

POWER SYSTEMS MODELLING OF A COMMUNITY ENERGY PROJECT

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ABSTRACT

This paper considers the concept of a digital twin for a micro-grid system. The digital twin utilises power system modelling to trigger different operational scenarios under normal and fault conditions to test the resilience of the micro-grid and help identify potential risks or issues prior to construction and commissioning.

INTRODUCTION

Micro-grid energy projects are an innovative method of supplying power to a local community. The projects are site specific, tailored to meet the user’s needs and consisting of numerous different energy sources from wind, solar, battery and back-up power. Demand profiles on the integrated networks can be complex due to non-traditional operating profiles and frequent demand switching, and as such the micro-grid needs to be resilient to these operations in addition to unforeseen faults and transients. Transient and quasi-dynamic simulations allow the owner to assess the micro-grid voltage and frequency response to assure the network’s resilience. The study presented herein looks at a micro-grid in Fife, Scotland where there is several Photo-Voltaic (PV), wind turbine, hydrogen fuel cell and batteries supplying a number of house loads with a back-up grid supply [1]. Several normal and abnormal fault scenarios were developed to test the network’s resilience to various abnormal operating scenarios.

DESIGNING A DIGITAL TWIN

The detailed design stage is a vital and necessary aspect of any project. Part of detailed design is to construct a ‘digital twin’ of the proposed electrical system on a power system modelling software environment. A digital twin is a virtual model of a system, process, or product that seeks to replicate the physical system of the design and is often created prior to construction to verify the operational characteristic of the design. This twinning of the virtual and physical systems allows analysis to be conducted across several operating configurations as often informs design optioneering before a system owner commits to the reality of a final design. In addition, the creation of a digital twin can identify potential issues and investigate mitigation measures, which later results in decreased downtime of the operational plant in the future. It can also be used to develop new opportunities and plan for the future modifications or expansion. A digital twin can cover the entire lifecycle of the micro-grid asset and where information is readily available, it is possible to model reliability of the plant including planned outages.

To support our client, a digital twin of the micro-grid was created using the power system modelling tool DiGSILENT PowerFactory based on the existing Single Line Diagram design. The site as seen in Figure 1 consisted of several renewable generators including; two

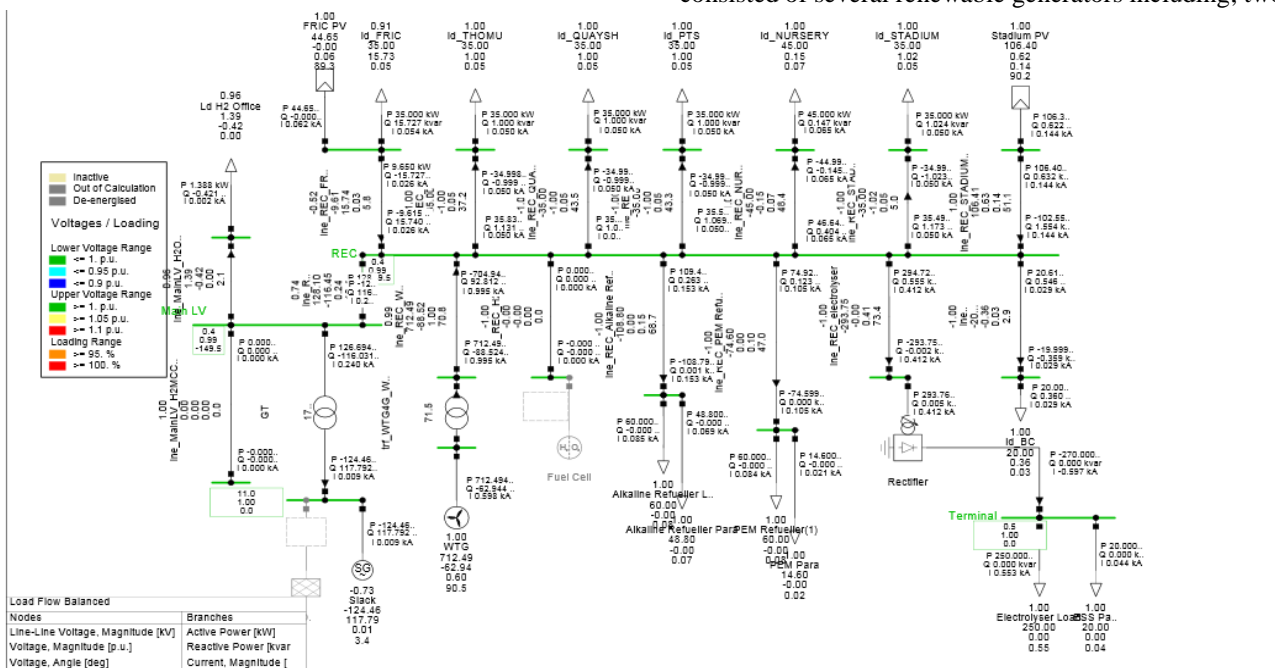


Figure 1: Micro-grid Digital Twin design

PV systems, a wind turbine and a hydrogen fuel cell with three parasitic electrolyser loads. All generators and loads connected within the micro-grid operate on a three-phase 415V LV electrical supply.

