Scaling down a small island control and distribution system for deployment as a Microgrid power solution in Africa

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***Abstract*-- Traditionally control of electrical power networks has been a centralized, top down system approach. These larger systems offered a wide span of control allowing the system operator to make informed decisions to manage load flows, and to manage the supply and demand by way of balancing the system. With the growth of embedded generation and other forms of renewable energy sources (RES) being connected to the distribution network this level of control is becoming required at the distribution level. This has led to putting more intelligence at the plant level which has allowed greater autonomy and more local decisions to be taken. Area based approaches have been considered, whereby the network is divided into smaller regions, allowing decision making and control to be closer to the plant, whilst retaining the benefits of a wider system view. With the growth in renewable energy sources being introduced at medium voltage (MV) this approach also enhances the ability to enable hosting of these diverse power sources. This paper reviews the suitability of taking a control system used to manage the supply of electricity of an island, and applying it to off-grid applications whilst supporting future opportunities to be part of the national utility infrastructure.**

***Index Terms*— MICROGRID, OFF-GRID, RES, SCADA, RTU, RMU, HOSTING**

I. Introduction

The developments of electrical distribution network control systems in Europe and USA have been focused on being more efficient with the assets they have, and more recently to enable the hosting capability for renewable energy sources. With the direction of achieving a greater degree of local control and autonomy this has led to the concept of the Microgrid. The Microgrid, which can be described as a set of interconnected loads and energy resources at the distribution voltage level, can operate in both island mode (off-grid) and grid connected mode. The author's company has provided the electric plant, control system and support infrastructure for managing an electrical grid on a relatively small island (similar to an off-grid network) in the Caribbean. This project provided immediate benefits to the system operator by enabling monitoring and controlling the electrical distribution network, but had also laid down the foundations to allow greater planning, more effective connection of distributed generation and renewable energy resources, as well as enabling the ability to manage customer resources.

II. Control System for an Island in the Caribbean

The project in the Caribbean was to design and implement a control system to manage the distribution of power and to improve the quality of service on the existing 11kV network supplying small industry, hotels and residences. The overall size of the island is shown in figure 1, being approximately 29km long by 8km wide. The island had a peak demand of approximately 40MW which was on a small grid supplied from a single power station, comprising 10 diesel generators and 12 feeders. The power was distributed throughout the island via more than 60 secondary substations, both of ground mount and overhead design. The generators were managed by their own control system but there was no means of monitoring and reporting the performance to the end user. Equally, there was no remote control of the electrical plant on the 11 kV distribution network.

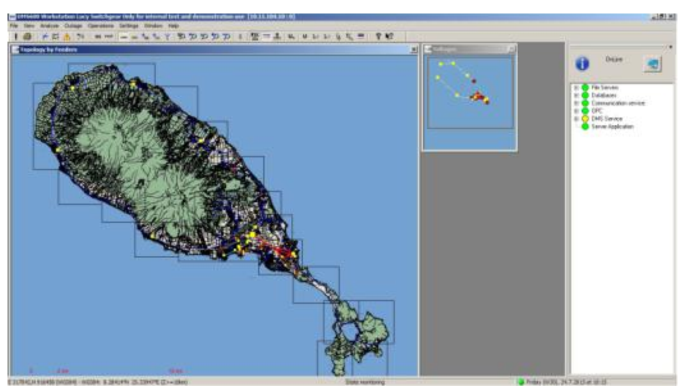

Figure 1: Overview of island

The project involved installing a SCADA system (Supervisory Control and Data Acquisition) at a centralized control centre to manage the outgoing feeders from the primary substation, and to monitor and control selected switchgear on the secondary distribution feeders. The overall

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schematic of the control system is shown in figure 2. The communications between the control centre and the secondary switchgear was a general packet radio service (GPRS) on a redundant 3G cellular system which provided sufficient bandwidth and resilience for controlling the ring main units (RMUs) and overhead switches on the distribution network. The control and monitoring at the RMUs and overhead switches was achieved by installing remote terminal units (RTUs) at key strategic points on the network. These RTUs were either applied as an automation retrofit kit (motor actuators to drive the switches controlled by RTU's) to existing [oil insulated] RMU's or in some cases new SF6 switchgear was installed, where the existing switchgear was not suitable for an automation upgrade.

