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Microgrid Controller

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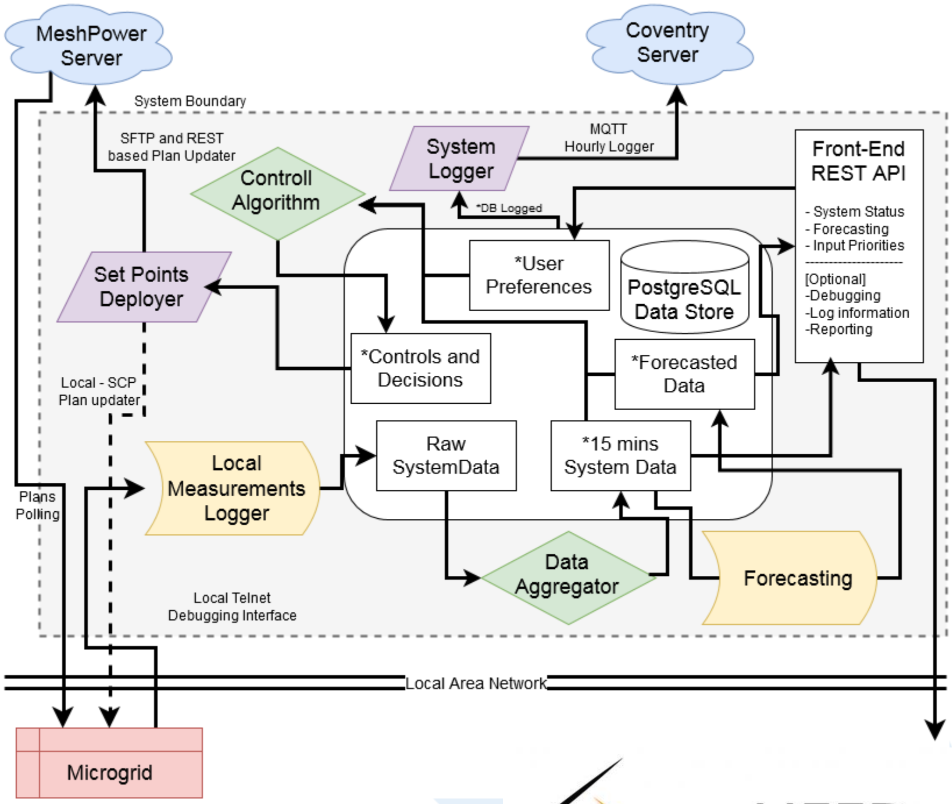
Overview

- Insight into the architecture and design of the controller
- Discussion on parameters, how they are calculated what they mean.
- Testing Scenarios review with issues and solutions
- Future Steps and planned outputs

Architecture

- All components run independently with a database linking them together through shared data.
- Components deployed as docker services where appropriate to increase reliability and control over them.
- System state to be logged locally and sent to a central server through MQTT
- Local and Web based gathering of system data is possible
- Quotas are deployed using the MeshPower system.