The micro-grid site was also connected to the local 11kV distribution network to provide back-up power during periods of low availability of local generation and/or very high demand. As a community energy provider, the loads are typical of a rural village. The loads included; the offices for the micro-grid owner, a nursery, football stadium, boat club and general residential loads. The information integrated into the model from the site included; equipment specifications, network point of connection details, loads profiles, generation, control systems, AC/DC rectifiers, and cabling. In addition, manufacturer equipment specifications were used to ascertain equipment ratings and impedances, all of which fed into the DIGSILENT model. In the physical system, the micro-grid is connected to the local Distribution Network Operator (DNO) and the overall strength of the off-site grid can impact the resilience of the micro-grid system. As such, adequate modelling of the impedance and short circuit rating of the external grid network is critical to digital twin analysis. This information is publically available from the DNO long term development statements published annually.

Modelling Assumptions

The digital twin model is reliant on available and accurate data provided by the micro-grid owner. However, in practise there are times where information cannot be attained due to early stage design maturity, missing information or intellectual property/product commercial sensitivity where a non-disclosure agreement (NDA) is in place between the system owner and supplier. In this project, the site owner was unable to release the manufacturer control algorithm due to a NDA being in place. The control algorithm enables monitoring and communication between the generators to balance the system against the house demand requirements. When this situation arises, it is necessary to make assumptions in the initial design of the power system model and then iteratively modify the control system to approximate the transient characteristics that are apparent in the real world system. The control system for the site was designed to operate on a preferential generator basis; i.e. it would favour on-site generation when available over grid power. Additionally, the renewable generators operate on a preferential basis, whereby the PV systems take precedence over the wind generation and all excess generation is exported to the DNO. To model this control algorithm, a 'virtual power plant' was created in DIGSILENT which allowed several separate generators to be dispatched individually and at different capacities to match the demand required by the micro-grid loads at any given time. By iteratively refining the generator dispatch, the 'virtual power plant' control algorithm was matched to the expected generation profiles as seen on

site. Other modelling assumptions are made using engineering judgement where it will not adversely affect the overall results of any simulations. The impedance effects of underground cables are considered negligible for short distances and some cable distances were estimated due to missing information.

POWER SYSTEM ANALYSIS

The power system analysis of the micro-grid consisted of three elements; static simulations, dynamic/transient simulations and quasi-dynamic simulations.

Static simulations consider the steady-state output of the system at a single point in time and for a defined set of parameters. Typically it is used as part of load flow and fault level studies to determine whether the proposed equipment is adequately rated and to determine equipment loading, current flows, power losses and generator short circuit contribution.

Dynamic/Transient analysis simulate a pre-defined event that changes the steady-state of the network and allows assessment of the effect that the event has on the remaining system. These simulations are used to simulate real-life events such as switching, circuit or busbar faults, and the tripping of equipment. Transient analysis may also be used to assess the capability of the system to 'clear the fault' and recover to a normal operating condition whilst monitoring system voltage/frequency.

Quasi-dynamic simulation utilises predicted or metered data from loads and generators over a set time period to provide a graphical output that can be a useful indicator of active and reactive power flows throughout the network. Quasi-dynamic simulation is used to identify any abnormal operating states or times of peak demand/generation.

Operation Scenarios

The micro-grid owner desired to understand the response of their micro-grid under various normal and abnormal operating scenarios using all three of the simulation techniques described above. The scenarios were developed to reflect likely events that could occur and also more onerous unlikely events that would place a high degree of stress on the micro-grid system. The static simulations considered the operating extremes of the micro-grid, i.e., Minimum demand with no renewable generation or building loads in service, parasitic loads are supplied by grid and maximum demand with renewable generation and building loads operating at high capacity, assuming a high output from renewable generation sources.

Multiple dynamic simulations were conducted to consider the start-up of electrolysers with minimal load, ramping up of fuel cell, wind turbine operation and unexpected trips of the PV and wind turbine plant. The most onerous scenarios considered were:

Case Study 1: The wind turbine is exceeding nominal power output at 110% with minimum PV generation, minimum building loads, and fuel cell in hot standby

mode. In this case study, the wind turbine is set to suddenly trip and the electrolysers will decrease to 0kW over one minute. The fuel cell is modelled to start after 40s and will take another 60s to reach full output.

