Enhancing Power System Resilience Through Smart Grid Technologies: A Geopolitical–Power System Resilience (GPSR) Framework for Energy Security

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How to Cite this Article:

ShashankSultaniya, & Mehta, P. K. (2026). Enhancing Power System Resilience Through Smart Grid Technologies: A Geopolitical–Power System Resilience (GPSR) Framework for Energy Security. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(7). https://doi.org/10.55041/ijcope.v2i7.002

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https://doi.org/10.55041/ijcope.v2i7.002

Abstract—The growing interdependence between global energy markets and electricity infrastructures has increased the vulnerability of power systems to geopolitical disruptions. The 2026 Iran energy crisis demonstrated how fuel supply uncertainty, energy market volatility, and disruptions in critical energy transportation routes can adversely affect electricity generation, operational reliability, and long-term energy security. Power systems with high dependence on imported fossil fuels are particularly exposed to such disturbances, resulting in increased generation costs, reduced operational flexibility, and heightened risks to grid stability. Consequently, enhancing power system resilience has become a strategic priority for utilities, policymakers, and researchers worldwide.

Although previous studies have extensively investigated energy security, smart grid technologies, and power system resilience, these domains are often examined independently, with limited attention given to the integrated influence of geopolitical risks on electricity network resilience. To address this research gap, this paper proposes a novel Geopolitical–Power System Resilience (GPSR) Framework that establishes a systematic relationship between geopolitical risk factors, power system vulnerabilities, smart-grid-based mitigation strategies, and resilience outcomes. The proposed framework consists of four interconnected layers: the Geopolitical Risk Layer, Power System Vulnerability Layer, Smart Grid Mitigation Layer, and Resilience Outcomes Layer.

A qualitative assessment of the 2026 Iran energy crisis is conducted to identify critical challenges affecting modern electricity systems and to evaluate the effectiveness of resilience-enhancing technologies, including demand response, battery energy storage systems, distributed energy resources, microgrids, and advanced metering infrastructure. The analysis indicates that smart-grid-enabled power systems can significantly improve operational flexibility, accelerate system recovery, and reduce the adverse impacts of geopolitical energy disruptions. The proposed GPSR framework provides a practical roadmap for integrating geopolitical risk considerations into future power system planning and smart grid development, thereby supporting the transition toward more secure, adaptive, and resilient electricity infrastructures.

Keywords— Power System Resilience, Smart Grid, Energy Security, Geopolitical Risk, Microgrid, Energy Storage.

I. INTRODUCTION

A. Background

The modern electricity sector operates within a highly interconnected global energy ecosystem where geopolitical developments can significantly influence energy availability, fuel prices, and power system operations. In recent years, geopolitical conflicts have emerged as a major source of uncertainty for energy markets, exposing vulnerabilities in national electricity infrastructures and highlighting the strategic importance of energy security. Disruptions in oil and natural gas supply chains, sanctions, trade restrictions, and transportation bottlenecks can create cascading effects across power systems, particularly in countries that rely heavily on imported fuels for electricity generation [1], [2].

The 2026 Iran energy crisis has renewed concerns regarding the resilience of electricity networks against geopolitical shocks. The crisis intensified market uncertainty in global oil and natural gas sectors, leading to fluctuations in fuel prices and increased operational risks for power utilities. Since fossil fuels continue to play a substantial role in electricity generation worldwide, any disruption in fuel supply can directly affect generation scheduling, operating costs, reserve margins, and grid reliability [3]. These challenges have emphasized the need for power systems that can maintain reliable operation under uncertain and rapidly changing energy conditions.

Simultaneously, the growing dependence of many nations on imported energy resources has increased their exposure to external geopolitical events. Countries with limited domestic energy resources often face elevated risks associated with fuel supply interruptions, price volatility, and energy market instability. As a result, traditional centralized power systems are becoming increasingly vulnerable to external disturbances that originate beyond national borders [4].

In this context, power system resilience has gained considerable attention among researchers, utilities, and policymakers. Unlike conventional reliability approaches that focus primarily on preventing failures, resilience emphasizes the ability of a power system to anticipate, absorb, adapt to, and recover from disruptive events. Emerging smart grid technologies, including demand response, battery energy storage systems, distributed energy resources, microgrids, and advanced metering infrastructure, offer promising solutions for enhancing system flexibility and reducing dependence on vulnerable fuel supply chains [5], [6].

