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Operator Training Simulator for Ethylene Plant

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In a petrochemical plant, training new operators to operate plant safely and consistent is a need. Conventional training for operators relies on senior operators' experience. When experience operator leaves or resigns, it will take longer duration to train new personnel to gain the equivalent experience of previous or senior operators. The operators control the plant by using Distributed Control System (DCS) as an interface and ensure the reliability and productivity of plant sustains. The more challenges they face, the more experience they gain. Most of the operators are trained by real time events they faced on the job but errors or plant upsets should be avoided. It is estimated that in the United States alone, 10 billion USD is lost annually in the process industry caused by errors when faced with plant upsets. Operator training plan is therefore the crucial step to reduce the losses as well as the risk of operating the plant. Operator Training Simulator (OTS) is an alternative solution to safely provide the operators with various realistic operational conditions of the plant, including start-up, shutdown, and emergency conditions. This article discusses on the methodology of building an OTS for Ethylene plant, that are beneficial for educating operator response when faced with critical process upsets and succeeding quicker start-up. A dynamic process model was developed to give accurate dynamic behaviour of the plant process mainly during start-up, shutdown and upset conditions. Testing and verification processes of the models such as Model Acceptance Test (MAT), Factory Acceptance Test (FAT) and Site Acceptance Test (SAT) were deliberated. Few issues or problems faced during the testing were also discussed. Based on the experience of developing the simulator, process model was developed using mass and energy balance method does not reflect the actual plant conditions. It might be suitable for commissioning a new plant. However, once the plant is started all the parameters need to be realigned to meet the actual plant data. Process model for existing plant should always apply the actual plant data as a primary data. Especially during MAT, FAT and SAT processes, experience of the panel man is the best input data to get the best output of the simulations.

1. Introduction

The success of plant operations is greatly dependant on the field and control room operators' competence and performance. The growing complexity of processes due to plants and control systems becoming more complex are shifting the attention to the management of abnormal situations, which are even more complex and frequent in nature (Colombo and Golzio, 2016). Studies on the 170 largest industries regarding the damage losses over the last 30 y in the hydrocarbon processing industry shows that 28 % were due to operational errors or plant upsets (Morgan et al., 1994). Operational errors due to lack of training and capability of handling plant upsets result in the largest average dollar lost of all accidents caused (Yang et al., 2001). Operator training plan is a crucial step to reduce the losses as well as the risks of operating the plant.
Operating training simulators (OTS) are virtual simulation tools used for training of panel operators in industry in writing procedures and operating plant (Gerlach et al., 2015). The simulation is an imitation of a plant generating time-series data, responding to operator actions, instructor initiated scenarios, and DCS actions (Patle et al., 2014). OTS provides the operational personnel with a realistic operation of the plant and the environment for the testing of various operational conditions, including start-up, shutdown, and emergency conditions safely (Reinig et al., 1998). Well-structured simulator based training programs are proven to be highly effective in improving practical experiences (Manca et al., 2013). Even though dynamic simulation has become crucial for plant designs, operator trainings and is widely used in petrochemical industries, there is still lack of

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integrated simulators in the ethylene crackers in Malaysia. This study has developed OTS for an Ethylene Crackers Plant. The DYNSIM^{TM} simulator was built in accordance to with the ethylene plant process design and integrated with the actual plant data. All the Emergency Shutdown Device (ESD) and control logic are replicated into the system as designed. The Human Machine Interface graphics were copied from the Distributed Control System (DCS) into the OTS. Figure 1 shows the methodology to complete the simulator.

