SPE/IADC
DRILLING CONFERENCE AND EXHIBITION
14–16 March 2017 | The Hague, The Netherlands

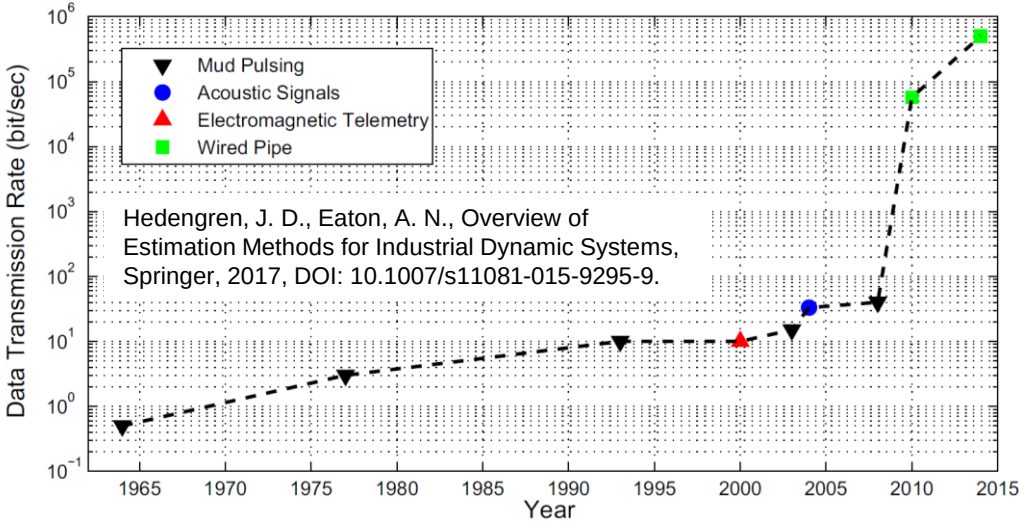
SPE-184610-MS
Improved Bottomhole Pressure Control with Wired Drillpipe and Physics-Based Models

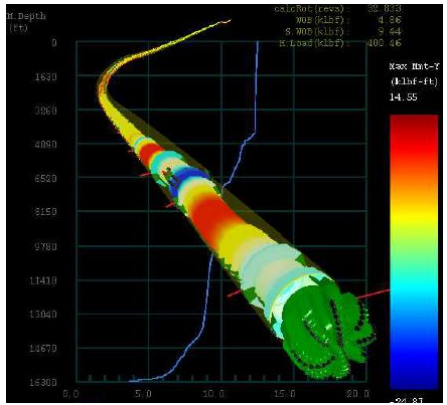
John D. Hedengren, Brigham Young University

Outline

- Opportunities and Challenges with MPD Automation
- Non-linearity in the MPD operation
- Nonlinear Model based Control Strategy (H-W Model)
- MPC Model Configuration (Controller Matrix)
- Normal Drilling and Pipe Connection (Performance comparison w/ PID)
- Multi-Variable Control Strategy for Kick Attenuation
- Conclusion

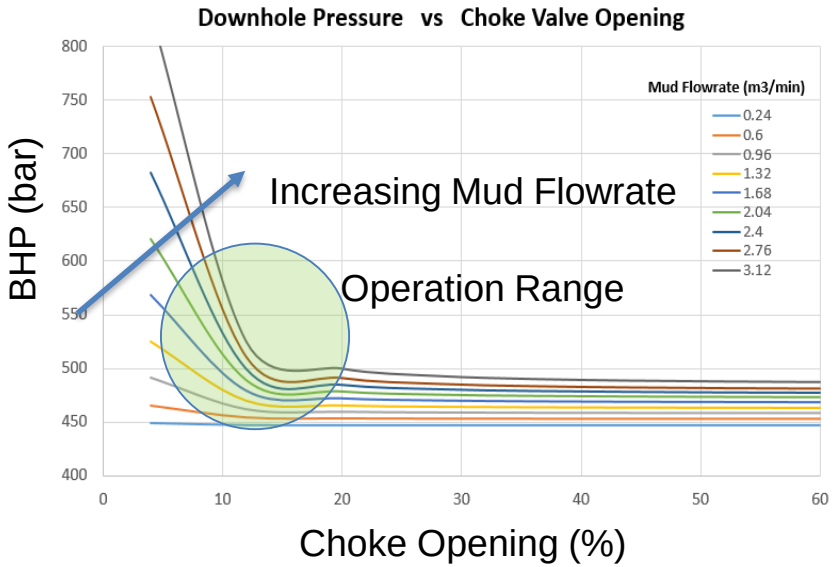
Advances in Downhole Data Access and Physics-based Models

