# SMART GRID TECHNOLOGY PRIMER: A SUMMARY

## BACKGROUND

Smart grids are digitally-enhanced versions of the conventional electricity grid, with a layer of communications network overlaying the traditional grid. They are a key enabler for energy security and reliability and integration of renewable energy resources. The differences in the characteristics of smart grids and conventional grids are summarised in *Figure 1*.

| Characteristic | Conventional Grid | Smart Grid |
|---|---|---|
| **Consumer participation** | Consumers are under-informed and non-participative with power system service provider | Informed, involved and active consumers - demand response and distributed energy resources |
| **Integrating generation and storage** | Dominated by central generation. Many obstacles exist for integrating distributed energy resources | Many distributed energy resources with plug-and-play convenience to supplement centrally generated base-load , focus on renewables |
| **Market evolution** | Limited wholesale markets, not well integrated. Limited opportunities for consumers | Mature, well-integrated wholesale markets, growth of new electricity markets for consumers |
| **Resiliency** | Vulnerable to natural disasters and malicious acts of terror | Resilient to attacks and natural disasters with rapid restoration capabilities. |

*Figure 1: Smart Grid vs. Conventional Grid Characteristics*

## EFFORTS TO ADOPT SMART GRID TECHNOLOGIES

Over the years, SP PowerGrid has been building up its efforts to progressively adopt smart grid technologies, e.g. self-monitoring and online condition monitoring for network assets using network wide sensors, network mesh topology, adaptive protection schemes and semi-automated self-healing network restoration features. *(See Figure 2)* There are also various monitoring and management systems in place in Singapore such as the Electricity Management System (EMS), Gas Monitoring System (GMS), Interruptible Load (IL) Monitoring System and Distributed Generator (DG) Monitoring System. These systems include state of the art real-time components that enable remote monitoring and control of various elements of the electrical system from generators to loads in the high voltage network.

