construction. The construction activities at the wellsite included installing surface control lines from the wellhead to the panel area, building the covered shelter for the intelligent well control panel and a temperature controlled room for the RTU and fiber optic multiplexer.

The intelligent well surface control units were tested in the shop prior to shipping to the wellsite for installation. The shop tests included connecting the unit to four downhole control valves on the shop floor and function testing the valves to multiple positions. A 10,000 ft reel of hydraulic control line was used in these tests to simulate the downhole control line in the wells and estimate the duration of each operation. These tests help to select the different time and pressure setting on the system. At the wellsite, the unit is placed in the shelter and connected to the electric power supply, to the intelligent well hydraulic lines from the wellhead and to the fiber optic multiplexer for communication to SCADA. Each wellsite field controller is assigned a unique IP address on the communication network.

The system is then pressure tested and all functions of sensors, actuators and PLCs are verified on location. The unit is function tested by moving the downhole valves of the well with the help of a laptop locally connected to the Ethernet port on the PLC at the well site. Production Engineers were involved at the installation as well as all the other function testing phases.

Configuration of Intelligent Well Supervisory Application

The intelligent well supervisor application was installed on a rack mounted server machine in the production facility. This server is connected via Ethernet to the multiplexer in the facility into the field wide fiber optic network to each wellsite multiplexers and finally to every in-field controller. The application server at production facility and the field controllers at each wellsite are assigned with a unique IP addresses enabling the application to communicate to every intelligent well controller in the field. The details of each well like number of downhole valves, depth, etc are then configured on the supervisory application. The downhole valves can be remotely operated from the production facility at this stage.

Interfacing the intelligent well supervisory application to field control/SCADA application to provide the control room operator the ability to function the intelligent wells was the last phase of the system installation. An OPC data hub was created in the intelligent well application to hold the tags required by the SCADA to operate the intelligent wells. The OPC control module application was then installed on the SCADA application to interface with the OPC data hub on the intelligent well application. This application completes the communication link from the SCADA console in the control room to the downhole valves in each intelligent well. Figure 5 shows the well control screen on the SCADA application where the operator can operate the downhole valves while simultaneously monitoring the data from the downhole gauges, surface multiphase flow meters and well data on the same screen

Field Operations

The successful integration of intelligent well control to the SCADA console provides the ability to control the downhole valves in an intelligent well while simultaneously monitoring data from the downhole sensors, multiphase flow meters on surface and other surface sensors. The operator can immediately identify the effect of operating a downhole valve on the well production in terms of water cut, downhole pressure etc. This data is transmitted via the company intranet to the engineers' desktop for further analysis and optimization.

Well Haradh-A1 was successfully flow-tested from the GOSP without the engineer having to go to the well site. This well is a 3 zone completion with a mother bore and two laterals. Each zone contains one downhole valve to control flow from it. The downhole flow control valves for the intelligent completion were operated from the central facility and data for the downhole gauge pressure and temperature were observed through the operator workstation. It was observed that the downhole gauge temperature and pressure readings decreased while closing all the laterals on the well and increase when the laterals were opened. The MPFM continuously records the gas oil ratio, water cut and oil flow rate and the surface pressure upstream and downstream of the surface choke were also remotely monitored.

Well Haradh-A2 was successfully operated from the SCADA workstation. This well is a 3 zone completion with a mother bore and two laterals. The naming convention used on the SCADA is L0 (mother bore), L1 (lateral 1) and L2 (lateral 2). The test comprised of closing all the tools and bringing them back to their initial positions before the tool moves. A view of the different positions of the SCADA screen has been shown in figure 5.

Currently, continuous testing for individual lateral is undergoing to ensure optimal performance and after around two years of production, the overall water-cut of the field is less than 1%.

Conclusions

- The commissioning of the automated surface control system for the intelligent wells has enabled the engineer at the control room to monitor well parameters and control the downhole valves for the IW directly from the SCADA application.

- This enables the wells to be tested as required without traveling to the wellsite and the test data is stored in the data base in real-time.

- The integration of the IW control, downhole gauge data and the MPFM data at the control application enables the production to be optimized.

- The facilities available in Haradh-III will accelerate the introduction of well optimization tools.