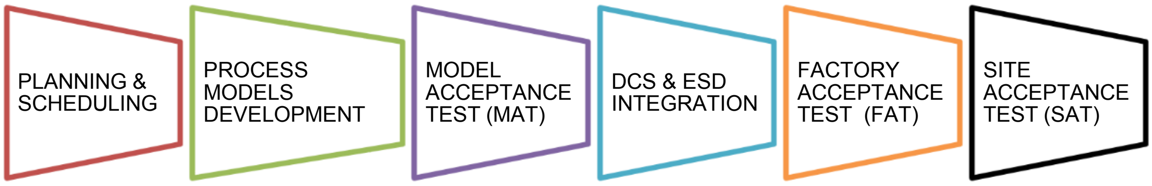

Figure 1: OTS development process

2. Process Models Development

2.1 Data collection and process boundaries

During the initial process, the Heat and Material Balance (HMB) data sheet for the plant was verified using plant design case based on the raw material feed, where the basis for ethane is 75 t/h and propane is 35 t/h. Comprehensive steady state HMB of the whole unit operations was needed for simulation with designed operating case. This is a very critical input as resemblance of the simulated model to the actual process was fully dependent on the HMB inputs. The scopes of the model were justified to meet the training purposes. There will not be any utilities such as flare headers, fuel gas headers, and others modelled. All the utilities were considered as boundary. All the process and instrument drawings (P&ID) were highlighted before translated into flow sheets. The isolation valves and pressure safety valves were identified to be modelled into the simulation. As marking up all P&ID, the notes and comments from system expertise were taken for modelling.

Table 1: General simulation assumptions

No	Type of Equipment	Simulation Assumptions
1	Compressor and Expander	Shall be modelled with performance curves (from equipment datasheet)
2	Pump	Shall be modelled with pump performance curves (from equipment datasheet)
3	Heat Exchanger	Shall be modelled with actual heat exchanger configuration (i.e. No. of tube, tube and shell length, etc.)
4	Distillation Column	Shall be modelled with actual dimension (tray numbers, diameter, etc.)
5	Reactors	Should be modelled with reaction kinetics or equilibrium data if available. As a minimum, conversion type reactor unit operation shall be used
6	Separator Vessels	Shall be modelled with the heat loss to the environment The rate of heat loss is dependent on the vessel temperature, the ambient conditions and overall heat transfer coefficient. This will allow the cooling of vessel contents during shutdown
7	Control Valve	Shall be modelled with control valve characteristics and actual CVs

2.2 Modelling the plant design into process flow sheets

From the marked up P&ID and data from Heat and Material Balance, the plant was designed into flow sheets. The particular system was drawn in flow sheets and all the equipment data were entered into the model. All the flow sheets were connected to produce one big integrated system. The integrated system was connected to the flow sheets from raw material feed till the product out to customer. The process models for an operator training system were developed to the level required for training needs. This section outlines how modelling standards and practices were implemented. The dynamic simulation model serves as the “virtual plant” for the OTS.
Thermodynamic method Soave-Redlich-Kwong (SRK) was used for the model. Table 1 shows the examples of general simulation assumptions. The list of equipment should be categorised according to the types of equipment in order to simplify the simulation assumptions. The Table 2 describes the equipment type and technical specifications required being key in into Data Entry Window for modelling as per Figure 2.

