The developing a smart grid control system based on Konnex electrical equipment and internet of things technology

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ABSTRACT

In this research, the authors present a method for developing a smart grid control system based on Konnex (KNX) electrical equipment and internet of things (IoT) technology to control and monitoring electrical energy processes such as: voltage, current, frequency, and power for independent or grid-connected power systems in industry and civil use. The system includes: KNX electrical equipment (KNX-connectivity), IoT control board, Solar panels that produce electricity to supply the system, battery storage devices, converters and controllers, power consumption loads, and many measuring, switching and protection devices for the system. With computer control programming devices, software, and control algorithms, access is possible via website, computer, smartphone, iPhone, and iPad. The goal is to monitor electricity and automatically control the smart building system, which is being used for high-end apartment buildings (luxury housing estate); offices, hotels, and garden villas. The system was researched and tested at the practice workshop for industrial factories and enterprises, bringing high results. The system aims to save energy in the context of increasingly depleted fossil energy, both in Vietnam and around the world.

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1. INTRODUCTION

Nowadays, the application of science and technology combined with advanced technology in the field of electrical engineering is being focused on and developed. In particular, electrical engineering - new and renewable energy combined with smart grid, control; remote monitoring and data collection of electricity are applied in the development of high-tech industry to improve production efficiency, ensuring sustainable development of green and sustainable energy technology. Because fossil energy sources are increasingly depleted, for countries around the world [1]–[5]. The internet of things (IoT) revolution combined with Konnex (KNX) smart electrical equipment (KNX electrical equipment and global standards for smart homes) has created significant changes in the lives of people now and in the future [6]–[8]. Nowadays, with the development of the internet, smart electrical equipment, smartphones, computers, electronics, and especially sensors, smart KNX electrical devices, IoT, combined with new renewable energy sources such as solar panels and endless sunlight are becoming a new trend in the world [9]–[13]. Developed countries in the world such as Germany, the Netherlands, the United States, China, Korea, Japan, Indonesia, and Vietnam, have been applying new electrical engineering technology, new renewable energy combined with new IoT and artificial intelligence, to improve the productivity of new renewable energy sources, in order to develop smart power systems, bringing high economic benefits. In addition, it also brings great profits when applying this new technology to monitor capacity, voltage, current, and control smart power systems for buildings; apartments, hotels, or tourist areas [14]–[19]. Monitoring the parameters of voltage, current, and capacity of the power grid is considered a very important issue in today's industry to save energy [5], [8], [20]–[23]. Along with the development of electrical and electronic engineering, IoT-AI technology is increasingly developing with the ability to interact, most of the electrical devices; new measuring and control devices today can be connected via the internet and the overall communication infrastructure brings high economic benefits in the field of monitoring, using electricity, economically and effectively [9], [10], [24]–[26].

Along time with the current development of science, there are many different types of electrical equipment such as Schneider, Mitsubishi, Panasonic, KNX, Lumi, and Crestron, KNX smart electrical equipment is being applied in the field of industrial electricity, smart electricity for buildings, combined with IoT and AI technology, always responding and performing in real time. In particular, the solar battery system that combines the development of KNX electrical equipment with IoT technology into an independent electrical system or a grid-connected electrical system [11]. In [4], research on IoT for building structures, based on cloud computing for medical health care. In [6], [9], research on IoT connected to smart home systems without combining with KNX electrical equipment, solar battery equipment self-supplies the system, for monitoring and control. Works [5], [8], [10] study KNX electrical equipment for the field of smart home automation control according to the requirements of KNX company, connecting, switching devices, and automatic consumption loads. In addition, works [12], [19] study the design of smart grid automation applications with IoT connection to many smart electrical and electronic devices. In general, the works have studied smart electrical and electronic devices from KNX, with IoT connection but have not been combined and developed a smart grid control system with solar batteries, based on KNX electrical equipment and IoT technology as the contents of this article.

