Integrating Scada in Future-Proof Engineering Education: A Conceptual Evaluation Anchored on Ched's Achieve Agenda

Sheila A. Fabian

REE, MSEE, College of Engineering, Department of Electrical Engineering, College of Engineering, Tarlac City, Tarlac State University, Philippines

Abstract

The proposed research conceptually judges the inclusion of the Supervisory Control and Data Acquisition (SCADA) systems in engineering education at Tarlac State University College of Engineering (TSU-COE) based on the Commission on Higher Education (CHED) ACHIEVE Agenda (2025-2030) and the TSU Future-Proof Education Plan (2025-2035). The study uses a mixed-methodology design, which combines a qualitative documentary analysis, engineering design review, and two descriptive surveys with 19 academic stakeholders and 22 professionals working with electric distribution utilities to examine the operational impact of SCADA on the reliability of the power system, as well as its strategic fit with existing higher education reform models. All the four pillars of the operation promoted by SCADA by utility practitioners included situational awareness and monitoring (composite mean = 4.63), automation and system response (M = 4.46), data analytics and predictive maintenance (M = 4.41), and cybersecurity and system continuity (M = 4.35). Respondents among academic people were confirmed that there was high strategic alignment with the digital transformation priority of the CHED ACHIEVE Agenda (WM = 4.58) and future accreditation preparedness (WM = 4.47). Nevertheless, a high exposure gap was found: 89.5% of faculty reported SCADA as one of the foundations of Industry 4.0, although only 31.6% of them had direct, hands- on experience. Based on these results, the paper offers a three-pillar conceptual model (Inputs-Processes-Outcomes) and a model of gradual development in laboratories to facilitate institutional implementation. The initial estimation of the costs of the implementation of the Bill of Materials shows that a full SCADA Trainer facility would cost around PHP 44.4 million. The results endorse the thesis statement that SCADA integration is not just a pedagogical addition but a strategic need to generate digitally adept graduates of engineering at the worldly competitive level in accordance with SDG objectives and national objectives of development.

Keywords: SCADA, Power System Reliability, Future-Proof Education, CHED ACHIEVE Agenda, Engineering Education, Tarlac State University

Introduction

The rapid economic and industrial development in Tarlac province is because the province has become a first-choice destination to commercial and institutional investments such as the TARI Estate and other developing special economic zones. This continued growth has generated a pressing need for affordable, high capacity and intelligent power infrastructure. Supervisory Control and Data Acquisition (SCADA)

systems have emerged to be the key digital infrastructure of the observation and management of the sophisticated systems underpinning modern energy grids in response (Hartek, 2025; Lee, 2025).
SCADA consists of the combination of hardware (sensors and Programmable Logic Controllers (PLCs), Remote Terminal Units (RTUs) and Human-Machine Interfaces (HMIs)) and software platforms to allow real-time monitoring, centralized control and automatic fault detection. The fact that SCADA has been developed since 1960s as isolated analog systems and evolved into full-fledged, IP-based systems networked in with Internet of Things (IoT), Artificial Intelligence (AI), cloud computing and edge computing is a paradigm shift in the conduct of modern utilities (Sepulveda-Cervantes et al., 2025; Miranda, 2024). Nonetheless, the associated technical breakthrough raises a parallel cybersecurity requirement, i.e. older communication frameworks, e.g. Modbus, DNP3, and IEC 60870-5, do not inherently embrace encryption, which makes interconnected SCADA settings vulnerable to denial-of-service attacks, Spoofing, and data management (Alanazi et al., 2023; d'Ambrosio et al., 2025).
In line with these technological advancements, there is a long-standing gap in skills between the skills required by the industrial sector and the skills acquired in the traditional engineering curricula. Philippine educational establishments, especially those facilitated by the Commission on Higher Education (CHED) are now called upon to address the challenge with the ACHIEVE Agenda (2025-2030)- a reform agenda that focuses on the digital transformation, lifelong learning, SDG-based research and innovation, and international competitiveness (Philstar.com, 2025). The Tarlac State University (TSU) Future-Proof Education Plan (2025-2035) has been on top of these national requirements and has placed itself as a powerful context by aligning its institutional plans in integrating SCADA in its engineering courses.
This paper deals with this meeting of industrial need and education change. The key point is that SCADA is a two- fold pillar that is not only the technical requirement of having a resilient and automated power grid in a steadily developing economy but also the educational need to modernize the engineering practice. With a carefully designed approach to SCADA implementation into the TSU-COE curriculum, the institution stands a chance to close the gap between theory and practice and create the globally competitive professionals who will be able to handle and protect the complex cyber-physical systems of the future (Adelakun and Adebesin, 2024; Zhan et al., 2025).