- The open architecture in the communication system avoided the need to embed the IW supervisor application in the SCADA and enables the easy inclusion of well optimization tools in the IW application.

- Selecting a single vendor for the intelligent wells has helped to make the surface integration to the SCADA easier.

Nomenclature

SCADA: Supervisory Control And Data Acquisition.
GOSP: Gas Oil Separation Plant.
RTU: Remote Terminal Unit.
PLC: Programmable Logic Controller.
OPC: Open Connectivity via Open Standards.
TCP / IP: Transmission Control and Data Protocol.
OPC DA: OPC Data Access (one of the OPC specifications).
OPC HAD: OPC Historical Data Access (one of the OPC specifications).
ICV: Interval Control Valve.
MPFM: MultiPhase Flow Meter.

Acknowledgement

The authors would like to thanks the Saudi Aramco and WellDynamics for granting permission to publish this work.

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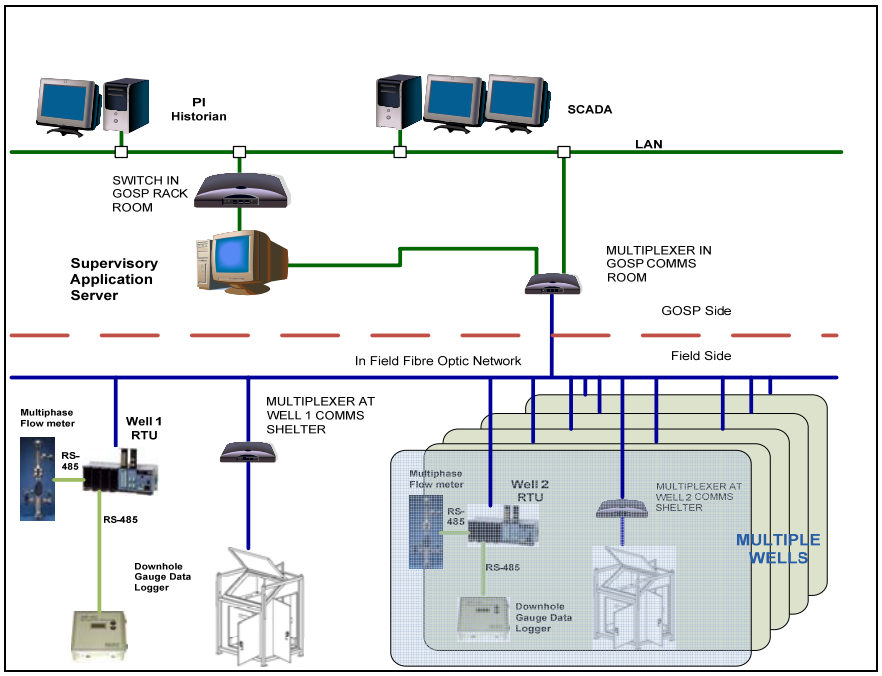

Figure 1: Overview of field communication.

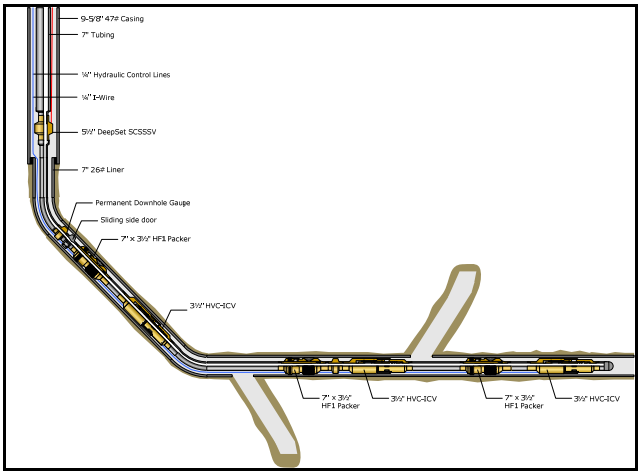

Figure 2: Intelligent well completion in Haradh-III.