In this study, the authors focus on researching and establishing a smart home monitoring and control system using KNX electrical equipment and IoT technology. The goal of this system is to control and monitor parameters: capacity, voltage, and current, for automatic load switching and on-off operations, automatic lighting control for buildings, villas, resorts, tourist areas, garden lighting, and automatic public lighting, on the basis of smart device applications, internet: computers, smartphones, and iPads, to improve the quality of the system, while still ensuring power quality according to IEEE519 standards.

2. THE CONTENT OF DESIGN OF MONITORING AND CONTROL SYSTEM COMBINING KNX ELECTRICAL EQUIPMENT AND IOT TECHNOLOGY

2.1. Research on design of monitoring control system and system modeling

The research and development of smart grid control systems includes both smart city and smart home, and in smart city there is also smart building about the integrated control system from renewable energy sources (solar panels and rooftop solar power), providing for a building or an apartment consuming electricity with the feature of using smart KNX electrical equipment. From there, KNX electrical equipment allows to combine with IoT technology to monitor, control automatic switching of consumption loads for the power supply system according to the demand for civil and industrial electricity loads, the system has the ability to connect to the national grid [26].

In Figure 1, the panels solar battery system installed on the roof of the building includes: photovoltaic (PV) panels (1) (to collect solar energy) to pass through the converter (2), connected to electrical equipment, using KNX smart electrical equipment and power supply (4), electronic equipment, battery storage system, two-way meter to measure electricity (3), national grid system (6). In addition, there is a system of internet network switching equipment, Wi-Fi, WiMAX, system monitoring and measuring equipment, power stabilization controller for the system, with both switching and protection measuring equipment [19].

In Figure 2 controllers and converter types such as DC-DC converters; DC-AC converters, phase-locked loop (PLL) converters, and PWM converters (enclosed by dashed lines). KNX electrical equipment is used to switch, load, connect electrical equipment and IoT (including ctr 2 controller). The system will measure and check circuit parameters such as voltage, current of the solar panel power source that produces electricity to charge the battery, thereby supplying different types of loads through the converter. The ctr 3 controller is a maximum power point tracking (MPPT) controller, stabilizing the power to obtain maximum energy for the system. The system outputs a semi-sine wave current and voltage at the output of the DC-DC converter and a sinusoidal wave at the output of the system's bridge inverter. To connect to the national grid, the system only needs to request a constant sinusoidal alternating current source. The parameters of the set quantity are provided by PLL and MPPT. To perform the grid connection task, to ensure strict control of the system's output parameters (amplitude, frequency, and phase), the current control loop will directly control the system's output current. In addition, the converter and controller using STM32 for microcontrollers to connect IoT devices to the Internet also work in parallel with the system, [9], [16], [22].

We can see that the MPPT control is still based on the P-V characteristics of the solar panel, however, the control parameter is the current, thus indirectly establishing the P-I characteristics of the solar panel. The calculation and comparison steps are shown in Figure 3 of the P&O algorithm. Thus, the MPP calculation for the system here follows the voltage values and power components of the solar panel to have an impact on the current, making the system work at the maximum power point to maximize the power obtained as shown in Figure 3.