Research Objectives

In particular, the following questions were aimed at being answered in the present study:

1. What are the key characteristics of SCADA systems monitoring, automation, data analytics, and cybersecurity, and how these characteristics enhance the power system reliability?
2. What does SCADA integration support or oppose about the CHED ACHIEVE Agenda (2025-2030), in general, and its pillars on digital transformation, lifelong learning, and SDG-based innovation, in particular?
3. What are the current issues and opportunities of the integration of SCADA into the instructional, research, and extension activities at TSU-COE?
4. Which theoretical framework is suitable in future-proofing the integration of SCADA into undergraduate electrical engineering courses to enhance graduate salience and global competitiveness?
5. What are the opinions of academic stakeholders about the readiness of SCADA integration and strategic alignment?
6. How do utility practitioners perceive the roles of SCADA in the reliability of the power system and the workforce

competency needs?

Research Hypotheses

The following hypotheses guided the investigation:

H_0: SCADA operations (monitoring, automation, data analytics, cybersecurity) have a positive and significant relationship with perceived reliability of the power system by utility practitioners.

H_2: There is high consistency between SCADA-enabled competencies and the strategic priorities of the CHED ACHIEVE Agenda as viewed by the academic stakeholders within TSU-COE.

H_3: The proposed three-pillar framework (Input-Processes-Outcomes) is a viable and contextually relevant model that can be used to guide the SCADA integration within the engineering education that is future-proof.

Methodology

Research Design

The research design used in this study was a mixed-methodological research design that combines the three complementary approaches to provide methodological triangulation: (1) qualitative documentary analysis, (2) descriptive survey research, and (3) an engineering design review. Peer-reviewed literature, technical standards, policy frameworks and manufacturer specifications were examined as the qualitative documentary analysis to set the theoretical and practical premises of SCADA integration. The empirical perceptions of two important stakeholder groups were taken in the descriptive surveys, and the engineering design review was used to generalize the technical specifications, which resulted in a preliminary SCADA laboratory setup and a Bill of Materials to TSU-COE.

Respondents and Sampling Technique

A purposive, non-probability sample was used in the study where 41 respondents were involved in two separate groups. Survey 1 was the sample survey of 19 academic stakeholders at TSU-COE, consisting of faculty members and department administrators of Electrical/Electronics (32%), Mechanical (27%), Industrial (27%), and Civil Engineering (14%). Survey 2 was conducted among 22 utility professionals who work in electric distribution companies and most of them are Electrical Engineers (61%), Automation and Instrumentation Engineers (17%), Technical Engineers (13%), and SCADA Network Managers (9%). Survey 2 sample consisted of the practitioners who were internationally exposed, especially those working with the utilities in Middle East, giving the cross-cultural and operational diversity to the results.

Research Instrument

There were two structured questionnaires that were designed and qualified to be used in this study. Survey Instrument 1 included the measurement of academic stakeholder awareness, perceived challenges, opportunities, and readiness towards SCADA integration at TSU-COE and the alignment with the CHED ACHIEVE Agenda and TSU Future- Proof Education Plan. Instrument 2 assessed the perceptions of utility practitioners regarding the SCADA functions and their effect on the power system reliability in four areas of operation, namely monitoring and situational awareness, automation and system response, data analytics and predictive maintenance, and cybersecurity and system continuity. Both tools used a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) with mixed-format with questions of

Likert-scale, multiple-response and single-response questions. Expert panel review was used to determine the content validity and Cronbach alpha coefficient was used to determine internal consistency.