Case Study 2: The micro-grid is supported by the on-site renewable generation to supply the building loads whilst the fuel cell is in hot standby mode. In this case study, several building loads are set to simultaneously trip at a peak demand.

Case Study 3: The micro-grid is supported by the on-site renewable generation to supply building loads whilst the fuel cell is in hot standby mode. A low level of building loads are in service. In this case study, several building loads are set to switch from DNO supply to micro-grid supply at 5 second intervals. The results of these studies are discussed in the following section.

POWER SYSTEM RESULTS

The results from the digital twin power system model were assessed using tabulated results and graphical outputs as necessary. Note that all simulations were run for an adequate time to allow the model to return to steady-state conditions.

Static Simulation

The load flow and fault level static studies showed the micro-grid was designed to accommodate the maximum loading as seen in Figure 1 and to derive the prospective short circuit current for the most onerous scenarios. The external grid has a design fault level of 15 kA (~286 MVA) which is deemed to be representative of a stable and strong network.

Figure 2 shows a quasi-dynamic simulation of all the generators operating with predicted active export profiles over a time period of a month.

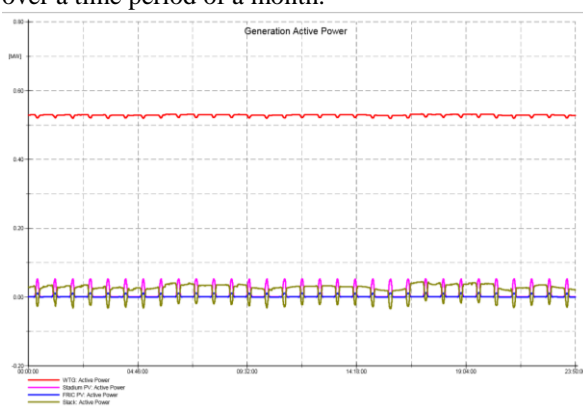


Figure 2: Active export of all renewable generators
Figure 2 was used to show how the on-site generators and the back-up grid may respond to each other for maximum demand in accordance with the virtual power plant control algorithm. The external grid was able to respond to the renewable fluctuations particularly during the solar peak hours. In this simplified test study, it was not necessary to consider the daily variances in load.

Quasi-dynamic Simulation

The wind turbine is an existing asset which has been previously connected to the grid for a number of years and as such 5 second metered data was available to illustrate the operational characteristics of the device over a three month period. The quasi-dynamic simulations showed irregular power flows which prompted further investigation of the wind turbine and the metered grid data. The investigation discovered several instances in which the reactive power import to the micro-grid was very high, often exceeding 100 kVAr and in some cases as high as 500 kVAr.

It was discovered that following the turbine momentarily dropping to 0 MW, it could take up to 3 minutes to re-accelerate back to nominal power at 0.97 power factor as shown in Figure 3. As the turbine re-accelerated, the device is importing excess reactive power with the resulting power factor being well below normal limits.

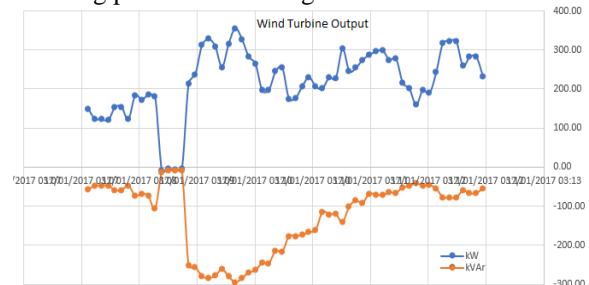


Figure 3: Wind turbine export/import power issue
The blue line indicating active power export and the orange line indicating reactive power import.

These results were confirmed using metered data at the point of connection which showed the drop in power factor of the micro-grid during these times. The metered data also showed that during these times the Grid voltages remained within legislative limits suggesting that the Grid was sufficiently resilient to the wind turbine reactive power inrush. Through further investigation the import of excessive reactive power was attributed to an internal capacitor failure within the turbine converter.

Dynamic/Transient Simulations

Case Study 1:

In this case study, the wind turbine was operated at 900 kW and then a sudden trip was simulated. The grid responded instantly to the wind turbine trip increasing power to the micro-grid and later decreasing as the fuel cell ramped up to full export as seen in Figure 4.

The micro-grid responds system with a <1% voltage dip during the transient and the system frequency fluctuates by 0.5 Hz from nominal. During this disturbance the voltage remained within $\pm 10\%$ operating range for the LV system. A 1% voltage fluctuation was also seen at the 11kV point of connection, which is within the $\pm 6\%$ operating voltage range for HV systems.