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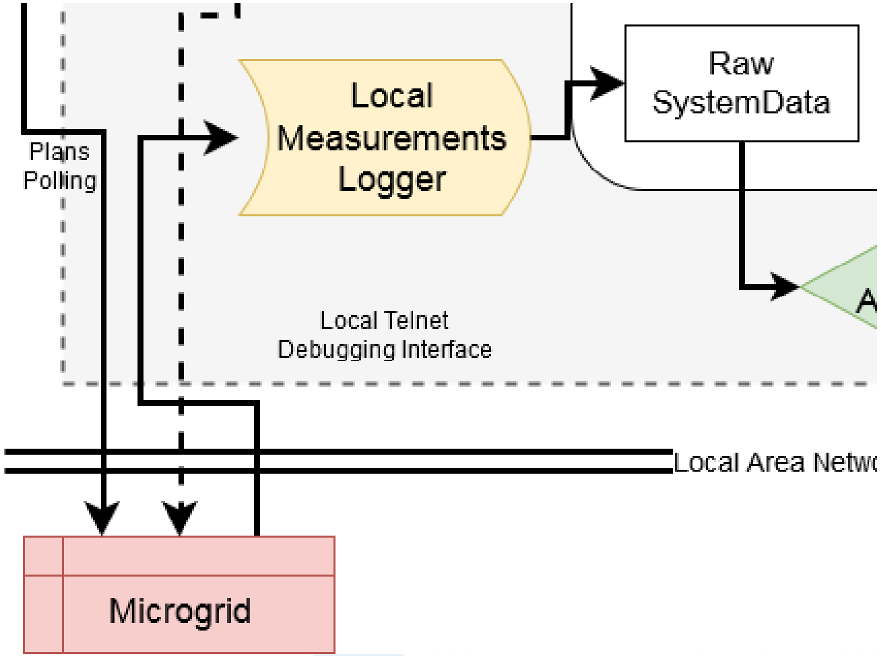
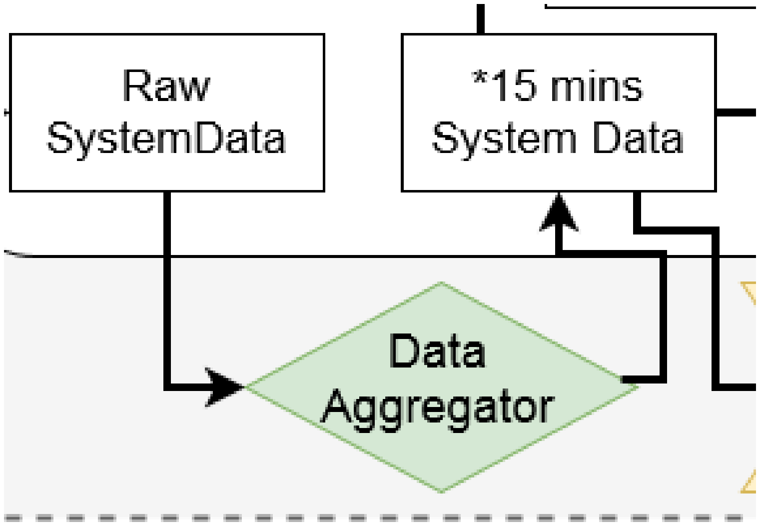
Architecture – Local Data Collector

- Collects data based on device mac addresses from the local system every 15 seconds using their telnet debugging interface
- Collects Victron and Meshpower data from the same place
- Collects quota and instantaneous consumptions as well



Architecture - Aggregator

- Read is the raw System Data values from time periods where there is no aggregation information
- Clean the data by removing peak and unreasonable values (2kw instantaneous consumption when 1.5kw is the max on the system)
- If data for a certain device on that hour is not available forecasted values are used

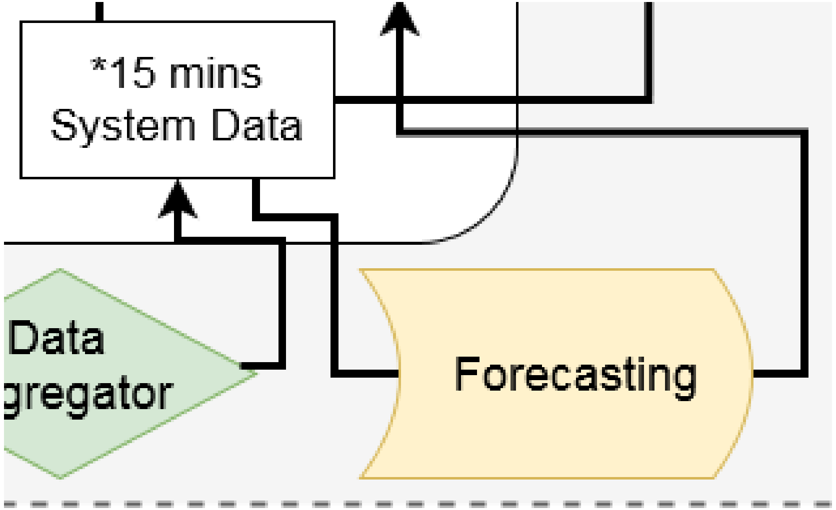


Architecture - Forecasting

- Forecasting reads values from the 15 minute aggregated cleaned data and generates a forecast for each consumer and producer of energy.

