**Initial Post**

Industry 4.0, defined by digitalization, automation, and cyber-physical system integration, has transformed the design, operation, and management of power and energy systems. Technologies such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and blockchain enable smart grids capable of coordinating distributed energy resources (DERs), renewable generation, and demand-side assets with greater efficiency (Makala & Bakovic, 2020; Liberati et al., 2021). Real-time monitoring, predictive maintenance, and digital twins enhance reliability, extend asset lifecycles, and lower operational costs (Fuller et al., 2020). Advanced forecasting and intelligent load management further support the integration of variable renewables, strengthening system stability (Hasan et al., 2025). Additionally, blockchain-based peer-to-peer (P2P) trading platforms are reshaping electricity markets by empowering prosumers and enhancing transparency (Aghahadi et al., 2024). Collectively, these technologies drive the decentralization, digitalization, and decarbonization of modern grids.

Building on these foundations, Industry 5.0 emphasizes human-centricity, sustainability, and resilience. While Industry 4.0 prioritized efficiency and automation, Industry 5.0 seeks to align advanced technologies with human intelligence and societal values (Ghobakhloo et al., 2023; Skėrė et al., 2025). In power systems, this shift strengthens clean energy transitions, decarbonization, and resilience against climate and cyber risks (IEA, 2021; Lopez et al., 2025). Human–machine collaboration, AI, and quantum technologies will enable adaptive, secure, and optimized operations (Alam et al., 2025; Hallo et al., 2025).

Together, Industry 4.0 and 5.0 are shaping smarter, greener, and more resilient infrastructures, ensuring greater renewable integration, consumer participation, and sustainability-driven innovation.

References

Aghahadi, M.; Bosisio, A.; Merlo, M.; Berizzi, A.; Pegoiani, A.; Forciniti, S. (2024). Digitalization Processes in Distribution Grids: A Comprehensive Review of Strategies and Challenges. Appl. Sci. 2024, 14, 4528. https://doi.org/10.3390/app14114528.

Alam, M.M., Hossain, M.J., Habib, M.A., Arafat, M.Y. & Hannan, M.A. (2025). Artificial intelligence integrated grid systems: Technologies, potential frameworks, challenges, and research directions, Renewable and Sustainable Energy Reviews, Volume 211, 115251, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2024.115251.

Fuller, A., Fan, Z., Day, C. & Barlow, C. (2020). Digital Twin: Enabling Technologies, Challenges and Open Research. IEEE Access, vol. 8, pp. 108952-108971. https://doi.org/10.1109/ACCESS.2020.2998358.

Ghobakhloo, M., Iranmanesh, M., Tseng, M. L., Grybauskas, A., Stefanini, A., & Amran, A. (2023). Behind the definition of Industry 5.0: a systematic review of technologies, principles, components, and values. Journal of Industrial and Production Engineering, 40(6), 432–447. https://doi.org/10.1080/21681015.2023.2216701.

Hallo, L., Hanzis, A., & Rowe, C. (2025). Humanity and AI: Collaborating for a Flourishing Planet Through Wise Decision-Making. Challenges, 16(1), 14. https://doi.org/10.3390/challe16010014.

Hasan, M., Mifta, Z., Papiya, S.J., Roy, P., Dey, P., Salsabil, N.A., Chowdhury, N. & Farrok, O. (2025). A state-of-the-art comparative review of load forecasting methods: Characteristics, perspectives, and applications, Energy Conversion and Management: X, Volume 26, 100922, ISSN 2590-1745, https://doi.org/10.1016/j.ecmx.2025.100922.

International Energy Agency (IEA). (2021). Net Zero by 2050 A Roadmap for the Global Energy Sector. Available on www. Iea.org/corrections.

Liberati, F., Garone, E., & Di Giorgio, A. (2021). Review of Cyber-Physical Attacks in Smart Grids: A System-Theoretic Perspective. Electronics, 10(10), 1153. https://doi.org/10.3390/electronics10101153.

Lopez, G., Pourjamal, Y. & Breyer, C. (2025). Paving the way towards a sustainable future or lagging behind? An ex-post analysis of the International Energy Agency's World Energy Outlook, Renewable and Sustainable Energy Reviews, Volume 212, 115371, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2025.115371.

Makala, B. & Bakovic, T. (2020). Artificial Intelligence in the Power Sector. International Finance Corporation (IFC), World Bank Group. https://doi.org/10.13140/RG.2.2.34011.18729.

Skėrė, S., Bastida-Molina, P., Skėrys, P., & Molina-Palomares, P. (2025). Empowering Industry 5.0: A Multicriteria Framework for Energy Sustainability in Industrial Companies. Applied Sciences, 15(16), 9170. https://doi.org/10.3390/app15169170.

