Analysis of the Economic and Environmental Feasibility of a Home Automation System

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Abstract. The current research was carried out to analyze the economic feasibility and contribution to homes and buildings automation in the field of environmental protection. The objective that led this study was to explore and investigate the increase in comfort and safety, as well as, the reduction in the electrical energy consumption, so that, it is possible to achieve greater energy efficiency in the No 3 building at the Technical University of Manabí (UTM) in Ecuador. In order to, investigate deeply the economic feasibility; it is relevant to be aware of the electric power and automation equipment cost that will be integrated into the Z-wave protocol. Moreover, the electric bill study contracted by the UTM this was developed initially with the monetary value of the electric power, which was regulated by the Electricity Control Agency. On regards to the environmental analysis, it was shown that the projection uses of the domotic system in the teaching building No. 3, not only reflected some economic and energy savings but also, it presented a considerable contribution to the environment, due to, the emissions reduction in CO2 to the atmosphere. To accomplish this environmental analysis, the CO2 Emission Factor was considered, regulated by the Ministry of the Environment, which is 0.7079 Kg CO2/kWh. It is important to mention that this value is applicable to all systems that are connected to the national electrical system. To validate the fulfillment of the outlined objective, it was considered two very important scenarios. The first one reflected the reduction of polluting emissions to the atmosphere, because of the use of the photovoltaic located in this build. The second one referred to the theoretical energy saving that will be obtained as the implementation of the home automation system.

Keywords. Energy management, smart grid, home automation, smart buildings, renewable energy sources.

1. Introduction

Currently, various systems that use so-called clean energies for electricity production are being studied and implemented, which must be efficient and comply with the safety protocols to achieve reliability in these systems [1]. One of the most used are Photovoltaic Solar Systems (SFV) which can be used autonomously, connected to the network or a combination of both [2]. In [3] a methodology is developed that allows monitoring the performance of photovoltaic systems by detecting faults. The research uses
practical data from a 7.5 kWp Grid-Connected Photovoltaic Solar System (SFVCR), concluding that the methodology used was able to detect and identify 100% of the simulated faults. In [4], a hybrid renewable energy generation plant is proposed that could supply a percentage of the total energy demand and reduce the environmental impact of conventional energy generation in the Caribbean region of Colombia.

The hybrid plant works with a photovoltaic (PV) system and wind turbine systems, connected in parallel with the grid to supply a fraction of the total energy demand. The proposed system features 441 photovoltaic panels and 3 wind turbines, reaching a net current cost (NPC) of $11.8 million and a low CO₂ production of 244.1 tons per year.

In recent years, different home automation control systems are being studied and developed to increase efficiency and comfort, in addition to reducing the costs of energy carriers. These systems are generally implemented and performed with various communication protocols to achieve the expected results [6], [7]. In [8] a wireless sensor network oriented to home automation applications is designed and implemented. In the experimental tests that were performed, a 12-meter line-of-sight range was obtained between sensor nodes, guaranteeing full coverage of the area of a single-family house.

In our research, a home automation system is developed using the Z-Wave protocol, which consists of a mesh-shaped network that uses radio waves to communicate different smart devices with each other, also allowing interaction with different WEB pages. The platform used, “Vera Home Automation”, allows to easily program our intelligent system giving the user the possibility of managing it in a simple, efficient and centralized way [9, 10, 11, 12, 13].

The description of the configuration of the implemented protocol is made from the use of the VERA platform [9] and the economic feasibility analysis and the contribution that the use of the home automation system has to the environment by reducing electricity consumption are made [14, 15, 16, 17, 18, 19, 20] and thus obtain greater energy efficiency in teacher building No. 3 of the Technical University of Manabi (UTM) in Portoviejo, Ecuador [9].

For the economic feasibility analysis, the cost of electrical energy and the smart equipment that will be connected to each other using the Z-Wave protocol must be known [21, 22, 23, 24, 25]. In Ecuador, the energy cost is regulated by the Electricity Regulation and Control Agency and an analysis is made of the contracted electricity bill, which for the UTM is medium voltage with regulated hourly demand. In addition, an analysis of the environmental impact of the use of this technology in teaching building No. 3 is carried out, which not only reflects savings on the economic and energy side, but also on the considerable contribution to the environment [26, 27, 28, 29, 30] by reducing CO₂ emissions to the atmosphere. To carry out this study, a CO₂ Emission Factor of 0.7079 Kg CO₂ eq/kWh was considered, data obtained from the Ministry of the Environment and which is applicable to all those connected to the National Electricity System (SEN). Due to the foregoing, two scenarios are considered: the first reflects the reduction of polluting emissions from the use of the photovoltaic micro-station located in this building, and the second refers to the economic and energy savings obtained by implementing the home automation system.

