A Novel Low Cost Automation of Transfer Switch Control for a Hybrid Solar Power System with Simulation

Leonardo A. Venancio Jr. and Alvin Y. Chua
Mechatronics Research Laboratory, Mechanical Engineering Department
De La Salle University, Manila, Philippines
Email: leonardo_venancio@dlsu.edu.ph, alvin.chua@dlsu.edu.ph

***Abstract*— This paper presents a new automation solution to hybrid solar power system originally installed in manual transfer but soon required automated transfer, whereas charge indicator is not available. While the solution is originally intended to resolve a particular problem in a facility in Laguna, the methodology of this paper is also applicable to setups with similar condition. The automation solution provides control over the transfer switch mechanism from grid to solar and vis-a-vis. The automation system incorporated the approximate linear relations between the state of charge and the terminal voltage. Charge analysis was conducted to the lead-acid battery bank of the setup and data were utilized to determine the sustainable maintaining percentage requirement of the bank before switching. The automation setup was realized through the ladder logic circuit created. Another automation solution was presented for a scenario of adding a third source of electricity – from an on-shore roof wind turbines. All logic circuits were simulated and proven working. Economic analysis of the proposed system was also conducted. Result shows that the automation solution is 30% cheaper than the commercial setup, while return of investment is at 88% in just one year.**

***Index Terms*— automatic transfer switch, photovoltaic module, Programming Logic Controller, simulation, solar, wind**

I. Introduction

The usage of solar power, particularly of PV modules is not new in the Philippines. Based on a 2018 Solarplaza study [1], the Philippines ranked fifth around the world, and first in Asia in terms of solar photovoltaic use for power generation. Being a tropical country, the Philippines has a great potential in harnessing solar energy. This is the reason why many make use of their available spaces on their rooftops and have solar panels installed in it to support primary lighting loads in an attempt to lessen their electricity dependence from the grid. More institutions are being attracted to this system not only to promote green energy, but also because electric rates in the country are not cheap. In fact, a 2018 Thinktank report [2] revealed that the average electricity price in the Philippines is second highest in the whole Asia, mainly because electricity rates are not subsidized by the government.

Basically, there are three types of PV module installation: grid-tied type, off grid type and grid-hybrid type. [3]. Grid tied is the most basic of all setup, where a battery bank is no longer need. The system provides energy mainly from the grid, but also rely on solar power whenever available. Off-grid setup meanwhile is being applied on areas isolated to the main power grid. It typically uses the combination of generator set and solar energy or other source of electricity. Lastly, grid-hybrid setup uses both the PV modules and the grid as source of electricity. Battery banks are used in this setup to primarily store excess electricity being collected by PV modules. Battery banks are either of lithium-iron or lead acid type. On a typical hybrid setup, power grid is held as main source of electricity while PV modules and its battery serves as secondary source of power.

Automation system is always incorporated to ensure synchronization, promote efficiency, increase productivity and reduce lead time to a certain technology. In the research of Yambot, Casano, Mina, Yu and Chua [4], system automation is utilized to control temperature and screw speed of a briquetting machine to guarantee the quality of the briquette output. In effect, it increased the production rate of the machine. Meanwhile, Martinez and Chua [5] make use of the automation concept to reduce energy consumption in ventilation of a building. Their system utilized ladder logic to simulate eight scenarios of combination and/or exclusion of air-conditioning unit and windows as mode of ventilation. The setup was proven to be effective in saving electricity to more than double the amount of setup installation.

The use of automation system to different types of PV module installations are widely being studied in various literatures. For instance, Cen, Kubiak, Lopez and Belharouak [6] utilized SCADA to design automation system for the combination of solar PV farm and microgrid through battery storage system in Qatar. Ghosh, Basu, Karkanar, Roy, Kumar, Chakraborty … and Hari [7] on the other hand made use of Arduino to provide automation for solar tracking system through

Manuscript received July 1, 2019; revised May 21, 2020.

doi: 10.18178/ijmerr.9.7.987-997

light dependent sensors. A similar setup was devised in the research of Kulkarni and Kulkarni [8] where LDRs are partnered to motion sensors to create a system of solar tracking where human intervention is reduced. The process, which was automated using Raspberry Pi aimed to be used at places where it is impractical for humans to conduct solar gain calculation. Meanwhile, a case study of Arafa, Said and Elwany in [9] make use of a programmable logic circuit to control transfer switches between solar and grid. A unique feature of the case study is the bisection of a residential home into different sections where the PLC can decide what type of source a section should depend on based on charge availability. Although the setup is complicated and doable, the application of it to an automation problem is vaguely seen.

Transfer switch mechanism meanwhile is an important component of a grid/hybrid setup, as it controls what should be used as an energy source – the power grid or PV module. As lengthily discussed in Reference [10] there are three modes of transfer switch mechanism, namely manual, non-automatic and automatic. Manual switching mechanism make use of knobs where the operator will manually switch back to the secondary source once outage happens using the first source. The length of outage depends on the availability of the operator. Non automatic switching mechanism on the other hand operates by pressing buttons. Shifting to secondary source happens inside the device through an electro-mechanical assembly. The setup still requires an operator before it works. This is lengthly discussed in the research of Lau, Song, Hall, Jiang, Lim, Perez, Wurfl, Ouyang, and Lennon [11]. Meanwhile, automatic transfer switch mechanism operates by a programmable setup devised to do the transfer switching after attaining a particular state by which it was programmed. However, the setup is viewed as expensive to acquire.

Various grid/hybrid setup being installed operates by manual or non-automatic switching. Whilst, through course of usage, the need for the setup to be changed to automatic switching arise. However, the acquisition price of a commercial transfer switch with controllers suitable for this application is quite high, amounting to Php 115,000.00 disregarding shipment fees [12]. Whereby a development of low cost automation of transfer switch for an already existing grid/ hybrid solar power system is needed to address the operational problem of this particular setup.

This study focused on the new design and simulation of an automation of transfer switch control for a hybrid back-up grid solar power system using PLC. Moreover, the determination of: the charging profile of an existing lead acid battery bank was done to determine the maintaining depth of charge as switching indicator. The economic benefits of the automation solution was also determined. The impact of incorporation of a wind source as other source of electric power was also analyzed. A case study on an existing system to gather data from the automation solution is also done to verify the results of the system. The sensing of currents and voltage of lead-acid batteries to determine the depth of charge were devised first before the commencement of the design process.

II. Hybrid Solar Systems

The considered setup in this study is the solar PV module system installed in the roof deck of an academic building in the province of Laguna, Philippines. The system has a rated capacity of 60kW powered by 60 pieces of solar panels. The system uses 12 lead-acid battery banks with a total battery capacity of 14400 W-Hr. The solar charger circuitry is composed of a hybrid Inverter, distribution boxes, two charge controllers and relays.

The system is a hybrid solar-grid power where solar energy serves as the main source while the grid provides back-up electricity in case the supply from the solar or the battery becomes inadequate. That distribution line supplies electricity for lighting to all the 15 classrooms of the three-story building and all the ventilation loads of the five classrooms in the third floor. All remaining loads of the building are solely connected to the grid.