**[Peer Response 1]**

The text effectively links Industry 5.0 principles — ethics, resilience, and human-centricity — to the aviation sector, using the 2024 CrowdStrike outage to illustrate systemic digital fragility. It succeeds in contextualizing Industry 5.0 as an evolution of Industry 4.0’s automation paradigm (Adel and Alani, 2024; Alves et al., 2023) and grounds abstract ideas through a relevant real-world example. However, the analysis remains largely descriptive, lacking a deeper theoretical framing of Industry 5.0 concepts such as cyber-physical systems, human-robot collaboration, and ethical AI governance (Xu et al., 2021). The discussion would be strengthened by applying a conceptual framework, such as Longo et al. (2020) human-centric resilience model, to link the case to actionable design or policy insights.

References

Adel, A., & HS Alani, N. (2024). Human-Centric Collaboration and Industry 5.0 Framework in Smart Cities and Communities: Fostering Sustainable Development Goals 3, 4, 9, and 11 in Society 5.0. Smart Cities, 7(4), 1723-1775. <https://doi.org/10.3390/smartcities7040068>.

Alves, J., Lima, T. M., & Gaspar, P. D. (2023). Is Industry 5.0 a Human-Centred Approach? A Systematic Review. Processes, 11(1), 193. <https://doi.org/10.3390/pr11010193>.

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0 — Inception, Conception and Perception. Journal of Manufacturing Systems, 61, 530-535. <https://doi.org/10.1016/j.jmsy.2021.10.006>.

Longo, F., Padovano, A., & Umbrello, S. (2020). Value-Oriented and Ethical Technology Engineering in Industry 5.0: A Human-Centric Perspective for the Design of the Factory of the Future. Applied Sciences, 10, Article 4182. <https://doi.org/10.3390/app10124182>.

**[Peer Response 2]**

This discussion effectively connects the principles of Industry 5.0— human-centeredness, resilience, and sustainability — to the airline industry’s IT vulnerabilities, using the 2017 British Airways (BA) system failure as a case study. The narrative appropriately highlights the economic,operational, and reputational consequences of the outage. However, the analysis remains descriptive and lacks the critical and theoretical depth expected in a discussion of Industry 5.0’s transformative implications.

Firstly, while the text cites Metcalf (2024) to frame Industry 5.0’s shift from automation to human-centric resilience, it does not explicitly explain *how* Industry 5.0 technologies — such as cyber-human systems, distributed intelligence, or ethical AI governance— could have mitigated such failures (Longo, Padovano & Umbrello, 2020; Xu et al., 2021). Secondly, the discussion could be enriched by addressing systemic resilience theory, which emphasizes redundancy, adaptability, and human oversight (Hollnagel, 2017). The critique of BA’s poor contingency planning would be more compelling if linked to socio-technical design principles inherent in Industry 5.0 (Nahavandi, 2019).

Finally, the references to data protection and probabilistic safety are tangential and not fully integrated into the argument. Overall, while relevant and well-motivated, the text requires stronger theoretical framing, analytical reasoning, and explicit linkage between Industry 5.0 ideals and practical resilience outcomes.

**References**

Metcalf, G.S. (2024). An Introduction to Industry 5.0: History, Foundations, and Futures. In: Nousala, S., Metcalf, G., Ing, D. (eds) Industry 4.0 to Industry 5.0. Translational Systems Sciences, vol 41. Springer, Singapore. <https://doi.org/10.1007/978-981-99-9730-5_1>.

Hollnagel, E. (2017). *Safety-II in Practice: Developing the Resilience Potentials*. Routledge.

Longo, F., Padovano, A., & Umbrello, S. (2020). Value-Oriented and Ethical Technology Engineering in Industry 5.0: A Human-Centric Perspective for the Design of the Factory of the Future. Applied Sciences, 10, Article 4182. <https://doi.org/10.3390/app10124182>.

Nahavandi, S. (2019). Industry 5.0 — A Human-Centric Solution. Sustainability, 11(16), 4371. <https://doi.org/10.3390/su11164371>.

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0 — Inception, Conception and Perception. Journal of Manufacturing Systems, 61, 530-535. <https://doi.org/10.1016/j.jmsy.2021.10.006>.

**Summary Post**

The text offers a thorough analysis of the technological and conceptual progression from Industry 4.0 to Industry 5.0, particularly in the realm of power and energy systems. Industry 4.0, characterised by digitalisation, automation, and cyber-physical system integration, has significantly transformed grid operations through technologies such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and blockchain (Makala & Bakovic, 2020; Liberati et al., 2021). These advancements enable smart grids to efficiently manage distributed energy resources and renewable generation, while tools like digital twins and predictive maintenance improve system reliability and reduce operational costs (Fuller et al., 2020; Hasan et al., 2025). Furthermore, blockchain-enabled peer-to-peer energy trading has decentralized electricity markets, increasing consumer empowerment (Aghahadi et al., 2024).