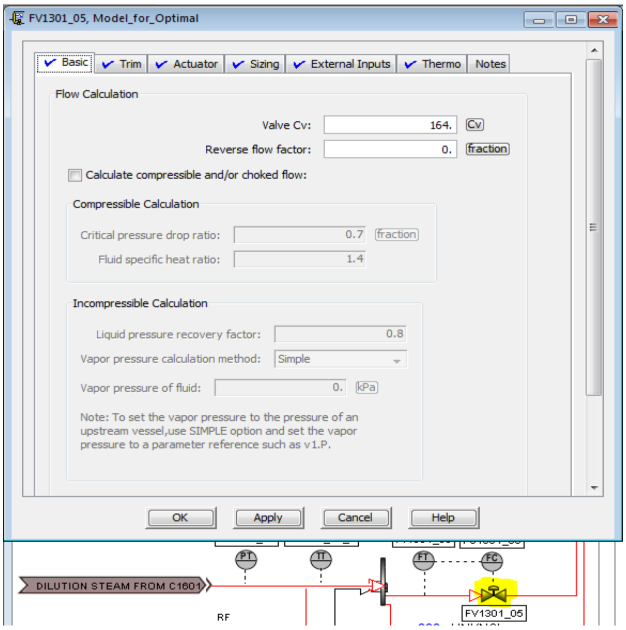

Figure 2: Data entry window for a control valve

Table 2: Technical specification for a few types of equipment

No	Type of Equipment	Technical Specifications
1	Distillation Column - Tray Columns	i. Diameter
		ii. Height
		iii. Number of trays and passes
		iv. Inlet position (tray number)
		v. Outlet position (tray number)
		vi. Tray dimensions (weir, down comer etc.)
		vii. Top pressure and bottom pressure
2	Heat Exchanger	i. U coefficient
		ii. Shell diameter and length
		iii. Tube diameter and length
		iv. Surface of heat exchanger
		v. Number of tubes
		vi. Shell & tube side calculated pressure drop with corresponding flow rate
3	Compressors or Expander	i. Nominal volumetric flow (m^3/s)
		ii. Nominal speed (rpm)
		iii. Performance curve
4	Centrifugal Pumps	i. Nominal volumetric flow (m^3/s)
		ii. Head at zero flow
		iii. Performance curve
		iv. Nominal speed (rpm)
		v. Running and stopping time
5	Reactors	i. Diameter
		ii. Height
		iii. Elevation
		iv. Level nozzle elevation (used for LT configuration)
		v. Reactions and catalyst packing information

3. Model Acceptance Test (MAT)

After the completion of plant modelling of the plant into the flow sheets, verifications of these flow sheets is required, which was done during Model Acceptance Test (MAT). The MAT was specified on design of the virtual plant but without any complex control loop. This verification includes checking the Dynsim flow sheets with respect to the scope marked P&IDs and for the completeness of the simulation model scope and simplifications. Test observations or comments were recorded in the pre-defined punch list format. Table 3 describes the examples of graphical findings captured during MAT.

Table 3: Examples of graphical findings during MAT

No	Area	Model Flow sheet	Priority	Description
1	Light	Generic	Medium	For all cryogenic exchangers the graphics need to be same as per DCS
2	Light	O22_37	Low	TV2212_03 bypass valve to be modelled
3	Light	O22_37	Low	C_2H_4 from E-3811 will join after HV2211_13
4	Light	O22_37	Low	PV2211_11 bypass valve to be modelled
5	Light	O22_37	High	AT2212_09 measures the CH4 product

4. DCS and ESD Integration

The DCS and ESD integration was done by copying all the data from actual plant and transfer to simulation through vendor software links. The HMI graphics and controls of the DCS were used “as-is” from the plant DCS graphics and control system. All control logic diagrams were gathered during data collection as per project planning. The DCS system includes modulating controls such as proportional–integral–derivative (PID) controllers as well as permissive, overrides, interlocks, trips, and alarms. The DCS controls for the systems and subsystems modelled were downloaded directly into the simulator hardware. ESD interaction was available to the operator or instructor from DCS (for DCS operated switches) or instructor station (for field operated switches). The instructor has access to all instruments and valves in order to recreate suitable training scenarios. The ESD control logic was linked to the model through vendor software as well. The ESD Hard Panel in control room, including only push buttons necessary for training operations, were emulated and displayed on the Field Operator Station. The emulation was a simplified representation of the layout and colours used on the actual control panels.

5. Factory Acceptance Test (FAT)

After the modelling acceptance test completed, the entire punch list was verified and solved. The controllers, emergency shutdown and basic control system were added up to the models. The overall flows sheets were integrated into virtual plant DCS for testing before the Factory Acceptance Test (FAT) done. The testing was be on the simulation machine and on virtual DCS. All the findings were be recorded and verified. The additional test that were performed was to verify malfunctions to determine whether the OTS models are capable of executing the malfunctions as configured and respond appropriately and compare the model response with the expected response. Each malfunctions tested were initiated from the steady state condition.