B. Problem Statement

Despite significant advancements in smart grid technologies and power system modernization, many electricity networks remain highly dependent on imported fossil fuels and centralized generation resources. Existing resilience studies primarily focus on natural disasters, cyberattacks, or technical failures, while the impact of geopolitical risks on power system resilience remains insufficiently explored. Consequently, there is a need for an integrated framework capable of linking geopolitical risk factors with power system vulnerabilities and smart-grid-enabled resilience strategies.

C. Research Objectives

The primary objectives of this study are as follows:

RO1: To analyze the impact of geopolitical conflicts on power system operations and energy security.

RO2: To identify key resilience challenges exposed by the 2026 Iran energy crisis.

RO3: To develop a Geopolitical–Power System Resilience (GPSR) Framework that integrates geopolitical risks, power system vulnerabilities, and smart grid mitigation strategies.

D. Contributions

This paper makes the following contributions:

Contribution 1: A systematic analysis of the 2026 Iran energy crisis from a power system and energy security perspective.

Contribution 2: A comparative assessment of historical energy crises to identify common resilience challenges and operational vulnerabilities.

Contribution 3: The proposal of a novel Geopolitical–Power System Resilience (GPSR) Framework that connects geopolitical risk indicators with smart-grid-based resilience enhancement mechanisms, providing a practical roadmap for future resilient power system planning.

II. LITERATURE REVIEW

A. Energy Security

Energy security has become a fundamental concern for modern economies due to the increasing interdependence between energy markets and critical infrastructure systems. The concept of energy security generally refers to the uninterrupted availability of energy resources at affordable prices while ensuring long-term sustainability and system stability [7]. Traditionally, energy security assessments have focused on fuel availability, supply diversity, affordability, and geopolitical stability. However, recent geopolitical events have demonstrated that energy security extends beyond fuel supply considerations and directly influences the reliability and resilience of electricity systems.

Global energy supply chains are particularly vulnerable to geopolitical disruptions because a significant portion of oil and natural gas resources is concentrated in politically sensitive regions. Supply interruptions, transportation constraints, sanctions, and trade restrictions can create substantial uncertainties in fuel markets, resulting in price volatility and operational challenges for electricity generation sectors [8]. Consequently, countries with high import dependency face elevated risks associated with external energy shocks.

B. Power System Resilience

The increasing complexity of modern power systems has shifted research attention from traditional reliability assessment toward resilience-oriented planning and operation. Reliability primarily focuses on the ability of a power system to provide continuous electricity service under normal operating conditions, whereas resilience emphasizes the capability to withstand, adapt to, and recover from high-impact disruptive events [9].

Recent studies have highlighted the importance of resilience in addressing a broad range of threats, including natural disasters, cyberattacks, equipment failures, and fuel supply disruptions. A resilient power system should not only minimize service interruptions but also restore critical operations within an acceptable recovery period [10]. Therefore, resilience has emerged as a strategic performance metric for future power system planning.

C. Smart Grid Technologies

Smart grid technologies are widely recognized as effective tools for enhancing power system resilience and operational flexibility. These technologies enable real-time monitoring, decentralized control, adaptive demand management, and improved integration of distributed energy resources.

Demand Response (DR) programs allow consumers to modify electricity consumption patterns in response to system conditions, thereby reducing peak demand and operational stress [11]. Similarly, Battery Energy Storage Systems (BESS**)** provide fast-response backup power and support grid stability during supply disruptions [12].

The integration of Distributed Energy Resources (DERs), including rooftop solar photovoltaic systems and small-scale renewable generators, reduces dependence on centralized generation and enhances local energy availability [13]. In addition, Microgrids can operate independently from the main grid during emergencies, thereby improving service continuity for critical loads. AI-based forecasting techniques have recently emerged as powerful tools for improving demand prediction, renewable generation forecasting, anomaly detection, and operational decision-making under uncertain conditions. These capabilities contribute significantly to power system resilience and adaptive grid management.[14].

