Proceedings of the 25th Conference of the Electric Power Supply Industry (CEPSI 2025)
28 October – 1 November 2025, Sands Expo & Convention Centre, Singapore ©2025
CEPSI 2025 Organizers. **Paper ID: P351**
Track C: SMART GRID, MICROGRID & DISTRIBUTED ENERGY TECHNOLOGIES

Challenges And Successful Completion Of Upgrading Emergency Generator System Into Microgrid

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Abstract— **Conventional standalone emergency generator is connected to electrical emergency switchboard. During power failure, the generator will start up and supply electricity to the emergency switchboard to power up the essential electrical services in the development. It is possible to interconnect the whole development emergency generators (sited at different locations) to the electrical network, for the development to be self-sufficient operating as an independent grid and share the electrical loading equally. The selection and placement of microgrid controllers into the power network for smooth operation needs careful consideration. Electrical safety consideration of the low voltage and high voltage installation need meticulous study and planning. This paper will discuss some of these points in this microgrid development. On top of the explanation of this microgrid network, site testing and commissioning (T&C) waveforms of the generators from startup to full operation in parallel and load sharing in the microgrid mode will be shown. Challenges faced, such as overcoming the inrush current of the power transformer will be presented, and the inrush current waveform showing the characteristic of the power transformer during energization will be shown. The microgrid will be able to integrate with other future distributed energy resources such as renewables and energy storage systems.**

Keywords—Generator, Microgrid, Transformer Inrush Current

I. Introduction

Power resiliency is vital for the operation of critical infrastructures such as hospitals, military and security establishments. These facilities must be able to operate continuously even in the event of a national power outage. Moreover, there is an increasing demand on electricity, due to the growing use of electronic devices, communications, electric vehicles and increasing number of supporting facilities such as data centres.

This project aims to transform a conventional electrical design of a development to a future proof electrical network that is able to integrate new green technology and initiatives. This is in agreement with the nationwide green movement which is announced and documented in Singapore Green Plan 2030, a "net zero emissions by 2050", target to advance the nationwide sustainable developments [1].

Critical infrastructures face limitations when it comes to grid failure [2], including cyberattack [3][4]; therefore it is common that generators are used during emergency situations [5][6]. Application of various methods and configurations of using generators has been studied before, including integrating with Energy Storage System (ESS) and smart grid [7]. It is also common that the generator operates in a unidirectional power flow into the network or the grid. In the new approach, there is a possibility for scalable renewables, ESS and other Distributed Energy Resources (DERs) to be integrated into such power networks.

This project endeavours to build an estate size smart grid to integrate low tension generators at various locations with microgrid components for power distribution through the high-tension network. Each cluster of the microgrids will be integrated together to form a larger independent network.

II. MICROGRID SETUP & OPEARTION

A microgrid can be defined as “a local energy grid with control capability, which means it can disconnect from the traditional grid and operate autonomously” [8]. The technical information shared here is part of a microgrid cluster; it aims to build the capability to support the power demand of facilities during a power failure. It consists of sets of generators with smart grid capabilities where it will be able to scale up to integrate with other microgrid clusters and with the upcoming ESS, utility scale renewables and DERs.

The microgrid is designed to operate in both grid-connected and islanded modes. In the grid-connected mode, energy demand is supplied by the main grid. In the islanded mode, the controllers will manage the generators to supply to the load. For this cluster of microgrid, the local standby generators, 2 numbers of 1800kVA and 1 number of 1000kVA, PRP (prime rated power) rating [9], are used to power up the electrical network.

TABLE I. GENERATOR SPECIFICATION

	Generator Specification		
	Engine Alternator		*Rating (kVA)*
Generator 1 [EMSB B3-1]	Mitsubishi S16R-A2PTAW2	Mecc Alte EC046 2S4A	1800
Generator 2 [EMSB B3-2]	Mitsubishi S16R-A2PTAW2	Mecc Alte EC046 2S4A	1800
Generator 3 [[EMSB B65]	MTU 16V2000G26F	Mecc Alte EC043 1M4A	1000

III. PLACEMENT OF CONTROLLERS

Microgrid controllers are used in this project to control and connect power supply to electrical loads. With an interconnected controller network in the CAN-bus (Controller Area Network-bus) system, it is able to manage and control the power and energy flow of the whole electrical network. The microgrid controller manages the microgrid distributed power and energy resources, balancing the loads and generation, and ensuring stable operation while also optimizing energy costs and integrating renewables.