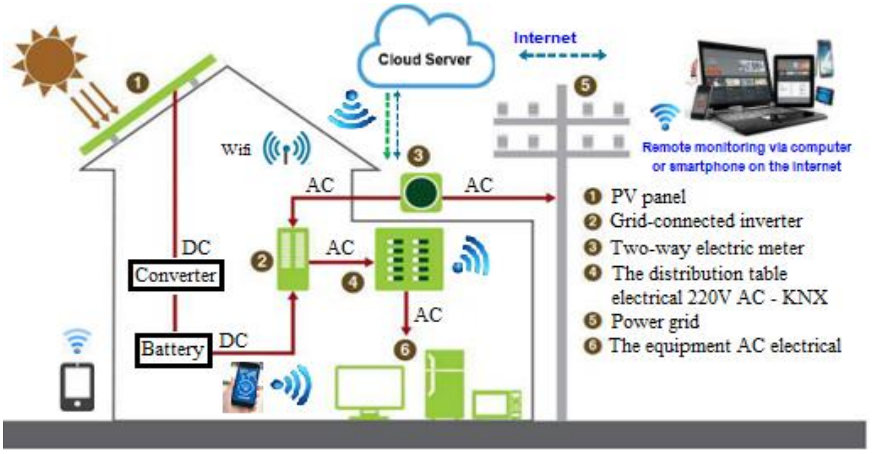


Figure 1. The KNX electrical equipment for buildings powered by grid-connected panels solar and IoT connectivity

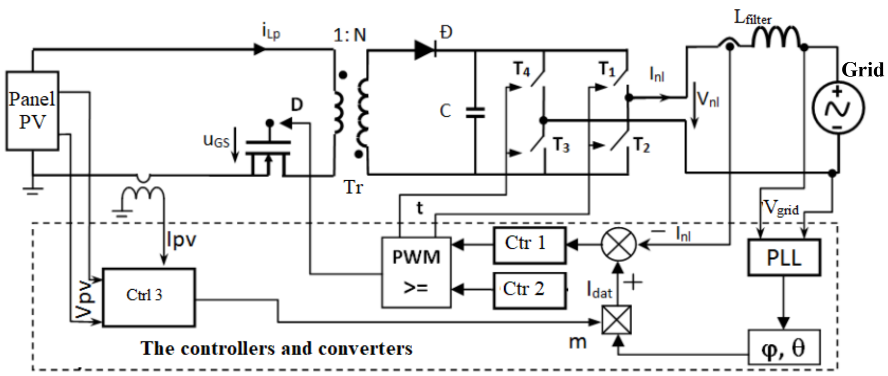


Figure 2. Block diagram of the controller structure of grid-connected PV system

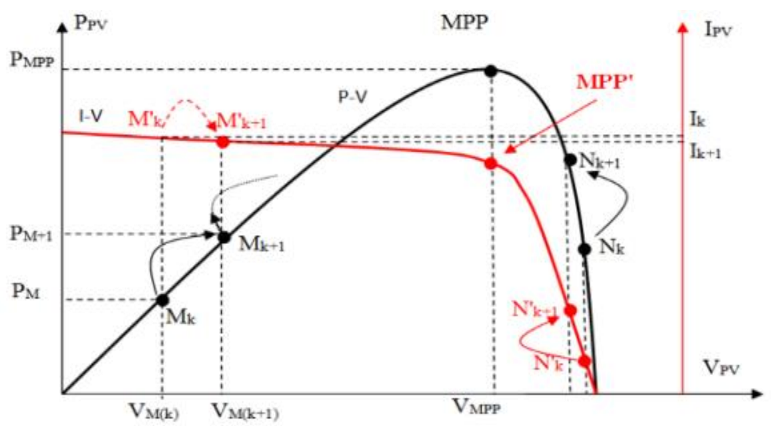


Figure 3. Application of numerical methods to find extreme solutions of MPPT problems

From Figure 4, we can see the characteristics of the power source parameters in solar power systems controlled by power electronics in general, the sinusoidal alternating current in the system has quantities such as maximum value (I), effective value, instantaneous value ($i(t)$), frequency (ω), phase (φ). And the instantaneous value of the current is the quantity that carries all the above information ($i(t) = I_{sin}(\omega t + \varphi)$). If the instantaneous current is the control variable, the system will simultaneously control all the quantities of the current. Based on the calculation and analysis of the power, voltage, and current values, given to the system. Then the grid voltage and phase angle will always be synchronized through the PLL based on the signal synchronization reference frame for the system, [9], [16]. This issue will stabilize the power capacity to be able to provide controllers, converters, electrical switching devices and load control for buildings, smart electrical systems using KNX electrical equipment. In addition, the system also has the ability to connect to the national grid in the case that the electricity produced from the solar battery device stored in the storage battery always reaches over 90% of the stored electricity.

