Automated operation of the Eluvaithivu mini grid wind, solar, diesel generator and battery integrated systems

[1]Ravindran N, [2]Ahilan K, [3]Atputharajah A
[1,2,3]Department of Electrical and Electronic Engineering, University of Jaffna Jaffna, Sri Lanka.
[2]ahilan.eng@gmail.com

Abstract: There are plenty of small islands all around the world as well as in Sri Lanka. These islands are generally separated from the main land. Therefore it is a challenge for the utility to provide reliable, quality power to the consumers economically. This challenge can be mitigated by the application of hybrid power plants, which include solar, wind, diesel generator and/or battery storage integrated systems. Eluvaithivu is an island which is located, twenty-two kilometers away from Jaffna peninsula, and the northern part of Sri Lanka. The total electrification capacity of this hybrid power plant is 60kW. The intermittent nature of the renewable energy power sources such as wind and solar in varying loads always causes stability issues. And also, specifically in this island network, there are difficulties in interconnecting renewable energy power plants together with diesel generator. This is because the synchronization of the diesel generator with the grid with battery as slack bus, causes control issues. Further, operational schedule of the power plants can be improved in such a way to produce reliable, quality power to the consumers economically. This automated operation can be achieved by modifying the existing control techniques of the system. The whole system modelled using PSCAD simulation and the results shows the feasibility of the new proposed automated operation of the power plant.

Keywords: domestic solar panels, wind power, standalone operation, hybrid power plant and renewable energy technologies.

Introduction

Increase the percentage of electrification of a country will enhance the living standard and improve the economic development in remote islanded or rural areas. There are plenty of small islands in Sri Lanka and all over the world. Delft, Nainathivu, Analaithivu, and Eluvaithivu are four islands that are located in the northern part of Sri Lanka. As these islands are separated by sea from the main land, they are not connected with the Ceylon Electricity Board (CEB) main grid. Instead of that, out of these four islands, Delft, Nainathivu, Analaithivu are electrified using small synchronous diesel generators. Because of the transportation cost of diesel barrels to the islands and the environmental pollutions of diesel power plant urge the utility to look for an alternative solution. Therefore, it is a challenge for the utility to provide reliable quality power to the consumers economically.

Further, a similar study carried out in Malaysia with islanded distribution systems. Here the proper control strategy established and the simulation results showed that the controller automatically coordinate and ensure the healthy operation of the system, in predefined islanded areas [7]. In Bangladesh, a five-year solar Mini grid service developed in Sandwip island ensured that the solar PV hybrid is a viable technical option for rural electrification [8].

But in Eluvaithivu, the power generation is from a hybrid plant which includes, solar, wind, battery and diesel generator system. As the wind and solar are freely available renewable energies in the island, it is more economical to use this environmental friendly mini hybrid grid. Further, this is the only power plant in this nature in the country and this is the outcome of the research studies made by CEB Engineer K.Ratneswaran for his Master of Science (M.Sc.) in KTH school of Industrial Engineering and Management under the supervision of Prof.A.Atputharajah and Dr. Jeevan Jayasuriya [1]. For the implementation, the total cost of this project was funded by Asian Development Bank (ADB) [2] and implemented by CEB.

Description about Power Plant

Eluvaithivu hybrid power plant consists of six number of wind turbines for a total capacity of 21kW, total capacity of 46.28 kWp solar panels and total capacity of 134.86 kWh Lithium-ion batteries. Other than this, there are two diesel generators with the capacity of 30kVA and 100 kVA are in operation in Eluvaithivu. Figure1 shows the Eluvaithivu island 400 V connection diagram.

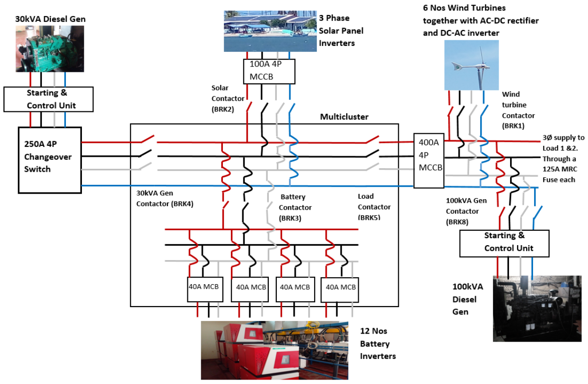

Figure 1: Eluvaithivu island 400 V solar, wind, battery and diesel generator hybrid power connection diagram.