However, the system lacks automation of transfer between solar and grid. In the occurrence of outages, manual transfer of switch is being conducted, allowing longer and unpredictable time before power comes back. A dual MTP automatic transfer switch was installed to solve the problem. However, the mechanism becomes ineffective on times where supply of solar gains is low. Since the ATS cannot ascertain the depth of charge of the battery, unwanted and repetitive automatic transfer occurrence is unavoidable.

Another problem of the system is the unavailability of charge indicators. Charge indicators are important for the automation so as to determine where and when automatic transfer should happen. A buffer supply of energy from the battery bank before the switching is important to avoid unnecessarily repetitive automatic transfers.

According to Reference [13], each lead-acid battery has an approximate charging time of 10-12 hours. This type of battery exhibits a unique pattern of charge cycle as detailed in Fig. 1. The pattern is composed of three stages: The constant current charge, the topping charge and the float charge. While stage 1 exhibits almost constant amount of current, the terminal voltage is increasing. During the second stage, current reading goes down exponentially while terminal voltage maintains. At this stage, the level of battery charge can provide sustainable supply which can last for hours. While on the final stage, both the current and voltage will decrease slowly.

The problem of state of charge estimation of hybrid electric setup is thoroughly discussed in the work of Pang, Farrell, Du and Barth [14]. They formulated an algorithm using theoretical formula and integration as The problem of state of charge estimation of hybrid electric setup is thoroughly discussed in the work of Pang, Farrell, Du and Barth [14]. They formulated an algorithm using theoretical formula and integration as a solution with consideration of internal battery parameters.

A similar approach was developed by Chiasson and Vairamohan [15] in which they devised a method using different formula integration. However, since both of this approach utilizes pure integration, the methods are deemed bias, have numerical errors, and the non-perfect knowledge of the battery's total charge. Meanwhile, the works of Coleman, Lee, Zhu and Hurley [16] concluded a concept of approximate linear relations between the depth of charge and the terminal voltage.

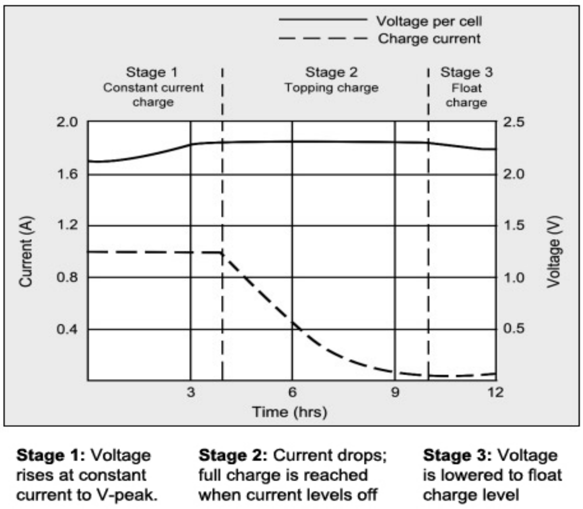


Figure 1. Charge Stages of a lead acid battery, as detailed from reference [13]

The conclusion of approximate linear relations is greatly considered as a way of charge indication in this study. In place of an actual charge indicator, the combination of current and voltage drop while charging is used to determine the depth of charge in relation to the theoretical charging cycle of lead acid battery as indicated above.

III. Solar Automation Transfer Process

This section discusses the methodology used in the research. It presented the analysis made on the charging profile, the automation concept and design, the automation equipment used, and the ladder logic programming of the automation design. The section also presented another automation concept where an inclusion of wind energy as third source of electricity is considered.

A. Analysis of Lead Acid Charging Profit

The determination of charging profile is pertinent in providing the automation solution for the ATS of hybrid solar power system. Ocular inspections were conducted to the setup. Since charge indicator for the lead acid battery bank is not available in the system, certain solutions were laid down to determine the level of charge of the lead acid battery bank. By considering the literatures on lead acid battery stated above, the researchers utilized the current and terminal voltages as indicator of charge cycle. A charging profile analysis was devised to record hourly the current and terminal voltage at the lead acid battery bank.

The bank was firstly drained by turning off the ATS after switching the energy source to solar power over a weekend. The blackout on the building indicated that the battery bank has been drained. Hourly recording of current and terminal voltage at the lead acid battery bank started at dawn while energy source was switched back to grid. The analysis ran for twelve hours to meet the optimum charging time requirement of the lead acid batteries.

To maintain sustainability and provide buffer supply before switching, a maintaining 60% of charge cycle is set before switching back to solar and 40% of charging cycle is set minimum level to shift the energy source back to grid. Its corresponding current and terminal voltage is used as level indicator for the automation design. Further result of this analysis is detailed in the succeeding chapter.

B. Automation Concept and Design

Fig. 2 details the automation concept and design used in the system. The system operates first by detecting

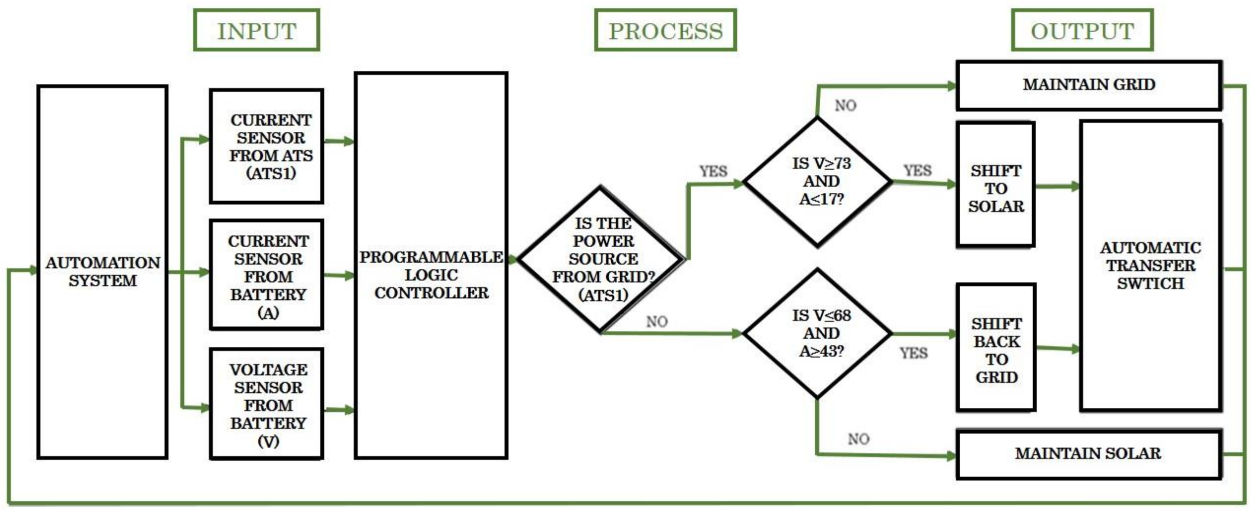


Figure 2. Flowchart of the solar-grid automated transfer process

electricity flow on the automatic transfer switch. This will determine whether the power source is from the grid or from the solar. Using current sensor and voltage transducer installed in the lead-acid battery bank, the charge level is determined. The system works by combining the values of the current and voltage to predict if the charge level is at 40% or 60%. Upon reaching a minimum requirement of 60% charge, the transfer switch will commence from grid to solar. Once the system determines that the charge is at a low 40%, the switch will be conducted from solar to grid until the 60% yield charge is met.