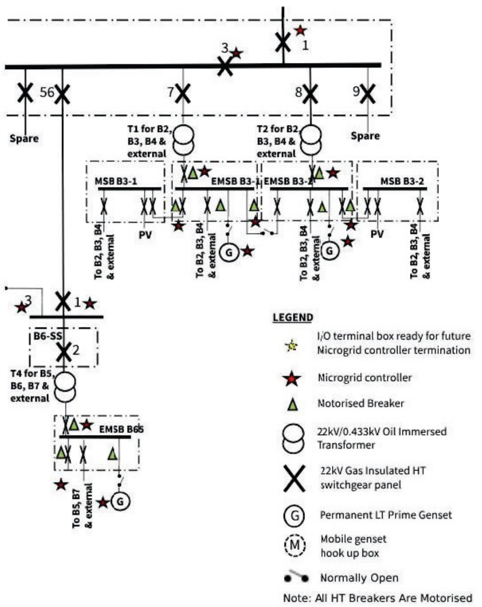

Fig. 1. Single Line Diagram

The controllers are placed in the strategic location in the electrical network, basically at the source of power, eg generators, and point of parallelling connections. The location of the microgrid controllers and the motorized breakers are shown in the single line diagram in figure 1. The controller GUI (Graphical User Interface) single line diagram is as shown in figure 2.

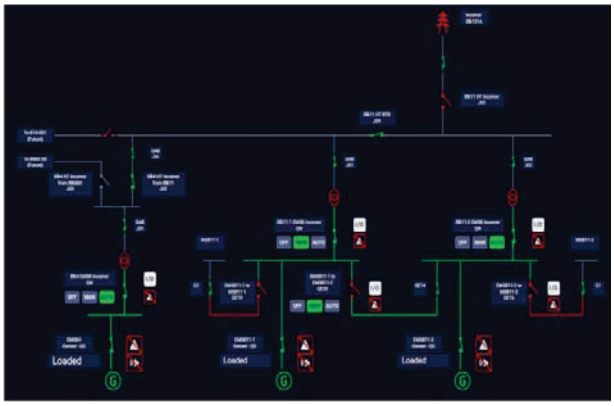

Fig. 2. Controller GUI -Single Line Diagram

IV. FERRO-RESONANCE PROTECTION CONSIDERATION

During normal operation, the development receives power supply from the power supply company’s electrical network, via 22kV incoming into its internal electrical distribution network. The 22kV intake is grounded at the grid substation incoming transformer via a 6.5: neutral to ground resistor (NGR)[10], figure 3.

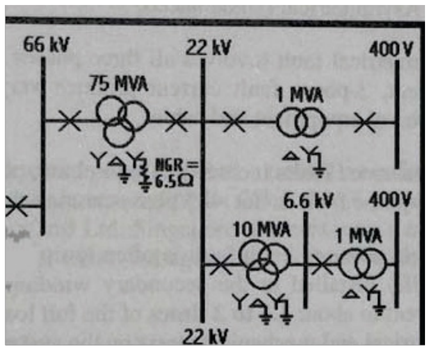

Fig. 3. Simplified network configurations of power supply company’s electricity network

Fig. 4. Voltage Clamping Device

During power failure from the grid, emergency generators will start up and power up the essential electrical services for each individual zones and buildings. Each individual zone can be interconnected and form a local independent island microgrid. When operating in this internal microgrid island mode, the primary power is delivered from the 400V generators and step-up to 22kV for the interconnection via the internal 22kV network

The local regulation for distribution power transformer is normally a delta-star transformer, with the low voltage side of the transformer star point grounded. When operating in island mode, the development power is disconnected from the external grid 22kV power supply; and the development power is from the distribution power transformers energized via the LV (Low Voltage) generators, with the HV (High Voltage) 22kV delta side of the transformer ungrounded. This poses risk of ferro-resonance [11][12] for any electrical switching operations. Ferro-resonance occurs between the inductance of the transformer and the capacitance of the HV lines and the switching equipment. Ferro-resonance can be initiated by switching, disconnection or by any transient events.

During ferro-resonance a significant overvoltage and concurrent current spikes can occur due to the saturation of magnetic circuits of the instrumentation VT (Voltage Transformer) at 22kV. This could lead failure of the VT and the physically coupled equipment, e.g. switchgear. To avoid this damage and eliminated this occurrence, a voltage clamping device (Figure 3) is installed in parallel with the VT at the 22kV switchgear to rapidly damp out any ferro-resonance oscillation that occurs, preventing potential damage and replacement of the voltage transformer.