Furthermore, Advanced Metering Infrastructure (AMI) facilitates real-time communication between utilities and consumers, enabling enhanced situational awareness and more effective demand-side management [15]. Collectively, these technologies contribute to the development of adaptive and resilient power systems capable of responding to external disturbances.

D. Research Gap

Existing literature has extensively investigated energy security, smart grid technologies, and power system resilience as separate research domains. Several studies have explored the relationship between energy security and geopolitical events, while others have focused on the technical benefits of smart grid technologies for improving system reliability and resilience. However, limited research has integrated geopolitical risk factors, power system vulnerabilities, and smart-grid-based mitigation strategies within a unified framework.

Furthermore, most resilience studies primarily address natural disasters, cyber threats, and technical failures, whereas the implications of geopolitical energy crises on electricity network resilience remain insufficiently examined. The 2026 Iran energy crisis provides a relevant case for understanding how fuel supply disruptions can influence power system performance and energy security. Therefore, there is a need for a comprehensive framework that systematically links geopolitical risks with resilience-enhancing smart grid solutions.

To address this gap, this paper proposes a novel Geopolitical–Power System Resilience (GPSR) Framework that integrates energy security considerations, power system vulnerabilities, and smart grid technologies into a unified resilience assessment approach.

TABLE I : COMPARATIVE ANALYSIS OF EXISTING STUDIES

Author	Year	Energy Security	Smart Grid	Geopolitical Risk	Power Resilience
Sovacool et al.	2020	✓	✗	✓	✗
Panteli and Mancarella	2015	✗	✗	✗	✓
Bompard et al.	2017	✓	✗	✓	✗
Fang et al.	2012	✗	✓	✗	✓
Olowu et al.	2018	✗	✓	✗	✓
Recent Smart Grid Studies	✗	✓	✗	✓	
Proposed GPSR Framework	✓	✓	✓	✓	

III. IMPACT OF THE 2026 IRAN ENERGY CRISIS ON POWER SYSTEMS

A. Energy Supply Disruption

The 2026 Iran energy crisis highlighted the vulnerability of modern power systems to geopolitical disturbances affecting global energy supply chains. Since oil and natural gas remain major fuels for electricity generation in many countries, uncertainties in fuel availability can significantly influence power system operations. Geopolitical tensions affecting critical energy-exporting regions often create concerns regarding the continuity of fuel supplies, transportation routes, and international energy trade [16].

One of the primary consequences of the crisis was the increased uncertainty surrounding oil supply availability. Market participants responded to potential supply disruptions by adjusting procurement strategies, resulting in fluctuations in fuel markets and increased operational uncertainty for power producers [17]. Countries with high dependence on imported fossil fuels were particularly exposed to these risks.

In addition, volatility in global liquefied natural gas (LNG) markets further increased concerns regarding fuel procurement and electricity generation planning. LNG-dependent power systems faced challenges related to fuel price instability and supply reliability, thereby increasing uncertainty in generation scheduling and long-term resource planning [18].

B. Electricity Sector Impacts

Fuel supply uncertainty directly affects electricity generation economics. As fuel prices increase, the operational cost of thermal power plants also rises, leading to higher electricity production costs and greater financial pressure on utilities [19]. In regions where fossil-fuel-based generation constitutes a significant portion of the energy mix, fuel price fluctuations can substantially influence wholesale electricity markets and utility expenditure.

The crisis also highlighted the limitations of conventional power systems that rely heavily on centralized generation resources. Rising fuel costs may force utilities to revise generation dispatch strategies, optimize reserve allocation, and increase reliance on alternative energy resources. Consequently, system operators face additional challenges in maintaining reliable and cost-effective grid operation under uncertain energy market conditions [20].

Furthermore, increased market volatility can affect investment decisions in generation infrastructure, energy storage systems, and grid modernization projects. These impacts emphasize the growing importance of operational flexibility and adaptive power system planning.

C. Emerging Power System Risks

The crisis exposed several emerging risks that are becoming increasingly relevant for modern electricity networks. One of the most significant challenges is the growing stress on power systems during periods of peak demand. Fuel supply uncertainty can reduce generation availability and limit the ability of utilities to respond effectively to demand fluctuations [21].