C. Automation Equipment

Fig. 3 details the simple illustrative diagram of the proposed system. It basically resembles a setup where PV modules are connected to charge controllers can either be stored in a DC battery bank or directly supplied to the inverter to change DC to AC. The converted AC electricity is controlled by an automatic transfer switch before it is being supplied to the loads.

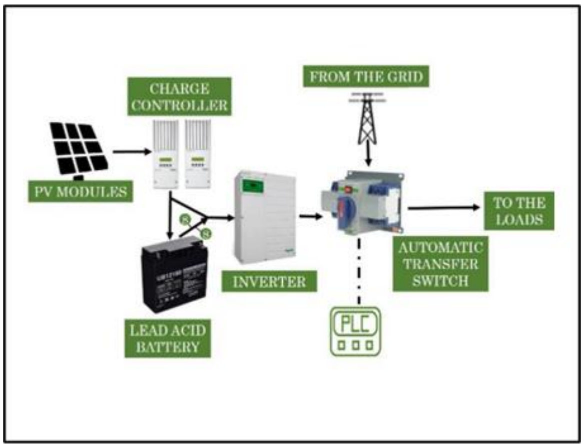


Figure 3 Illustrative diagram of the proposed system

To enable the automation process, charge sensors were installed to the ATS while voltage and current sensors were also installed near the lead acid battery. PLC is installed in the ATS to control the transferring of electric source between grid and solar energy.

As recommended, the PLC to be used in the setup is a Micrologix 1400 which belongs to the Allen-Bradley® MicroLogix™ family of controllers from Rockwell Automation. The said unit is detailed in Figure 4. The features of the unit that suits the required PLC includes full ASCII (read/write) capability, online editing of ladder logic while the program is running, a built-in LCD with backlight controller and I/O status viewing and simpler interface. Its modules can have up to 38 1/O points which can be expanded up to 7 expansion I/O modules (1762 I/O) with 256 discrete I/O. This is suitable in such cases that more types of energy sources will be used and simultaneously controlled. Additional features include 10K words user program memory and 10K words user data memory and up to 128K bytes for data logging and 64K bytes for recipe.

Figure 4. Micrologix 1400 [17]

The suggested automatic transfer switch unit to be used is a 2P 63A 230V MCB type as shown in Figure 5. Its rated voltage 400V/230V and rated current up to 63A. The mechanism of ATS works as such when one power goes wrong, it will automatic connect one or several load circuits from one power to the other power automatically, to ensure normal power supply of load circuit switch.

Figure 5. 2P 63A 230V MCB Automatic Transfer Switch [18]

For the current sensing, the module to be used is 1414-CCZ10FZWZDE Current sensor still from Rockwell Automation as detailed in Figure 6. Its power supply is self-powered, with 100ms response time. The device has an amp range between 0-50A and has a maximum Amp capacity of 190A. This specification is suitable because the only needed sensing range is from 17-43A while the maximum amperage of the profile is up to 51.3. Moreover, its output is between 0-10V DC.

Figure 6. 1414-CCZ10FZWZDE Current sensor [19]

Meanwhile, the suggested voltage sensing device is AcuAmp VACT150-42L voltage transducer with voltage measurement up to 150V. The unit is detailed in Figure 7. It has 250ms response time and has an operating temperature capacity up to 50°C. Meanwhile it has an output current range from 4-20 mA proportional to rated voltage in both sinusoidal and non-sinusoidal situation.

Figure 7. AcuAmp VACT150-42L voltage transducer [20]

For the inclusion of a third source of power – using solar turbine, the automatic transfer switch is suggested to be changed from MCB type to Suntree ATS to accommodate 3 phase-model. The unit is shown in Figure 8. The unit has 3 poles and 630 amps capacity.

Figure 8. 3P Suntree ATS 60amps [21]

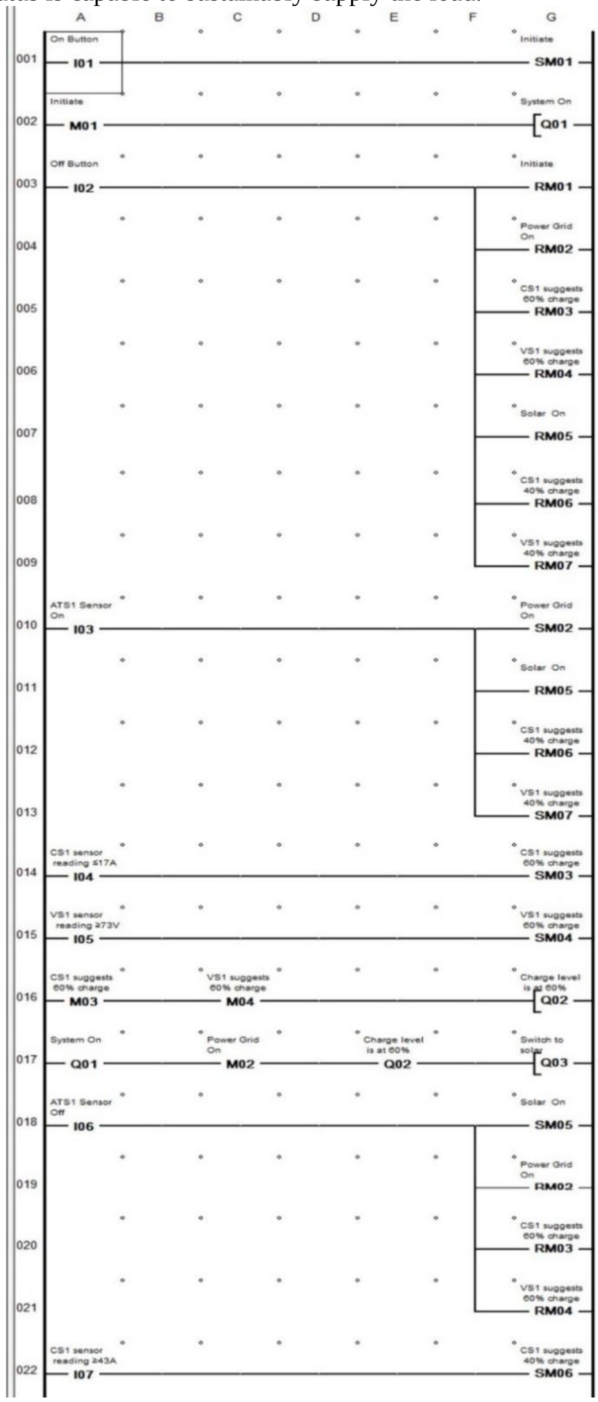
B. Automation Program

In conducting the programming part of this research, Picosoft v6 was utilized to demonstrate and simulate the automation design. The software is of free access and suitable to the suggested PLC. Detailed in Table I are the programming elements and their corresponding function. Meanwhile, Figure 9a detailed the ladder logic of the automation transfer from grid to solar and 9b for the transfer from solar to grid.