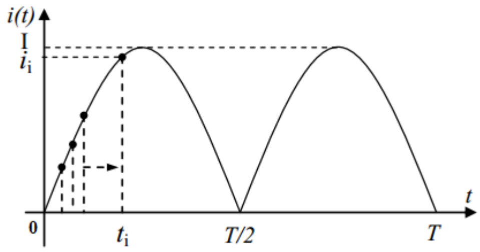


Figure 4. The graph explains the process of current tracking at a given time

2.2. The build algorithms and control programs for the system

Researching the construction of algorithms, controllers, monitoring and programs to program controls for smart grid control systems based on KNX electrical equipment and IoT technology, we study the system structure. The system in Figure 5 includes: (1) solar panels, control panel 1 controls the solar panel system, (2) DC disconnect, (3) solar charge controller, (4) battery bank, (5) inverter/charger, (6) monitoring and IoT connector. (7) Device is a critical load distribution panel, (8) main distribution panel KNX electrical panel includes: control panel 2, load L1 represents the lighting system, water pump system, exhaust system, air conditioning system, water heater system, automatic gate system; L2 load includes curtain system, sound system, (9) utility meter connected outside the room; (10) utility grid provides electricity when needed.

In which, solar battery size (60×60) cm; X-Pro MF44B19FL battery (40 Ah – 12 V); size (187×127×203) mm, electrical cabinet 1 includes: three-phase and 1-phase ap to mat switching system; logo hardware, KNX power supply, KNX central controller, curtain module, lighting module, and includes many other switching, measuring and protection devices. The detailed arrangement of the KNX smart electrical equipment installed inside electrical cabinet 1 is shown in Figure 6. The electrical cabinet 2 includes: inverter controller, smart charging controller from solar battery to battery, Arduino ESP8266 circuit module and current measuring sensors, voltage sensors, Dcom 4G module, some power modules and many other switching and protection devices. High-configuration computer with internet access, control program interface installed with KNX software, (with full information and manual instructions). The overall view of the implemented experimental control system model can be seen in Figure 7.

General working principle for the system (for simulation and experimentation): this is the integration of two systems into a complete system including: on-grid system (grid-connected system): produces electricity from solar panels into 220 V AC / 50 Hz electricity to connect to the grid. off-grid system (independent system): solar panels are produced to produce electricity through a converter to the battery, from there through an inverter to 220 V AC / 50 Hz electricity to supply the load when there is no grid power. The system is capable of connecting to the grid. When starting the system, the battery is always given priority to be charged from the solar panel until full. At this time, the on-grid system is not working. Suppose when the battery power is full (charged from the solar panel), the system will automatically convert DC electricity into AC electricity through the inverter (with power filter); into 220 V- 50 Hz AC electricity to connect to the grid. (The system's output voltage has the same frequency and phase as the grid power, which can be single-phase or three-phase). When the grid power is lost, the system will automatically take DC power from the battery and PMT to convert it into AC-220 V power to supply the priority load. KNX electrical equipment can connect to the network and control loads such as lights, curtains, sound, lighting, air conditioning, heating and cooling, controlled according to scenarios via the internet with the domain name of the KNX company that comes with the switching device. The manual mode: turn on the system and control the system by connecting the power source and load through manual on/off devices (push buttons and switches). The system after being supplied with electrical energy from the solar battery through the converter and back to the battery; then the inverter supplies the system using KNX electrical equipment. Video and test programming at the link on YouTube as: *https://youtube.com/watch?v=m4f6ccMzCtk*.

