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INTERNATIONAL TINKER INNOVATION & ENTREPRENEURSHIP CHALLENGE (i-TIEC 2025)

"Fostering a Culture of Innovation and Entrepreneurial Excellence"



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23 January 2025
PTDI, UiTM Cawangan Johor
Kampus Pasir Gudang

ORGANIZED BY:

Electrical Engineering Studies, College of Engineering
Universiti Teknologi MARA (UiTM) Cawangan Johor
Kampus Pasir Gudang

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Editors

Aznilinda Zainuddin
Maisarah Noorezam

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A-ST059: REVOLUTIONIZING POWER RESILIENCE: INNOVATIVE OPTIMIZATION FOR DISTRIBUTED GENERATION INTEGRATION

Fathiah Zakaria, Ismail Musirin, Norziana Aminudin, and Dalina Johari
Centre for Electrical Engineering Studies, Universiti Teknologi MARA, Shah Alam,
Selangor, Malaysia

Corresponding author: Ismail Musirin, ismailbm@uitm.edu.my

ABSTRACT

Ensuring resilience in power systems against extreme events such as hurricanes is a critical challenge in modern grid management. This study introduces an innovative optimization framework for Distributed Generation (DG) integration, utilizing Evolutionary Programming (EP) and Artificial Immune System (AIS) techniques to enhance power system performance. These methods determine the optimal placement and sizing of DG units to minimize power losses and bolster system resilience. The framework was validated on the IEEE 30-Bus Reliability Test System (RTS), simulating hurricane-induced disruptions. Results demonstrated significant reductions in power losses and notable improvements in resilience indices across various scenarios, with AIS outperforming EP in most cases. The study also highlighted the ability of DG to mitigate the impact of line outages and maintain system stability under varying reactive power loads. Key advantages of this approach include precise optimization, adaptability to extreme events, and scalability for larger networks. Socio-economically, the framework supports energy security and promotes sustainability through efficient DG integration, reducing reliance on centralized power sources. With its robustness and commercialization potential, this innovation offers utility providers a cost-effective solution for grid modernization and resilience enhancement, addressing the growing demand for reliable and sustainable energy systems in a dynamic environment.

Keywords: Distributed Generation (DG), Power System Resilience, Optimization Techniques, Loss Minimization

1. Product Description

The proposed solution is an innovative optimization framework for Distributed Generation (DG) integration designed to enhance power system resilience against disruptive events, such as hurricanes. Utilizing advanced Evolutionary Programming (EP) and Artificial Immune System (AIS) techniques, the framework identifies optimal placement and sizing of DG units, significantly minimizing power losses and improving grid stability. Its adaptability to varying load conditions and extreme scenarios makes it highly effective for modern power systems. The framework's unique features include its ability to handle complex optimization problems, precise DG placement, and seamless scalability for larger networks. The AIS optimization outperforms traditional techniques, demonstrating superior accuracy and efficiency in achieving resilience improvements. Its integration of DG as a compensating device ensures sustained power delivery even during system disruptions. This innovation has significant socio-economic and environmental benefits, including enhanced energy security, reduced greenhouse gas emissions, and better utilization of renewable energy

sources. By decentralizing energy production, it supports a sustainable transition to resilient and reliable power grids, ensuring uninterrupted services for critical sectors. With strong commercialization prospects, the framework offers utility providers a cost-effective, scalable solution to modernize grid infrastructure and address growing energy demands, aligning with global goals for sustainable and resilient energy systems.

2. Method Flow Chart and Model Description

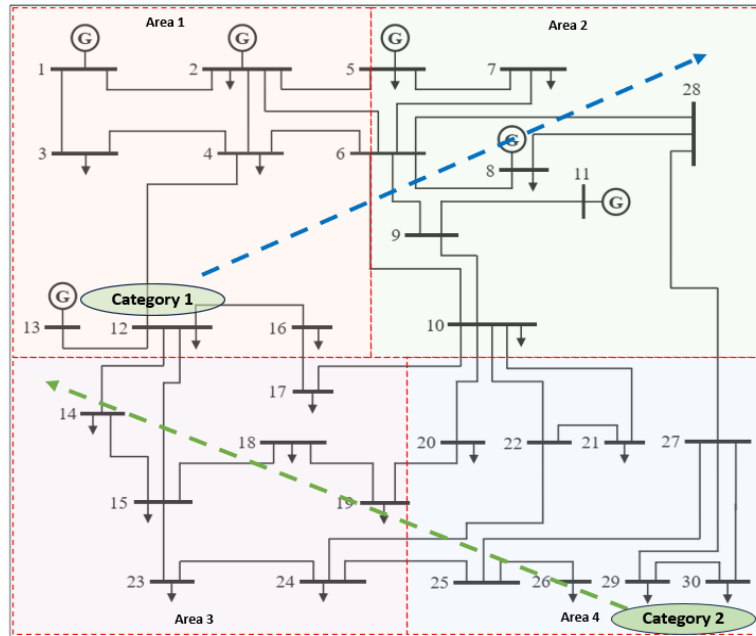


Figure 1. Hurricane Impact Zones and Patterns on the IEEE 30-Bus RTS

The study examines the impact of DG placement on resilience and power loss in the IEEE 30-Bus RTS under hurricane-induced disruptions. The system, divided into four regions, simulates two scenarios with failure probabilities derived from fragility curves based on hurricane wind speeds, causing outages in specific buses.