TABLE I. PROGRAMMING ELEMENTS

Element	Function
Input Basic Unit	
I01	On Button
I02	Off Button
I03	ATS Sensor On
I04	Current Sensor ≤17A
I05	Voltage Sensor ≥73V
I06	ATS Sensor Off
I07	Current Sensor ≥43A
I08	Voltage Sensor ≤68V
Output Basic Unit	
Q01	Automation On
Q02	Charge cycle is at 60%
Q03	Switch to solar
Q04	Charge cycle is at 40%
Q05	Switch to Grid
Markers	
M01	Initiate
M02	Power Grid On
M03	Current Sensor suggests 60% charge
M04	Voltage sensor suggests 60% charge
M05	Solar is on
M06	Current Sensor suggests 40% charge
M07	Voltage Sensor suggests 40% charge

As detailed in Fig. 9 from line 1-17, the automation starts after pressing the on button I01. This will activate marker M01 which in turn will turn on the system Q01. Once the ATS Sensor detects electric charge at the distribution line from the grid, marker M02 will recognize that grid power is On. This will disable all markers for 40% charge indication. Once current senses a reading ≤17A, marker M03 will activate. If voltage sensor reads ≥73V, marker M04 will activate. If both markers activate simultaneously, Q02 will activate ensuring that the charge cycle is at 60%. This will trigger Q03 to actuate the ATS to shift to solar since charge status is capable to sustainably supply the load.



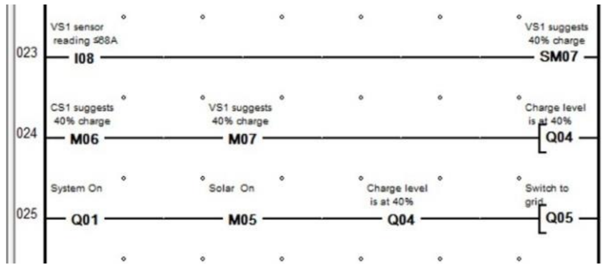


Figure 9. Ladder Logic of the proposed automated transfer from grid to solar and from solar to grid

On the other hand, If ATS sensor can't detect electric charge at the distribution line from the grid 106, then marker M05 will activate, indicating that the solar power is in use, as detailed in Fig. 9 line 18-25. This will disable all markers for 60% charge cycle indication. Once current sensor senses ⩾43A, marker M06 will be activated. If voltage sensor detects ⩽68V, marker M07 will be activated. If both markers M07 and M06 activates simultaneously, the Q04 will be activated indicating that the charge level is at 40%. This is considered low enough to trigger Q05 to switch the ATS back to grid.

Meanwhile, the I02 serves as off button, in which once activated, all markers will shut off. This can also serve as emergency stop in case sensing or the actual program fails.

C. Three Source Automation Process

The researchers also considered the scenario of installation of three on-shore small roof mini wind turbines with same capacity as that of the solar panels, and Absorbent Glass Mat (AGM) battery bank to store electric energy from the turbine. With such condition, a triple acting transfer switch is needed. This third source of energy is set to serve as additional back-up in such cases that the supply of solar energy is inadequate for the load. This makes shifting to the grid a farther third option which will only arise if the two renewables run out of electricity. The flowchart of the automation process will also change.

The researchers also considered the scenario of installation of three on-shore small roof mini wind turbines with same capacity as that of the solar panels, and Absorbent Glass Mat (AGM) battery bank to store electric energy from the turbine. With such condition, a triple acting transfer switch is needed. This third source of energy is set to serve as additional back-up in such cases that the supply of solar energy is inadequate for the load. This makes shifting to the grid a farther third option which will only arise if the two renewables run out of electricity. The flowchart of the automation process will also change.

Figure 10 presented the modified flowchart of the automation process with three source of energy at hand: solar energy from PV modules, wind energy from small roof wind turbines and the grid. Sensors were also installed in the AGM battery banks where the electricity generated from wind is stored. Once the solar energy becomes inadequate, switching to grid won't immediately happen. In place, sensors from AGM will determine if charge is enough to supply the load. Once the charge level is deemed enough, shifting to wind occurs. If otherwise, the ATS will transfer the source back to grid.

Table II detailed the additional elements used in the incorporation of wind energy as the third source of electricity. It is clearly indicated that additional current sensor (CS2) and voltage sensor (VS2) has been added to the AGM battery bank. The suggested depth of charge monitored is similar to that of the solar: namely 60% and 40% respectively. Meanwhile the tabulated reading of amperage and voltage needed in estimating the depth of charge is also similar to that of the solar.

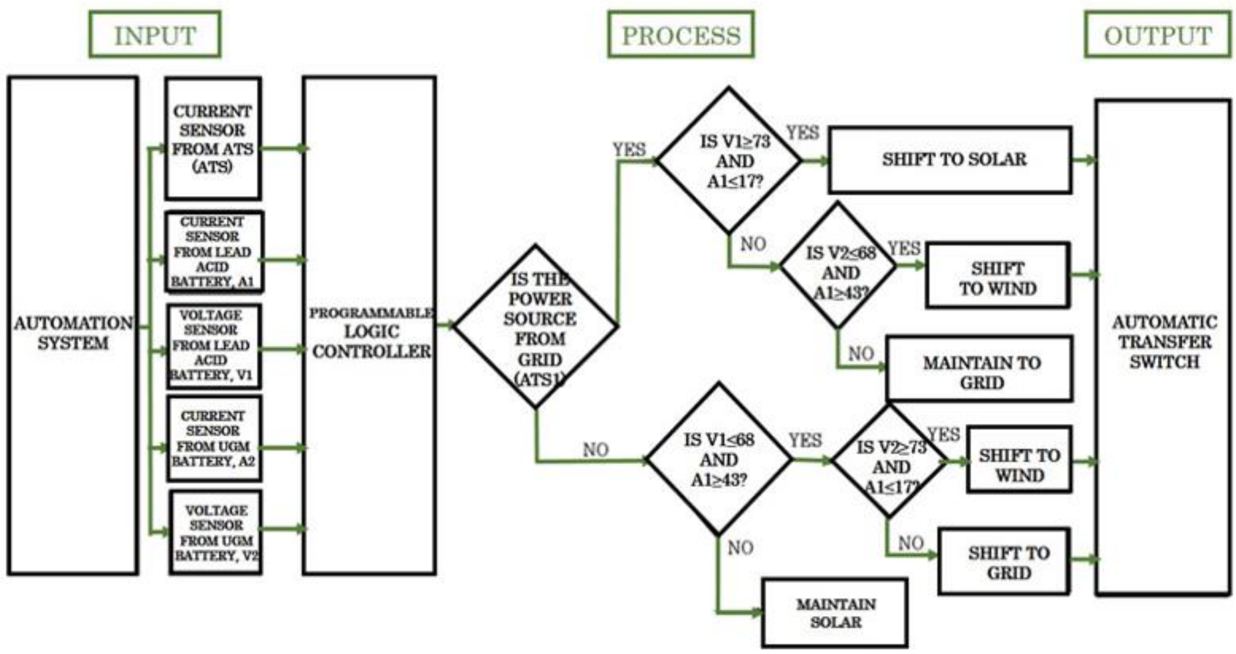
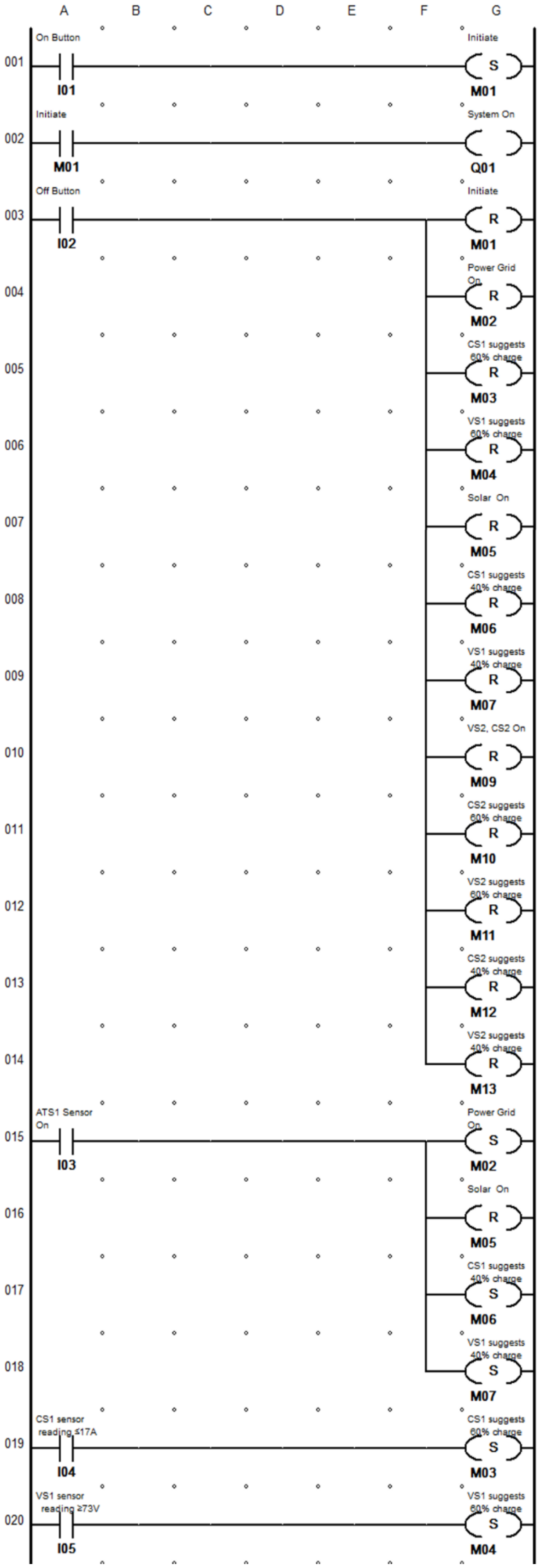