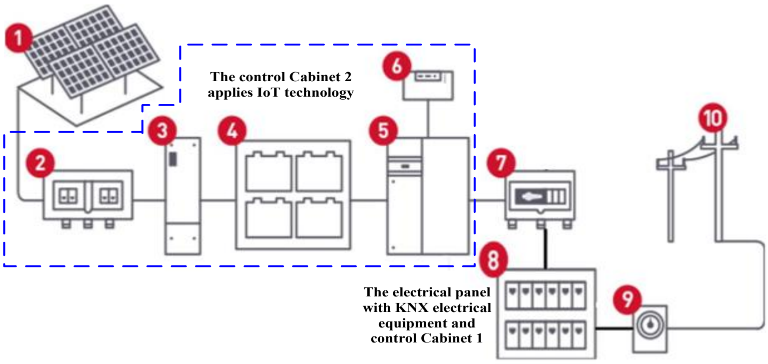


Figure 5. Structural diagram describing the solar panel system connecting the KNX panel model and the grid

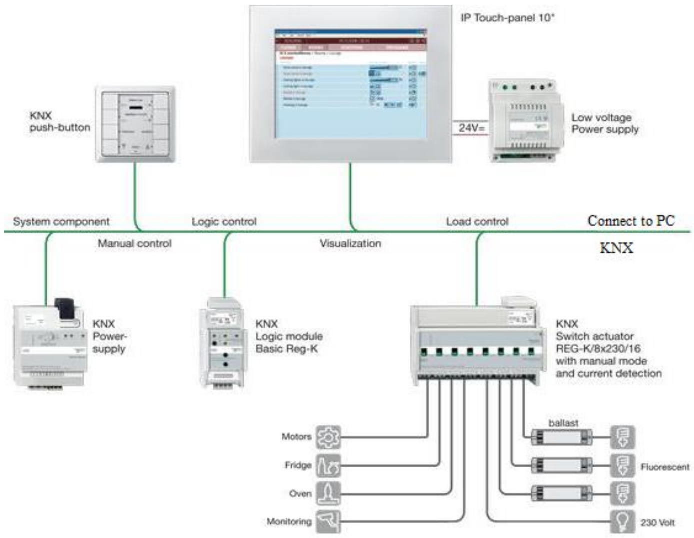


Figure 6. The KNX smart electrical equipment for the system inside the electrical cabinet 1

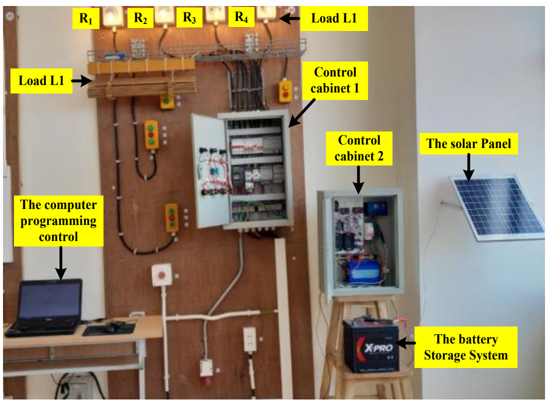


Figure 7. Image of experimental model of KNX smart electrical control system powered by PV panel

The explaining algorithm flowchart: values of voltage, current, frequency, power, and temperature, humidity. There are 2 control modes: automatic mode and manual mode. Automatic mode: temperature above 26 ºC (sunny) will automatically allow charging through the converter, to the battery for power storage. The sound and light system, air conditioning operates normally. If the temperature is below 12 ºC, the air conditioner will be turned on in hot mode, humidity < 40% will turn on the air conditioner in cool mode, humidity > 80% will control the air conditioning system to run in dry mode and will automatically work (or can be turned on by on/off mode). If the air quality in the room is not guaranteed (when the sensor reports), the air purifier will operate automatically to filter the air in the house or room. If there is a fire, the sensor system will be automatically activated and the water pump will operate to reach the fire location. In this mode, it is possible to connect via IoT and website, via phone app.