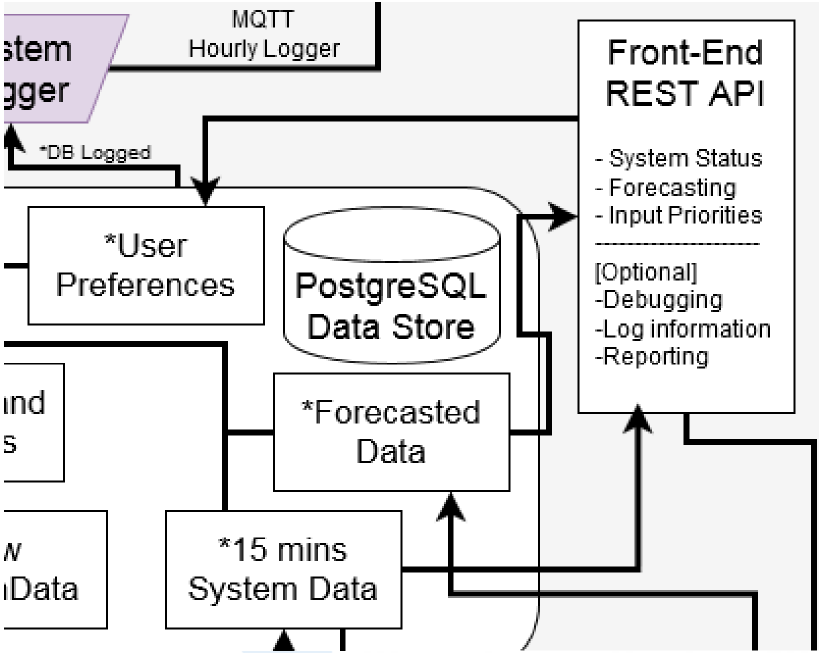
- The forecasted data is hourly and is 24h hours ahead and is updated every 15 minutes

- The algorithm is detailed in future slides



Architecture – Front End

- Provides and API for the Scene interface
- Uses forecasted and historic data to provide required information on :
  - battery energy available (kwh)
  - power consumption (kw)
  - solar pv power generation (kw)
  - solar pv energy generation 24h (kwh
  - solar pv energy generation 30days (kwh)
  - energy consumption 24h (kwh
  - energy consumption 30days (kwh)
- It also allows the interface to send back user priority preferences that is saves to the database