6. Site Acceptance Test (SAT)

Following the approval and success of the FAT, the overall simulator package were delivered, assembled, installed and tested at plant site. Testing were done as per MAT and FAT. All findings were recorded and rectified to meet the requirements. Once the Site Acceptance Test (SAT) was done, all documentations were verified and documented. Trainings were provided for particular personnel especially for the instructors and maintenance. Figure 3 shows the illustration of real plant converted to virtual plant.

7. Acceptance Test Verification Results

During the verification test, all the findings were captured into few categories which were graphics, steady state, and malfunctions. When critical parameters were compared with actual plant parameters, some parameters were not met. This was due to some controller set points that were set differently HMB. Few important HMB data were also varied from the actual plant data. This caused most of the other parameters’ values to also be different from the actual plant data. Table 4 shows some examples of the critical parameters’ comparison between the plant data and the modelling value 1 at steady state before the changes. The parameters were corrected as model value 2 to meet the actual plant to fit the training purposes. Set points for the controllers were changed based on the plant data. Most of the graphical findings during MAT were on process line not modelled properly such as control valve bypass line, drains to flare and transmitter tapping. Most of the time, the simulation fails to represent as what the real plants system is due to people who are testing the simulation are not familiar with the plant process and the control system. Requirement for experience panel operator for testing is a need.