Manual mode (turn on by on/off mode): control air conditioner, control water pump system, hot and cold system, turn on/off lighting, outdoor lighting, and sound system. Instead of performing analysis, expressions, calculations and mathematical equations, the authors of the study put forward technical requirements to ensure full functionality of the power supply system for smart homes. From there, the study built the program code to upload to the on chip above and assembled the circuit to meet the technical requirements based on the control program algorithm flowchart illustrated in Figure 8. The system monitors and controls the switching of equipment, power source, voltage, and capacity for smart homes, using KNX smart electrical equipment. In addition, with manual mode, the system always allows integration via remote control on the electromagnetic wave platform (transverse wave in the direction of transmission like radio waves), the system always ensures high sensitivity from the control to the electrical cabinet located in the house for each room and each floor. The system allows (with expansion modules) to improve the quality of control, increase high performance with smart features for the building.

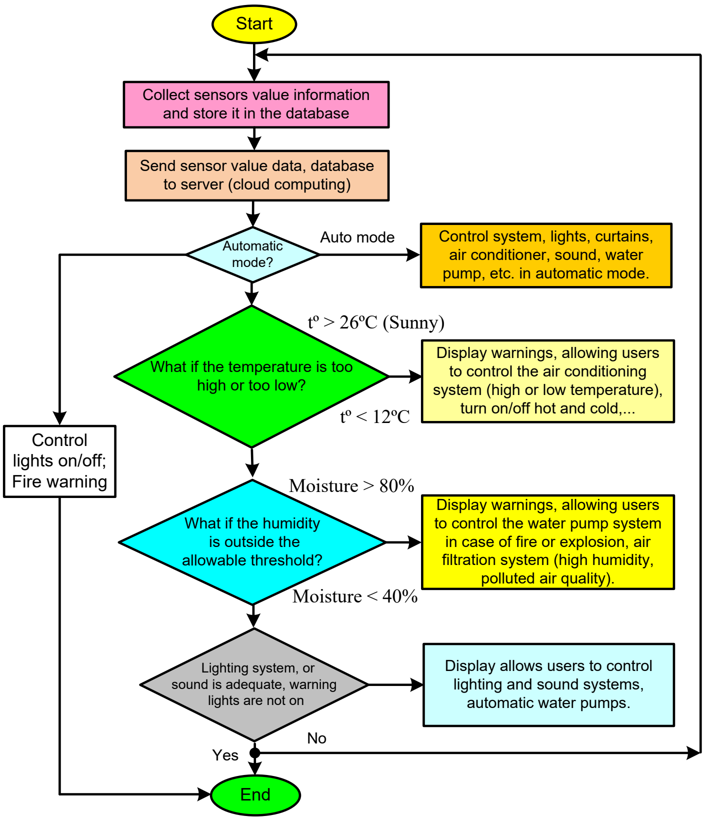


Figure 8. Algorithm diagram for control and monitoring of a single-unit building system

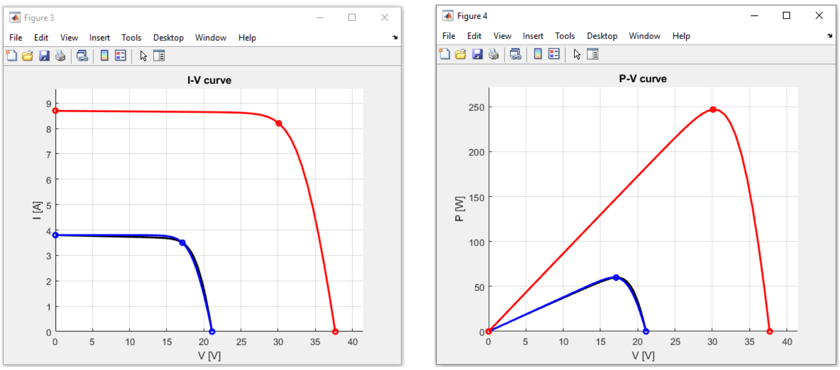
3. RESEARCH RESULTS AND DISCUSSION

From the studies: calculation, analysis, algorithm model building and programming, the authors have given some results of system monitoring and control on IoT platform via Website with access devices such as phones, personal computers, iPhone, and iPad. Internet connection is a computer with the address: *https://tramsacuneti0012.000webhostapp.com*.