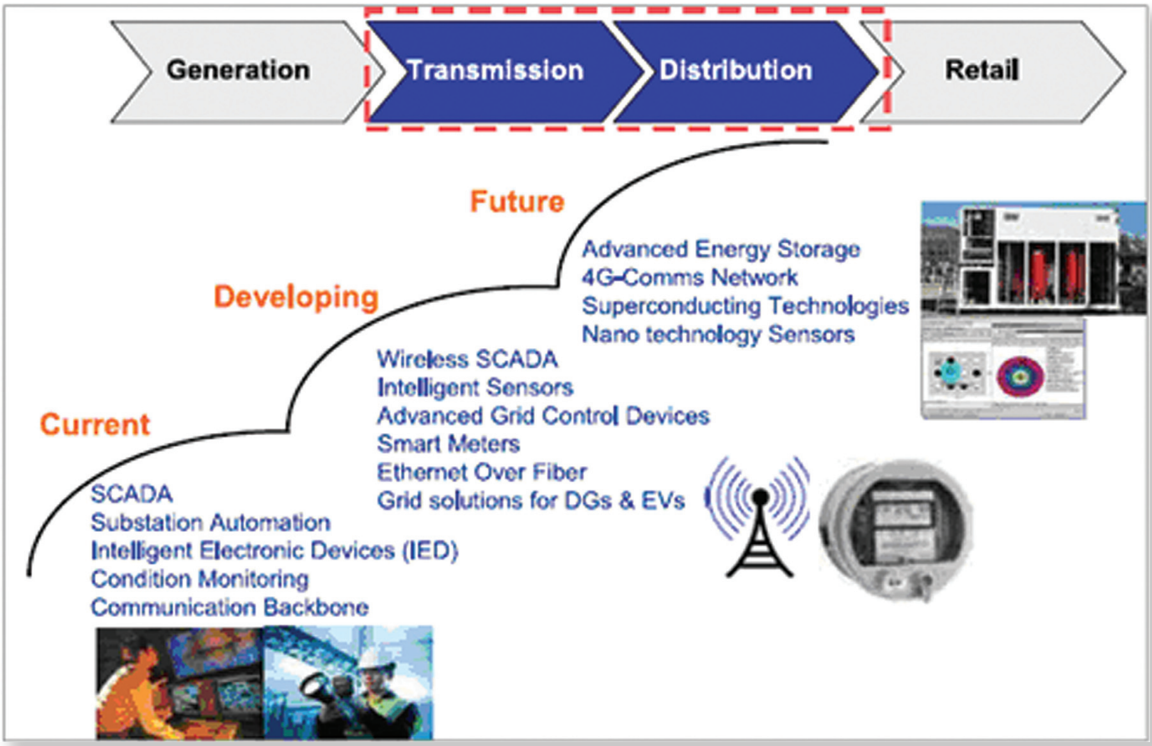


*Figure 2: An overview of SP PowerGrid's initiatives in making the grid more intelligent*[1]

## Electricity Grid in Singapore

The electricity grid in Singapore is currently amongst the most reliable and robust in the world with intelligent systems already installed in the generation and transmission network. The grid performance of Singapore's electricity network far exceeds that of other cities and countries. Network losses are reported to be only around 3%. *Figure 3* shows the historical grid performance of Singapore in terms of interruption indicators such as System Average Interruption Duration Index[2] (SAIDI) and System Average Interruption Frequency Index[3] (SAIFI).

[1] CEPSI 2010, document presented at The Conference of the Electric Power Supply Industry (CEPSI) held at Taipei in October 2010.http://www.aesieap0910.org/upload/File/PDF/5-Poster%20Sessions/PP/PP0202/PP0202008/PP0202008_FP.pdf (Accessed 3 March, 2011)

[2] SAIDI is the average outage duration for each customer served, and is measured in units of time.
SAIDI = (sum of all customer interruption duration)/(total number of customers served)

[3] SAIFI is the average number of times an average customer would experience.
SAIFI = (total number of customer interruptions)/(total number of customers served)

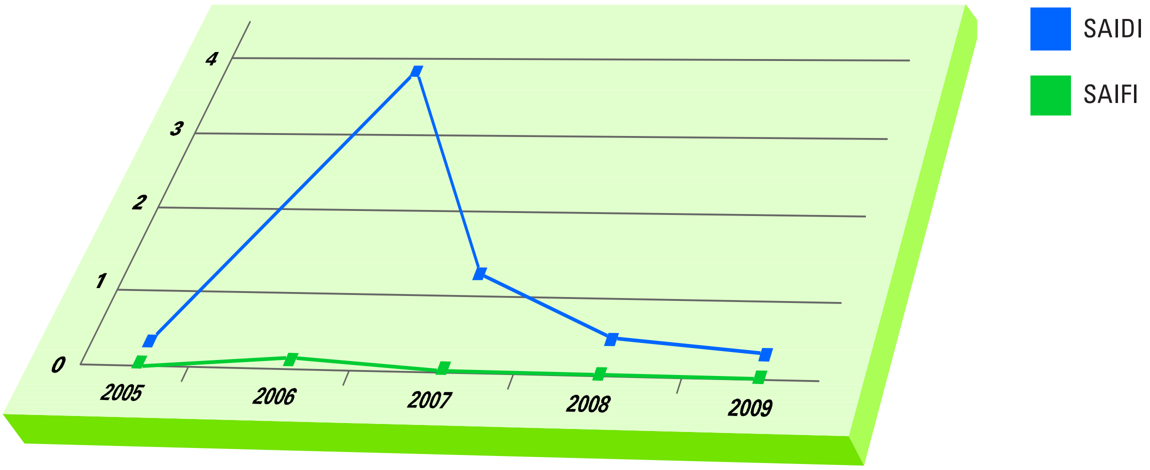


*Figure 3: Singapore Grid System Performance (Source: EMA)*

The current grid in Singapore is already smart, but the grid still employs conventional grid technologies, and the last-mile distribution network[4] can be upgraded to meet:

a. continued growth in demand;
b. the integration of increasing number of variable renewable energy sources and electric vehicles;
c. the need to improve the security of supply;
d. facilitate full retail competition; and
e. enhance delivery of electricity through better communication with households and businesses.