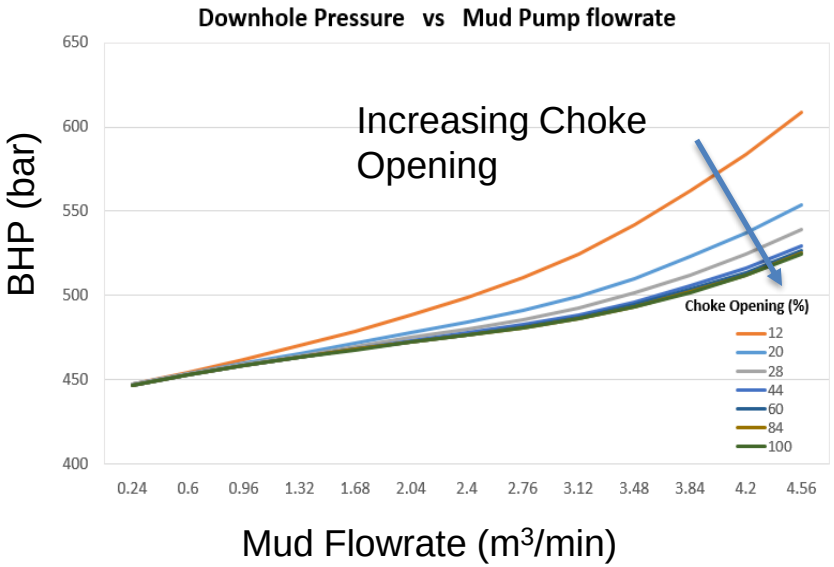




See https://github.com/APMonitor/drilling

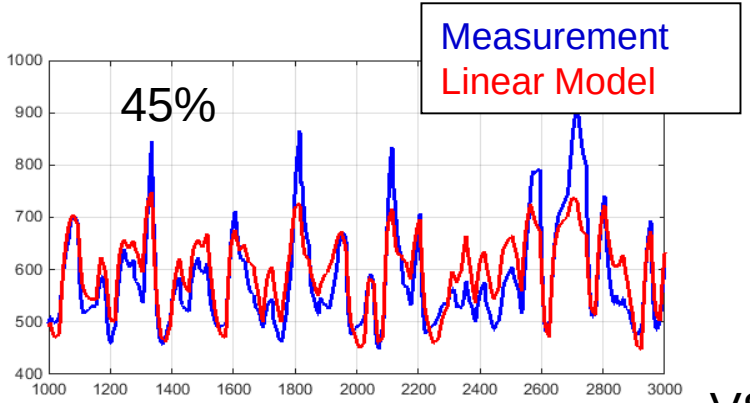
Nonlinearity in Managed Pressure Drilling



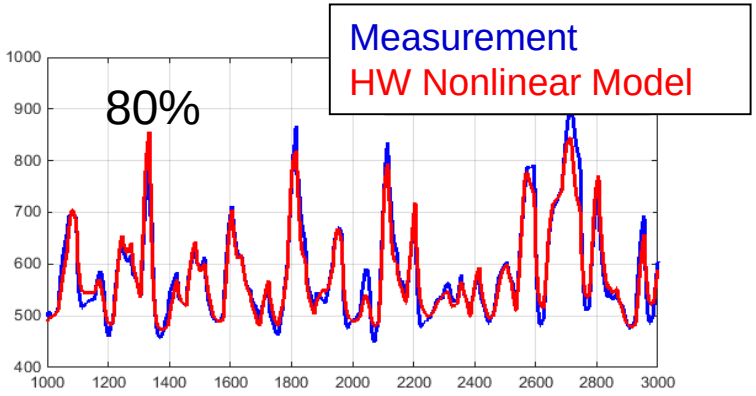


Why is the Nonlinear Model needed in Drilling?