2. Methodology
The development of the research work has several stages, first, the scenes are added, in which the name must be located for each of the scenes that you want to add. In these scenes, the devices to be used in the home automation project can be selected, Figure 1, and they can be programmed the times in which they will carry out specific tasks [8].
We can view the different types of installed devices by clicking on "Select a device". If some of them are not properly installed, you must go to the Devices option and click on the "Add devices" button where the additional Device options are displayed. In Figure 2 you can see all the devices that are compatible with this protocol.

Once the device that you want to add in the project has been identified, the procedure that the interface of the Vera Home page indicates must be followed. For example, if we want to add the “6 in 1 Multisensor” device, the technical specifications must be found in the manual of the device, and when clicking on it the following page is displayed, see Figure 3.
Figure 3. Registration window of the equipment to be installed

Figure 4 shows the registration of all the devices that will make up the system.

Figure 4. Devices added in the system

Once the device has been added, the scenes are created, see Figure 5. To access it, place the cursor on the word “Scene” shown on the left side of the screen and then click on the word "Add a scene" located on the right side of the window.
Then the device to which the scene will be created is selected with the conditions required by the user, see Figure 6. In this case the 6-in-1 Multisensor is used.

Subsequently, the option that best suits the function to be performed is chosen. This device is responsible for detecting movement as long as the 6-in-1 Multisensor is armed or disarmed; finally, the order is validated, see Figure 7.
To continue with the configuration process, click on “Next Step”, as shown in Figure 8.

Figure 9 indicates the action that the device needs to perform, clicking on ”What do you want to happen?”, Provided that the 6-in-1 Multisensor is armed or disarmed.
Figure 9. Programming corresponding to the action to be executed.

Figure 10 shows how the place where the home automation element is to be located within the room is selected. In this case it is going to be located in one of the outlets that are located in the teachers' office of Teacher Building No. 3 of the “Electricity Career”.

Figure 10. Selection of devices to use

The window that shows the state of the switch, on or off, when the outlet is armed or disarmed, is shown in Figure 11. In this case, the ignition is chosen, and the order is validated.
To finalize the scene configuration, the “Step 3” option must be pointed out, which defines the scene’s execution time, its working mode, as well as the user to whom it must be notified. It should be noted that to receive the notification you must download an application called VeraMobie available in the Play Store and that is compatible for Android and iOS operating systems.

Figure 12 shows how you define how you want to run the scene. There are four options available: vacation, home, night, and absent; from which you can select the ones you consider necessary, having the possibility to mark them all. In our case, all are marked and then the word “Done” is clicked.

Once the configuration of the work scene is completed, the economic feasibility analysis of the proposed project is carried out. In the investigation, it became necessary to know the cost of electrical energy, and the cost of home automation equipment that works with the Z-Wave protocol.

In the economic analysis, it was necessary to know the rate contracted by the UTM, which is a medium voltage rate with hourly demand. This rate is regulated by the Electricity Regulation and Control Agency, which also regulates existing penalties due to a low power factor (fp). Said agency establishes that when the average value of the power factor is less than 0.6, the distribution company will make a notification to inform the user of the suspension of the electric power service. This service will be restored when the value of the f.p > 0.6 (Electricity Regulation and Control Agency, 2018).
3. Discussion and Results

Table 1 shows the total monetary value that the UTM has to pay. The value to be paid is $ 822.29 and takes into account the cost of the electrical energy consumed plus the penalty for low power factor.

Table 1. Electricity billing in a trial month

| Monthly energy consumption without the application of the Z-Wave home automation protocol | Energy Cost | Consumption | Unit | Total value |
| --- | --- | --- | --- | --- |
| Power 7:00 am-22:00pm | $ 0.095 | 4288.25 | kWh | $ 407.38 |
| Energy 22:00 pm-7:00am | $ 0.077 | 287.74 | kWh | $ 22.16 |
| Monthly demand | $ 4.576 | 29 | kW | $ 132.70 |
| Amount to be paid | | | | $ 562.24 |
| Average power factor | 0.63 | | | |
| Low power factor penalty (fp) | 0.46 | | | |
| Low penalty fee payment | | | | $ 258.63 |
| Commercialization | | | | $ 1.41 |
| Total value to pay | | | | $ 822.29 |

By implementing the home automation system using the Z-Wave communication protocol, savings of over 30% of total electricity consumption can be obtained. The economic analysis also showed that up to 60% can be saved on the building's lighting system. Finally, it is considered that by varying the temperature in the air conditioning system by one degree, savings of up to 5% will be obtained; for this reason, the proposed proposal assumes a savings of 35%.