This is part of the premise of the Intelligent Energy System which seeks to test technologies which will be useful in meeting these objectives listed above. *(See Figure 4)*

[4] The last mile distribution network refers to the final leg of the transmission system that delivers electricity to the individual end-users, and is characterised by consumer-oriented and consumer-driven energy management initiatives such as advanced metering infrastructure.

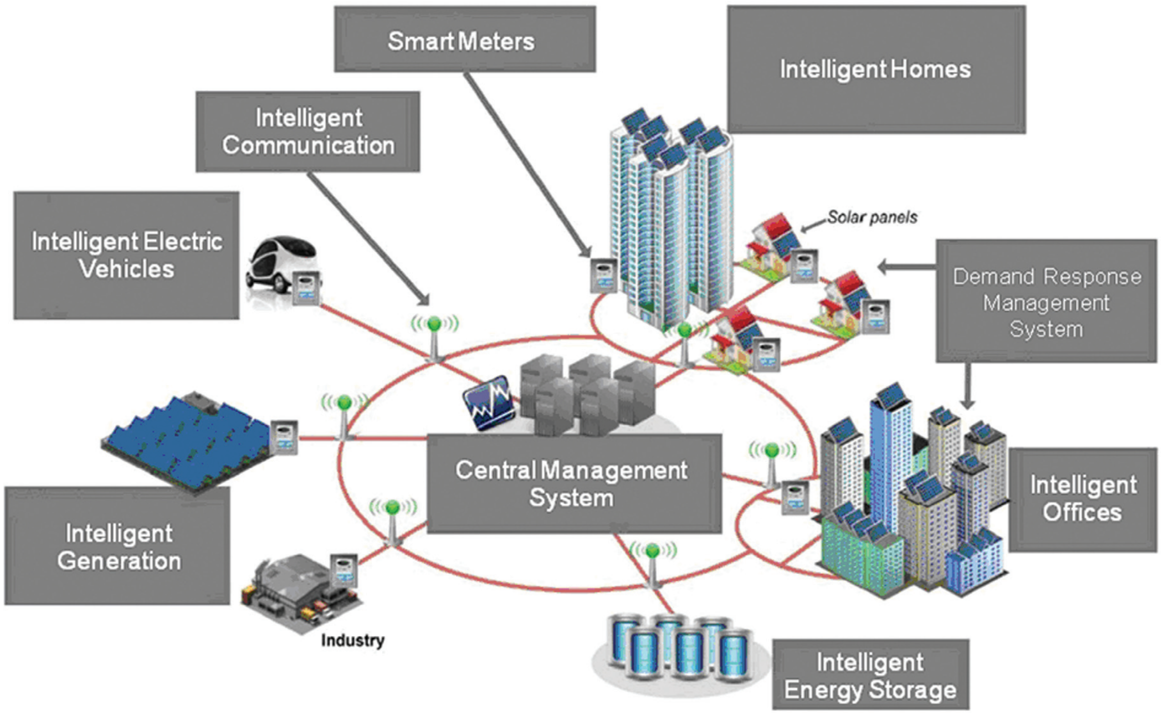


*Figure 4: Intelligent Energy Systems*[5]

Singapore's electricity grid consists of more than 20,000 km of underground cables interconnecting more than 9,800 substations in the transmission and distribution networks. Intelligent systems are currently installed in the upstream transmission and distribution systems. Future intelligent systems need to be installed in the last-mile connections and Distributed Generation (DG) integration systems.

## KEY DRIVERS FOR SMART GRID

The authors assess that existing grid may have to be upgraded:

(A) To support greater integration of distributed generation, such as renewable sources

Current annual electricity demand is 42 terawatt-hour (TWh).[5] Singapore's grid can currently accommodate up to 350 megawatt-peak (MWp) of renewable electrical energy, such as Photovoltaics (PV).[6] If the grid is to be able to accommodate more distributed generation, such as renewable energy in the future, without a loss in its reliability and robustness, the grid has to be able to:

a. Control peak generation of electrical energy from multiple/distributed generation sources;

[5] Energy Market Authority (EMA, Singapore), 'Introduction to the National Electricity Market of Singapore' (July 2009).
[6] Opening remarks by CE/EMA at the Solar Awards Ceremony on 30 Nov 2010.

b. Level out instantaneous fluctuations from renewable electricity generation, through the matching of electricity demand with supply within the grid;
c. Direct fossil fuel plants to generate less electricity when renewable electricity generation peaks, and vice versa;
d. Manage electricity demand by momentarily disabling non-critical electrical loads when the overall demand exceeds supply; and
e. Activate energy storage systems.