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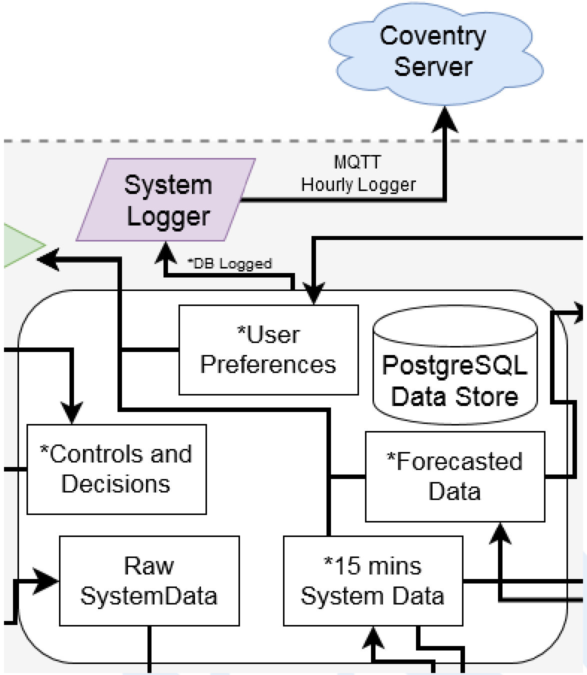
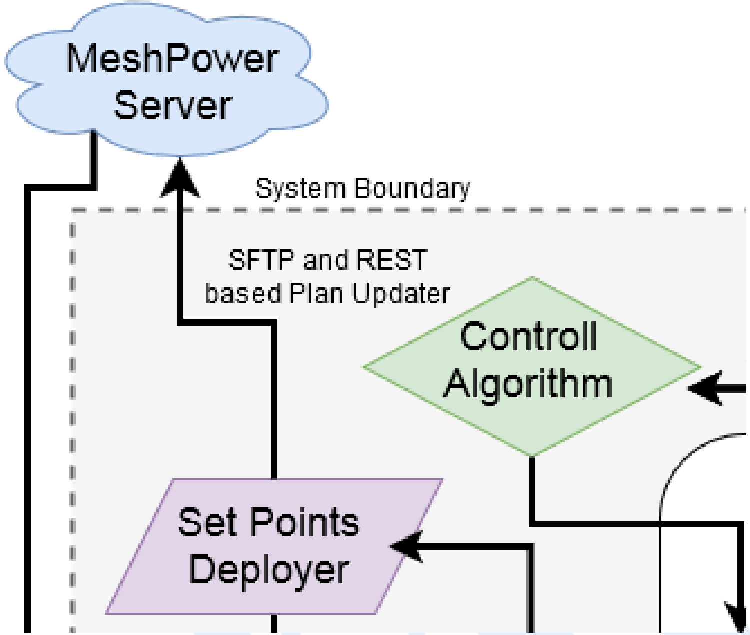
Architecture – System Logger

- The System Logger creates a snapshot of the systems every 15 minutes, saves it to the database and sends the log via MQTT to a Coventry university server.
- The parameters are detailed in the upcoming slides



Architecture – Controller and Enactor

- The details on how the controller decides on quotas is below
- The enactor retrieves existing quotas from the MeshPower sftp server and checks whether these have changed. If they have it updates them.
- After a Quota is updated it needs to be enabled on their website through a WebSpoofer element.



Parameters and Calculations Deployed System

- System Parameters
  - Transmitted; message_id; mem; cpu; storage_perc; storage_free; temperature; user_actions
- Historic Values
  - hist_system_load; hist_consumed_energy; hist_generated_energy – Per_Device_Values
- Forecasted - Per_Device_Values
- Quota 1;Quota2; Priority per Device Groups
- 15 minute cleaned Average for Power consumption
  - Nursery1_Lights, Nursery1_Sockets, Nursery2_Lights, Nursery2_Sockets, Playground_Lights, Playground_Sockets, Streetlights
- Devices (30)
  - streetlight_no_1 streetlight_no_2 streetlight_no_3 playground_no_1 playground_no_2 playground_no_3 playground_no_4 playground_no_5 playground_ac_socket_no_1 playground_ac_socket_no_2 nursery_ac_socket_1a_no_1 nursery_ac_socket_1a_no_2 nursery_ac_socket_1b nursery_ac_socket_1c nursery_1a_cpe_no_1 nursery_1a_cpe_no_2 nursery_1b_cpe_no_3 nursery_1b_cpe_no_4 nursery_1c_cpe_no_5 nursery_1c_cpe_no_6 nursery_ac_socket_2a_no_1 nursery_ac_socket_2a_no_2 nursery_ac_socket_2b nursery_ac_socket_2c nursery_2a_cpe_no_7 nursery_2a_cpe_no_8 nursery_2b_cpe_no_9 nursery_2b_cpe_no_10 nursery_2c_cpe_no_11 nursery_2c_cpe_no_12
- Device Groups (7)
  - ursery1_lights; nursery1_sockets, nursery2_lights, nursery2_sockets, playground_lights, playground_sockets