Table 1. Area and Buses

<i>Area</i>	<i>Buses</i>
1	1,2,3,4,13,12,16,6,5
2	5,6,7,8,9,10,11,28
3	14,15,17,18,19,23,24
4	20,21,22,25,26,27,29,30

Table 2. Line Outages of IEEE 30-Bus RTS

<i>Scenarios</i>	<i>Wind Categories</i>	<i>Affected Area</i>	<i>Failure Probability</i>	<i>Bus Number Experienced Outage</i>
1	1 (74-95 mph)	1 & 2	0.23	2, 4, 13, 16
2	2 (96-110 mph)	3 & 4	0.48	14, 17, 19, 24, 21, 25, 27

Power loss was analyzed under four conditions: pre-disruption (Loss_Set), post-disruption (Loss_ Outage), and with DG placement optimized using EP and AIS techniques. DG installation significantly reduced power losses and improved resilience indices (R1 to R2). For instance, in Scenario 1, the AIS technique enhanced resilience at Bus 26 from $R1 = 0.16$ to $R2 = 0.88$ for $Q_d = 10$ MVar, showed effective performance with optimal DG sizing and placement.

The analysis highlights the ability of DG to reduce power losses and enhance system resilience under disruptive events. By optimizing DG placement and sizing, the study emphasizes the role of advanced methodologies in improving power system performance and stability during natural disasters.

3. Novelty and uniqueness

The proposed framework offers a novel comparative analysis of two advanced optimization techniques, Evolutionary Programming (EP) and Artificial Immune System (AIS), to enhance power system resilience through optimal Distributed Generation (DG) integration. Unlike conventional approaches, this study evaluates the unique strengths and effectiveness of these methods in addressing the challenges of precise DG placement and sizing under disruptive conditions, such as hurricanes. The AIS method stands out with its inspiration from the biological immune system, providing superior accuracy and faster convergence compared to EP, especially in complex optimization scenarios. EP, on the other hand, showcases robust capabilities in solving global optimization problems. The comparative analysis highlights their respective performance in minimizing power losses and improving resilience indices. A key novelty lies in the framework's focus on resilience metrics, quantifying improvements in system stability and power reliability. By employing DG as a compensating device, the study demonstrates significant enhancements in grid performance during extreme events. This approach provides insights into the applicability of each technique for varying operational scenarios, offering utility providers an evidence-based methodology to select the most effective optimization strategy for sustainable and resilient power systems.

4. Benefit to mankind

This optimization framework for Distributed Generation (DG) integration enhances power system resilience, ensuring reliable electricity supply during disruptive events such as hurricanes. By reducing power losses and improving grid stability, it supports critical

services like healthcare, communication, and emergency response, minimizing the socio-economic impact of power outages on communities.



Figure 2. Comparison of Loss Values of EP And AIS with Load Variation for Scenario 1(a) and Scenario 2(b).

Table 3. Overall results of dg placement, total loss and resilience for scenario 1.

BUS	Q_d	DG Location			DG Sizing (MW)			Loss	R1	R2
	(MVar)	DG ₁	DG ₂	DG ₃	DG ₁	DG ₂	DG ₃			
SCENARIO 1										
EP										
26	10	17		20	41.60	70.12	91.03	8.78	0.17	0.93
	20	17	5	20	41.60	70.12	91.03	10.81	0.19	1.14
	25	17	5	20	41.60	70.12	91.03	12.84	0.22	1.36
29	10	17	5	20	41.60	70.12	91.03	8.66	0.17	0.92
	20	17	5	20	41.60	70.12	91.03	9.92	0.18	1.05
	25	17	5	20	41.60	70.12	91.03	11.06	0.20	1.17
30	10	17	5	20	41.60	70.12	91.03	8.65	0.17	0.91
	20	17	5	20	41.60	70.12	91.03	10.08	0.18	1.06
	25	17	5	20	41.60	70.12	91.03	11.46	0.20	1.21
AIS										
26	10	19	5	16	77.02	82.78	12.54	8.52	0.16	0.88
	20	19	5	16	77.02	82.78	12.54	10.52	0.19	1.08
	25	19	5	16	77.02	82.78	12.54	10.82	0.18	0.94
29	10	19	5	16	77.02	82.78	12.54	8.40	0.16	0.87
	20	19	5	16	77.02	82.78	12.54	9.64	0.17	0.99
	25	19	5	16	77.02	82.78	12.54	10.77	0.19	1.10
30	10	19	5	16	77.02	82.78	12.54	8.40	0.16	0.86
	20	19	5	16	77.02	82.78	12.54	9.80	0.18	1.01
	25	19	5	16	77.02	82.78	12.54	11.16	0.20	1.14

The framework promotes the integration of renewable energy sources, such as solar and wind, reducing reliance on fossil fuels and decreasing greenhouse gas emissions. This contributes to a cleaner environment and aligns with global sustainability goals, supporting efforts to combat climate change. Its ability to optimize DG placement and sizing ensures efficient energy use and enhances the reliability of modern power grids. Scalable and cost-effective, the framework enables utility providers to meet growing energy demands while safeguarding essential infrastructure, benefiting both urban and rural populations by ensuring energy security and sustainability for future generations.