The operation of Eluvaithivu plant is designed in such a way that the battery bus as the slack bus to control the grid voltage at 400V. Further the operation of 30kVA is designed so that in between 3PM to 3AM if the State of Charge (SOC) of the battery is less than 50%the generator will be ON, and once the SOC reaches 90% the generator goes to OFF. But in between 3AM to 3PM if the State of Charge (SOC) of the battery is less than 33% the generator will be ON, and once the SOC reaches 50% the generator goes to OFF. However, it can be further improved with predictive analysis. That is also presented in this paper. Actually, this research was started to solve the real-world problem in Eluvaithivu hybrid power plant using simulation

Slack bus Control of the battery inverter

All the power plants in Eluvaithivu are connected to a common 400 V three phase AC bus. Here the battery bus is considered as the slack bus for the voltage and frequency control and it is connected to the common 400 V AC bus through breaker BRK3. The active and reactive power control of the battery inverter shown in Figure2, here the battery DCLink voltage Vdclink3 is used to derive angle BTeeta which then used to control the gate pulse of the three-phase battery inverters six number of IGBT switches. This holds the voltage magnitude and frequency (phase angle) of the grid by providing required active and/or reactive power. The magnitude of the voltage was taken as 6% above the rated voltage (326V), 346V. From this magnitude and the phase angle three phase voltages were calculated.

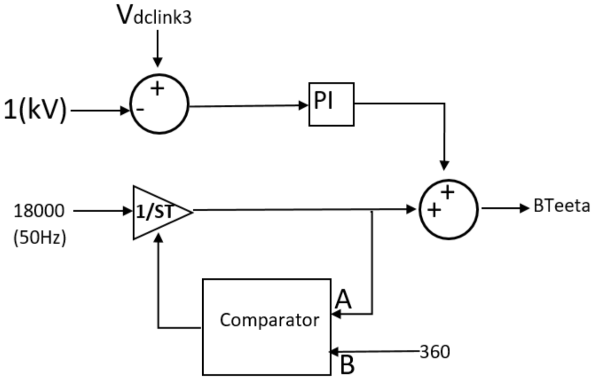

Figure 2: Slack bus control of the battery

Active and Reactive Power Control of the solar panel inverter.

Here solar panel inverter is connected to the common 400 V AC bus (Grid) through breaker BRK2. Figure3 shows active power control of the solar panels. Here the solar inverter DCLink voltage Vdclink2 and the measured voltage vector phase angle STeeta1 is used to derive solar control angle STeeta, which then used to control the gate pulse of the three-phase solar inverters six number of IGBT switches. This DC Link voltage regulatory control ensure whatever the generated active power from the solar panel will be transferred to the grid.

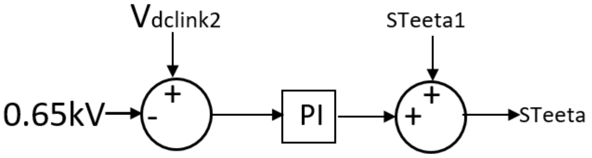

Figure 3: Active power control of the solar panel.

The reactive power control operates the solar inverter at its unity power factor mode operation. This shows in Figure 4. Here the measured reactive power value of the solar panel QS at the connection point to the 400 V bus, used to derive Solarmag, which then used to control the reactive power output of the solar panel systems to the grid.

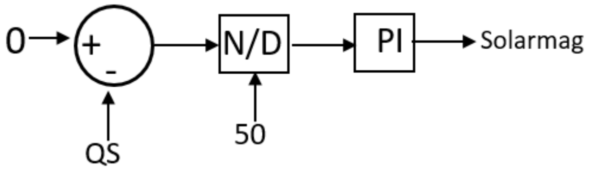

Figure 4: Reactive power control of the solar panel.

C.Active and Reactive Power Control of wind turbine inverter.

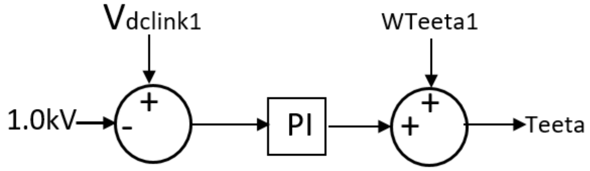

Figure 5: Active power control of the wind turbine inverter.

The wind turbine inverter is connected to the common 400 V AC bus through breaker BRK1. Figure 5 shows the active power control of the wind turbine inverter. Here the wind turbine inverter DCLink voltage Vdclink1 and the measured voltage vector phase angle WTeeta1 is used to derive wind power control angle Teeta, which then used to control the gate pulse of the three-phase wind inverters six number of IGBT switches. Further the measured value of the wind turbine reactive power output QW at the connection point used to derive Windmag, which then used to control the reactive power output of the wind turbine to the grid. This is shown in Figure 6.