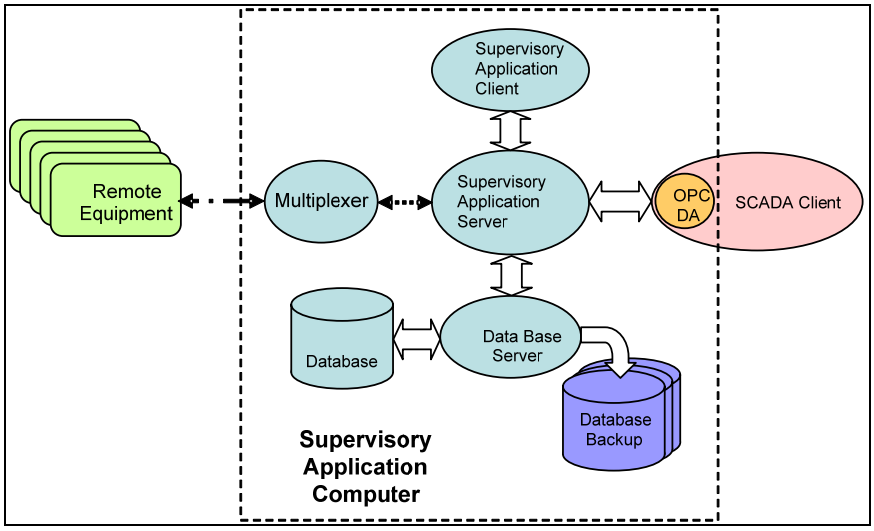

Figure 3: Overview of intelligent well supervisory application.

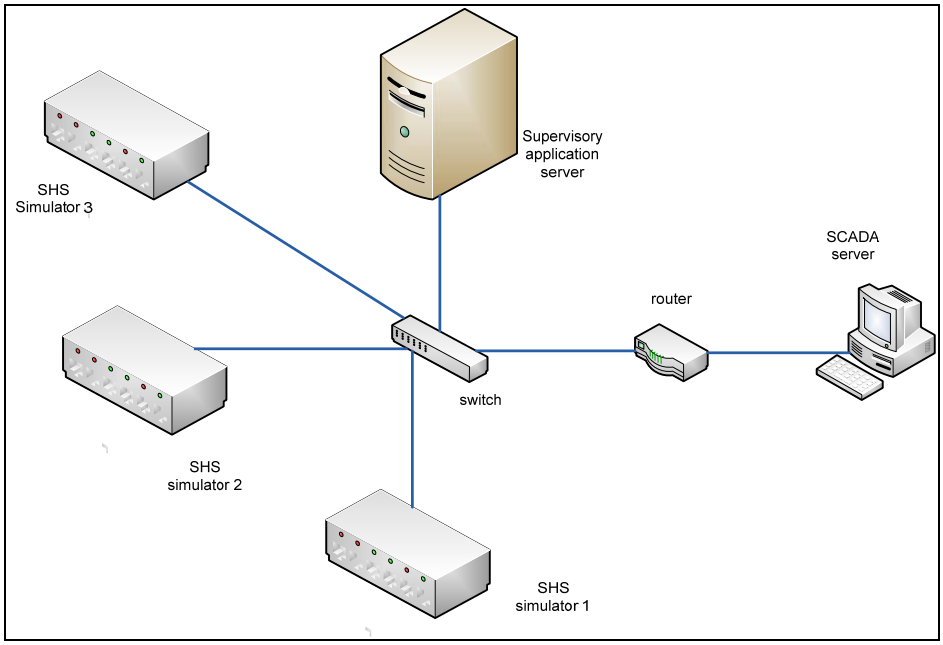

Figure 4: Equipment setup for system integration test.

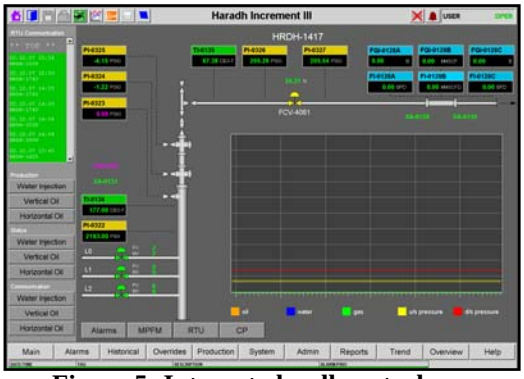

Figure 5: Integrated well control screen.