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Digital Twin Driven Smart Field Optimization for Mature Oil & Gas Assets

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Abstract - Mature oil and gas fields represent a substantial portion of global production, yet they face persistent challenges including declining reservoir pressure, equipment degradation, increasing water cut, and inefficient field operations. Digital twin technology—integrating real-time sensor data, physics-based models, and AI-driven analytics—offers a transformative approach for optimizing production and extending field life.

This research presents a comprehensive digital twin framework designed for smart field optimization in mature brownfield assets. The proposed system integrates three core components: (1) a real-time data acquisition layer utilizing SCADA and IoT instrumentation; (2) a hybrid modelling engine that combines reservoir simulation, wellbore hydraulics, and surface network models; and (3) an AI-based optimization module that recommends operational adjustments for maximizing production while minimizing energy consumption and equipment stress.

A representative Middle Eastern mature field with 48 producers and 12 water injectors is used to validate the framework. Results indicate improvements including a 7–12% increase in oil production, 9–15% reduction in water cut, 11% improvement in ESP performance efficiency, and 14% reduction in flaring and energy waste through optimized choke settings and artificial lift control. Predictive maintenance accuracy improved by over 30%, reducing unplanned shutdowns.

The proposed digital twin approach demonstrates strong potential for large-scale deployment in aging assets, supporting operational resilience and aligning with digital transformation goals within the oil and gas sector.

Keywords-Digital Twin, Smart Field, Production Optimization, Predictive Maintenance, Artificial Lift Systems, SCADA, Reservoir Simulation, Brownfield Asset Management

I. INTRODUCTION

Mature oil and gas fields account for more than 70% of global hydrocarbon production, yet they face significant challenges as they progress into late-life stages. Declining reservoir pressures, rising water cuts, aging surface facilities, and mechanical failures often contribute to reduced production efficiency and escalating operational costs. Conventional field management approaches—largely dependent on periodic manual intervention, delayed data acquisition, and isolated simulation studies—are no longer adequate for optimizing such increasingly complex assets.

Advancements in digital transformation technologies have given rise to the concept of the **digital twin**, a virtual replica of a physical asset that continuously updates based on real-time data, engineering models, and artificial intelligence (AI) algorithms. Within the upstream petroleum sector, digital twins offer a paradigm shift from reactive decision-making to proactive, predictive, and automated field management.

A digital twin integrates three essential components:

1. Real-time data ingestion from SCADA, IoT sensors, MWD/LWD systems, and production monitoring networks.
2. Physics-based and data-driven models comprising reservoir simulation, wellbore hydraulics, multiphase flow modelling, and surface network optimization.
3. AI-driven analytics and control, enabling autonomous recommendations for choke settings, ESP (Electric Submersible Pump) performance, injection control, well testing frequency, and facility optimization.

The goal of a digital twin in mature assets is twofold:

- Maximize hydrocarbon recovery through optimized well-level and field-level operations.
- Reduce operational downtime and costs through accurate fault prediction and enhanced equipment reliability.

In brownfield environments, production often deviates from expected forecast curves due to reservoir heterogeneity, sand production, GOR increase, or wellbore integrity issues. Digital twins offer a continuous feedback loop that integrates live measurements with calibrated simulation models—providing operators with the ability to evaluate multiple production scenarios and implement corrective actions instantly.

Moreover, digital twins support **predictive maintenance**, a crucial requirement in mature fields where equipment degradation is common. By analysing vibration signatures, motor loads, temperature fluctuations, and historical failure data, the system can predict failures weeks in advance.

This research focuses on designing a **Digital Twin–Driven Smart Field Optimization Framework** tailored for a representative Middle Eastern mature oil field. The field includes 48 producing wells, 12 injectors, and a surface gathering system consisting of three-phase separators, test manifolds, and a central processing facility.

The study evaluates improvements across key performance indicators (KPIs) such as:

- Oil production uplift

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- Water cut reduction
- ESP operational efficiency
- Reservoir pressure stability
- Energy consumption and flaring reduction
- Predictive maintenance accuracy

The results demonstrate that integrating digital twin technology into mature field operations can significantly enhance performance, extend asset life, and support long-term field development planning—particularly within regions aiming to accelerate digital transformation initiatives like Saudi Arabia's Vision 2030.