Building on these foundations, Industry 5.0 emphasizes human-centricity, sustainability, and resilience, aligning technological development with ethical and societal considerations (Ghobakhloo et al., 2023). It underscores the role of human–machine collaboration, ethical AI, and emerging quantum technologies in fostering adaptive, secure, and resilient energy systems (Alam et al., 2025; Hallo et al., 2025). This paradigm shift from automation-driven efficiency to human-centred resilience promotes decarbonization and climate adaptability (IEA, 2021; Lopez et al., 2025).

The discussion critically observes that while case studies, such as the 2017 British Airways IT outage and the 2024 CrowdStrike failure, effectively highlight digital vulnerabilities, they remain largely descriptive and lack deep theoretical grounding. Applying conceptual frameworks, such as Longo et al.’s (2020) human-centric resilience model and Hollnagel’s (2017) systemic resilience theory, would better connect Industry 5.0 principles to practical policy and design interventions. Overall, the text emphasizes Industry 5.0’s potential to create intelligent, sustainable, and ethically informed energy infrastructures while advocating for stronger analytical rigor linking technological innovation to human resilience.

References

Aghahadi, M.; Bosisio, A.; Merlo, M.; Berizzi, A.; Pegoiani, A.; Forciniti, S. (2024). Digitalization Processes in Distribution Grids: A Comprehensive Review of Strategies and Challenges. Appl. Sci. 2024, 14, 4528. <https://doi.org/10.3390/app14114528>.

Alam, M.M., Hossain, M.J., Habib, M.A., Arafat, M.Y. & Hannan, M.A. (2025). Artificial intelligence integrated grid systems: Technologies, potential frameworks, challenges, and research directions, Renewable and Sustainable Energy Reviews, Volume 211, 115251, ISSN 1364-0321, <https://doi.org/10.1016/j.rser.2024.115251>.

Fuller, A., Fan, Z., Day, C. & Barlow, C. (2020). Digital Twin: Enabling Technologies, Challenges and Open Research. IEEE Access, vol. 8, pp. 108952-108971. <https://doi.org/10.1109/ACCESS.2020.2998358>.

Ghobakhloo, M., Iranmanesh, M., Tseng, M. L., Grybauskas, A., Stefanini, A., & Amran, A. (2023). Behind the definition of Industry 5.0: a systematic review of technologies, principles, components, and values. Journal of Industrial and Production Engineering, 40(6), 432–447. <https://doi.org/10.1080/21681015.2023.2216701>.

Hallo, L., Hanzis, A., & Rowe, C. (2025). Humanity and AI: Collaborating for a Flourishing Planet Through Wise Decision-Making. Challenges, 16(1), 14. <https://doi.org/10.3390/challe16010014>.

Hasan, M., Mifta, Z., Papiya, S.J., Roy, P., Dey, P., Salsabil, N.A., Chowdhury, N. & Farrok, O. (2025). A state-of-the-art comparative review of load forecasting methods: Characteristics, perspectives, and applications, Energy Conversion and Management: X, Volume 26, 100922, ISSN 2590-1745, <https://doi.org/10.1016/j.ecmx.2025.100922>.

Hollnagel, E. (2017). Safety-II in Practice: Developing the Resilience Potentials. Routledge.

International Energy Agency (IEA). (2021). Net Zero by 2050 A Roadmap for the Global Energy Sector. Available on www. Iea.org/corrections.

Liberati, F., Garone, E., & Di Giorgio, A. (2021). Review of Cyber-Physical Attacks in Smart Grids: A System-Theoretic Perspective. Electronics, 10(10), 1153. <https://doi.org/10.3390/electronics10101153>.

Lopez, G., Pourjamal, Y. & Breyer, C. (2025). Paving the way towards a sustainable future or lagging behind? An ex-post analysis of the International Energy Agency's World Energy Outlook, Renewable and Sustainable Energy Reviews, Volume 212, 115371, ISSN 1364-0321, <https://doi.org/10.1016/j.rser.2025.115371>.

Longo, F., Padovano, A., & Umbrello, S. (2020). Value-Oriented and Ethical Technology Engineering in Industry 5.0: A Human-Centric Perspective for the Design of the Factory of the Future. Applied Sciences, 10, Article 4182. <https://doi.org/10.3390/app10124182>.

Makala, B. & Bakovic, T. (2020). Artificial Intelligence in the Power Sector. International Finance Corporation (IFC), World Bank Group. <https://doi.org/10.13140/RG.2.2.34011.18729>.