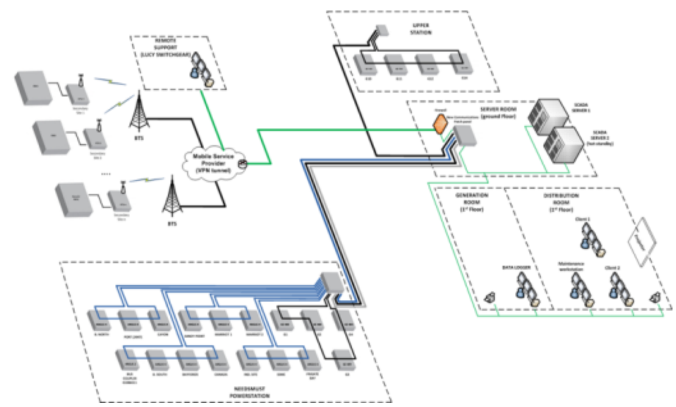

Figure 2: Overall schematic

An important contributing factor to the success of this project was working with the utility customer, whose overall requirement was to develop a reliable electrical distribution infrastructure to improve the quality of service to end users on the island. The SCADA displays were customised to meet specific needs of the customer (system operator). The control room displays during the final stages of commissioning are shown in figure 3.

Figure 3: Control room displays

The benefits the customer sought were to see a reduction in the number of unplanned outages, having shorter outages, and being able to respond rapidly to the loss of supply. The additional benefits the solution provided were improved operational efficiencies and enhanced asset management information. This also laid down a foundation to support growth in RES on the island.

III. OFF-GRID DEVELOPMENT IN AFRICA

The Caribbean island project is effectively a 'large' isolated Microgrid. In moving to an off-grid application the RMUs will provide the interface to the national utility when in non-islanded mode, but there will also be a transformation to low voltage (LV) for the distribution of power within the Microgrid. The communications system provided on the Caribbean project is suitable for off-grid projects in Africa as mobile phones and the supporting cellular communications infrastructure are in common use. The communications access and use of information is still relevant, and will be used to help enable the hosting capacity of the Microgrid.

As the electrification rate in Africa is relatively low for the majority of the countries, the energy availability is a key requirement for economic development. The work developed in reference [1] supports that the implementation a Microgrid will improve accessibility to electricity, and proposes a typical Microgrid architecture supporting improved reliability, accessibility and making use of location specificity.

The control and automation architecture deployed on the Caribbean island electrical distribution system can be scaled down to be more specifically applicable to meet the requirements of a Microgrid in an island mode (off-grid) and connected mode. The requirements for the management of an electrical distribution network on an island are not dissimilar from the requirements in developing an off-grid application in Africa. Figure 4 shows a potential scaled down structure of the Caribbean project, the main difference being that the majority of the distribution is low voltage, and the control system (if required) is in the form of a laptop computer which inherently has a type of short duration uninterruptable power supply (UPS).

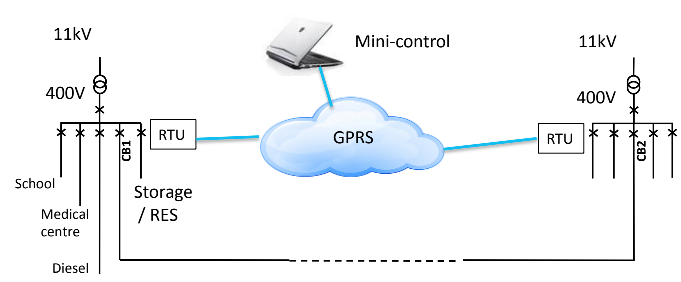

Figure 4: Microgrid structure

The voltage level of a Microgrid is normally determined by generating capacity and load level of the network. Technically, it may be that the voltage level of Microgrid is equal to the voltage of the distribution system it connects to, but it will be required to interface to the utility network via a distribution transformer. This will be the point of common coupling (PCC) to the utility network should the Microgrid operate in non-islanded mode. This is a common solution in many countries and the author's company has been involved in this type of connection [3].

When the energy supplied from the embedded generation within the Microgrid is sufficient to support the load then the utility network connection is not essential and the local community may find it economically beneficial in doing this. Equally, for the utility in times of peak load, if the local generation can supplement the supply from the utility, then there is no need to cater for the maximum upstream capacity. This is an advantage to the utility because it removes the need for reinforcement.

IV. COMMUNITY ENGAGEMENT

A key factor with developing a Microgrid in Africa would be community engagement as explained in reference [2]. This research highlighted that some of the challenges with the take-up of off-grid projects were because they can be of poor design, have a lack of local involvement, and suffer from a difficulty in transferring maintenance skills to the local community in order to make the solution sustainable.

The research concluded that local participation in technological choice and structural arrangements were essential to making the off-grid project a success. Community engagement will support the reason for developing a Microgrid and can provide the business case. For example, there are requirements to provide electrical lighting for schools in the evenings, and to provide power for refrigeration at the medical centers for storing vaccines. The control of the Microgrid can be used to enable greater hosting of embedded generation, which means this will encourage local entrepreneurs to make use of local assets and energy sources to produce electricity to support this grid.