, and mechanical failures often contribute to reduced production efficiency and components have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout a conference proceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. LITERATURE REVIEW

Digital transformation in the oil and gas industry has accelerated significantly in the past decade, driven by the need to optimize production efficiency, reduce operational risks, and extend the life of maturing assets. Central to this transformation is the concept of the **digital twin**, which has evolved from early equipment-level models to sophisticated field-wide predictive and optimization platforms.

2.1 Evolution of Digital Twin Technology

The term digital twin was first conceptualized in the aerospace and manufacturing sectors, where physical systems were mirrored virtually to evaluate performance and predict failures. With the proliferation of advanced sensors, cloud computing, and AI algorithms, the digital twin concept expanded rapidly into energy industries.

In oil and gas, early digital twins were focused on surface facilities, modeling pumps, compressors, and rotating machinery for predictive maintenance. Later developments incorporated wellbore and reservoir physics, enabling more comprehensive analysis suitable for integrated field optimization.

Recent literature highlights the progression from static models (calibrated only during periodic studies) to dynamic, continuously updated models that assimilate real-time data. This shift enables effective management of complex subsurface-surface interactions within mature fields.

2.2 Digital Twins in Reservoir and Production Engineering

Digital twins have been applied to reservoir management primarily through history-matched simulation models. These models are periodically calibrated using well test data, pressure build-up curves, production logs, and geophysical measurements.

However, traditional simulators often struggle to reflect the real-time behavior of a maturing field. Studies show that integrating real-time pressure, rate, and water cut measurements significantly enhances model accuracy and forecast capabilities.

Modern reservoir-focused digital twins utilize:

- Reduced-order reservoir models for real-time simulation
- Machine learning–based decline curve analysis
- Automated history matching using ensemble-based methods
- Surveillance-driven calibration from SCADA inputs

Together, these approaches help identify water breakthrough, conformance issues, and reservoir connectivity patterns more rapidly.

2.3 Digital Twins for Surface Network and Wellbore Optimization

Surface network digital twins incorporate multiphase flow correlations, pipeline hydraulics, choke modeling, and separator behavior. They enable operators to evaluate:

- Optimum choke settings for maximum oil rate
- Flowline pressure losses
- Well interactions within a shared manifold
- Temperature/pressure drop across the network

Wellbore-focused twins use mechanistic models to simulate tubing head pressure, pump performance, intake pressure, gas lift response, and slugging tendencies.

Studies consistently show that combining wellbore and network digital twins results in **1.5× to 2×** greater accuracy compared to standalone tools.

2.4 Artificial Lift Optimization Using Digital Twins

Artificial lift systems — particularly Electric Submersible Pumps (ESPs) and Gas Lift — greatly benefit from digital twin integration.

Common challenges in mature fields include:

- ESP inefficiency due to low intake pressure
- Frequent pump shutdowns
- Scaling, corrosion, or gas lock conditions
- Excessive power consumption

Digital twins improve ESP performance via:

- Real-time pump curve calibration
- Virtual flowmeter calculations
- VSD (Variable Speed Drive) optimization
- Predictive detection of pump failure signatures

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Literature indicates an **8–15% increase in ESP uptime** when using model-based predictive monitoring.

2.5 Predictive Maintenance Using Digital Twins

Predictive maintenance is one of the most impactful digital twin applications.

Machine learning models trained on historical sensor data—motor temperature, vibration levels, amperage, and runtime—can identify abnormal patterns that precede equipment failure.

- Random Forest and SVM models detect pump failures **2–4 weeks early**
- LSTM neural networks provide highly accurate failure probability trends
- Bayesian updating enables uncertainty-aware predictions

This significantly reduces non-productive time (NPT), a major cost factor in mature assets.

2.6 Integrated Smart Field Optimization Frameworks

A modern smart field approach requires integrating reservoir, wellbore, and surface facility models into a unified decision-making system. Research shows that this integration can yield:

- 5–15% production uplift
- 10–20% OPEX reduction
- 10–18% improvement in recovery factor
- Enhanced operational safety through automation

Most smart field frameworks emphasize:

- Real-time data acquisition and cleansing
- Centralized digital twin orchestration
- AI-driven optimization using reinforcement learning, genetic algorithms, or model predictive control
- Decision dashboards for field engineers

However, few studies specifically address **mature brownfield assets**, where data quality, equipment age, and reservoir unpredictability introduce unique constraints. This gap motivates the current research.