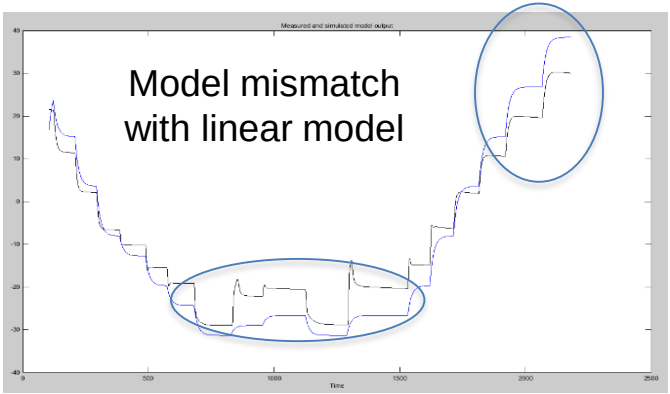
BHP (bar)

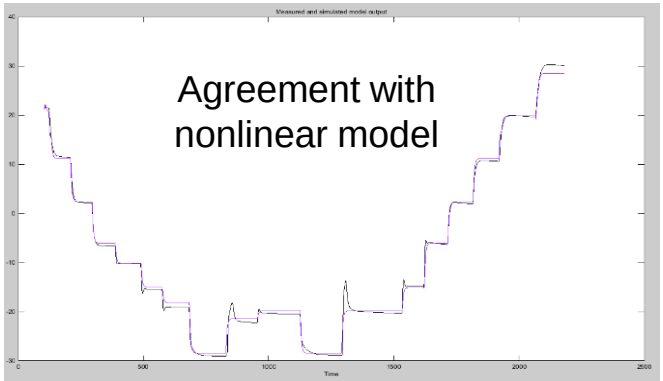


VS



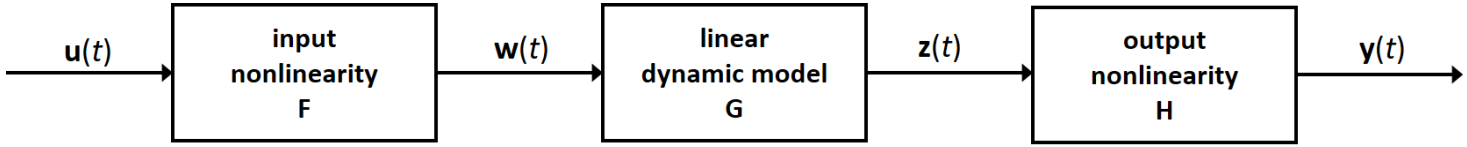
BHP



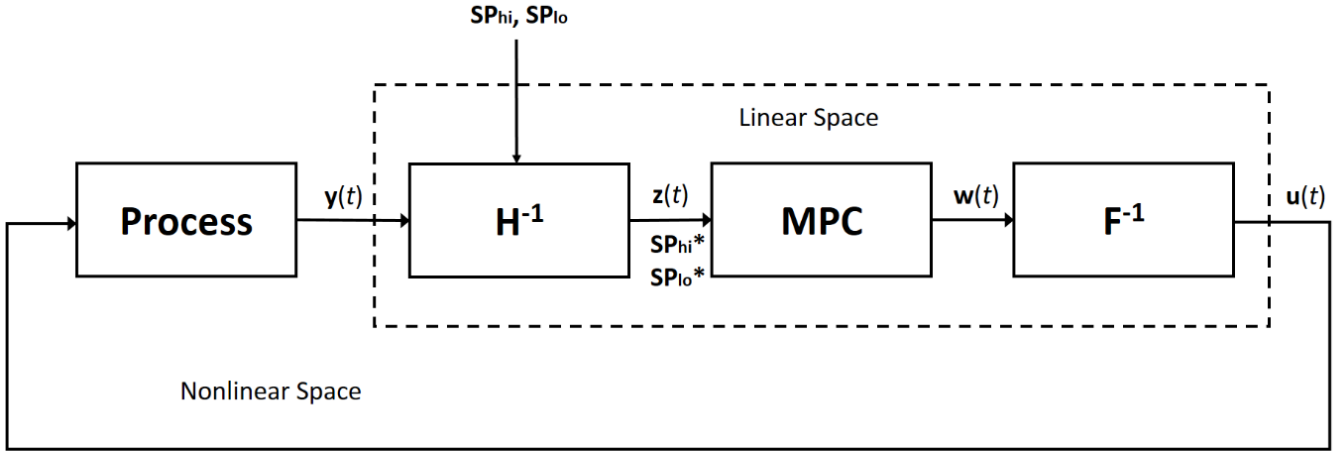


Hammerstein – Winner Nonlinear Approach

Model Structure

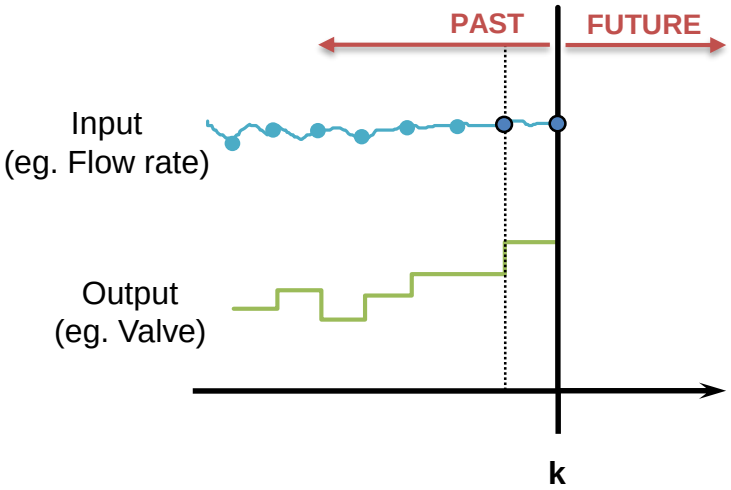


HW Model In the MPC Controller

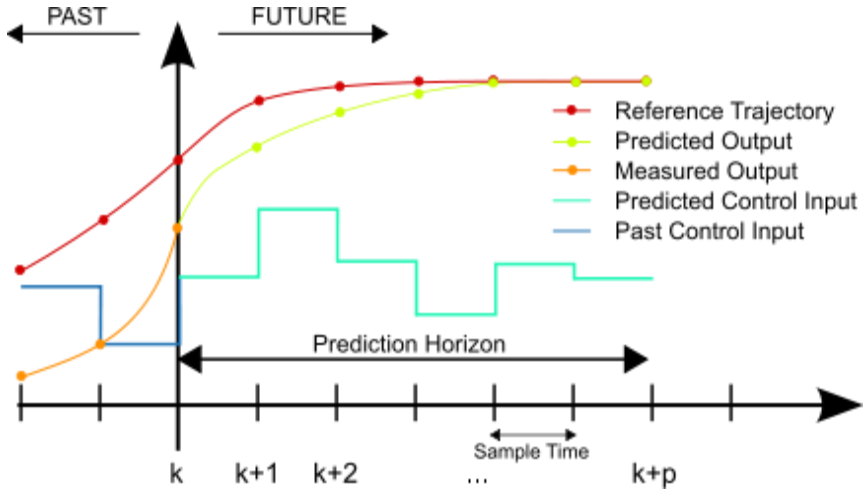


Advantages of Model Predictive Control

Conventional (PID)



Advanced (MPC)



“sees” into the future to make optimal MV moves

Advantages of Model Predictive Control

		MV / DV		
		Choke Opening (Z_{choke})	Back Pressure Pump (q_{back})	Main Mud Pump (q_p)
CV	BHP (P_{bit})	-	+	+
	Flow Balance (q_{bal})	-	+	+

- **Manages multiple CVs and MVs simultaneously (MIMO Control)**
- **Disturbance compensation**

Case Study

Three common scenarios in drilling operation

1. Normal Drilling Operation
2. Pipe Connection Procedure
3. Kick Attenuation

Vertical Well Configuration (WeMod)