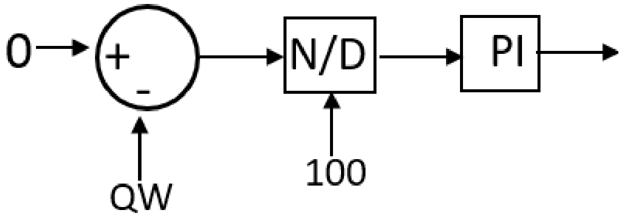

Figure 6: Reactive power control of the wind turbine.

Control of the wind turbine Inverter

Three phase rectifier is used to rectify, the three phase AC voltages Vta1, Vtb1 and Vtc1 from the wind turbine to the DC voltage DCLink1. Then this DCLink1 voltage invert to three phase AC voltages. The output voltages of the wind turbine inverter are Vaw, Vbw and Vcw. This inverter output voltages and the frequency are controlled by the gate pulses Patop, Pabot, Pbtop, Pbbot, Pctop, and Pcbot to the six number of IGBT switches in the inverter circuit. There are various comparators used to derive these gate pulses. One of this IGBT pulse generation comparator is shown in Figure 7.

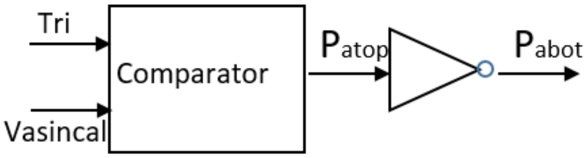

Figure 7: IGBT pulse generation comparator.

This produces gate pulses Patop, Pabot which control the wind turbine output voltage Vaw. Here one of the comparator control signal Tri generated from a pulse generator of triangular pulse of 1000 Hz frequency and 50% of duty cycle. The generation of the other signal Vasincal shown in figure 8. Similarly, Vbsincal and Vcsincal are used to control the wind turbine output voltages Vbw and Vcw. Further, this similar control technique is used to control the solar panel three phase output voltages Vas, Vbs, Vcs and the battery three phase output voltages Vab, Vbb, Vcb.

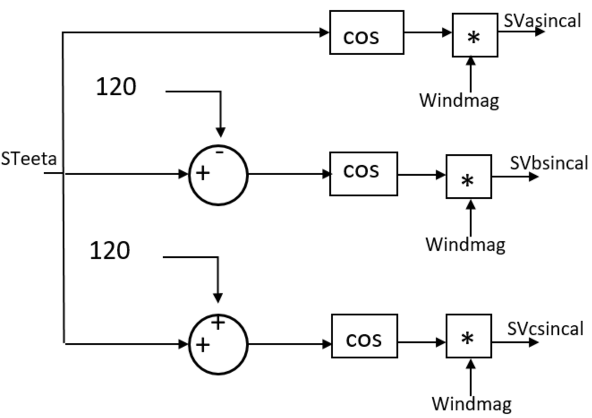

Figure 8: Generation of ‘Vasincal’ ‘Vbsincal’ and ‘Vcsincal’.

Synchronization control of wind and solar plants with battery as slack bus.

Here the battery bus considered as the slack bus, hence the batterys derived phase angle BTeeta already considered for the calculation of Teeta and STeeta in wind and solar power generation which is shown in Figure 3 and Figure 5. Further the DCLink voltage regulatory control adjust the phase angle. This ensures the synchronization control of the voltage wave forms. So that the inverter control in wind and solar automatically ensure the synchronization of the output waveforms with battery voltages. Therefore, the output waveforms of the solar panels Vas, Vbs, Vcs and the output waveforms of the wind turbine Vaw, Vbw, Vcw synchronous with the battery voltages Vab, Vbb and Vcb.

Governor droop control of the 30kVA diesel generator.

There is a 30 kVA diesel generator is in the hybrid power system. The torque control of this diesel generator is shown in Figure 9, where the measured mechanical speed of the machine in revolution per minute Wm and the measured mechanical torque Tmech1 of the machine is used to control the output torque Tmech2 of the machine. The synchronization operation was done through vector base PLL techniques developed and reported in reference [3].

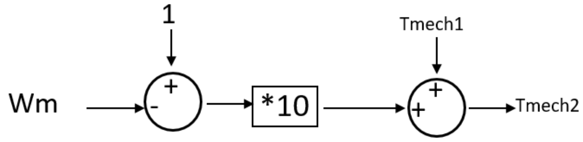

Figure 9: 30kVA diesel generator governor droop control.