Data Analysis

The quantitative data of the surveys were performed based on descriptive statistics with frequencies, per cent distributions and weighted means (WM) with standard deviations. The following scale (4.50-5.00 (Strongly Agree/Excellent), 3.50-4.49 (Agree/Very Satisfactory), 2.50-3.49 (Neutral/Satisfactory), 1.50-2.49 (Disagree/Fair) and 1.00-1.49 (Strongly Disagree/Poor)) was used to interpret survey items. Thematic coding was used to process the qualitative data acquired in the documentary analysis, which includes the organization of the results within the key analytical areas SCADA architecture and functions, cybersecurity governance, workforce competency alignment, and integration of educational policy. The design review of engineering solution would integrate technical requirements and vendor reports into a consistent laboratory installation and cost/efficiency analysis.

Results and Discussions

SCADA Characteristics and their Effect on the Power System Reliability

In Survey 2, utility practitioners gave uniform and high mean ratings in all the four SCADA operational domains, agreeing that SCADA is an important instrument in ensuring power system integrity. Table 1 presents the descriptive statistics for each domain.

Table 1. Attitude towards Utility Practitioners regarding the Effect of SCADA on Power Reliability (n = 22).

SCADA Operational Domain	Composite Mean	Std. Dev.	Interpretation
Situational Awareness & Monitoring	4.63	0.28	Strongly Agree
Automation & System Response	4.46	0.31	Strongly Agree
Data Analytics & Predictive Maintenance	4.41	0.33	Strongly Agree
Cybersecurity & System Continuity	4.35	0.36	Strongly Agree
Overall Mean	**4.46**	**0.32**	**Strongly Agree**

Situational Awareness and Monitoring recorded the greatest composite meaning (M = 4.63) as it is the universal opinion of practitioners that real-time visibility of electrical parameters such as voltage, current, frequency, and feeder loading is the defining benefit of SCADA implementation. According to practitioners, the early fault detection abilities resulted in a decrease in Mean Time to Repair (MTTR) and a better SAIDI and SAIFI index. Automation and System Response (M = 4.46) has been recommended as an essential mechanism that will remove any human error in switching and provide consistent procedural compliance in abnormal situations of the system. Data Analytics and Predictive Maintenance (M = 4.41) indicated the increasing tendency toward the proactive maintenance of the assets, whereas Cybersecurity and System Continuity (M = 4.35) accentuated the need of the appropriate governance of security as a precondition of the stable digital grid operation. Such results are consistent with Hartek (2025), Mohan et al. (2025), and Nuruzzaman and Rana (2025), who all support the fact that SCADA is an essential part of modern distribution utility management.

SCADA Integration and Alignment with the CHED ACHIEVE Agenda

The results of Survey 1 showed that TSU-COE faculty and administration believe that the SCADA-enabled curricula have a strong and significant connection with the strategic priorities of the CHED ACHIEVE Agenda. The weighted mean scores of four most important alignment indicators are listed in table 2.

Table 2. Academic Stakeholder Perceptions of SCADA Alignment with CHED ACHIEVE Agenda (n = 19)

Alignment Indicator	Weighted Mean	Std. Dev.	Interpretation
Digital Transformation & Real-Time Analytics	4.58	0.29	Strongly Agree
Future Accreditation Readiness	4.47	0.32	Strongly Agree
Lifelong Learning & Micro-Credentialing	4.42	0.34	Strongly Agree
Industry Workforce Readiness Alignment	4.38	0.37	Strongly Agree
Overall Weighted Mean	**4.46**	**0.33**	**Strongly Agree**