Figure 10. Modified flowchart of the solar-wind-grid automated transfer process



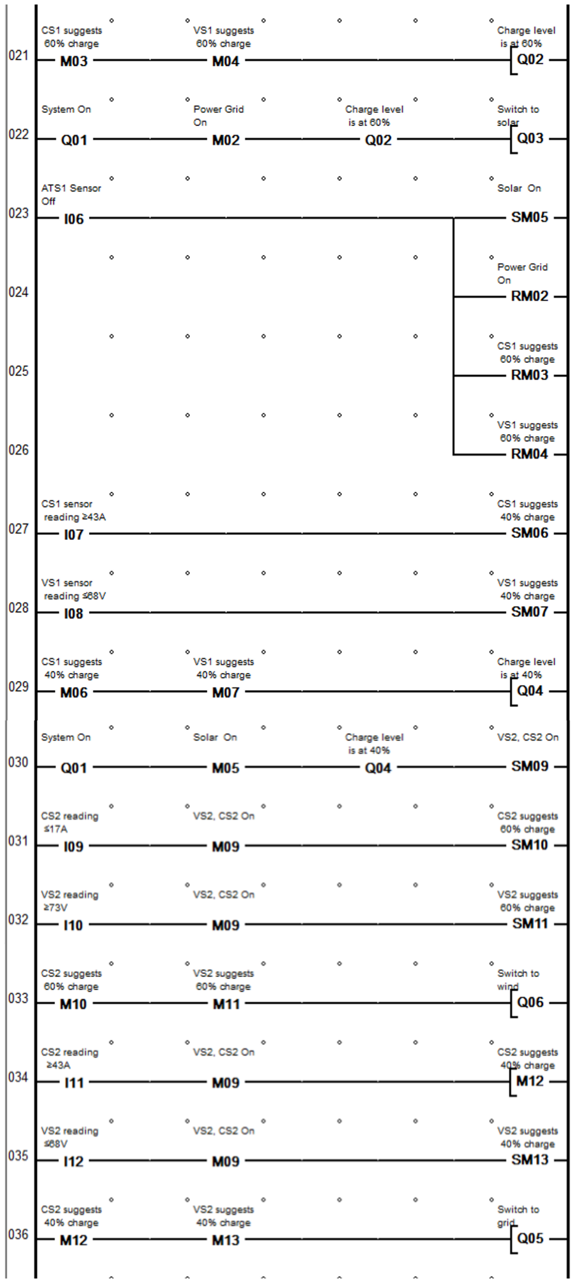


Figure 11. Ladder Logic of the modified automated transfer system of Solar-Wind-Grid

TABLE II ADDITIONAL PROGRAMMING ELEMENTS FOR WIND-SOLAR-GRID SETUP

Element	Function
Input Basic Unit	
I09	CS2 reading ≤17A
I10	VS2 reading ≥73V
I11	CS2 reading ≥43A
I12	VS2 reading ≤68V
Output Basic Unit	
Q06	Switch to Wind
Markers	
M09	VS2, CS2 On
M10	CS2 suggests 60% charge
M11	VS2 suggests 60% charge
M12	CS2 suggests 40% charge
M13	VS2 suggests 40% charge