Synchronization control of 100kVA diesel generator.

Other than the 30kVA diesel generator, there is a 100kVA diesel generator also available at Eluvaithivu that can be connected to the loads separately (as it is now) or with synchronization (proposed in this paper) of the existing hybrid power plants.

The governor droop control and synchronization control of the 100kVA generator is also arranged using the similar techniques, used in 30kVA generator.

Based on the Battery State of Charge (SOC) the 100 kVA generator's output power is been adjusted to operate as the optimistic system.

Realistic battery model

The realistic battery model was developed as per explained in [4]. However, its energy capacity has been adjusted to match with Eluvaithivu battery model.

Eluvaithivu Load

There are two feeders supplying the whole island of Eluvathivu. Which are notified by load1 and load2. The capacity of the real and reactive power of load1 was taken as 35kW and 17kVAr and 'load2' was taken as 25kW and 12kVAr respectively.

Simulation Results

Here the Synchronization of wind and solar voltages with battery inverter three phase output voltages achieved by the proposed control techniques. This is shown in Figure 10. The variation of the phase angles of battery wind and solar are shown in Figure 11. Further wind, solar and battery currents shown in Figure 12. Comparison of one phase voltages of battery, wind and solar are shown in Figure 13.

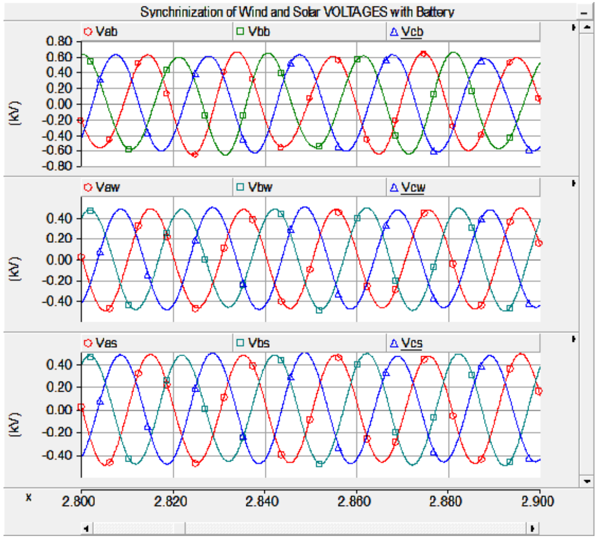

Figure 10: Synchronization of wind and solar voltages with battery inverter three phase output voltages.

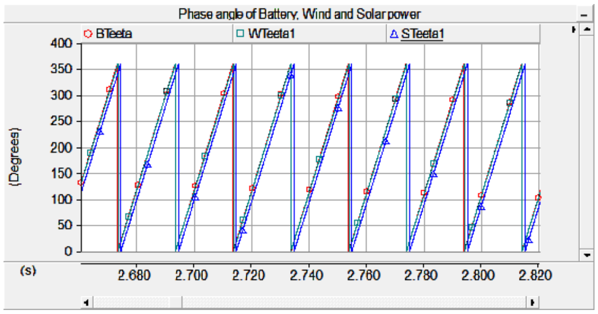

Figure 11: variation of the phase angles of battery wind and solar

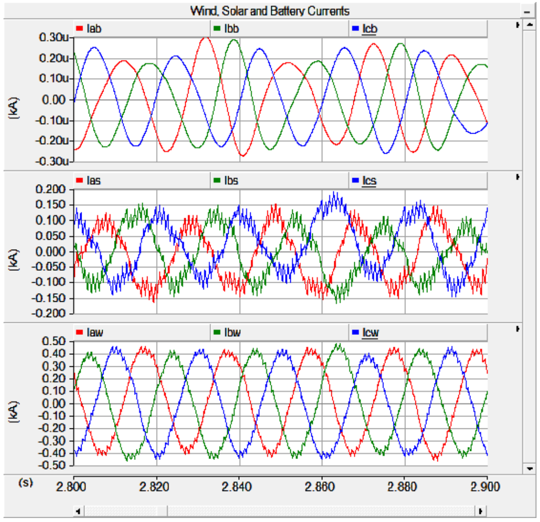

Figure 12: Wind, solar and battery currents.