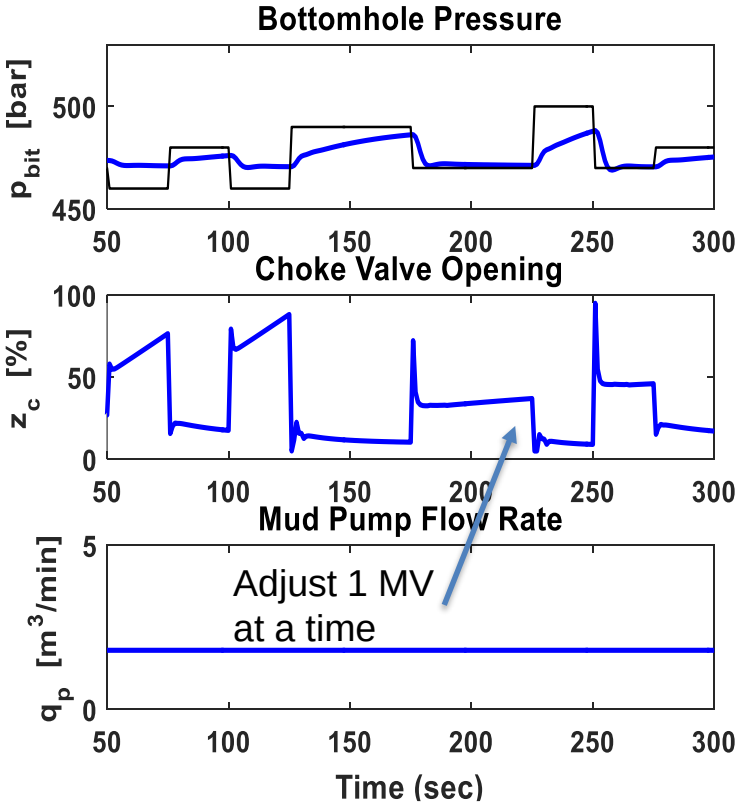
Parameter	Value (AES)	Value (SI)
Well depth	11,800 ft	3,600 m
Riser inner diameter	19’’	0.48 m
Water depth	590 ft	180 m
Casing inner diameter	9’’	0.23 m
Casing depth	7,100 ft	2,164 m
Drill string average outer diameter	4.5’’	0.12 m
BHA length	150 ft	45.7 m
BHA average outer diameter	6.7’’	0.17 m
Open hole/bit size	8.5’’	0.2 m
Reservoir depth	9840 ft	3,000 m
Reservoir Pore Pressure	401.0 bar/1.364 s.g.	401.0e+05 Pa/1.364 s.g.
Initial mud density	1.24 s.g.	1.24 s.g.