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Data Cleaning and Aggregation

- Power consumption and system state values are recorded at every 10s intervals
- The raw data is aggregated using a mean for each 15 minute period
  - Where data is not available NaN values are recorded

Currently Implemented

Parameters and Calculations Testing Environment

- 15 minute cleaned Average for Power consumption
  - Nursery1_Lights, Nursery1_Sockets, Nursery2_Lights, Nursery2_Sockets, Playground_Lights, Playground_Sockets, Streetlights
- System Parameters
  - Consumed_Energy, Generated_Energy, Battery_SoC, System_Load
- Quotas
  - Nursery1_Lights, Nursery1_Sockets, Nursery2_Lights, Nursery2_Sockets, Playground_Lights, Playground_Sockets, Streetlights
- Priorities
  - Nursery1_Lights, Nursery1_Sockets, Nursery2_Lights, Nursery2_Sockets, Playground_Lights, Playground_Sockets, Streetlights

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Forecasting - Basic

- Forecasting is currently a simple weighted typical value for each hour for both consumption, generation and System_Loads
  - $E\_forcast_h^{dev} = E_{historic_h}^{dev}(d-1) * 0.6 + E_{historic_h}^{dev}(d-4:d-2)$*0.4, where h is the hour; dev is the device and d is the current day, while d-1 is the previous day and so on
- The battery SoC and other parameters can be then calculated beased on these values.

Energy Forecasting - Consumers

- Basing it on this paper:
  - https://www.sciencedirect.com/science/article/pii/S1876610219310008
- LSTM forecasting has proven to be more accurate than ARIMA SARIMA and ARMAX
- LSTM requires more resources to run and might be an issue for Raspbery pi systems.
- Running multiple models has even higher requirements especially when it comes to re-training the data
- ARMA (**Auto Regressive Moving Average(ARMA)** was a close second and is more lightweight
  - Testing and evaluating it based on below:
    - https://medium.com/auquan/time-series-analysis-for-finance-arma-models-21695e14c999

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Energy Forecasting – PV Panels

- Using the basis of this paper:
  - https://www.mdpi.com/1996-1073/12/9/1621
- Using just the Clear sky model for now
- SOLIS Clear sky model
  - https://www.sciencedirect.com/science/article/pii/S0038092X08000406
  - Using simplified version available in python
  - We calculate the GHI,DNI and DHI based on the *ineichen* model
- Using parameters to get the irradiance on the panel
  - Loutzenhiser P.G. et. al. "Empirical validation of models to compute solar irradiance on inclined surfaces for building energy simulation“ 2007, Solar Energy vol. 81. pp. 254-267
  - Calculating the total irradiance based on GHI,DNI, DHI, solar_zenith, solar_azimuth surface_tilt and surface_azimuth. Based on [2] Perez, R., Seals, R., Ineichen, P., Stewart, R., Menicucci, D., 1987. A new simplified version of the Perez diffuse irradiance model for tilted surfaces. Solar Energy 39 (3), 221–232.
- Irradiance to power:
  - https://www.sku.ac.ir/Datafiles/BookLibrary/45/John%20A.%20Duffie,%20William%20A.%20Beckman(auth.)-Solar%20Engineering%20of%20Thermal%20Processes,%20Fourth%20Edition%20(2013).pdf
  - Power= irradiance *PanelArea*efficiency
    - Area = 21.3 ?
    - Efficiency = 15.5
- Using 60% of the value as a conservative estimate in case of clouds

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Battery Model

- Using the basis of this paper:
  - https://ris.utwente.nl/ws/files/28201914/A_comprehensive_model_for_battery_State_of_Charge_prediction.pdf
- No considering battery deterioration
- Not considering battery fade as for the 24h time periods we use it is relatively small
- Estimating the state of charge as the available Stored Energy of the battery/ maximum stored energy of the battery
  - Charging efficiency set to 80% as based on the below article as a mean value, although at the 80-100% SOC's we are working at it should be 50%
    - https://ieeexplore.ieee.org/abstract/document/564417
  - $\Delta St = Ce * \Delta Ct - \Delta Dt$ – where St is Stored Energy; Ct is Charged Energy; Dt is Discharged energy and Ce is Charge Efficiency.