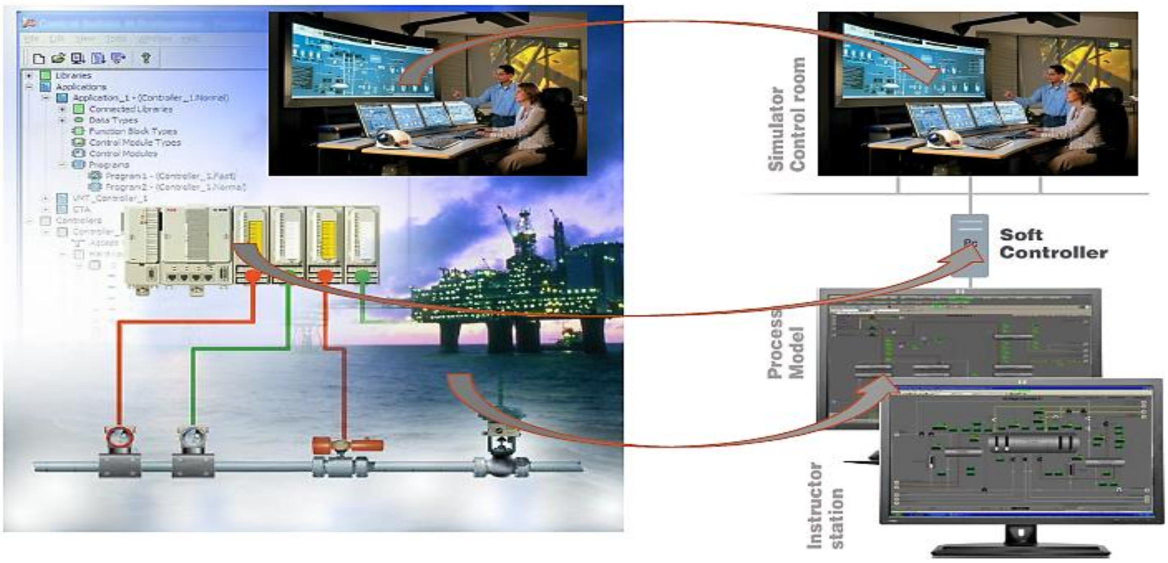

Figure 3: Real plant converted into virtual plant

Table 4: Difference between plant data and model value during MAT testing

Tag	Description	Plant Data	HMB	Model Value 1	Model Value 2	Unit
OL1201:FI08	CO_2 abs tails flow	76	80	95	83	t/h
OL1201:PDI04A	CO_2 abs delta P lower section	293	294	275	265	$mbar_g$
OL2211:TI06	C_3 to deeth from C_3 abs bottom	11	5	4	6	°C
OL2211ANZ:AI04D	C_2H_4 prod C_2H_6	< 138	< 80	213	114	ppm
OL2212:TC03	TG to TG exp1 temp control	16	8	6	16	°C
OL2214:TC01	C_2H_4 prod vapour temp control	8	-7	-5	8	°C
OL2232:PC03	C_3H_6 to C_3C 1st stage drum	1	1	1	1	bar_g
OL2301:PC02A	TG Exp 1 inlet pressure control	28	28	29	28	bar_g
OL2303:PDI04F	C2 abs top chimney D/P	91	44	46	85	$mbar_g$
OL2331:TI07	Raw H_2 separator O/H	-162	-157	-155	-160	°C
OL2402:PDI12A	C2 splitter total D/P	550	535	725	553	$mbar_g$
OL2402:TI04	C2 splitter tray 11	-13	-11	-15	-13	°C
OL2402:TI09	C2 splitter tray 75	-34	-30	-31	-30	°C
OL2402ANZ:AI15C	C2 splitter top C_2H_6	< 138	< 80	212	130	ppm
OL2417:FC03A	C_2H_4 prod to storage flow control	10	4	4	12	t/h

For start-up and shutdown, most of the findings were the operations of valves are not as per intended design. Some of the valves were resized to get normal flow as per plant data during start-up and shutdown of the plant. Experienced panel men tested the models by shutting down the process and starting up back from steady state. Same test was done for FAT and the test was done using the DCS graphics rather than testing on the process flow sheets. Figure 4 shows the DCS graphics with the operator and instructor interface.

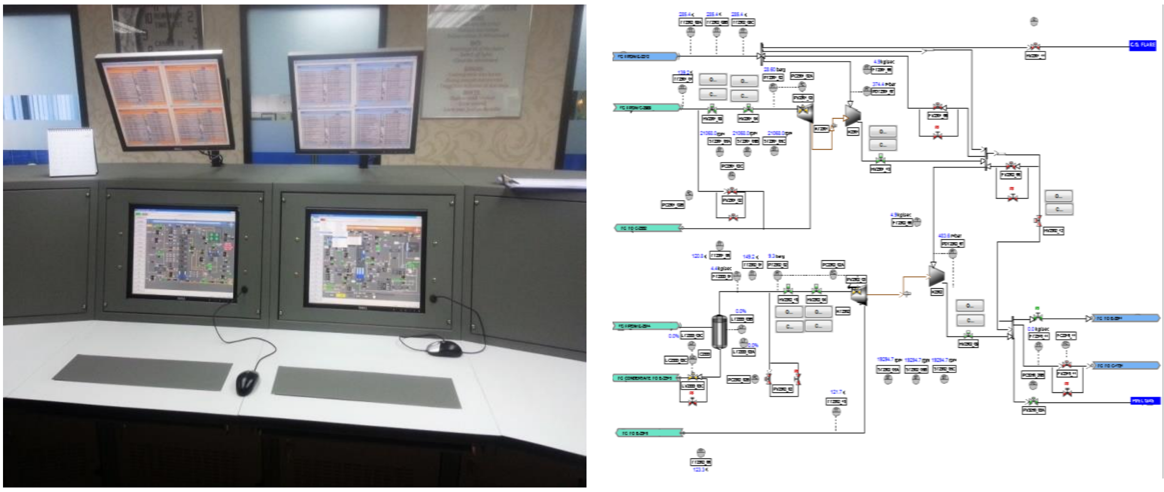

Figure 4: Virtual operator graphics (left) and instructor graphics (right)

8. Conclusions

The OTS is capable of simulating behaviours that accurately reflect normal and transient conditions. The response of the OTS models resulting from operator action, no operator action, improper action, automatic process control action, and inherent operator characteristics shall be realistic within the limits of the specified performance criteria. The most important tasks after developing the flow sheet are to test the model and compare with the real plant behaviour. During testing, experience panel man is the best choice to get the best output of the simulations. The malfunctions are tested to have best training simulation experience. The simulations indeed meet the operator training objective. It educates the operators to take action when possible event or upset takes place.

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