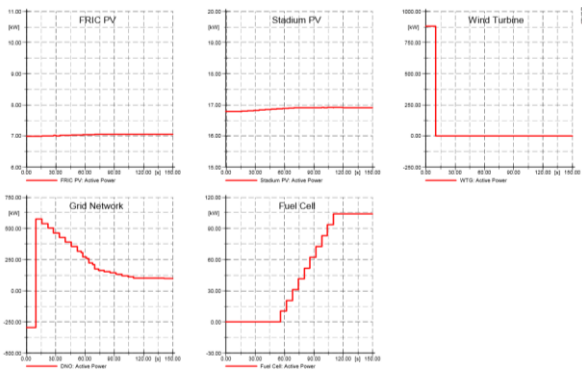


Figure 4: Generator response to turbine trip

Case Study 2:

In this case study a worst-case demand loss situation was modelled whereby several of the largest building loads were set to unexpectedly trip whilst at peak demand. Prior to the fault, the micro-grid generation was exporting ~6 kW of additional generation to the DNO. This scenario resulted in an increase to ~90 kW post fault. The voltage and frequency across the network remain at nominal levels as shown in Figure 5.

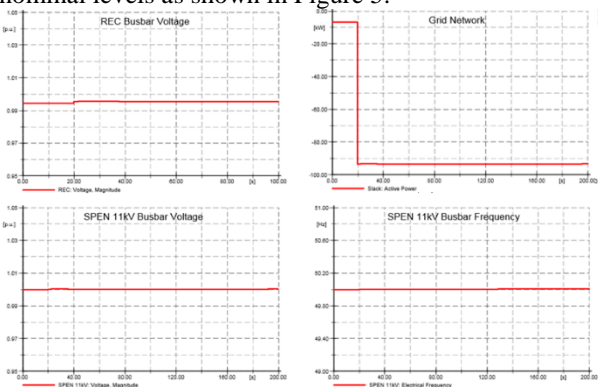


Figure 5: Voltage/Frequency responses to load trip

Case study 3:

In this case study, several of the largest building loads were switched from the DNO to the micro-grid in 5 second intervals. Initially, the Grid network was absorbing the excess generation from the micro-grid however, as the building loads were incrementally switched on, this export reduced to ~37 kW whilst the voltage and frequency remain at nominal levels.

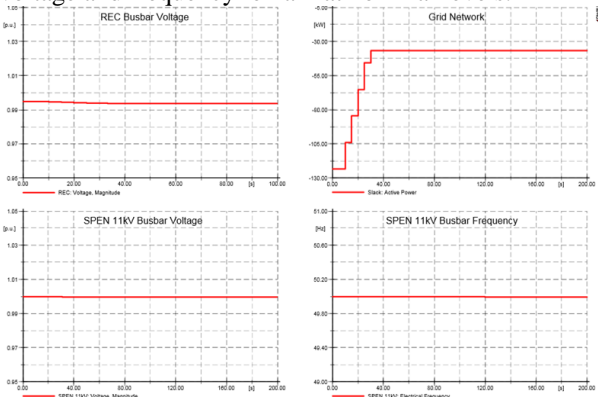


Figure 6: Voltage/Frequency responses to rising load

CONCLUSION

Power system studies are often a requirement prior to the connection to the distribution network with new sites having to provide assurance to the DNO that they will remain within engineering standard limits and the Distribution Code. The power system analysis of the digital twin discussed herein adequately demonstrated the satisfactory operation of the micro-grid and that it remained within acceptable LV voltage limits with negligible frequency variation under various strenuous events. Onerous scenarios considered included the loss of the wind turbine and simultaneous loss of building loads. These simulations showed a transient response wherein the voltage and frequency fluctuations at the point of connection varied by 1%

The external grid in all dynamic/transient simulations was shown to be able to respond to the changing demands of the network, balancing the on-site generation, grid supply power and demand loads whilst remaining within legislative limits. It was demonstrated that the grid was able to respond rapidly to unforeseen trips so that the building loads and other generators remain connected during the transient faults.

From the power system analysis conducted of the 10 scenarios, it was deemed that the micro-grid is resilient for various potential faults that could occur. This resiliency is supported by the local 15 kA fault level at the point of connection which suggests the local DNO network is stable and resilient to faults.

The power system analysis also highlighted an existing issue in the wind turbine which may not have been noticed until maintenance was conducted.

This process has allowed the client to better understand how the micro-grid responds to on-site network faults and further builds confidence that their network is resilient to various fault conditions. The model was also used to predict future load growth in the building loads as assess how these impacted upon the more onerous operating scenarios. This project demonstrates the value that can be offered to a micro-grid owner and operator through comprehensive and robust digital twinning of their network, identifying and reducing potential at the design stage that can be costly and cause significant time delays risks to a project during construction or commissioning stages.

REFERENCES

- [1] Micro-grid case study assessed on real life client project: Bright Green Hydrogen. Website: (<http://www.brightgreenhydrogen.org.uk/>)