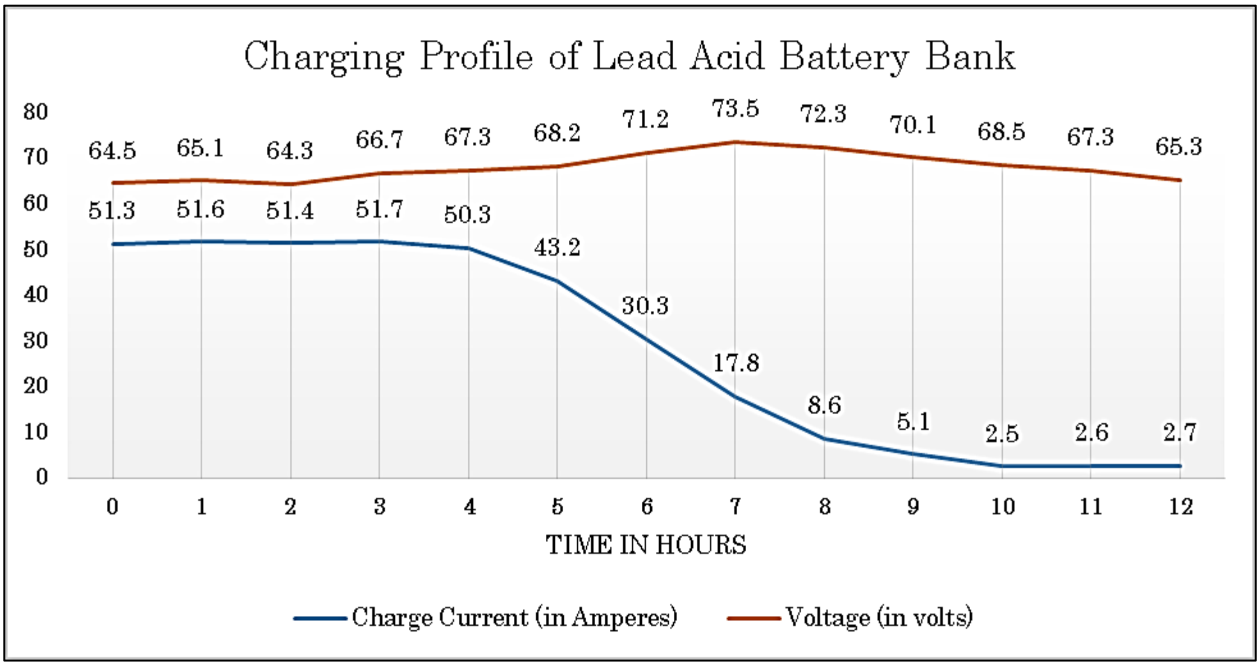


Figure 12. Line Graph of the charging profile of Lead acid Battery bank

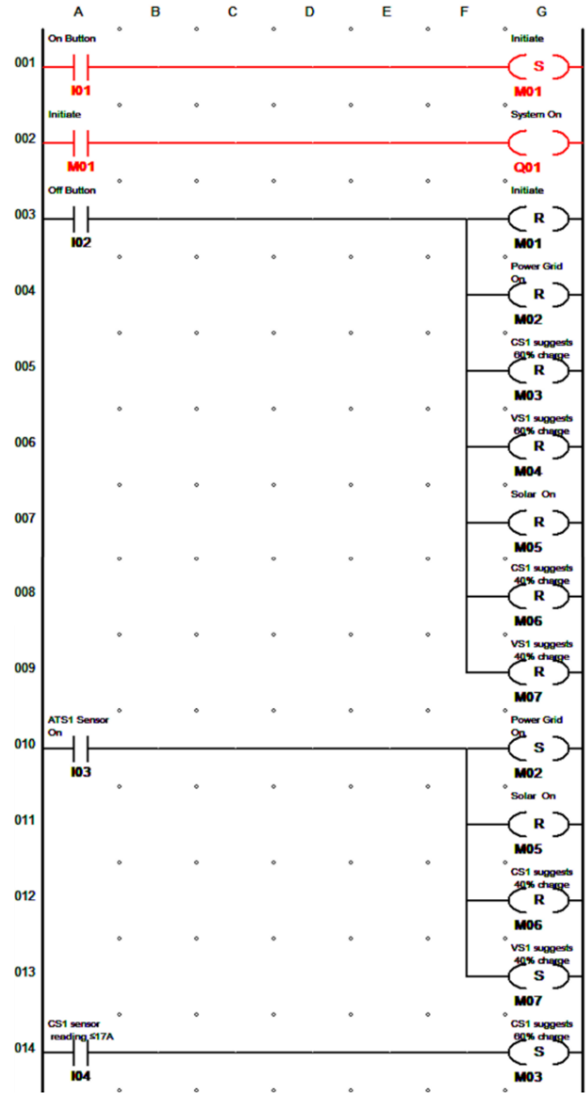
IV. Results

A. Lead-Acid Battery Charge Cycle Analysis

After the conduct of the charge cycle analysis, the tabulated current and terminal voltage was presented in a form of line graph. Figure 12 presented the result on a 12-hour long cycle. From this data, the researchers designated the fifth hour, with 68V and 43A or 40% of the charge cycle as the ideal maintaining level of the bank to which transfer to grid is needed upon its attainment. Moreover, the seventh hour, with 73V and 17A or 60% of the charge cycle is designated as the ideal maintaining level of the bank advisable for the solar energy to be utilized regardless of the weather conditions. These data were used in the decision making of the ladder logic.

B. Ladder Logic Simulation for Two Source Automation Process

Figure 13 presented the sample simulation of the programming circuit from Picosoft 6 showing the scenario of transfer switch from Grid to solar. As indicated by red color, the system first sensed ATS1 (I06), triggering marker M05. Upon attainment of the required combination of voltage and current from their respective sensors, I07 and I08, markers M06 and M07 triggered Q04. The output Q04 denotes that low charging level is sensed at 40%. Meanwhile, three markers were needed to trigger the transfer switch, output Q05. These are: Q01 which indicates that the power is On, M05 which indicates that the Solar Power is on, and Q04. The simulation shows that once these conditions were met, the transfer from Grid to Solar, Q05 commenced. The simulation also presented that once the system recognizes that the source is from grid, all markers for 60% charge cycle determination will be disabled to avoid multiple charge level detection.



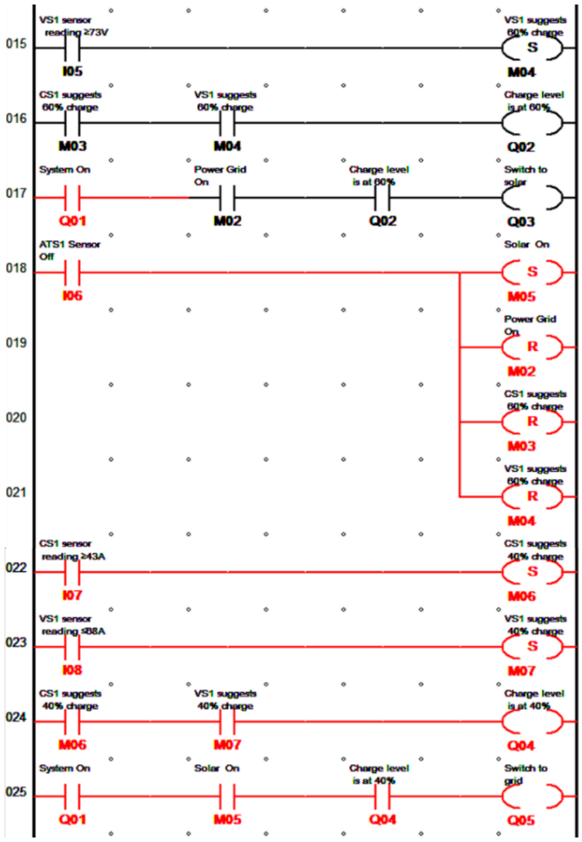
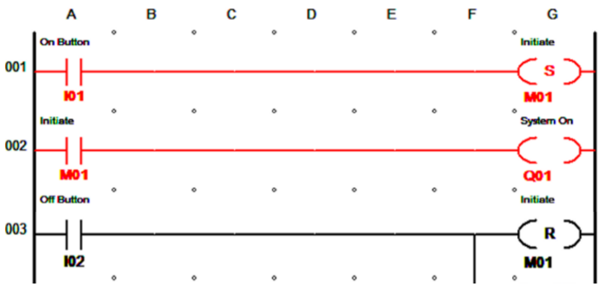
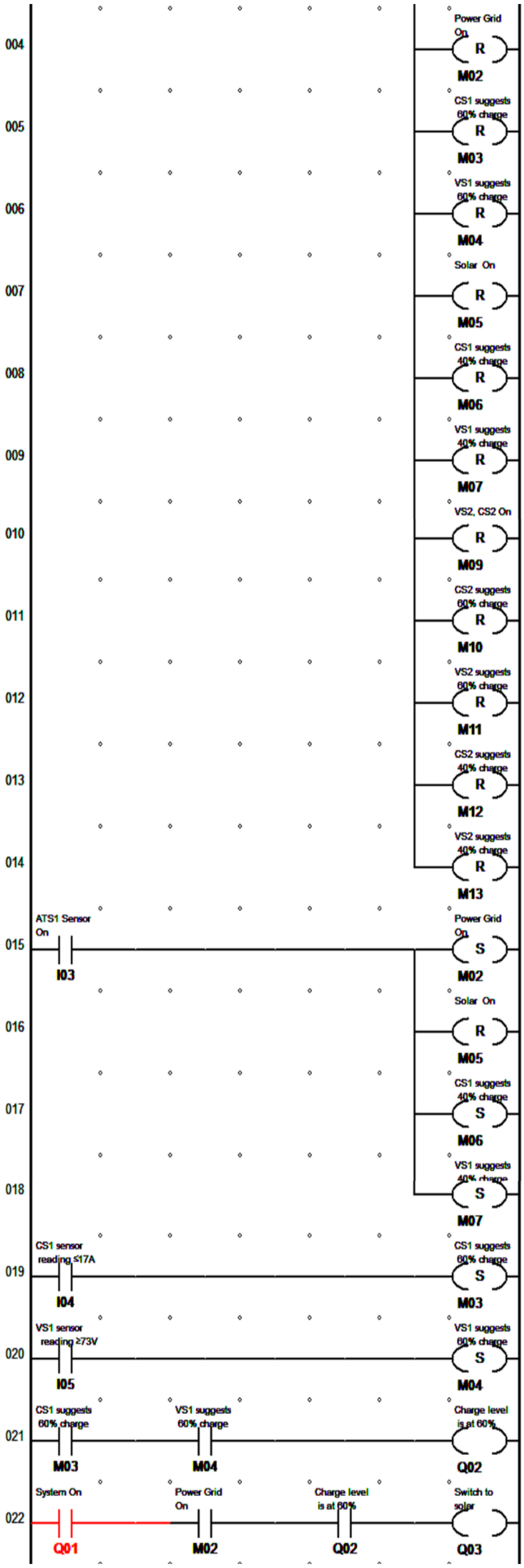