First, we have the data parameters to build a simulation model on MATLAB Simulink R2024a; embedded computer as: the system includes a PV panel in the form of: SunPower SPR-305E-WHT module with: capacity 305.226 W; maximum voltage U_{mp}= 54.7 V; maximum current I_{mp}= 5.58 A; open circuit voltage: U_{oc}= 64.2 V; current I_{sc}= 5.96 A; battery capacity is 100 kW; voltage at maximum capacity (V_{mp}) “PV array” is 273.5 V; current at maximum capacity (I_{mp}) “PV array” is 368.28 A and some other calibration parameters during the simulation of the grid-connected PV system to achieve high quality. Boost converter, ambient temperature 25 ºC to 30 ºC; medium range solar radiation. Power converter with grid connected inverter; with MPPT controller incorporating P&O algorithm (to calculate the voltage rise and fall in cycles to assist in finding the maximum power operating point) as per Figure 9.

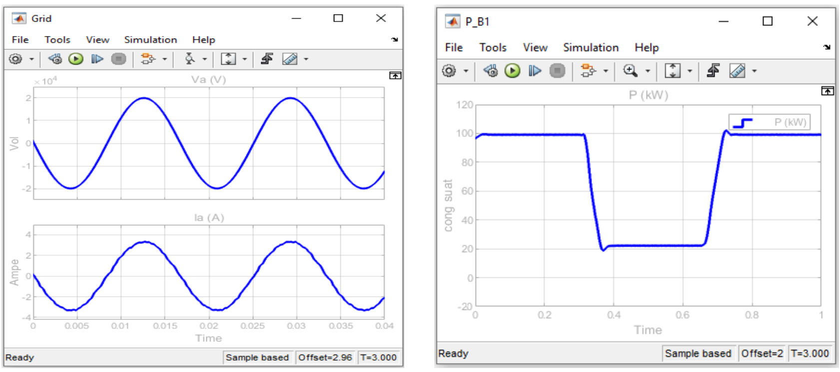
In Figure 10, the simulation result on MATLAB Simulink with voltage value of 20 kV and current of 3.8 kA, 100 kW capacity of the system is activated, converted through the converter to connect to the grid when the solar panel system produces electricity and stores over 90% of the stored electricity. The grid-connected system works stably, works with high quality, and can be applied in practice in today's industry. From the model of Figure 7, the authors monitor and automatically control the connection of IoT with smartphones, personal computers, and iPads, and we get the results as shown in Figure 11.

From the results of accessing the system, we have the following comments: the research on the monitoring control system, tested on the devices, has proven the correctness of the calculation, design, manufacturing and control algorithm model to monitor the PV panel system with KNX smart electrical devices. System monitoring parameters: I (A), U (V), P (w), and f (Hz) are correct in real time, Figure 11 and Figure 12. This data has many practical meanings for application in the field of smart electricity, new and renewable energy today. The data is continuously updated via the internet, proving that IoT technology is being researched by scientists in reality today. This issue can be expanded to other research in the field of IoT such as: monitoring in the field of green agriculture and monitoring green energy in industry, bringing many high scientific and practical meanings.