Table 2 shows the electric energy billing which considers the possible estimated monthly savings. In addition, it is observed that the total value to be paid is $ 525.27, which demonstrates the energy savings that can be obtained.
In Figure 13 it is observed that the theoretical saving is $297.19 per month, so there will be an annual saving of $356.27. If it is considered, in the near future, to generalize the results obtained to other university buildings, it would considerably increase energy savings, improving the return time of the investment made. In addition to contributing to energy savings, the implementation of the home automation system project will contribute to the improvement of the power factor in said building.

Figure 13. Theoretical savings by applying the Z-Wave Protocol

The data for the analysis of the feasibility of the project are shown in Table 3, which shows the approximate values of the cost of implementation of the home automation devices of the system, the annual maintenance, the discount rate and the useful life of the installation.

| Elements                  | Costs      | Rate off | 10% |
|----------------------------|------------|----------|-----|
| Home Automation Devices    | $17 357.84 |          |     |
| Annual maintenance         | $100.06    | Useful life (years)   | 20  |
| Total value                | $17 457.84 |          |     |

Table 4 allows visualizing the final results of the feasibility analysis, where it is shown that the implementation of the home automation project is feasible, considering only building No. 3, since the payback time of the investment is 8 years.

| Table 4. Results of the feasibility analysis |
|---------------------------------------------|
| VAN $12152.49                                |
| TIR 19.4%                                   |
| ROI 1.70                                     |
| PAY-BACK (years) 8                           |

In Figure 14 you can see the possible behavior of the feasibility analysis.
Table 5 shows the environmental impact produced using the mini-PV plant. In it you can see the total emissions generated into the atmosphere by analyzing different consumption; it also refers to the amount of tons of CO\textsubscript{2} that would cease to be emitted into the atmosphere thanks to the implementation of the photovoltaic micro-plant, which value is 2.55 tons of CO\textsubscript{2} equivalent. Total emissions to the atmosphere are 36.32 tons of CO\textsubscript{2} equivalent, which allows determining the annual consumption of the building, which is 51304.28 kWh.

Table 5. Environmental impact from the use of the mini-photovoltaic plant

| Consumption                        | Unit | Gas emission | Unit |
|-----------------------------------|------|--------------|------|
| Power consumed from the grid      | 54911.89 kWh | 38.87 ton CO\textsubscript{2} |
| Annual energy produced by the mini-plant | 3607.66 kWh | 2.55 ton CO\textsubscript{2} |
| Total equivalent energy           | 51304.28 kWh | 36.32 ton CO\textsubscript{2} |

Knowing the decrease in CO\textsubscript{2} emissions to the environment by the implementation of the photovoltaic micro-plant, the study aims to further reduce these emissions using the Z-Wave protocol. Table 6 collects the results obtained from this analysis.

Table 6. Environmental impact of the implementation of the home automation system

| Consumption                        | Unit | Gas emission | Unit |
|-----------------------------------|------|--------------|------|
| Total energy using the Z-Wave protocol | 34656.86 kWh | 24.53 ton CO\textsubscript{2} |
| Energy consumed from 10:00 pm to 7:00 am | 1208.52 kWh | 0.85 ton CO\textsubscript{2} |
| Total energy consumed             | 33448.34 kWh | 23.68 ton CO\textsubscript{2} |
4. Conclusions
For the implementation of the proposed home automation system, an economic and environmental analysis was performed, resulting in the feasibility of its installation. This home automation system, in addition to contributing to energy efficiency, comfort and safety, will have the capacity to contribute to the reduction and correction of different electrical anomalies that exist in this building.

The result obtained in terms of projected savings is 35%, which corresponds to a value of $297.19 per month, $3566.27 per year. These values demonstrate the feasibility of this proposal by reducing 15.19 tons of CO2 equivalent emissions of polluting gases into the atmosphere.

In order to achieve a greater reduction in CO2 emissions into the atmosphere, the consumption of electrical energy from the network must be reduced, and for this, the implementation of the home automation system has been considered, so in future research, the design of a photovoltaic plant will be carried out. Have the capacity to cover all the energy consumption of the UTM, and with it the implementation of an energy storage system. In addition, to obtain a better optimization of the electrical energy from this renewable energy source, it must be connected to the home automation system, which is intended to be done through the use of intelligent electrical networks based on the creation of an artificial neural network.

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