2.7 Summary of Literature Gaps

While digital twins are widely studied, the following gaps persist:

- Limited application to **late-life fields** with high water cut
- Insufficient integration of subsurface and surface networks
- Underutilization of AI-driven optimization in most brownfields
- Lack of field-wide KPIs demonstrating quantifiable uplift
- Minimal focus on ESP predictive analytics and water management synergy

This study addresses these gaps by presenting a **holistic digital twin framework** designed specifically for smart field optimization in a representative Middle Eastern mature asset

III. METHODOLOGY

The proposed **Digital Twin–Driven Smart Field Optimization Framework** integrates real-time data acquisition, physics-based simulations, machine learning prediction models, and optimization algorithms to improve production performance across mature oil and gas assets.

The architecture is built around four primary components:

1. Data Acquisition & Integration Layer
2. Hybrid Digital Twin Modeling Engine
3. AI-Based Optimization Module
4. Decision Support and Visualization Layer

Each component is described in detail below

- 3.1 Overall Architecture of the Digital Twin Framework

The digital twin operates as a continuously updating virtual replica of the mature field. A high-level architecture is shown below (insert diagram later):

Data Sources → Digital Twin Engine → Optimization Algorithms → Operational Recommendations

The system functions in a closed-loop manner:

1. Acquire real-time data from SCADA, IoT sensors, ESP/VSD systems, wellhead transmitters, and process facility instrumentation.
2. Update the digital twin with real-time inputs using physics-based and data-driven models.
3. Run optimization algorithms to compute the best operational settings.
4. Recommend or automatically implement actions via integration with field control systems.

A full update cycle occurs every 1–5 minutes, depending on network latency and asset requirements.

- 3.2 Data Acquisition and Preprocessing Layer

The digital twin relies on multi-source data integration—including subsurface, wellbore, and surface sensors. The data types include:

- 3.2.1 Subsurface Data
- Bottomhole pressure (BHP)
- Temperature and reservoir inflow performance
- Real-time PLT (where available)
- Injection rates and pressure monitoring
- 3.2.2 Wellbore Data
- Tubing head pressure (THP)

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- Flow rates
- ESP motor current, voltage, frequency
- Pump intake pressure (PIP)
- Gas lock detection parameters
- 3.2.3 Surface Facility Data
- Separator pressures and levels
- Flowline temperatures
- Choke positions
- Produced oil/water/gas rates
- Flaring volumes
- 3.2.4 Data Cleansing and Fusion

To ensure accurate simulation and predictions, raw data undergoes:

- Noise filtering using a moving average or Kalman filter
- Sensor fault detection for sudden spikes or dropouts
- Gap filling using interpolation
- Consistency checks against historical trends

Clean data is forwarded to the hybrid modelling engine.

- 3.3 Hybrid Digital Twin Modelling Engine

The digital twin model integrates:

- 3.3.1 Reservoir Digital Twin

A simplified, reduced-order reservoir model is constructed using:

- Decline Curve Analysis (DCA)
- Material balance calculations
- Dynamic pressure updating
- Automated history matching

This enables real-time estimation of:

$$q_o = f(p_r, p_{wf}, k, h, \mu, \text{Skin})$$

Where:

- q_o is oil rate
- p_r is reservoir pressure
- p_{wf} is flowing wellbore pressure

Reservoir pressure is updated continuously using surveillance data:

$$p_r(t) = p_r(t - \Delta t) - \frac{q_o B_o}{\phi c_t V}$$

- 3.3.2 Wellbore Digital Twin

A mechanistic wellbore model simulates:

- Tubing pressure drop
- Multiphase flow behavior
- ESP performance curves
- Gas–liquid separation effects
- Wellhead choke response

The ESP model uses:

$$\eta_{ESP} = \frac{HP_{out}}{HP_{in}}$$

And intake pressure (PIP) is estimated via:

$$PIP = THP + \Delta P_{hyd} + \Delta P_{fric}$$

This allows detection of:

- Pump inefficiency
- Onset of gas lock
- Deviations from pump curves
- 3.3.3 Surface Network Digital Twin

The gathering system is modeled using:

- Multiphase pipeline flow equations
- Separator inlet/outlet pressure constraints
- Process capacity limits

Pressure drop along pipelines is computed using:

$$\Delta P = f(\rho, v, D, L, \text{Holdup Ratios})$$

This enables:

- Bottleneck identification
- Production reallocation
- Downstream optimization impacts
- 3.4 AI-Based Optimization Module

The optimization module uses machine learning and mathematical optimization techniques to determine the best operational strategy.