(a) (b)

Figure 9. Simulation results of current, voltage and power values of solar battery system obtained: (a) current and voltage, and (b) power



(a) (b)

Figure 10. Simulation results of current, voltage and power values at the output side of the system (when connected to the grid): (a) voltage waveform, and (b) power waveform

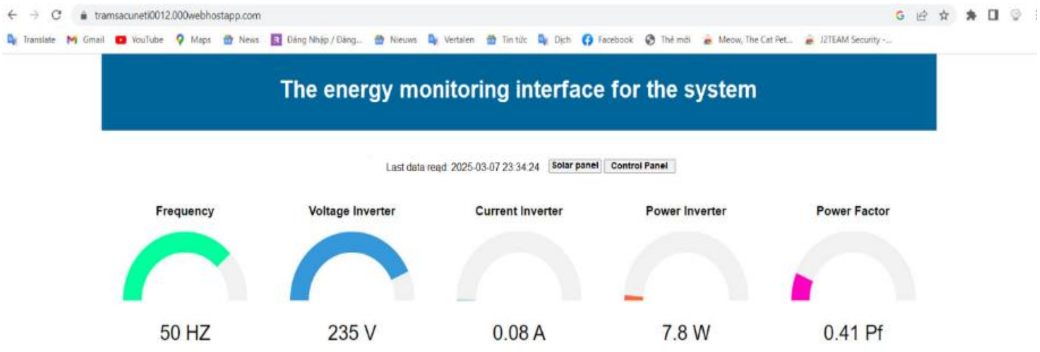


Figure 11. The interface accessed system monitoring via personal computer and mobile phone

The data reading table last 10 values

Number of Measurements	Location	Voltage Battery(V)	Current Battery(A)	Power Battery(W)	Voltage Inverter(V)	Current Inverter(A)	Power Inverter(W)	Energy Inverter(Kwh)	Reading time
1383	Tramsac1	11.92	0.66	7.80	235.00	0.08	7.80	0.02	2025-03-07 23:34:24
1382	Tramsac1	11.92	0.64	7.60	235.00	0.08	7.70	0.02	2025-03-07 23:34:20
1381	Tramsac1	11.92	0.64	7.60	234.90	0.08	7.70	0.02	2025-03-07 23:34:16
1380	Tramsac1	11.92	0.65	7.70	234.70	0.08	7.60	0.02	2025-03-07 23:34:13
1379	Tramsac1	nan	nan	nan	234.80	0.08	7.60	0.02	2025-03-07 23:34:09
1378	Tramsac1	11.92	0.66	7.80	234.90	0.08	7.80	0.02	2025-03-07 23:33:58
1377	Tramsac1	11.92	0.66	7.80	234.80	0.08	7.70	0.02	2025-03-07 23:33:54
1376	Tramsac1	11.92	0.66	7.80	234.70	0.08	7.90	0.02	2025-03-07 23:33:50
1375	Tramsac1	11.92	0.65	7.70	234.90	0.08	7.90	0.02	2025-03-07 23:33:44
1374	Tramsac1	nan	nan	nan	235.10	0.08	7.90	0.02	2025-03-07 23:33:40

Figure 12. The statistics table metrics to access data with the last 10 values

4. CONCLUSION

The article has researched and developed a smart grid monitoring and control system based on KNX electrical equipment and IoT technology for application in smart electrical models for buildings, office buildings, and villas. The system allows monitoring of voltage, current, power, frequency, parameters and simultaneously gives warnings when exceeding the allowable threshold for any parameter. In addition, the system can be automatically controlled via smartphones, tablets, according to user requirements for automatic control by pressing buttons on smartphone applications, personal computers. The system is designed in the form of hardware and software modules that are then integrated into a monitoring and control unit. Design a user application on smartphones for use via applications and Android operating system. From the above research results, we can see that the monitoring and control system has been tested in practice at the electrical installation practice room of NA2 House, No. 353 Tran Hung Dao, Nam Dinh Ward, Ninh Binh Province. The measurement results collect data from the control circuit system of the electrical cabinet 2. This shows that the monitoring and control on the computer and the phone, compared and evaluated with the measurement results from the actual specialized measuring devices are the same. Thereby, it shows that the difference in parameters between the monitoring device and the specialized measuring device is insignificant. The monitoring and control system meets the requirements of the smart home monitoring and control model in Vietnam. This is a solution that contributes to solving the problem of energy and saving energy, when the problem of energy shortage for countries is currently being studied.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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