**(B) To be able to integrate electric vehicle (EV) charging infrastructure.**

Smart grids provide advanced control systems and communication networks needed to charge numerous EVs in a way that does not create unforeseen "charging peaks" in electricity demand that over-stress the grid. Unlike conventional grid technology, which is not able to respond to surges in demand, a better charging infrastructure will convey stability to the grid by smarter management in the form of instantaneous matching of electricity supply with demand.

**(C) To allow better energy management, outage management and improved grid reliability, which could successfully delay the need to build more power plants and upgrade of the grid.**

A smart grid will facilitate full retail contestability to consumers (via smart meters). Such smart metering can help to shave peak demand and drive energy efficiency, via active demand-response. In addition, the enhanced energy management allows for improved grid reliability and outage management via the use of more interruptible loads to deal with sudden instantaneous spikes in demand. e.g. In the UK, supermarkets turn off their cold rooms as necessary. This optimisation of current energy assets, i.e. 'spinning reserves'[7], delays the need to build more power plants and upgrade of grids. These deferred capital investments for the power sector will result in cost savings.

## EXISTING SMART GRID PROJECTS IN SINGAPORE

In Singapore, the Intelligent Energy System (IES) project is the first large-scale deployment to gather feedback on the distribution network, with a $30 million investment funded by Singapore Power and the Singapore Government. In collaboration with the Nanyang Technological University (NTU) and industry partners, the IES project will be testing various smart grid applications and solutions in real-life demonstrations, for 4,500 customers.

Other test-beds such as the Experimental Power Grid Centre (EPGC) and the Pulau Ubin Intelligent Micro-Grid project focus on testing the integration of renewable energy sources in a grid-connected and off-grid environment respectively.

Details of the various test-beds are given in the *Appendix*.

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[7] Spinning reserve refers to the excess power generation capacity that is available by increasing the power output of generators that are online.

## AREAS OF R&D FOR SINGAPORE

Smart grid technology research and test-beds in Singapore will enable the implementation of:

a. Advanced Metering Infrastructure (AMI) and demand response as key enablers of consumer-focused grid management;
b. Integration and control of Distributed Generation and renewables into the grid; and
c. Integration of EV charging infrastructure into the grid.

In a dense, highly urbanised environment, Singapore is well-placed to test-bed nascent technologies in smart grid-related implementation and research. AMI and demand response technologies are of immediate importance to introduce intelligence into the grid connectivity, and to build a wide base of smart meters for renewables and EV integration. Although potential for renewable energy generation may be limited locally in the early years, a demonstration of grid integration capabilities will allow Singapore to emerge as a key technology provider for renewable energy integration systems worldwide. Our land constraint also offers an opportunity to study the complexity of EV infrastructure in a constricted area in a controllable manner.

## $CO_2$ REDUCTION ENABLED BY SMART GRID

With smart grids, there is scope for $CO_2$ reductions due to improved energy efficiency, new mechanisms such as demand response management and the integration of more renewables into the grid. The impact depends on deployment and penetration of the smart grid technology in the mass market. *Figure 5* shows the various GHG emission reduction mechanisms enabled by a Smart Grid.

| GHG emission reduction | Mechanism |
|---|---|
| End-use efficiency improvement | Energy saving effects of consumer information and feedback |
| Facility efficiency improvement | Fine-tuning of air-conditioning, lighting systems, etc. |
| Improved utilisation of power plants | Demand response from dynamic pricing and load curtailment |
| Cleaner transport | Facilitation of EV and Plug-in Hybrid EV (PHEV) deployment |
| Integration of distributed renewable energy | By facilitating bidirectional power flow and voltage control on Medium and Low Voltage networks |