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Control Algorithm–Baseline

- Algorithm based on Space shared Resource allocation
- At every 15 minutes the algorithm runs a set of calculations based on forecasted and measured data:
  - It Calculates the available Energy in the system:
    - E_Generated (Until 6Am reset) = SUM(PV_Generation(hourly)), where the values are after the current Timestamp
    - E_avail = (Battery_SoC-50.0)/100.0*21.1+E_Generated(Until 6Am reset)
  - Based on the Forecasting for each device summed by groups the total consumption of the system is calculated.
  - If the total consumption of the system is higher than the Energy Available Quotas need to be in imposed
    - Device groups are taken by their priority levels and quotas are imposed based on energy availability:
      - Example. If total *E_avail* is 7kw but the devices and system will use a total of 7.4 and the lowest priority device will use 1.4kw than it will receive a limit of 1kw consumption until reset.
    - This group_limit is then distributed by share to each device
    - For Lights the group Wh limits need to be translated to minutes of light. This can be done by taking the average on value for each light and dividing the Wh available
- Considering inaccuracies in measurement and forecasting a 15% over-estimation is considered on each device

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Control Algorithm-Example

- Considering the forecasted Data from the table below and an analysed period of two hours. With a 2.1kw battery

	timestamp	Nursery1_Lights	Streetlights	Consumed_Energy	Generated_Energy	Battery_SoC	System_Load	Nursery1_Lights_Priority	Streetlight_priority
Measured	19/08/2019 06:00	14	5	69	0	52.5	50	1	2
Forecasted	19/08/2019 07:00	7	14	72	21	50.08	51	1	2
	19/08/2019 08:00	9	9	66	48	50	48	1	2

Available Energy = (Battery_SoC-50.0)/100.0*2100+E_Generated = (52.5-50) /100*2100+(21+48)=121.5

Consumed Energy = 72+66 = 138Wh

Required Energy Difference = Available Energy - Consumed Energy = -16.5Wh

There is a deficiency so quotas need to be impose, starting from the device with the least priority:

Streetlight – Total Consumption: 23Wh; Deficit = 16.5Wh, so the total consumption needs to be capped to 6.5Wh or a quota imposed of 0.28.

This quota is the distributed equally to all the streetlights so ideally they turn off at the same time once hitting the quoat. Streetlight Remains the samev

timestamp	Nursery1_Lights	Streetlights	Consumed_Energy	Generated_Energy	Battery_SoC	System_Load	Nursery1_Lights_Priority	Streetlight_priority	Nursery1_Lights_Quota	Streetlight_Quota
19/08/2019 07:00	7	6.5	64.5	21	50.5	51	1	2	1	0.45
19/08/2019 08:00	9	0	59	48	50	48	1	2	1	0.0

The quotas are imposed as usage limits, so the streetlights will have 0.45 quota for the first hour and a quota of 0 for the second

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Control Algorithm–Scheduling GA

- With the GA method the quota can be of 3 types
  - Binary – A device is either on or off in an hour
  - Percentage – Of the total energy available to be consumed only a certain percentage is allowed
  - Limits – kWh limits are imposed for each hour irrespective of the actual consumption
- The quotas are hourly per device group
- Each individual consists of 168 genes that are
  - Binary: either 0 or 1 (2 possible values)
  - Percentage: Values between 0.0 and 1.0 with 2 decimal step (20 possible)
  - Limits: in Wh with a step of 50wh
- Currently:
  - Roulette wheel selection of Individuals
  - 5% Elitism of each generation
  - Crossover is a selection between the two genes; a mean could possibly be better
  - Mutation is at 5% with each gene having a change of getting a new value; increment/decrement might be a better idea

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Control Algorithm–Scheduling GA

- Considering a optimisation scenario for 3 hours and two devices the gene looks as in the table to the right. It is applied to the original data to generate the one in the table below it.