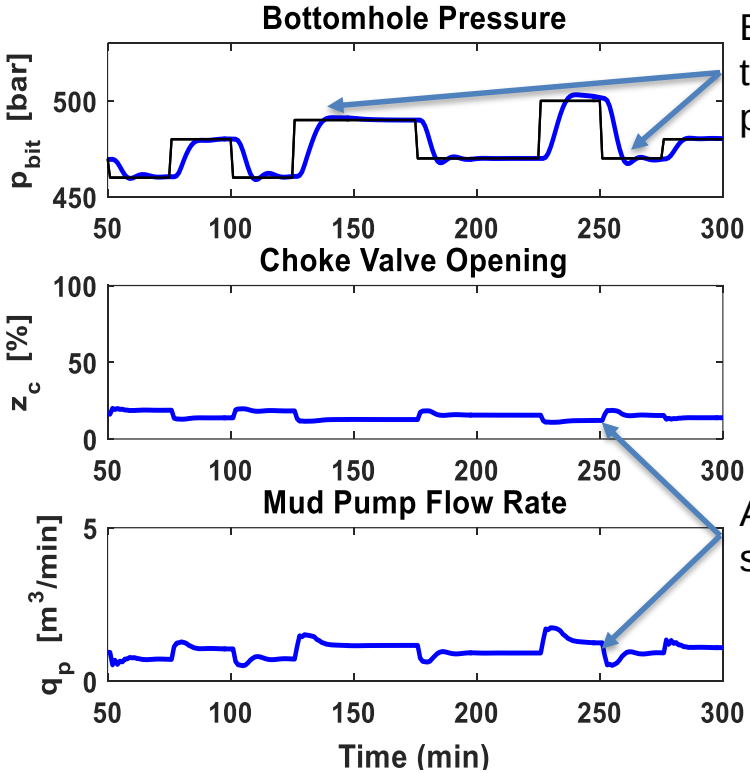
Normal Drilling

CV

MV1

MV2





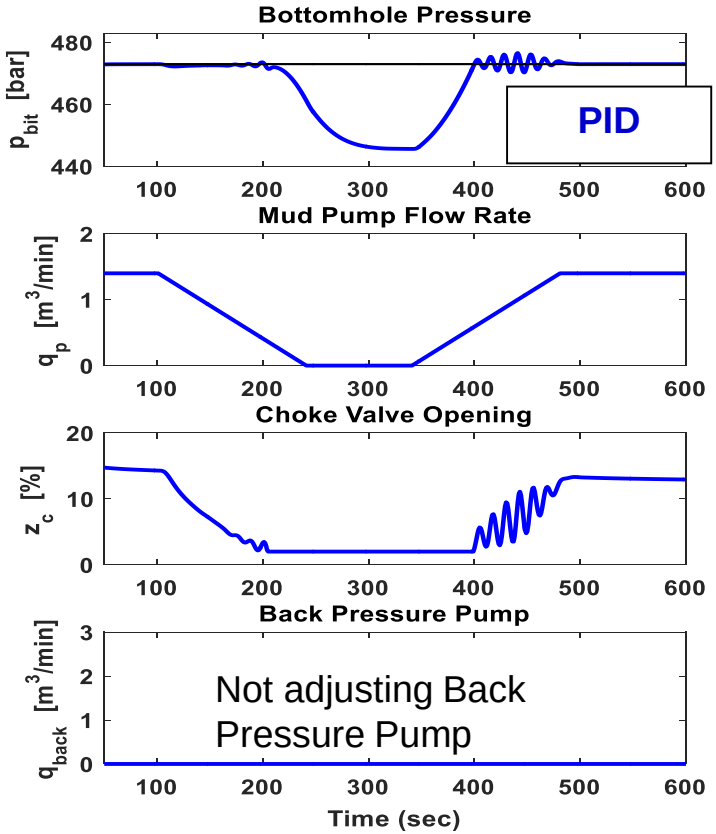
Better Setpoint tracking performance

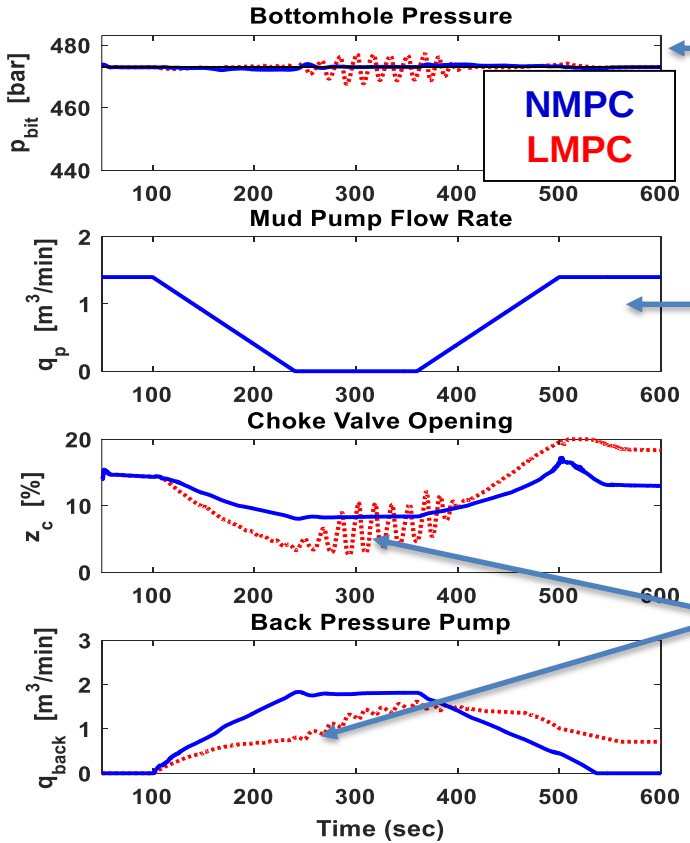
Adjust 2 MVs simultaneously

PID (conventional controller)

NMPC (new controller)

Pipe Connection





Keep the BHP within ±1bar variation w/o Oscillation

Compensate the Ramping movement of the Main Mud Pump

LMPC causes the Oscillation

Control Strategy for Kick Attenuation

- During Gas influx, Closed Loop Control Actions for normal operation will accelerate the Gas influx

Gas Influx

↓

BHP Increased

↓

Choke Valve Open
Mud Flow / Back Pressure Pump Decrease
(Wrong Control Action)

↓

BHP Decreased

↓

More Gas introduce to the wellbore
(Undesired Result)

Gas Influx

↓

Turn off the BHP CV

↓

Control the Flow Balance CV only

↓

Choke Valve Close
Mud Flow / Back Pressure Pump Increase
(Correct Control Action)