*Figure 5: GHG emission reduction mechanisms enabled by a Smart Grid*

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## SMART GRID TESTBEDS IN SINGAPORE

### Intelligent Energy System (IES) Pilot Project

In November 2009, the Energy Market Authority (EMA) launched a pilot project "Intelligent Energy System" (IES) with the aim to test a range of smart grid technologies to enhance the capabilities of Singapore's power grid infrastructure. Specifically, the IES pilot project seeks to develop and test the following components of a smart grid:

- Advanced Metering and Communications Infrastructure
- Demand Response Management Systems
- Management Systems for Distributed Energy Sources

The focal point of the project was chosen to be at the Nanyang Technological University (NTU), which has the research and technological capabilities to facilitate the testing of the various smart grid applications and solutions. Beyond the NTU site, the pilot will also be deployed in other locations, including the neighbouring CleanTech Park at Jalan Bahar, as well as selected residential, commercial and industrial buildings (e.g. the Punggol Eco-Precinct). This facilitates a comprehensive evaluation of various applications and communication methods for different building configurations, for example multi-dwelling buildings (e.g. HDB housing) with many users in close proximity may need a different communications solution than landed housing, where the users are more spread out.

The total budget for the IES pilot project is $30 million, funded by the Government and Singapore Power. The project contains 2 phases as shown in *Figure A1*.

| Phase | Timeline | Goals |
|---|---|---|
| **Phase-1** | 2010-2012 | • Implementation of the enabling infrastructure viz. smart meters and the communication system<br>• Establishing smart metering communication protocols and standards |
| **Phase-2** | 2012-2013 | • Introduce Smart Grid applications for residential customers such as in-home monitoring displays and choice of electricity pricing plans<br>• Introduce applications for industrial and commercial customers such as improved energy management systems and automation systems for monitoring and control |

*Figure A1: The IES project implementation plan*

Besides offering direct benefits to customers, the IES pilot will help to strengthen the power system capabilities and network efficiency in Singapore. Singapore Power's subsidiaries, SP PowerGrid and SP Services, are therefore key partners with EMA on the project.

In terms of industry partners, EMA has appointed Accenture Pte. Ltd. (Accenture) to design and implement the IES pilot project. Accenture has been appointed for Phase 1 of the IES pilot project and it will be working with its selected partners including ST Electronics (Info-Comm Systems), Oracle, Hewlett Packard, Power Automation. Control4 and Greenwave, in designing and implementing this phase of the project. The overall management of the Phase 1 of the IES and various parties involved are depicted in *Figure A2*. In Phase 2 of the pilot, other companies may be brought in to provide smart grid applications and services.

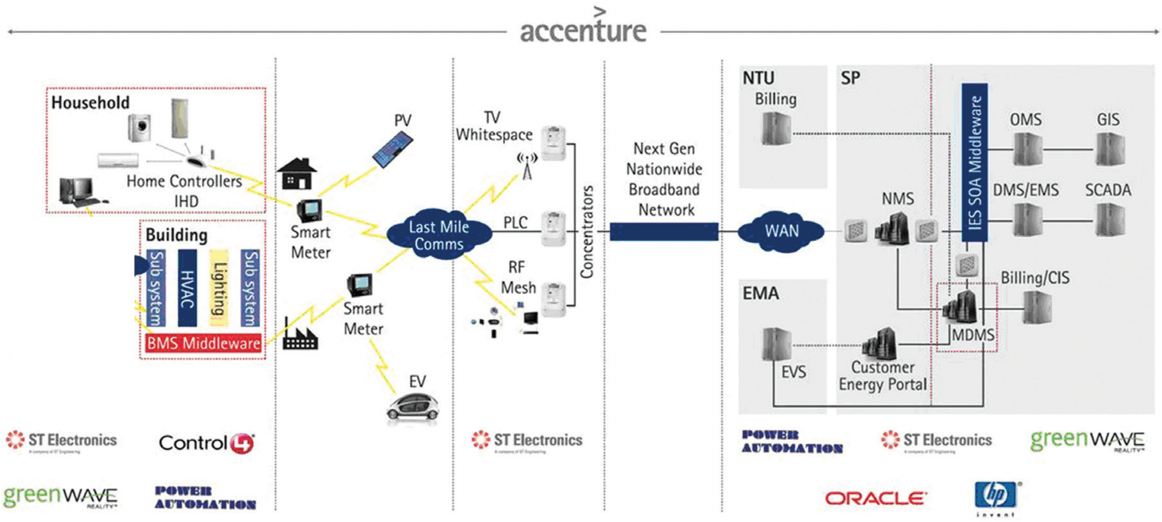


*Figure A2: Overall Management of the IES Project.*[8]