Digital Transformation and Real-Time Analytics had the highest alignment score (WM = 4.58) and it can be concluded that faculty are closely linked to SCADA integration with the CHED ACHIEVE Agenda digital transformation requirement. Future Accreditation Readiness (WM = 4.47) and Lifelong Learning and Micro-Credentialing (WM = 4.42) represent the awareness of the position of SCADA to meet the accreditation standards and facilitate pathways to stackable credentials. Aligned with the cross-stakeholder agreement regarding the applicability of SCADA competencies to current labor needs is Industry Workforce Readiness Alignment (WM = 4.38). The findings attained here align with those reported by Adelakun and Adebesin (2024), Akram et al. (2022), and Reyes et al. (2025), who underline that technology-based curricula lead to the creation of better employed graduates with high professional levels.

Faculty Exposure Gap: Exposure and Practical Competence

One of the key results of Survey 1 is that there is a huge gap between the awareness of the strategic role of SCADA among faculty and the practical experience of the technology among faculty. Among the 19 academic respondents, 89.5% admitted that SCADA is a key aspect of the industry 4.0 engineering practice. Nevertheless, the percentage of respondents with any direct hands-on experience with SCADA tools or platforms was low at 31.6% and high at 68.4% attempting SCADA learning knowledge though they have never been exposed to the operation of SCADA. In addition, although 63.2 percent identified themselves as conversant with SCADA concepts at a theoretical level, 36.8 percent admitted that they were not aware of the concepts at the least at the conceptual level. This gap in exposure is a huge stumbling block to successful SCADA-based instruction, and the application of organized faculty development programs is critical. The same is reported by Guan and Despi (2025) and Akram et al. (2022) who specify that technology integration proficiency of teachers is one of the key factors that determine that educational technology adoption is successful.

The Three-Pillar Model of Conceptual Framework of SCADA Integration

Based on the triangulated results of documentary study analysis, engineering design study review, and two surveys, the study outlines a Three-Pillar Conceptual Framework, which should be used to systematically incorporate SCADA in the engineering programs of TSU-COE (Figure 2).

PILLAR 1: ENABLING INPUTS	PILLAR 2: Learning Procedures:	PILLAR 3: Outcomes.
Infrastructure readiness Faculty digital competence Cybersecurity governance CHED policy alignment Industry partnerships	Experiential laboratory instruction Analytics-driven learning SDG-based research projects Industry exposure programs Micro-credential pathways	Digital graduate competence Enhanced employability International competitiveness Essential institutional accreditation preparedness Contribution to SDGs

Figure 2. Conceptual framework of three pillar SCADA integration in future-proof engineering education at TSU-COE.

Pillar 1 (Enabling Inputs) includes the institutional conditions of integration: sufficient laboratory facilities, a policy on cybersecurity governance, the development of faculty aptitude, compliance with the frameworks of CHED and TSU policies, and the active collaboration with distribution utilities and technology providers. Pillar 2 (Learning Processes) brings to life the learning activities in terms of experiential SCADA laboratory sessions, instruction on analytics, research activities based on SDGs, industry immersion programs, the creation of micro-credential programs. Pillar 3 (Outcomes) identifies the outcomes of successful integration; verified graduates with digital competencies, better employment prospects, global professionalism, and institutional development and progress through accreditation standards. This model resembles the Input-Process-Output models that are promoted in modern literature on outcomes-based education (Tushar and Sooraksa, 2023; Zhan et al., 2025).

Review of Engineering Design Preliminary Laboratory Design and Cost Estimate

The engineering design review consolidated the technical requirements of RTU/PLC vendor documentation, IED datasheets, HMI platform documentation, and the SCADA software licensing documentation. The proposed TSU- COE SCADA Trainer (Smart Grid Experimental Laboratory) is designed as a modular platform with scalability in the form of five main subsystems (1) SCADA Server and HMI Workstation, (2) PLC/RTU Field Simulation Panel, (3) Power System Simulation Interface, (4) Cybersecurity and Network Infrastructure Module and (5) IIoT/Edge Computing Gateway. The initial Bill of Materials approximates the total implementation costs to be around PHP 44.4 million that comprises of hardware purchase, software licenses, installation, cybersecurity infrastructure and educating the faculty. The process of staged development is suggested, with HMI visualization and simple automation (Phase 1) must be implemented initially, followed by the move to analytics and cybersecurity testbed systems (Phase 2 and 3).