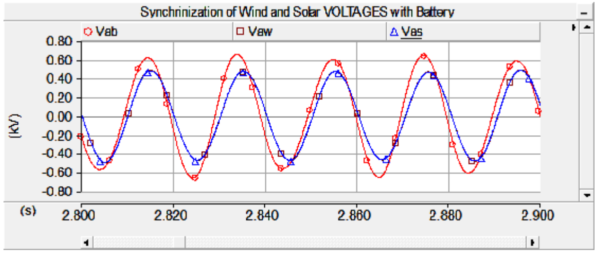

Figure 13: Comparison of one phase voltages of battery, wind and solar.

Further, the power sharing to the load achieved by wind, solar, battery and diesel generator power sources shown in Figure 14. Here the required active and reactive power of the load mainly served by wind, solar and battery power sources. As the required power could be able to serve by these renewable energy plants, diesel generator is in OFF mode.

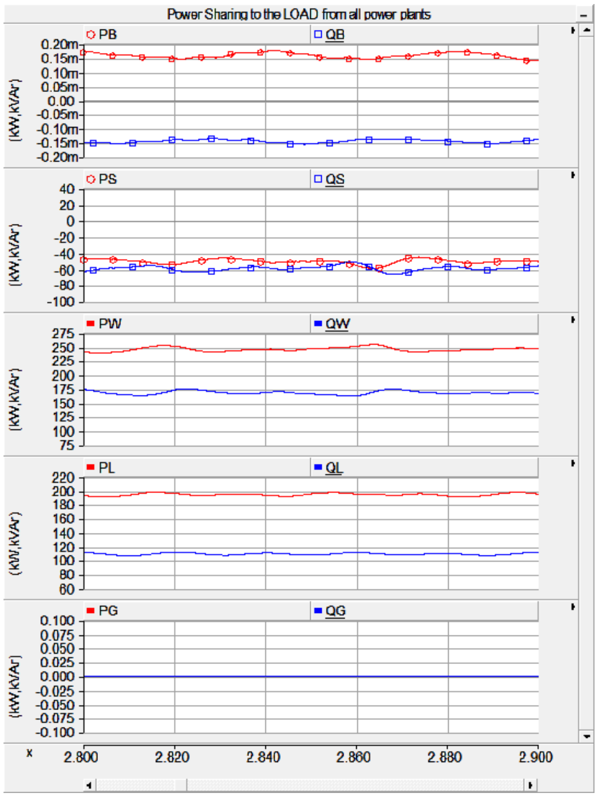

Figure 14: Power sharing to the LOAD from wind, solar, battery and diesel generator.

Conclusion

As there are plenty of small islands all around the world as well as in Sri Lanka. This type of automated operation of the hybrid power plants ensures the reliable power to the customers economically by achieving environmental friendly power generation.

One of the challenges to adapt this system to other islands such as Delft, Nainathivu, Analaithivu is the battery cost. But this also can be mitigated by increasing the number of customers.

Acknolowedment

We would like to thanks Ceylon Electricity Board (CEB) for their valuable supports refer to this research. Further we also extend our appreciation to University of Jaffna for their

continuous guidance.
Further, also would like to thank University College of Jaffna for their continuous interest in research studies.

References

[1] K, Ratneswaran, MSc thesis Hybrid Power System for Eluvaithivu Island, Sri Lanka

[2] Deployment of hybrid renewable energy systems in mini grids. Asian development bank 2017.

[3] T, Nithusiga, S,N,Kopisankar, Ahilan, K and Atputharajah, A. Internal report submitted to the department of Electrical and Electronics Engineering, Faculty of Engineering, University of Jaffna. May 2024.

[4] Ravindran, N, Kokulavasan, T, Nithusiga, S, Ahilan, K and Atputharajah, A, “Optimum control with minimum battery storage for islanded micro grid operation powered by solar PV”. 4th IEEE conference on Innovations in Power and Advanced Computing Technologies (i-PACT2023), held on 8th-10th of December 2023 in Malaysia.

[5] Salem Batiyah, Nasibeh Zohrabi, Sherif Abdelwahed, Roshan Sharma. “An MPC-Based Power Management of a PV/Battery System in an Islanded DC Micro grid”. IEEE, 2018.

[6] On the road to achieving full electrification in Sri Lanka. Asian development bank April 2023.

[7] Hasmaini Mohamad, Nofri NY Dahlan, Ab Halim Abu Bakar, Hew Wooi Ping and Hazlie Mokhlis “Islanding Control Strategy for A Distribution network” IEEE, 2013.

[8] Hasna J. Khan, Asma J. Huque, Kaysar Ahmed, Rafiur Rahman, Tanvir Ahmed, and Rashedul Alam “Five Years of Solar Mini grid Service in Sandwip Island of Bangladesh” 4th international conference ICDRET, 2016.