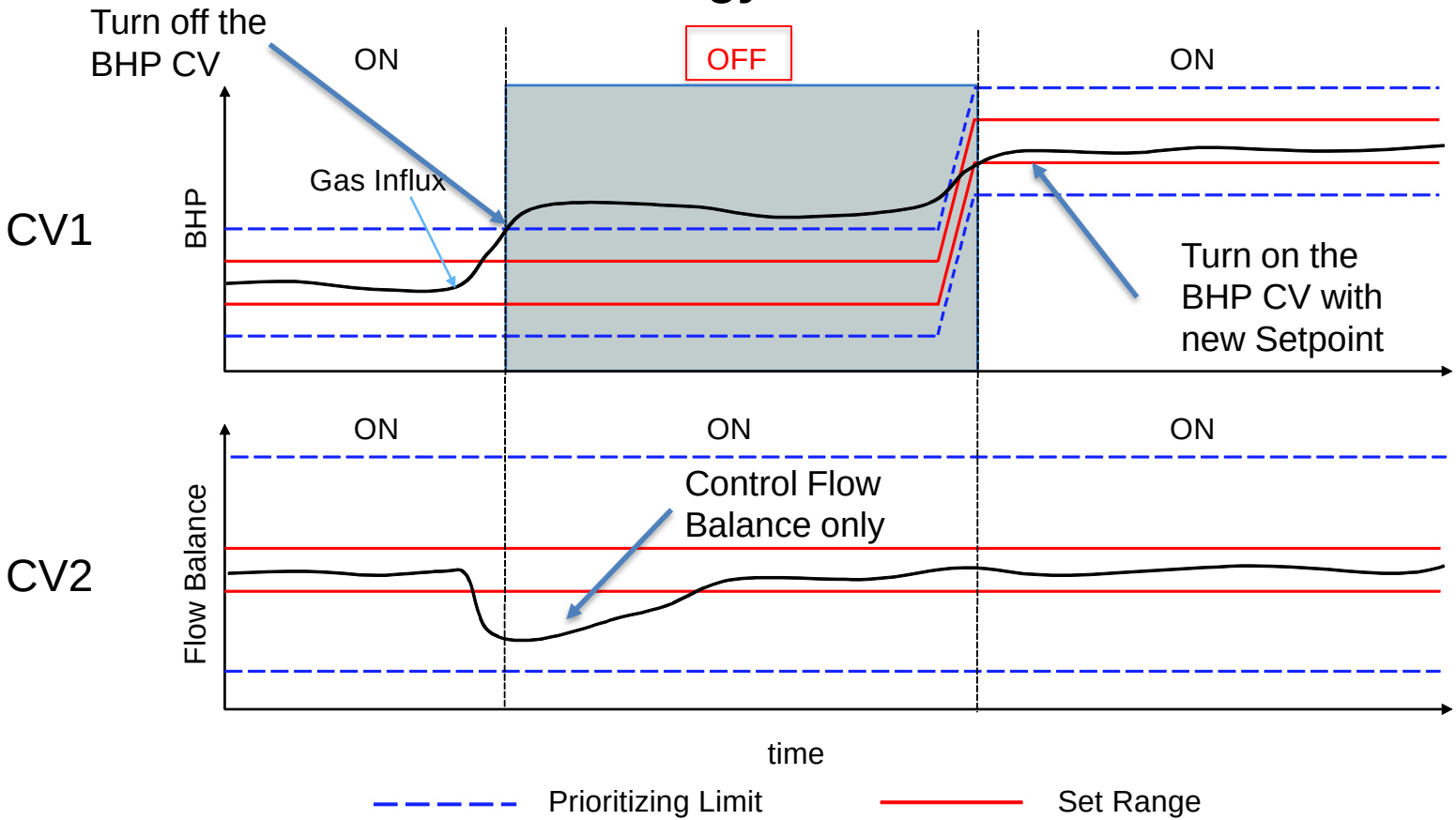
↓

BHP Increased
(Against the Higher Reservoir Pressure)

↓

Block the Gas Influx
(Desired Result)