Another important concern is the potential reduction in reserve margins. Adequate reserve capacity is essential for maintaining system reliability during unexpected disturbances. However, prolonged fuel supply constraints may affect reserve availability and increase operational vulnerability [22].

Additionally, the crisis highlighted limitations in grid flexibility. Traditional power systems with limited integration of distributed energy resources, energy storage systems, and demand response programs may experience difficulties adapting to rapidly changing operating conditions. Consequently, improving flexibility has become a critical requirement for enhancing resilience against future geopolitical disruptions [23].

TABLE II: OBSERVED IMPACTS OF THE 2026 IRAN ENERGY CRISIS

Impact Area	Effect	Power-System Consequence
Fuel Supply	Supply uncertainty	Generation planning challenges
Fuel Price	Price escalation	Higher operating costs
LNG Market	Increased volatility	Dispatch uncertainty
Grid Flexibility	Reduced adaptability	Operational challenges
Reserve Margin	Potential reduction	Reliability concerns
Energy Security	Increased risk exposure	System vulnerability
Electricity Market	Cost fluctuations	Financial pressure on utilities
Generation Planning	Resource uncertainty	Reduced operational efficiency

IV. PROPOSED GEOPOLITICAL–POWER SYSTEM RESILIENCE (GPSR) FRAMEWORK

A. Framework Architecture

The literature review and impact assessment presented in the previous sections indicate that existing resilience studies primarily focus on technical failures, cyber threats, and extreme weather events, while the influence of geopolitical energy disruptions remains insufficiently addressed. To overcome this limitation, this paper proposes a novel Geopolitical–Power System Resilience (GPSR) Framework that systematically links geopolitical risks, power system vulnerabilities, smart-grid-based mitigation mechanisms, and resilience outcomes.

The proposed framework provides a structured methodology for understanding how external geopolitical disturbances propagate through energy supply chains and ultimately affect power system performance. Furthermore, the framework identifies smart grid technologies that can mitigate these impacts and enhance overall system resilience.

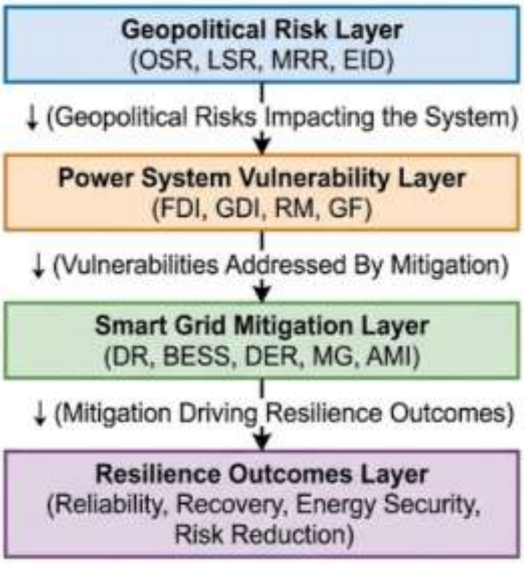

FIGURE 1. Proposed GPSR Framework

The framework assumes that geopolitical disturbances first influence energy markets and fuel supply chains. These disturbances subsequently increase vulnerabilities within electricity systems. Smart grid technologies act as resilience enablers that reduce vulnerability and improve system adaptability, resulting in enhanced reliability, faster recovery, and improved energy security.

B. Geopolitical Risk Layer

The first layer captures external geopolitical factors that may disrupt fuel availability, increase market uncertainty, and influence electricity generation planning.

(1) Oil Supply Risk (OSR): Oil Supply Risk represents the probability of disruptions in crude oil production, transportation, or international trade. Since oil remains an important energy resource in several regions, supply uncertainty can increase electricity generation costs and create operational challenges [24].

(2) LNG Supply Risk (LSR): LNG Supply Risk reflects exposure to disruptions in natural gas supply chains. Given the growing dependence on natural gas-based generation, fluctuations in LNG availability may significantly affect generation adequacy and electricity prices [25].

(3) Maritime Route Risk (MRR): Maritime Route Risk measures the vulnerability of energy transportation corridors. Disruptions in strategic shipping routes can delay fuel deliveries and increase energy market volatility.