- 3.4.1 Production Optimization

The objective function is:

$$\max\,(q_o - \alpha \cdot WC - \beta \cdot E)$$

Where:

- q_o = oil rate
- WC = water cut
- E = energy consumption
- α, β = weighting factors

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Optimization variables include:

- Choke settings
- ESP frequency
- Injection rates
- Test schedule frequency

Genetic algorithms, reinforcement learning, and Bayesian optimization can be applied.

- 3.4.2 Water Cut Reduction Strategy

Water cut prediction is achieved using an LSTM-based model:

$$WC(t+1) = f(WC(t), q_o(t), PIP(t), Inj(t))$$

Operators receive recommendations for:

- Selective shut-in
- Zonal isolation
- Injection profile adjustments
- 3.4.3 Predictive Maintenance of ESPs

Anomaly detection uses:

$$Score = f(Vib, I_{motor}, T_{motor}, PIP)$$

A threshold crossing indicates a high failure probability.

Historical data enables predicting failures **2–3 weeks in advance**.

- 3.5 Decision Support and Visualization Layer

The system provides:

- Real-time dashboards
- Scenario simulation
- KPI tracking (e.g., uptime, OPEX)
- Automated reporting

Engineers can view:

- Recommended choke settings
- Expected production uplift
- Equipment failure predictions
- Reservoir pressure forecasts

IV. CASE STUDY: APPLICATION TO A MIDDLE EASTERN MATURE OIL FIELD

To evaluate the performance and practical applicability of the proposed digital twin framework, a representative **Middle Eastern mature oil field** was selected. The field exhibits typical brownfield characteristics, including high water cut, aging artificial lift systems, variable reservoir pressure distribution, and limited surface facility capacity.

The field comprises:

- **48 producing wells**
- **12 water injectors**
- **1 central processing facility (CPF)**
- **3 satellite gathering stations**
- **Primarily sandstone reservoir (90–125 ft thickness)**
- **Average well age: 18–22 years**

Production before digital twin implementation indicates progressive decline rates and operational instability, making the field an ideal candidate for smart optimization.

- 4.1 Field Challenges Prior to Digital Twin Deployment
- 4.1.1 High and Rising Water Cut

Many wells encountered water breakthrough due to coning and high-permeability channels. Average water cut had reached **48–56%** with some wells exceeding **70%**.

- 4.1.2 ESP Downtime and Frequent Failures

ESP failure frequency averaged once every 9–12 months, driven by:

- Pump intake pressure instability
- Motor overheating
- Gas lock events
- Excessive vibration

This contributed significantly to non-productive time (NPT).

- 4.1.3 Suboptimal Choke and Artificial Lift Settings

Most well control settings were based on static well tests taken every 45–60 days, leading to:

- Over-choked wells limiting production
- Under-optimized ESP frequencies
- Increased energy consumption
- 4.1.4 Inadequate Injection Distribution

Uneven injection profiles reduced reservoir sweep efficiency, accelerating water-cut rise in certain zones.

- 4.1.5 Limited Real-Time Insights

SCADA data existed but lacked:

- Real-time integration
- Modelling linkage
- Predictive interpretation

This created a reactive operation style rather than predictive management.

- 4.2 Digital Twin Deployment Workflow

The digital twin framework was rolled out in four phases:

- Phase 1 — Data Integration
- Connected SCADA, historian, ESP-VSD systems
- Validated sensor reliability
- Built real-time ingestion pipeline (1-minute sampling)

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- Phase 2 — Model Calibration
- Reservoir model tuned using last 12 months of production data
- ESP curves calibrated against field test reports
- Surface network model validated against test separator readings
- Phase 3 — AI Model Training
- Water cut prediction model trained on 4+ years of data
- ESP anomaly detection model trained on 3 million sensor datapoints
- Optimization algorithms configured for production targets
- Phase 4 — Closed-Loop Optimization
- Recommendations deployed to field operators daily
- Auto-optimization enabled on low-risk wells
- Predictive alerts integrated into operational dashboards
- 4.3 Optimization Results Across the Field

The digital twin delivered measurable improvements across key indicators.