The IES pilot project is expected to complete by 2013. If the pilot is successful, the EMA intends to progressively roll out workable solutions for Singapore revolving around the IES, including further opening up of the electricity retail market for competition and enabling households to enjoy the benefits of competition. This pilot project will lay the foundations for an even more intelligent energy system in Singapore and bring the capabilities of the power grid to the next level, thereby ensuring that the electricity infrastructure is ready for the future.

[8] Accenture, 'Understanding Consumer Preferences in Energy Efficiency', Accenture end-consumer observatory on electricity management (2010).

## Experimental Power Grid Centre

The Experimental Power Grid Centre (EPGC) was founded with a vision for Singapore to lead in ushering new technologies for intelligent and decentralised power distribution, interconnection and utilisation. EPGC contributes to scientific and economic development through collaboration with industry, universities and public agencies to develop new technologies that can be implemented both locally and worldwide.

EPGC's diverse pool of researchers provides a multi-disciplinary approach to solving complex energy-related problems. It will employ around 20 to 25 people including 15 PhDs and researchers.

The Experimental Power Grid Facility is currently under construction on Jurong Island, and is due to be completed by end 2011. It features a 1 MW re-configurable multiple bus Low Voltage distribution system that can allow experiments on different power network topologies. A dedicated fibre-optical link, connecting this facility to a command and control centre in Fusionopolis on mainland Singapore, facilitates remote monitoring and control of this experimental grid. *(Figure A3)*

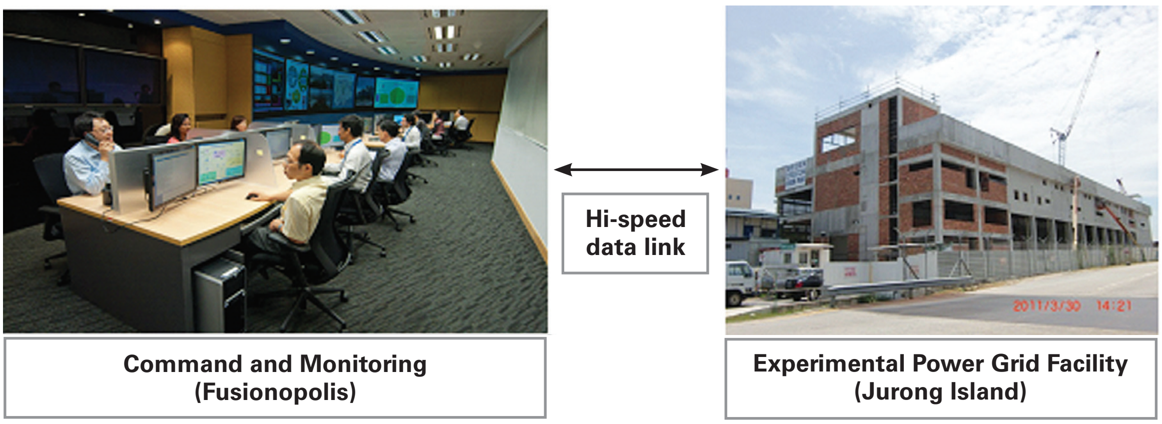


*Figure A3: EPGC facility and remote command and control centre*

In addition, various energy sources and their emulators such as wind turbine emulators will also be connected to the experimental grid. Emulators can emulate pre-programmed operating conditions and thus enable researchers to carry out experiments in smart energy areas for different geographical locations.