	Nursery1_Lights	Streetlights
Hour 1	0.4	0.25
Hour 2	0.8	1.0

Original Table

timestamp	Nursery1_Lights	Streetlights	Consumed_Energy	Generated_Energy	Battery_SoC	System_Load	Nursery1_Lights_ Priority	Streetlight _Priority	Nursery1_Lights _Quota	Streetlight_ Quota
19/08/2019 07:00	7	14	72	21	51.21	51	1	2	1	0.45
19/08/2019 08:00	9	9	66	48	50	48	1	2	1	0.0

Resulting Table

timestamp	Nursery1_Lights	Streetlights	Consumed_Energy	Generated_Energy	Battery_SoC	System_Load	Nursery1_Lights_ Priority	Streetlight _Priority	Nursery1_Lights _Quota	Streetlight_ Quota
19/08/2019 07:00	2.8	3.5	57.3	21	51.78	51	1	2	0.4	0.25
19/08/2019 08:00	7.2	9	64.2	48	51.01	48	1	2	0.8	1.0

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Fitness Function – Energy factor

The energy needs to be distributed according to its availability for a sustainable consumption. For this purpose, the value needs to adjust dinamically over the time, at each time slot, t, according to the energy available and the battery *State of Charge* (SoC). Hence, the energy value can be defined as

$$E_v(t) = \frac{(1 - E_a(t)) \times (1 - SoC(t))^2}{1W}$$

Where $E_v(t)$ is the energy value and $E_a(t)$ the energy available at each t-th time slot. Note that, the higher is the energy available or the SoC, the lower is the value.

Fitness Function – Penalty factor

In order to improve the battery lifetime, a penalty factor is introduced. This factor increases as the amount of energy required is enough to decrease the SoC for less than 50% at any time slot, t, or using appliances when there is no energy available. Hence, the penalty factor can be defined as below.

$$F(t) = \begin{cases} \sum_{t \in T} 1, & E_a(t) = 0; SoC(t) \leq 50\% \\ \sum_{t \in T} 0, & otherwise \end{cases}$$

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Fitness Function – Dissatisfaction factor

A dissatisfaction degree is also introduced as at time slots of low SoC or not enough energy available, the user will not be able to use all desired appliances. Thus, this factor is modelled according to the priority of the appliance and its energy quota, as follows

$$D_a(t) = (1 - Quota_a(t)) \times P_a$$

where $D_a(t)$ represents the lack of energy available for the appliance a, $quota$ is the amount of energy available to be used for the appliance and P_a is the priority of that appliance.

Fitness Function – Complete

The energy needs to be distributed according to its availability. Therefore, the value of have to be considered for a sustainable consumption. Hence, the value can be defined as

$$\min f(x) = w_1 \sum_{t \in T} C(t) \times E_v(t) + w_2 \sum_{t \in T} F(t) + w_3 \sum_{t \in T} D(t)$$

where $C(t)$ is the user consumption in time slot t, and w is the weight of each factor.

Fitness Function – Application

The fitness of a system is calculated at every hour. It is applied to the data below as shown.