(4) Energy Import Dependency (EID): Energy Import Dependency quantifies the extent to which a country relies on imported fuels for electricity generation. Higher dependency generally increases exposure to geopolitical disturbances and supply shocks [26].

C. Power System Vulnerability Layer

The second layer translates geopolitical disturbances into measurable power system vulnerabilities.

(1) Fuel Dependency Index (FDI): FDI measures the proportion of electricity generation dependent on imported fossil fuels. Systems with higher FDI values are more vulnerable to fuel supply disruptions.

(2) Generation Diversity Index (GDI): GDI evaluates the diversity of electricity generation resources. A diversified generation portfolio generally improves resilience by reducing dependence on a single energy source [27].

(3) Reserve Margin (RM): Reserve Margin represents the availability of backup generation capacity beyond expected demand levels. Adequate reserves improve the ability of the system to withstand supply uncertainties.

(4) Grid Flexibility (GF): Grid Flexibility reflects the capability of a power system to respond to rapid changes in generation and demand. Flexible systems are better equipped to accommodate disruptions and maintain reliable operation [28].

D. Smart Grid Mitigation Layer

The third layer consists of technologies capable of mitigating the impacts of geopolitical energy disruptions and enhancing operational resilience.

(1) Demand Response (DR): Demand Response programs enable consumers to modify electricity consumption patterns during critical periods, reducing peak demand stress and improving operational flexibility [29].

(2) Battery Energy Storage Systems (BESS): Battery Energy Storage Systems provide fast-response energy support, frequency regulation, peak shaving, and backup power during disturbances. Their ability to respond rapidly makes them a critical resilience-enhancing technology [30].

(3) Distributed Energy Resources (DERs): DERs, including rooftop solar photovoltaic systems and distributed renewable generation, improve local energy availability and reduce dependence on centralized generation infrastructure [31].

(4) Microgrids (MG): Microgrids can operate independently from the main grid during emergencies, ensuring continuous electricity supply to critical facilities and enhancing local resilience [32].

Advanced Metering Infrastructure (AMI)

AMI facilitates real-time monitoring, communication, and demand-side management, enabling more efficient and adaptive grid operation [33].

E. Resilience Outcomes

Implementation of the proposed smart grid technologies is expected to generate several resilience benefits.

(1) Improved Reliability : Enhanced operational flexibility and diversified energy resources reduce the likelihood of service interruptions.

(2) Faster Recovery: Smart grid technologies improve situational awareness and restoration capabilities, reducing recovery time following disturbances.

(3) Enhanced Energy Security: Increased utilization of local energy resources reduces dependence on vulnerable fuel supply chains and strengthens energy security [34].

(4) Reduced Operational Risk: Improved flexibility and distributed resource integration reduce operational uncertainty associated with geopolitical energy disruptions.

F. Proposed GPSRI Conceptual Index

To facilitate future quantitative implementation, a conceptual **Geopolitical–Power System Resilience Index (GPSRI)**is proposed. The index provides a foundation for assessing the resilience of power systems against geopolitical energy disruptions.

The conceptual GPSRI can be represented as:

$$GPSRI = (\Sigma W_i M_i) / (\Sigma W_j V_j)$$

where:

M_i = Smart-grid mitigation indicators
(DR, BESS, DER, MG, and AMI)

V_j = Geopolitical and vulnerability indicators
(OSR, LSR, MRR, EID, and FDI)

W_i and W_j represent weighting coefficients assigned to each indicator.

A higher GPSRI value indicates greater resilience against geopolitical energy disruptions. Although the present study focuses on conceptual framework development, future research may determine optimal weighting factors using multi-criteria decision-making approaches such as Analytic Hierarchy Process (AHP), Fuzzy-AHP, TOPSIS, and expert evaluation techniques [35].

TABLE III : PROPOSED GPSRI INDICATOR WEIGHT MATRIX

Indicator	Symbol	Proposed Weight
Oil Supply Risk	OSR	0.15
LNG Supply Risk	LSR	0.10
Maritime Route Risk	MRR	0.10
Energy Import Dependency	EID	0.15
Fuel Dependency Index	FDI	0.15
Grid Flexibility	GF	0.15
BESS Penetration	BESS	0.10
Microgrid Deployment	MG	0.10

The proposed weights are conceptual and intended to demonstrate the applicability of the GPSRI methodology. Future studies may refine these weights using empirical datasets, expert judgment, and advanced decision-making methodologies.