5. Innovation and Entrepreneurial Impact

The optimization framework for Distributed Generation (DG) integration represents a significant innovation in power system resilience enhancement. By leveraging advanced computational techniques, Evolutionary Programming (EP) and Artificial Immune System (AIS), the framework addresses critical challenges in DG placement and sizing, ensuring efficient energy use and enhanced grid stability during extreme events. Its adaptability to dynamic conditions and focus on resilience metrics set it apart, enabling utility providers to modernize grids cost-effectively while integrating renewable energy sources. The framework's ability to reduce power losses and improve system reliability creates value for both energy providers and consumers, supporting a transition toward sustainable energy solutions. From an entrepreneurial perspective, this innovation opens avenues for commercialization as a scalable, data-driven tool for grid management. It empowers energy stakeholders to adopt advanced optimization strategies, positioning them competitively in the growing market for resilient, smart energy systems, and fostering economic growth and sustainability.

6. Potential commercialization

The optimization framework for Distributed Generation (DG) integration offers substantial commercialization potential in the energy sector. With a focus on scalability and adaptability, this framework provides utility providers with an innovative tool to enhance power grid resilience and operational efficiency during disruptive events. Its ability to optimize DG placement and sizing ensures minimized power losses, improved grid stability, and seamless integration of renewable energy sources. This solution is particularly appealing to energy providers looking to modernize infrastructure while addressing the growing need for sustainable and reliable electricity. It is especially valuable in regions vulnerable to extreme weather events, providing a cost-effective method to reduce outages and sustain critical services. Compatible with diverse network sizes and conditions, the framework supports widespread deployment in both urban and rural areas. Notably, the algorithm employed in this innovation has been granted a copyright certificate by MyIPO and has also been published in SCOPUS-indexed platforms, highlighting its credibility and readiness for commercialization. This positions it as a competitive product in the global energy market, driving innovation and supporting the transition toward smarter, more resilient energy systems.

7. Authors' Biography



Fathiah Zakaria received her Bachelor's degree (Hons) in Electrical & Electronics Engineering from Universiti Teknologi Petronas (UTP) in 2008 and her MSc in Electrical Engineering from Universiti Teknologi MARA (UiTM) in 2014. She is currently pursuing a PhD in Electrical Engineering, specializing in power system, at UiTM Shah Alam, Malaysia. Since 2014, she has been a lecturer at UiTM. Her research interests include artificial intelligence, optimization, and power system.



Prof. Ir. Dr. Ismail Bin Musirin obtained Bachelor of Electrical Engineering (Hons) in 1990 from Universiti Teknologi Malaysia, MSc in Pulsed Power Technology in 1992 from University of Strathclyde, United Kingdom and PhD in Electrical Engineering from Universiti Teknologi MARA (UiTM), Malaysia in 2005. He is currently a Professor of Power System at the School of Electrical Engineering (formerly known as the Faculty of Electrical Engineering), College of Engineering, UiTM and headed the Power System Operation (POSC) Computational Intelligence Research Group. His research interest includes Power System Stability, Distributed Generation Optimization, Artificial Intelligence Applications, Optimization Algorithms Derivations and Machine Learning Applications.



Dr. Norziana Aminudin is a Senior Lecturer at Universiti Teknologi MARA (UiTM) Shah Alam and an active member of the Power System Operation Computational Intelligence Research Group at UiTM. Her research focuses on artificial intelligence, with expertise in optimization techniques, machine learning, and risk assessment in power systems. Since 2007, she has contributed extensively to the field through numerous journal publications and conference papers, advancing innovative solutions for modern power system challenges.



D. Johari     received her PhD degree in Engineering Sciences with Specialization in Atmospheric Discharges from Uppsala University, Sweden in 2017. She obtained her MSc degree in Electrical Engineering from Universiti Teknologi MARA (UiTM), Malaysia in 2008 and B.Eng. in Electrical Engineering (Hons) from the University of Liverpool, UK in 1999. She worked as an operation & maintenance engineer from 2000 to 2003 and continued as a senior planning engineer until 2005. D. Johari now serves as a senior lecturer at UiTM, Shah Alam, Malaysia. She is also a graduate member of the Board of Engineers Malaysia (BEM). Her research interests includes lightning physics, lightning protection, lightning prediction, high voltage engineering, power system and artificial intelligence. She be contacted at dalinaj@uitm.edu.my.