The weights used for w1;w2 and w3 are 0.3.

timestamp	Nursery1_Lights	Streetlights	Consumed_Energy	Generated_Energy	Battery_SoC	System_Load	Nursery1_Lights_Priority	Streetlight_Priority	Nursery1_Lights_Quota	Streetlight_Quota	Utility
19/08/2019 07:00	2.8	3.5	57.3	21	51.78	51	1	2	0.4	0.25	0.0
19/08/2019 08:00	7.2	9	64.2	48	51.01	48	1	2	0.8	1.0	0.0

Utility for hour 7:00 - $E_v(t) = 4.25\text{x}10\text{^}6$

$C(t) \times E_v(t)$ = 2.68x10^7 C(t)=6.3W

$F(t)$ = 0.0

$D(t) = 2.1$

$Util$(19/08/2019 07:00) $f(x)$ = 8.85x10^6

Utility for hour 8:00 - $E_v(t) = 4.32\text{x}10\text{^}6$

$C(t) \times E_v(t)$ = 7x10^7 C(t)=16.2W

$F(t)$ = 0.0

$D(t) = 0.2$

$Util$(19/08/2019 08:00) $f(x)$ = 2.31x10^7

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Simulation Environment V1

- Recreates the Microgrid in a testing environment based on historic data to be used in GA based optimisation
- A python script served pre-processed historic data and enacted control parameters.
- Matlab was used to run a Genetic Algorithm based optimisation

Issues:

- Using system commands to run python scripts and sharing data through file meant that it took 0.81 seconds to evaluate a single control parameter and 8 hour to get the result in Fig. SE-V1

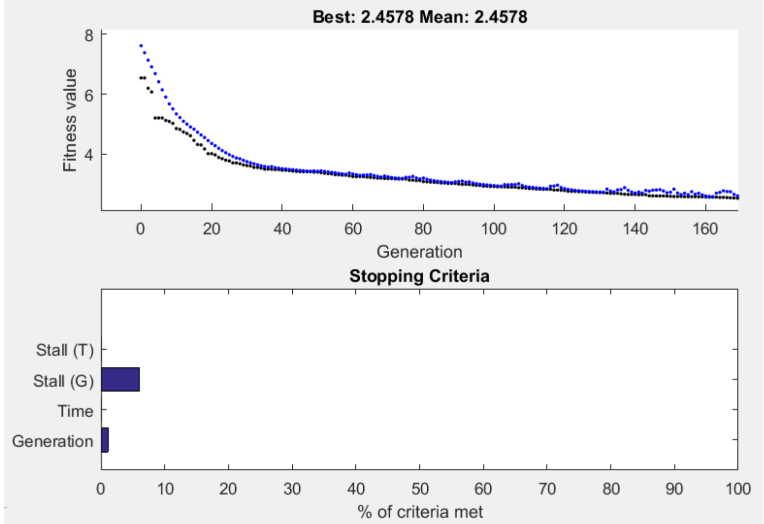

Figure SE-V1 – GA Run of optimising Depth of Discharge using the Simulation Environment V1

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Simulation Environment V2

- Allows modifications to be made to the original microgrid environment by scaling the batteries, pv panels an possibly varying consumers.
- Fully coded in python to increase processing speed (0.12s for an evaluation as opposed to 0.84 (SSD) and 2.4(HDD))
- Modified GA to suit the peculiarities of the problem

Testing and Evaluation

- Testing of functionality and business logic of components done based on the testing plan put together with Scene
- The Control Algorithm and GA as well as future components will be evaluated using a defined set of plots that showcase how various utility function and system parameters changed/behaved during operation.
  - Components to be Evaluated in this way: Controllers; Forecasting; Aggregation
- Health and Status monitoring dashboard/Digital Twin in Coventry with Alarms, weekly status reports possible

Conclusions and Outputs

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- The physical deployment aims to demonstrate the functioning of each component and test how a stable easy to understand controller would work
- The work done by Leonardo aims to identify a utility function for the microcontroller
- The testing environment will give us the graphs and metrics to evaluate each deployment.
- Optimisation approaches will be compared and their results analysed on how well they improve the system utility – These would consider deployment constraint as well.

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