G. Novelty of the Proposed Framework

The proposed GPSR framework contributes to the literature in three important ways.

First, it explicitly incorporates geopolitical risk indicators into power system resilience assessment, an area that remains relatively underexplored in existing studies.

Second, it establishes a direct linkage between energy security challenges and smart-grid-based mitigation strategies, thereby connecting policy-level concerns with technical resilience solutions.

Third, the introduction of the GPSRI concept provides a foundation for future quantitative resilience assessment and benchmarking of power systems under geopolitical uncertainty.

Consequently, the proposed framework offers a comprehensive roadmap for integrating geopolitical risk considerations into future power system planning, smart grid deployment, and energy security strategies.

V. COMPARATIVE EVALUATION OF SMART GRID SOLUTIONS

The increasing frequency of geopolitical energy disruptions has highlighted the importance of smart grid technologies in enhancing power system resilience. However, different technologies provide varying levels of resilience benefits, implementation complexity, response speed, and investment requirements. Therefore, a comparative assessment is conducted to evaluate the effectiveness of major smart grid solutions under conditions of fuel supply uncertainty and energy market volatility.

TABLE IV :COMPARISON OF SMART GRID TECHNOLOGIES FOR RESILIENCE ENHANCEMENT

Technology	Implementation Cost	Response Speed	Resilience Benefit
Demand Response (DR)	Low	Fast	Medium
Battery Energy Storage Systems (BESS)	High	Very Fast	Very High
Microgrids (MG)	Medium–High	Fast	Very High
Distributed Energy Resources (DERs)	Medium	Medium	High
Advanced Metering Infrastructure (AMI)	Low	Fast	Medium
AI-Based Forecasting	Medium	Very Fast	High

The comparative analysis indicates that Battery Energy Storage Systems (BESS) and Microgrids provide the highest resilience benefits among the evaluated technologies. Battery storage systems offer rapid response capability, enabling frequency regulation, peak shaving, emergency backup support, and enhanced operational flexibility during supply disruptions. Similarly, microgrids can operate in islanded mode during major disturbances and maintain electricity supply to critical loads, thereby significantly improving system survivability.

Distributed Energy Resources (DERs) also contribute substantially to resilience by reducing dependence on centralized generation and enhancing local energy availability. The integration of distributed renewable generation can improve energy security while simultaneously reducing exposure to fuel price volatility.

Demand Response (DR) and Advanced Metering Infrastructure (AMI) are identified as the most cost-effective solutions. These technologies require comparatively lower capital investment and can be deployed rapidly to improve operational flexibility and demand-side participation. Demand response programs enable utilities to reduce peak demand stress during fuel supply shortages, while AMI provides the communication infrastructure necessary for real-time monitoring and intelligent energy management.

AI-based forecasting technologies have emerged as an important resilience-supporting tool. Accurate forecasting of electricity demand, renewable generation, and energy market conditions can improve resource scheduling and operational decision-making during uncertain geopolitical conditions.

Discussion

The results suggest that no single technology can independently address all resilience challenges associated with geopolitical energy disruptions. Instead, a coordinated deployment strategy combining multiple technologies is required.

For utilities with limited investment capacity, Demand Response and AMI represent the most economically attractive options due to their relatively low implementation costs and immediate operational benefits. Conversely, utilities seeking maximum resilience enhancement should prioritize Battery Energy Storage Systems and Microgrids because of their superior capability to maintain power supply during severe energy disruptions.

Based on the proposed GPSR framework, an integrated combination of BESS, Microgrids, DERs, and Demand Response is expected to provide the highest resilience improvement against future geopolitical energy crises. Such a multi-layered approach enhances system flexibility, reduces dependence on imported fuels, improves recovery capability, and strengthens overall energy security.

VI. POLICY IMPLICATIONS AND FUTURE DIRECTIONS

The findings of this study highlight the growing need to incorporate geopolitical risk considerations into power system planning and energy policy development. As electricity systems become increasingly interconnected with global energy markets, governments, utilities, and researchers must adopt proactive strategies to enhance resilience against future energy disruptions.