V. Operation

During initial testing, attempt was made to power up the 22kV electrical network via transformer T4, 1000kVA, from generator 3, 1000kVA. The attempt was not achievable, as the overcurrent protection was activated and trip the system due to high current.

A detail study was made; and a second testing was scheduled with an alternative plan, and the results are presented in this paper. Load banks were installed at EMSB B3-1, 600A to simulate base load condition. Similarly, load banks are installed at EMSB B3-2, 800A. Generator 1 (EMSB B3-1) and generator 2 (EMSB B3-2) were powered up and parallelled with the bus coupler between EMSB B3-1 and EMSB B3-2 closed. After the two generators were paralleled, an attempt was made to energized transformer T1, 2000kVA.

This attempt was smooth and the 22kV internal distribution network was successfully energized. Since the internal distribution network was energized, generator 3 was able to pick up the common voltage via transformer T4, synchronized and closed onto the network to share the development load.

For final test, bus-coupler was opened, transformer T2 was closed to check if generator 2 can re-synchronized and closed into the network to share load. This test was successful.

Power analyzers were deployed during the second T&C, and were installed at both generator 1 and generator 2, to record the voltage and current waveforms to collect and analyze the testing results. Figure 9 and figure 10 shows the setup.

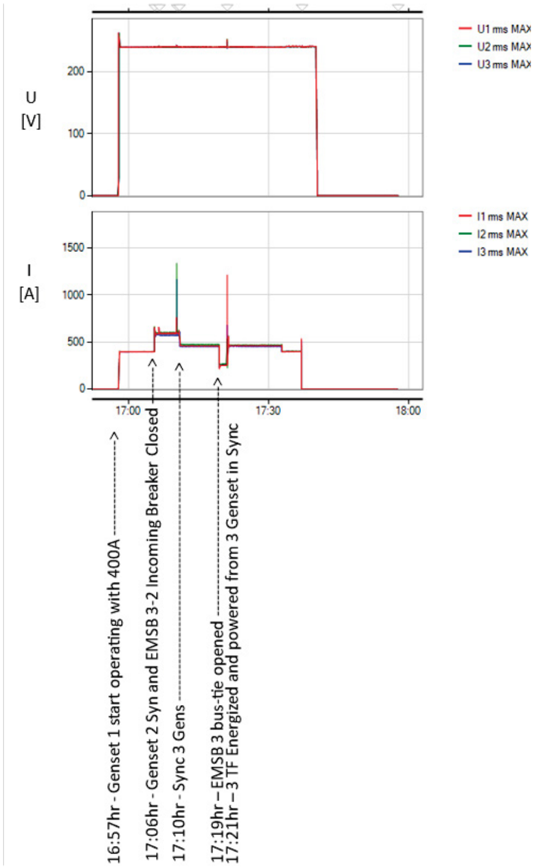

Fig. 5. Generator 1 Waveforms

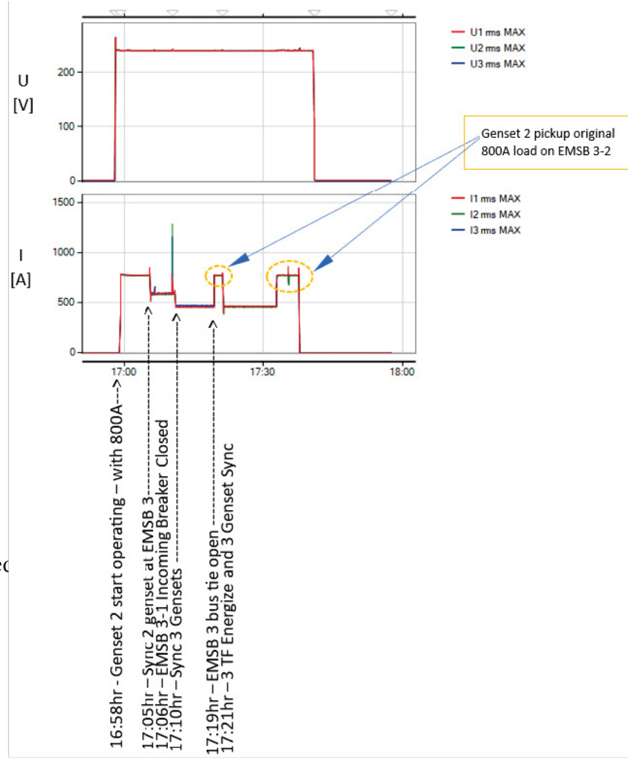

Fig. 6. Generator 2 Waveform

Figure 5 shows the voltage and load sharing waveform at generator 1, and figure 6 shows the voltage and load sharing waveform at generator 2, with time and operation notation

Figure 7 shows the inrush current recorded at generator 1 which is drawn by transformer, T1, during energization. Generator 2, with the same capacity as generator 1, is in parallel operation with generator 1, shared half of the require inrush current to energization transformer, T1, 2000kVA. The inrush peak current capture at generator 1 is approximately 3400A peak, after subtracting the emergency base load of 840A peak.