V. HOSTING GENERATION

The ability to enable the Microgrid to host generation is important in this concept because this helps the wider community to exploit income generating opportunities through providing access to embedded generation and renewable energy sources.

The control elements of the Microgrid can not only be used for managing the voltage on the grid, but also for managing the amount of generation. It will be important to keep the Microgrid operational within its voltage and thermal limits through increasing and curtailing generation. In some cases it may be required that some generation is constrained, and in others instructed to increase. This will provide opportunities for local supply of RES and diesel generation.

VI. INTEGRATION INTO THE LOCAL UTILITY NETWORK

Whilst it is important that the local community have a sense of ownership, it is more than likely that the Microgrid will be owned by the local utility company. The electrical point of connection will be via the distribution transformer at the 400V interface. Having a basic measurement and control infrastructure will enable integration into the utilities control system, as shown in figure 5. The communication with the utility control system will use standard open protocols such as DNP 3.0 or IEC 60870-5-101/IEC 60870-5-104.

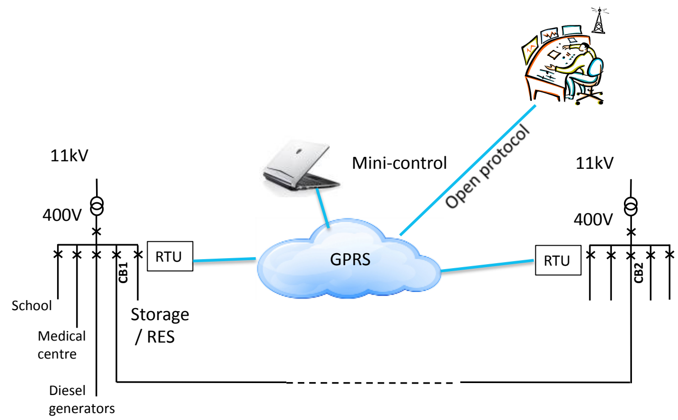

Figure 5: Microgrid interface to utility

This is consistent with modern control system architectures and enables the ability to integrate the Microgrid control functionality and architecture into the utility SCADA system.

This functional structure will support the local utility through being an integral part of its network when in connected mode, and by being self-sufficient when in island mode. This will allow the utility to maximise grid utilisation without reinforcement. The local control for the Microgrid provides the management interface to the utility SCADA. This structure can be replicated as a local building block in a geographical area, or as a consistent approach for the utility network across different regions. Each one of the Microgrids can form part of a wider network, as illustrated in figure 6.

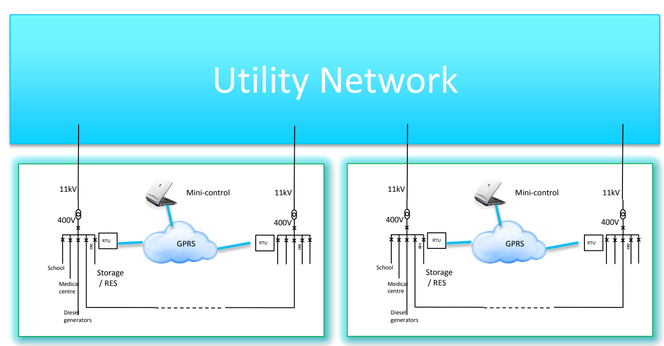

Figure 6: Expansion of Microgrid infrastructure

However, in making the Microgrid suitable for connecting to the utility national grid, the Network Codes (for that particular country) must be considered. In addition, this system is now exposing the utility SCADA to a wider environment and so it will be important that cyber security is implemented. Although not covered in this paper, the particulars of IEC 62351 [4] will need to be considered.

VII. CONCLUSIONS

Availability of electrical power is essential for the economic development of rural areas in Africa. The development of a Microgrid will increase accessibility to electricity and support growth in rural areas.

Microgrids contain generation and load. The ability to disconnect from and parallel with the utility system is a function of running the Microgrid. Through adopting open standards there is the ability to upscale the Microgrid and develop clusters of such areas supporting the utility in planning and management of its distribution network.

An enabler to achieving this will be with the adoption of international standards as these will support integration of the Microgrid into the larger Utility network.

VIII. REFERENCES

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IX. BIOGRAPHIES

Tim Spearing is responsible for the product management of the automation business in Lucy Electric. These range from secondary RTUs to complete SCADA and automation solutions. Tim is a Chartered Engineer, a Member of the IET, and a key supporter and contributor to IET Developments in Power System Protection (DPSP), the IET Midlands Power Group in the UK, the UK Smart Grid Forum, and EU Smart Grid Task Force

Rick St. John is the Regional Director at Lucy Electric South Africa. He has over 40 years' experience in the industry holding many senior positions. He is currently on the management committees for several organisations including AMEU.