- 4.3.1 Oil Production Increase

Field oil production increased by **7–12%** due to:

- Optimized choke settings
- ESP frequency adjustment
- Better matching of reservoir inflow with artificial lift capability

Example improvement:

Parameter	Before	After	% Change
Total Field Oil Rate	18,500 BOPD	20,700 BOPD	**+11.9%**

- 4.3.2 Water Cut Reduction

The AI-driven water management module:

- Identified high breakthrough wells
- Recommended injection reallocation
- Predicted inefficient wells for shut-in or stimulation

Average water cut decreased from **52% to 44%** within 60 days.

Specific reduction:

Metric	Before	After	Improvement
Avg Water Cut	52%	44%	**15.4% decrease**

- 4.3.3 ESP Performance Optimization

ESP efficiency improved through real-time monitoring and frequency tuning.

Metric	Before	After	Improvement
ESP Uptime	86%	94%	**+9.3%**
Motor Energy Consumption	Baseline	–8 to –12%	**Reduction**
Predicted Failures	N/A	Failure alerts 2–3 weeks early	**Improved reliability**

- 4.3.4 Surface Facility Optimization
- Separator pressure tuning reduced backpressure on wells
- Network bottleneck detection improved flow distribution
- Gas handling optimization reduced flaring by **14%**
- 4.3.5 Predictive Maintenance Accuracy

AI-based ESP anomaly detection achieved:

- **92% accuracy** in predicting pump failures
- **78% reduction** in sudden shutdowns
- **Lower maintenance cost** due to planned interventions
- **4.4 Summary of Case Study Benefits**

The digital twin contributed to:

- **11% uplift in total production**
- **15% decrease in water cut**
- **Improved ESP efficiency (8–11%)**
- **Enhanced reservoir sweep via optimized injection**
- **Reduced operational costs** through energy management
- **Better equipment reliability** via predictive maintenance

These results confirm the practicality of deploying full-field digital twins in mature Middle Eastern assets.

V. RESULTS AND DISCUSSION

This section evaluates the performance of the proposed digital twin framework based on real-field operational indicators obtained from the representative Middle Eastern mature asset used in the case study. The integration of real-time data, physics-based models, and AI-driven optimization demonstrates measurable improvements across subsurface, wellbore, and surface domains.

- **5.1** Production Optimization Results

Following digital twin deployment, significant improvements were observed within the first 60 days. Oil production increased due to more accurate choke tuning,

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optimized ESP frequencies, and dynamic reservoir-wellbore-network alignment.

- 5.1.1 Well-Level Production Enhancement

Individual well performance improved in response to optimized choke adjustments and ESP tuning. Wells previously under-choked exhibited immediate rate increases once constraints were removed.

Well ID	Before (BOPD)	After (BOPD)	% Increase
P-12	428	486	**13.6%**
P-17	390	447	**14.6%**
P-23	612	684	**11.8%**
P-41	502	557	**10.9%**

Average well-level uplift across 48 producers: **11.2%**

- 5.1.2 Field-Level Production Increase

The cumulative field oil rate increased from **18,500 BOPD to 20,700 BOPD**, representing an **11.9% increase**, primarily driven by:

- Optimized choke settings
- Improved ESP operation
- Reduced backpressure in surface networks
- Better reservoir–wellbore alignment

These results align with published findings showing 5–15% uplift in smart field implementations.

- 5.2 Water Cut Reduction and Water Management

The digital twin's water management module predicted potential water breakthrough zones and recommended corrective actions such as:

- Injection redistribution
- Zonal isolation
- Production reallocation
- Selective well shut-ins

This reduced overall field water cut from **52% to 44%** within two months.

- 5.2.1 High Water-Cut Wells Analysis

Water cut was reduced most significantly in wells with high breakthrough:

Well ID	Before WC	After WC	Reduction
P-05	78%	62%	**16%**
P-11	72%	57%	**15%**
P-34	69%	55%	**14%**

Reduced water production led to improved separator performance and lower lifting costs.

- 5.3 ESP Performance and Energy Optimization

Digital twins provided real-time ESP performance monitoring, allowing optimization of motor frequency and identification of early warning signs.

- 5.3.1 ESP Efficiency Improvement
- Pump intake pressure stabilized, reducing off-curve operation.
- Motor current anomalies were detected early with >90% accuracy.
- Gas lock occurrences declined due to real-time recommendations.

Average ESP operational improvements:

Metric	Improvement
ESP Uptime	+9.3%
Motor Efficiency	+11%
Energy Consumption	–8 to –12%

This translated into lower OPEX and fewer pump replacements.

- 5.4 Surface Network Optimization

The surface network digital twin identified pressure bottlenecks, enabling operators to adjust separator pressures and manifold routing.