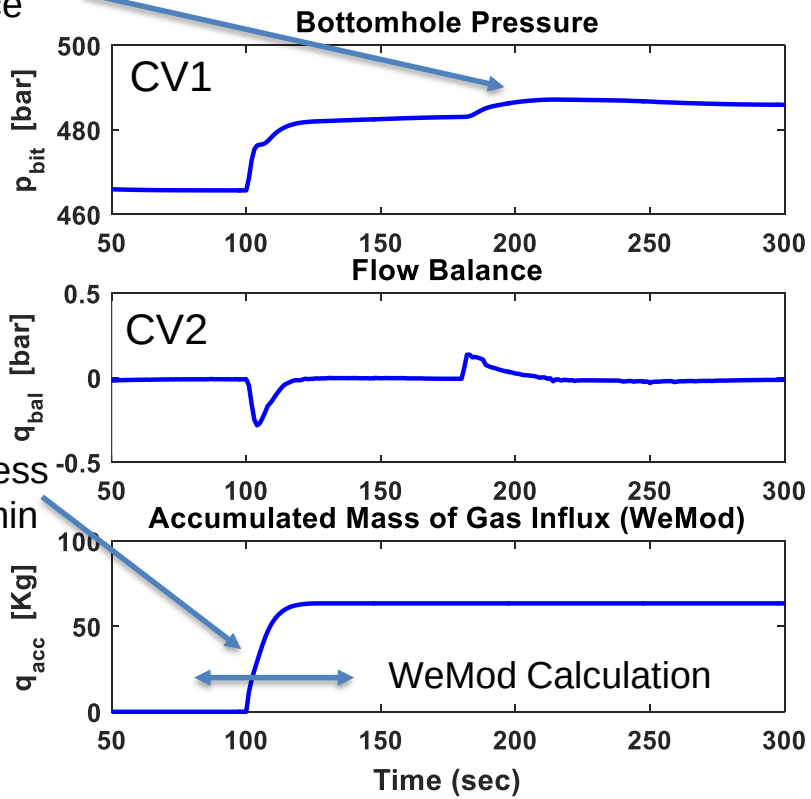
Control Strategy for Kick Attenuation

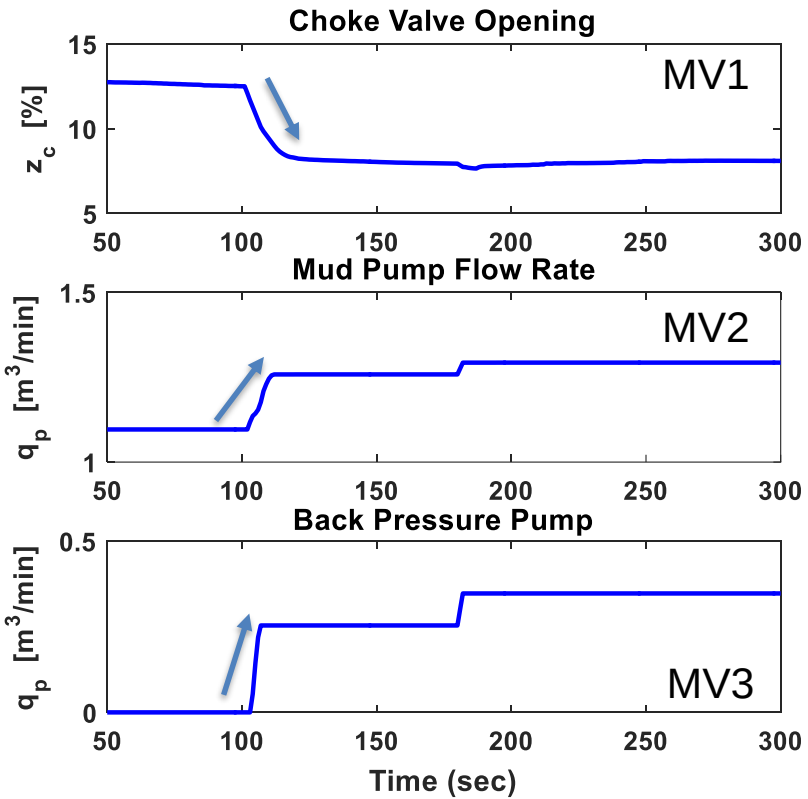


Kick Attenuation Control

Settle down at new BHP balance

Takes less than 1min





Conclusion

- HW NMPC has better set point tracking in normal operation because it simultaneously moves two MVs at the same time (choke valve opening and mud pump flow rate)

- HW NMPC controls the BHP within +/- 1 bar for pipe connection, as opposed to the +/- 20 bar deviation with the PID controller

- HW NMPC attenuates a kick within 1 minute and quickly stabilizes the BHP

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Acknowledgements

Junho Park, Thomas Webber, Brigham Young University
Reza Asgharzadeh Shishavan, Occidental Petroleum Corporation

Questions Welcome