CONCLUSION

This paper finds out that incorporation of SCADA systems in the undergraduate engineering courses in TSU-COE is not just a pedagogic choice but strategic need, in line with industrial needs, national education reform agenda, and sustainable development agendas. The triangulated information of utility practitioners (Survey 2), academic stakeholders (Survey 1), documentation-based information, and engineering design analysis alike are the ones that determine SCADA as a core technology to the reliability of power systems as well as the modernization of educational systems.

The effect of SCADA on its operations was confirmed by utility practitioners with a significant consistent composite means of all four pillars of reliability (overall M = 4.46, Strongly Agree). The academic stakeholders also highly concurred on the CHED ACHIEVE Agenda (WM = 4.46, Strongly Agree) with the deepest support on the digital transformation and real-time analytics integration (WM = 4.58). The SSIB-reported exposure gap, however, in which 89.5% of faculty members are aware of the centrality of SCADA to Industry 4.0 but only 31.6% have experience in this area, is the most significant obstacle to a successful integration and requires specific institutional response.

The Three-Pillar Framework (Enabling Inputs, Learning Processes, and Outcomes) has a logical and contextually tested roadmap to SCADA integration at TSU-COE that can serve as an example of digital transformation that other Philippine and regional HEIs may follow to achieve the goals of digital transformation. The initial SCADA Trainer Bill of Materials sets the technical and financial feasibility parameters under which the institutions can plan, and the staged development model gives them a realistic course of action through which they can implement in stages under the institutional resource constraints.

RECOMMENDATIONS

Within the findings and conclusions of this study, the following recommendations will be provided to the institutional leaders, curriculum planners, and policy implementers:

1. Infrastructure and Governance. TSU-COE ought to pursue a progressive model of SCADA laboratory development, which has its own capital budget and sustainability lifecycle plan that includes equipment maintenance, software license and calibration cycles. A spokesperson SCADA Laboratory Supervisor ought to be hired with a clear mandate on cybersecurity management, resource planning and coordination within the industry.
2. Faculty Capacity Building. There should be a systematic faculty development program in which exposure gaps can be identified and their development is carried out: certification in SCADA fundamentals, placement in industrial attachments with distribution utilities, and advanced training on communication protocols (Modbus, DNP3, IEC 61850), data analytics, and cybersecurity governance. It is suggested to collaborate with SCADA vendors to have training programs subsidized.
3. Curriculum Integration. The application of core materials such as Power Systems Analysis, Protective Relaying, Industrial Automation and Energy Analytics needs to have the SCADAcompetencies entrenched in the outcomes- based course mapping. Lifelong learning and professional development aligned micro-credential pathways (short courses and digital badges) are to be developed according to CHED ACHIEVE priorities.
4. Industry-Academe Partnerships. Memoranda of agreement with the distribution utility and automation technology suppliers should be formalized so that the organization can easily access guest lectures, internship pipelines, research collaboration, and access to clean operational datasets to use in assisting a student to study. Applied learning environments should be created by developing extension programs like micro grid pilots on campus.
5. Cybersecurity Mandate. SCADA cybersecurity training: network segmentation, access control, incident response protocols, secure operations management, and so on, are all required core competencies to be integrated into the applicable courses as opposed to being an optional add-on.
6. Monitoring and Evaluation. An educational monitoring and evaluation framework based on student competency rubrics, laboratory use metrics and longitudinal graduate tracer surveys must be created to determine how SCADA integration affects the performance of instruction, graduate employability and institutional accreditation performance in the long run.

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