Figure 13. Ladder Logic Simulation of the automated transfer from Grid to Solar

C. *Ladder Logic Simulation for Three Source Automation Process*

Figure 14 details the simulation for the ladder logic circuit for three-way power source. It demonstrated the scenario of transfer from solar to wind. This will only occur once the solar energy available from the bank yields to a limiting 40% charge level. As presented in the Figure 14, after triggering of I07 and I08, markers M06 and M07 was set respectively. Thus Q04 was triggered denoting that solar power is at low charge level at 40%. Instead of switching to grid, output Q04 set marker M09 on, denoting that voltage and current sensors on AGM will start sensing. Upon sensing, VS2 and CS2 triggered markers M10 and M11 denoting that the system measured that AGM is at sustainable charge level of 60%. These two markers were needed to trigger output Q06, the transfer from solar to grid.





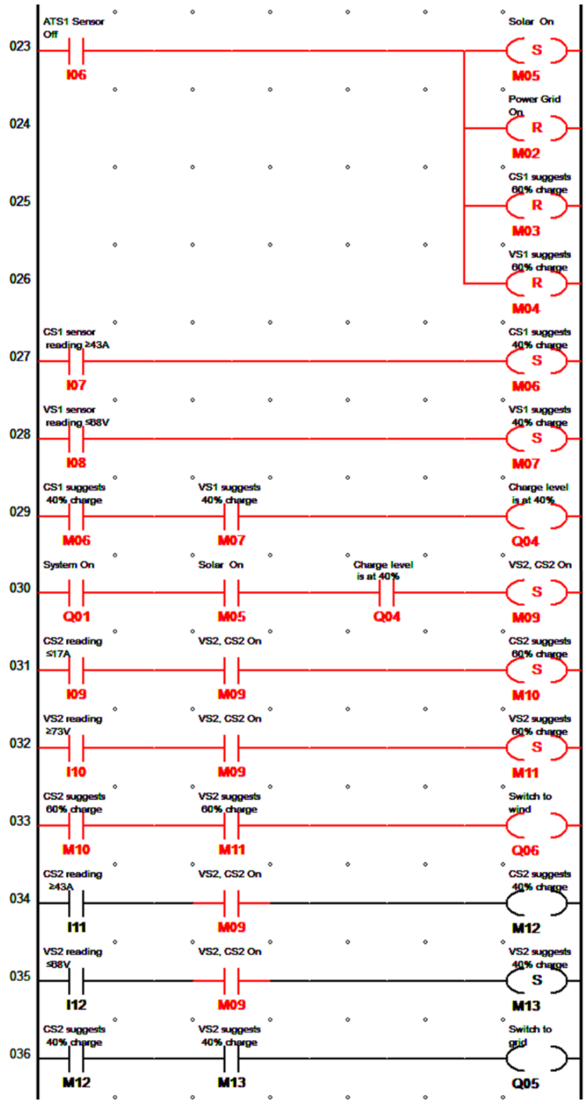


Figure 14. Ladder Logic Simulation of the automated transfer from Solar to Wind

D. Economic Analysis

The cost of the system acquisition and installation was computed which amounted to Php 38,000.00 The breakdown of this cost is presented in Table III. This automation solution is cheaper and much accessible unlike its commercial counterparts. An actual automatic transfer switch regulated by controllers like that of Thompson TS870 [12] is only available overseas. The unit can only provide one phase shift at maximum 250amps. Moreover, the cost of the actual unit, disregarding shipping fees amounts to Php 115,000.00. The cost of the automation solution is roughly 33% of the commercial TS870.

The return of investment, or ROI is computed as a ratio of the investment gain to the cost of investment. The considered investment gain of the system is the amount of electricity being saved while using solar, computed in a span of one year. Meanwhile, the cost of investment considered is the previously computed cost of the automation system.

TABLE III. ESTIMATED COST OF AUTOMATION SYSTEM

Equipment/ Expenses	Cost in Php
Micrologix 1400	16000.00
MCB ATS	4000.00
Current Sensors	6000.00
Voltage Transducer	7000.00
Installation and Material Expenses	5000.00
Total	38000.00

In computing the investment gain, the system is assumed to utilize an estimate of 1.5 kW of solar energy in an hour. This equals the same amount of energy saved from the grid. It is also assumed that the system will depend on solar for around 8 hours in a day, 365 days in a year. Meanwhile, the assumed cost of kWh consumption according to local electric concessionaire, Meralco is P 9.8385. Using these data, the total Investment Gain amounted to P43,092.63. Furthermore, the return of investment was calculated to be at 88.18% in just one year of implementation.

V. CONCLUSION

The paper presented a new automation solution of transfer switch for a hybrid solar power system. An existing PV module setup with lead acid battery bank as energy storage was used to gather data for the automation setup. The research presented a method of battery charge level determination through the use of current and voltage sensors. It utilized the findings of [16] on the approximate linear relations between the state of charge and terminal voltage.