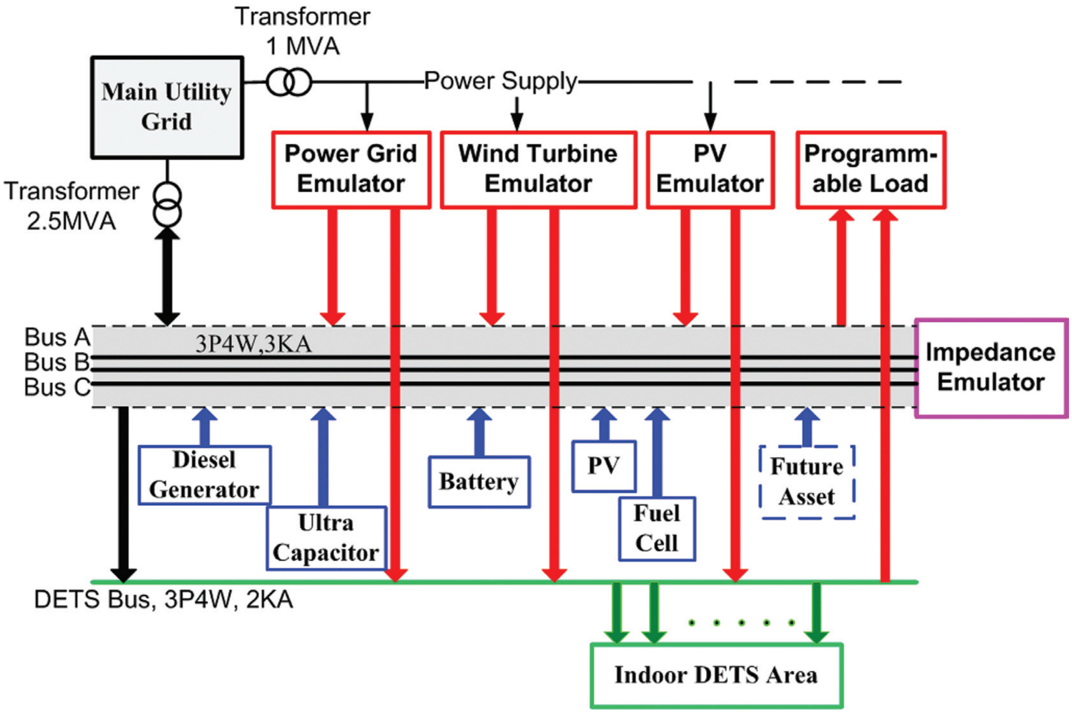


*Figure A4: Electrical Conceptual Diagram of Experimental Power Grid Facility*

The EPGC facility also allows for the validation of concepts and technologies for future novel energy and grid systems, allowing companies and agencies to make valuable quantitative assessments before bringing technologies to larger-scale test-beds. *(Figure A4)* By working with partner agencies, namely the Economic Development Board (EDB), Energy Market Authority (EMA), Jurong Town Corporation (JTC) and National Environment Agency (NEA), EPGC is able to participate in this whole-of-government approach and contribute towards the national agenda of increasing energy resilience through the enhancement of our energy infrastructure, and supports Singapore's efforts in becoming a "living lab" for new technologies.

## Pulau Ubin Intelligent Micro-Grid Project

Many remote areas in the world still lack proper access to electricity. One major reason is the lack of economic viability to lay power transmission cables due to the modest demand of these remote areas. EMA has embarked on a test-bedding project to develop an intelligent micro-grid infrastructure with clean and renewable energy technologies on Pulau Ubin.

With the intelligent micro-grid, we will be able to test-bed close-to-market clean and renewable technologies, and facilitate the deployment of market-ready ones. There is also potential for the micro-grid model to be exported and implemented in other remote areas of the region, through rural electrification projects, thereby creating a more vibrant clean and renewable energy sector in Singapore.

Contingent on the selection of a suitable proposal, and the appointment of a developer and owner-cum-operator for the project, the focus in 2011 will be on the development of the intelligent micro-grid infrastructure. A "Request-for-Proposals" for the test-bedding of close-to-market, clean and renewable energy technologies is also planned for the next stage. This will boost Singapore's vision of becoming a "living laboratory" for the test-bedding of new energy technologies.