A. Policy Implications for Governments

Governments should prioritize energy diversification strategies to reduce dependence on a limited number of fuel sources and supply routes. A diversified energy portfolio consisting of renewable energy, domestic generation resources, and distributed energy systems can significantly reduce vulnerability to geopolitical shocks [31]. In addition, the development and maintenance of strategic energy reserves can provide temporary protection against fuel supply interruptions and market volatility during crisis situations [32].

Accelerating the deployment of renewable energy technologies is another critical policy objective. Increased penetration of solar, wind, and other renewable resources can reduce reliance on imported fossil fuels while improving long-term energy security and environmental sustainability [33].

B. Implications for Utilities

Electric utilities should increase investment in smart grid infrastructure to improve operational flexibility and adaptive response capabilities. Technologies such as advanced metering infrastructure, demand response systems, and distributed energy resource management systems can support more resilient grid operation under uncertain energy market conditions [34].

Utilities should also prioritize the integration of battery energy storage systems and microgrids. These technologies provide operational flexibility, enhance backup power capability, and improve system recovery following major disruptions [35]. The combined deployment of storage systems and distributed generation can significantly strengthen grid resilience against future geopolitical energy disturbances.

C. Future Research Directions

Although the proposed GPSR framework provides a conceptual foundation for resilience assessment, future studies should focus on developing a Quantitative Geopolitical–Power System Resilience Index (GPSRI) capable of measuring resilience performance using real-world operational data. Multi-criteria decision-making techniques, fuzzy logic methods, and optimization approaches may be employed to determine appropriate weighting factors for resilience indicators [36].

Furthermore, the integration of Artificial Intelligence (AI) and machine learning techniques presents significant opportunities for future resilience assessment. AI-based forecasting models can improve demand prediction, renewable generation forecasting, anomaly detection, and operational decision-making under uncertain geopolitical conditions [37]. Such approaches can support the development of adaptive and self-healing power systems capable of responding effectively to future energy security challenges.

Overall, strengthening energy diversification, expanding smart-grid deployment, and advancing quantitative resilience assessment methodologies will be essential for building secure and resilient power systems in an increasingly uncertain geopolitical environment.

VII. CONCLUSION

The increasing occurrence of geopolitical conflicts has highlighted the growing interdependence between global energy markets and electricity infrastructures. The 2026 Iran energy crisis demonstrated that disruptions in fuel supply chains can significantly influence electricity generation, operational flexibility, energy security, and overall power system performance. As modern power systems continue to rely on imported fossil fuels, geopolitical disturbances are becoming an increasingly important source of operational risk that must be incorporated into resilience planning and decision-making processes.

This study examined the implications of geopolitical energy disruptions from a power system perspective and proposed a novel Geopolitical–Power System Resilience (GPSR) Framework for enhancing resilience through smart-grid-based solutions. The framework establishes a systematic relationship between geopolitical risk factors, power system vulnerabilities, smart grid mitigation technologies, and resilience outcomes.

Several key findings emerged from this research. First, geopolitical conflicts can directly affect electricity security by creating uncertainty in fuel availability, increasing energy market volatility, and disrupting electricity generation planning. Second, high dependence on imported fossil fuels increases the vulnerability of power systems to external shocks and supply disruptions. Third, smart grid technologies, including demand response, battery energy storage systems, distributed energy resources, advanced metering infrastructure, and microgrids, play a significant role in improving system adaptability and operational flexibility. Fourth, among the evaluated technologies, microgrids and battery energy storage systems demonstrated the strongest potential for mitigating the impacts of geopolitical energy disruptions due to their ability to support local energy autonomy and rapid system recovery.

The proposed GPSR framework contributes to the existing literature by integrating energy security, geopolitical risk assessment, and smart grid resilience within a unified conceptual model. The framework provides a practical roadmap for utilities, policymakers, and researchers seeking to develop resilient and adaptive power systems capable of withstanding future geopolitical uncertainties. Future research may extend the framework through the development of a quantitative Geopolitical–Power System Resilience Index (GPSRI) and the incorporation of artificial intelligence-based resilience assessment techniques.

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