Charge cycle analysis was conducted and the maintaining charge percentage was determined: 40% minimum to switch back to grid and 60% minimum to switch to solar. Ladder logic was developed by setting the respective voltage drop and current at that percentage level as trigger to actuate the transfer switch.

Moreover, the addition of a third source of energy – an onshore roof small wind turbines was considered. The wind power was set as back up source of electricity in cases of low solar energy collection on the PV modules. This makes the grid power as the last option of electricity. Its addition to the choices of energy paved way for the development of a new logic circuit.

Both the two-way and three-way energy sources were simulated using Picosoft 6 and the ladder logic circuits sufficed the requirements of both systems. Economic advantage of the proposed automation solution was also analyzes. It found out that this solution is cheaper by 33% to that of an existing commercial model available in the market.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Mr. Venancio conducted the data gathering, programming, and writing of this research paper. Dr.

Chua oversaw the whole research process, verified the accuracy of the simulation and the economic analysis.

REFERENCES

[1] M. Dorothal, "Top 25 Solar Plants Southeast Asia," 24 May 2018. [Online]. Available: https://www.solarplaza.com/channels/top-10s/11881/top-25-solar-plants-southeast-asia/.

[2] "Probing the high cost of electricity," 1 OCtober 2018. [Online]. Available: https://www.doe.gov.ph/energist/probing-high-cost-electricity.

[3] Energy Informative, "Grid tied, off-grid and hybrid solar systems," 2019. [Online]. Available: https://energyinformative.org/grid-tied-off-grid-and-hybrid-solar-systems/.

[4] A. Yambot, L. Casano, R. Mina, K. Yu, and A. Chua, "Automated Screw Type Briquetting Machine as A Small Business Venture," *International Journal of Automation and Smart Technology*, vol 6, no 4, pp. 185-189, December 2016

[5] D. Martinez, and A. Chua, "New Design and Automation Concept of an Energy-Efficient, Tertiary Building for Mixed-Mode Ventilation System," *International Journal of Automation and Smart Technology*, vol 7, no 4, pp. 163-178, December 2017

[6] Z. Cen, P. Kubiak, C. M. López, and I. Belharouak, "Demonstration study of hybrid solar power generation/storage micro-grid system under Qatar climate conditions," *Solar Energy Materials and Solar Cells*, vol 180, pp. 280-288, July 2018

[7] D. Ghosh, R. Basu, S. M. Karmakar, A. Roy, A. Kumar, J. Chakraborty ... and U. Hari, "Grid-tie rooftop solar system using enhanced utilization of solar energy," *in Proc. 8th Annu. Industrial Automation and Electromechanical Engineering Conf (IEMECON)* IEEE, 2017, pp. 275-277.

[8] S. N. Kulkarni, and M. N. Kulkarni, "Automation of solar panel assessment system," *In Proc. 2nd International Conf. on Communication and Electronics Systems (ICCES)* IIEE, 2007, pp. 672-676.

[9] M. I. A. Arafa, E. Said, and M. Elwany, "An optimized design criteria of non-outage and power reduction for hybrid solar-grid system (residential homes—case study)," *in 19th International Middle East Power Systems Conference (MEPCON)* IIEE, 2017, pp. 59-62.

[10] Taylor Power Systems, "Transfer Switch Types," September 2011. [Online]. Available: http://www.taylorpower.com/pdfs/TPS-ATS-Types.pdf. [Accessed 10 May 2019].

[11] D. Lau, N. Song, C. Hall, Y. Jiang, S. Lim, I. Perez-Wurfl, Z. Ouyang and A. Lennon, "Hybrid solar energy harvesting and storage devices: The promises and challenges," *Materials Today Energy*, vol 13, pp. 22-44, February 2019

[12] Thompson Power Systems, "Controllers and Annunciators-TSC870," 2013. [Online]. Available: https://www.thomsonps.com/Controllers_and_Annunciators/TSC_870/.

[13] "BU-403: Charging Lead Acid," 2010. [Online]. Available: https://batteryuniversity.com/learn/article/charging_the_lead_acid_battery.

[14] S. Pang,, J. Farrell, J. Du, and M. Barth, "Battery state-of-charge estimation" *in Proc. of the American control conf. (Cat. No. 01CH37148)* IEEE, 2001, Vol. 2, pp. 1644-1649.

[15] J. Chiasson, and B. Vairamohan, B, "Estimating the state of charge of a battery," *IEEE Transactions on Control Systems Technology*, vol. 13, no. 3, pp. 465–470, July 2005.

[16] M. Coleman, M, C. K. Lee, C. Zhu, and W. G. Hurley, "State-of-charge determination from EMF voltage estimation: Using impedance, terminal voltage, and current for lead-acid and lithium-ion batteries," *IEEE Transactions on Industrial Electronics*, vol. 54, no.5, pp. 2550–2557, Oct 2007.

[17] Indiamart, "Allen Bradley Micrologix 1400 , 1766-L32BXB," [Online]. Available: https://www.indiamart.com/proddetail/allen-bradley-micrologix-1400-1766-l32bxb-18970769662.html. [Accessed 10 May 2019].

[18] AliExpress, "2P 63A 230V MCB type Dual Power Automatic transfer switch ATS," [Online]. Available: https://www.aliexpress.com/item/32786834934.html?productId=32786834934&productSubject=2P-63A-230V-MCB-type-Dual-Power-Automatic-transfer-switch-ATS. [Accessed 10 May 2019].

[19] Allen-Bradley, "Current Sensor," 2010. [Online]. Available: https://literature.rockwellautomation.com/idc/groups/literature/documents/in/1414-in019_-en-p.pdf. [Accessed 10 May 2019].

[20] AutomationDirect, "VACT150-42L," [Online]. Available: https://www.automationdirect.com/adc/shopping/catalog/sensors_-z-_encoders/current_-a-_voltage_sensors_(ac_-a-_dc)/voltage_transducers/ac_voltage_transducers/vact150-42l. [Accessed 10 May 2019].

[21] Alibaba, "3P Suntree ATS 60amps," [Online]. Available: https://www.alibaba.com/product-detail/China-Suntree-3-Phase-Automatic-Transfer_60462955387.html. [Accessed 10 May 2019].

Mr. Leonardo A. Venancio Jr. is a graduate student taking Master of Science in Mechanical Engineering in De La Salle University, Manila, Philippines. He finished his bachelor's degree in Mechanical Engineering in Laguna State Polytechnic University, Santa Cruz, Laguna, Philippines. He has a graduate scholarship funded by the Engineering Research and Development for Technology (ERDT) consortium and the Department of Science and Technology – Science Education Institute (DOST-SEI) Philippines.

Dr. Alvin Y. Chua is a Full Professor of the Mechanical Engineering Department of De La Salle University, Philippines. He earned his BSME, MSME, and Ph. D. in ME at De La Salle University-Manila. He conducted his dissertation research at the University of New South Wales, Australia. He received a special citation for the 2003 NAST-DuPont Talent Search for Young Scientists (Mechanical Engineering). He has published several papers in international conferences like Conference on Decision and Control (CDC), and Advance Intelligent Mechatronics (AIM). His research interests are on mechatronics, robotics, optimal estimation and controls.