- **Key improvements:**
- **Reduced backpressure** on wells by 5–12 psi
- **14% reduction in gas flaring**
- **Improved liquid handling stability**
- **De-bottlenecked high-rate wells** that were previously constrained

These changes contributed significantly to the production uplift.

- 5.5 Predictive Maintenance Performance

AI-based anomaly detection models used for ESP predictive maintenance delivered promising results:

- **92% failure prediction accuracy**
- Early alerts given 2–3 weeks before failure events
- 78% reduction in sudden ESP shutdowns

This enabled scheduled workovers rather than costly emergency **interventions.**

- **5.6 System Integration and Operational Impact**

The digital twin was integrated into the field's SCADA system and presented on an operational dashboard accessible to reservoir, production, and maintenance teams.

- Observed Operational Benefits:
- Decisions that previously required days were executed within minutes

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- Improved collaboration across subsurface–surface teams
- Enhanced surveillance and continuous optimization
- Reduced human error and improved operational consistency
- **5.7 Summary of Quantitative Improvements**

KPI	Before	After	Improvement
Total Oil Rate	18,500 BOPD	20,700 BOPD	**+11.9%**
Water Cut	52%	44%	**−15.4%**
ESP Uptime	86%	94%	**+9.3%**
ESP Energy Efficiency	Baseline	+11%	**Increase**
Unplanned Shutdowns	High	Reduced by 78%	**Lower NPT**
Gas Flaring	Baseline	−14%	**Reduction**

These results demonstrate the significant operational impact of deploying a fully integrated digital twin system in mature oil fields.

VI. CONCLUSION

This study presents a comprehensive **Digital Twin–Driven Smart Field Optimization Framework** designed to enhance the performance of mature oil and gas assets. By integrating real-time sensor data, physics-based reservoir and wellbore models, machine learning prediction engines, and advanced optimization algorithms, the framework enables continuous and automated decision-making across subsurface, wellbore, and surface domains.

The application of the digital twin to a representative Middle Eastern mature field produced clear operational benefits, including:

- **11.9% increase in total oil production**
- **15.4% reduction in water cut**
- **9.3% improvement in ESP uptime**
- **8–12% reduction in energy usage per ESP**
- **14% decrease in gas flaring and overall emissions**
- **78% reduction in unplanned shutdowns**
- **92% accuracy in ESP failure prediction**

These results reaffirm the transformative potential of digital twin technology for optimizing brownfield operations, extending field life, and enabling data-driven decision-making aligned with digital transformation initiatives such as **Saudi Arabia's Vision 2030**.

The study also demonstrates that a hybrid digital twin approach—combining data-driven and physics-based models—provides significantly higher accuracy and robustness than either approach alone. This allows operators to detect performance anomalies early, forecast well behavior more reliably, and optimize production at both well and field levels.

VII. LIMITATIONS

While promising, the proposed digital twin framework is subject to several limitations:

1. Data Quality Dependence: Poor-quality or missing SCADA data can compromise prediction accuracy.
2. Model Calibration Sensitivity: Reservoir and ESP models require periodic recalibration for best performance.
3. Computational Requirements: Real-time optimization may demand high-performance computing resources.
4. Integration Complexity: Full integration with legacy SCADA or DCS systems may require custom engineering.
5. Operational Adoption: Introducing new workflows can require training and organizational alignment.

Addressing these limitations will be essential for large-scale rollouts across diverse field environments

VIII. FUTURE WORK

Several enhancements are recommended for future development:

8.1 Real-Time Autonomous Control

Integration of closed-loop control for fully automated choke management and ESP frequency modulation.

8.2 Integration with Geomechanics

Coupling with geomechanically models to improve prediction of sand production and well integrity risks.

8.3 Multi-Field Optimization

Extending digital twin systems to optimize clusters of fields sharing common facilities.

8.4 Drone and Robotics Integration

Use of remote inspection robots and drones for physical asset monitoring.

8.5 CO_2 Emissions and Energy Optimization

Embedding carbon footprint forecasting and energy optimization into the twin.

8.6 Advanced Physics-Based Modelling

Inclusion of 3D reservoir simulation proxies to enhance subsurface accuracy.

These improvements will further strengthen the digital twin's role as a cornerstone of future smart oilfield architectures.

IX. CONFLICT OF INTEREST

The author declares **no conflict of interest** regarding this study.

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