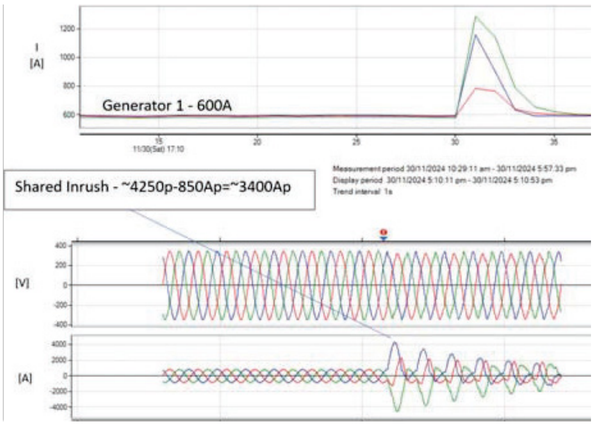

Fig. 7. Inrush Current of Transformer T1 During Energisation

Figure 8 shows the alternator manufacturer technical datasheet, EC046 2S4A, for the 1800kVA alternator. The alternator is able to provide a maximum of 3 times the rated current for 10 seconds, which is approximately 8000A. This is above the require inrush current of 3400A peak (3400A_P). The inrush current required by the 2MVA transformer is supplied by 2 generators and approximated to 2 x 3400A_P ÷ 1.414 = 4809A_{rms}. This is equivalent to 3.33MVA of inrush power, which is 1.66 times of a 2MVA transformer rating. Based on the retrieved measure value in this project, to black start a 2MVA transformer, a factor of 1.66 times of transformer rating power, 3.33MVA, is required to energize a transformer, before subsequence downstream operations are possible. The dual generators parallel capacity has ensured security and reliable black start capability. This design value and paralleling method has been tested, and has established an assured means to energize the transformer and form the microgrid.

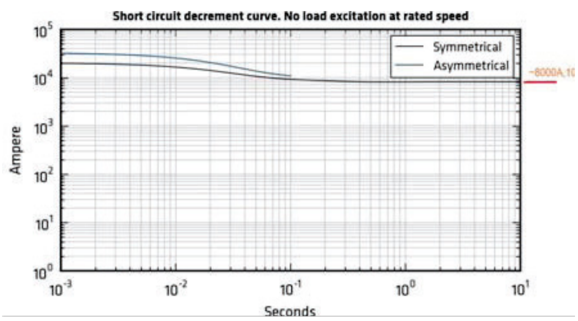

Fig. 8. Alternator Technical Data Sheet, EC046 2S4A, 1800kVA

A proper estimation and computation of the capacity of the transformer during design stage is very important, because without this important step being established, a common voltage and grid will not be able to be formed for the rest of the power system equipment to be connected. These technical data and real time waveforms captured are shared here for any future required electrical design works and reference.

Fig. 9. Power Analyser Setup

Fig. 10. Rogowski Coil Hook Up

VI. Conclusion

Unlike synchronous sources, non-synchronous sources such as photovoltaics are connected through power inverters, and by themselves may not be sufficient to actively provide mechanical inertia to load support. This project is part of a multi-cluster microgrid development in a smart grid, which will integrate utility scale renewables and energy storage systems for black start, ride through and grid forming capability. It is also to develop demand side response capability to support flexible loads.

This paper demonstrated a successful conversion of a traditional electrical network into a smart microgrid system. It has given the single line diagram with the strategic placement of microgrid controllers, highlighted the importance and provision of high voltage instrumentation transformer ferro-resonance protection for an ungrounded 22kV system, synchronising operation of generators, load sharing and distribution transformer energisation. A generating power of

1.66 times of 2MVA transformer has been established and required to black start the power transformer. The capture real time load sharing waveforms of the generators, measured inrush current with respect to typical alternator capability is shared here for any future works and reference.

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