SMART GRID INDEX
"HOW SMART IS YOUR GRID?"

Bok Soon, Au[1]; Kwong Mian, Sim[2]
[1,2]SP Engineering Council, SP Group, Singapore
[1]auboksoon@spgroup.com.sg
[2]simkm@spgroup.com.sg

Abstract - **Smart Grid development is a priority for most utilities around the world. What makes a power grid "smart" and how can this smartness be measured? Studies so far stopped short at creating a simple, quantifiable and yet useful index for benchmarking of grid smartness.**

This paper outlines a framework and methodology to measure and benchmark the smartness of power grids, using publicly available information. The methodology defines seven dimensions of a smart grid. Specific attributes and proxies of each dimension are selected to assess the performance of the grid. The results are consolidated to form the Smart Grid Index (SGI).

We applied the methodology to benchmark various utilities around the world. From the score of each utility in seven dimensions, its strengths and weaknesses were identified. The results help utilities to gauge their progress of smart grid development, and set key performance indicators and targets. They also enable identification of utilities with best practices in each dimension.

The Smart Grid Index framework is a useful tool to gauge utilities' progress in the journey to develop smarter grids.

1. INTRODUCTION

The world's energy landscape is undergoing rapid transformation with increasing decarbonisation, decentralisation and digitalisation. Facing these challenges, smart grid development has become a priority for most utilities around the world. What makes a power grid "smart" and how can this smartness be measured? Studies so far stopped short at creating a simple, quantifiable and yet useful index for benchmarking of grid smartness.

Traditionally, performance of electrical networks are measured using reliability indices, viz. SAIDI and SAIFI. SAIDI indicates the average duration of electricity interruption per customer per year, while SAIFI indicates the average number of supply interruptions per customer per year. These indices have been the cornerstone of electricity network business to set reliability targets and development plans for continuous improvement to better serve customers.
However, expectations are changing as the energy landscape transforms. Green targets, and maturity of technological development in DERs as well as incentives set out by policy makers have driven the proliferation of DERs at an exponential rate. Utilities face challenges of integrating these entrants sustainably to remain efficient and reliable. Using the traditional SAIDI & SAIFI reliability indices alone is now inadequate to set developmental targets for the next phase of transformation.

2. METHODOLOGY

Based on the definitions of smart grid by the European Union Commission Task Force [1] and the U.S. Department of Energy Smart Grid Task Force [2], we identified key dimensions of a smart grid. We developed a framework that guides smart grid development to deliver value to customers. The key dimensions are:

1. Monitoring & Control
2. Data Analytics
3. Supply Reliability
4. DER Integration
5. Green Energy
6. Security
7. Customer Empowerment & Satisfaction

From our own experience in gathering data within the organisation, we concluded that it would be extremely challenging and time consuming to obtain data from various utilities to carry out a benchmarking study. Learning from the concept of the Big Mac Index[4], we considered the following factors in designing the methodology for the SGI:

1. The concept of the index is to be simple, quantifiable, and yet useful to measure the dominant traits of grid smartness.
2. The inputs into the benchmarking process should be based on publicly available information.

3. The index should incorporate measures of both systems & processes implemented and the outcomes achieved to quantify their effectiveness.

Figure 1 illustrates how the seven dimensions work together in a smart grid. In a smart grid system, continuous awareness of the grid's status is critical and make possible by using monitoring and control systems such as SCADA. These systems also provide real-time network data, remote operation capabilities and enhancement of decision making. The data gathered from monitoring and control systems can be analysed and applied in asset planning and renewal, network operation and maintenance. Moreover, certain real-time data, such as energy consumption and pricing information, can empower customers to make informed decisions to lower energy costs. Strengthening network security is also critical to ensure supply reliability. Physical security, network security and cyber security are components of this dimension.

With the growing number of DERs connecting to the grid, integrating DERs onto the grid without jeopardising stability has become crucial for sustainable grid operation. The capability to integrate DERs and facilitating the use of green energy will ultimately bring greater value to customers.

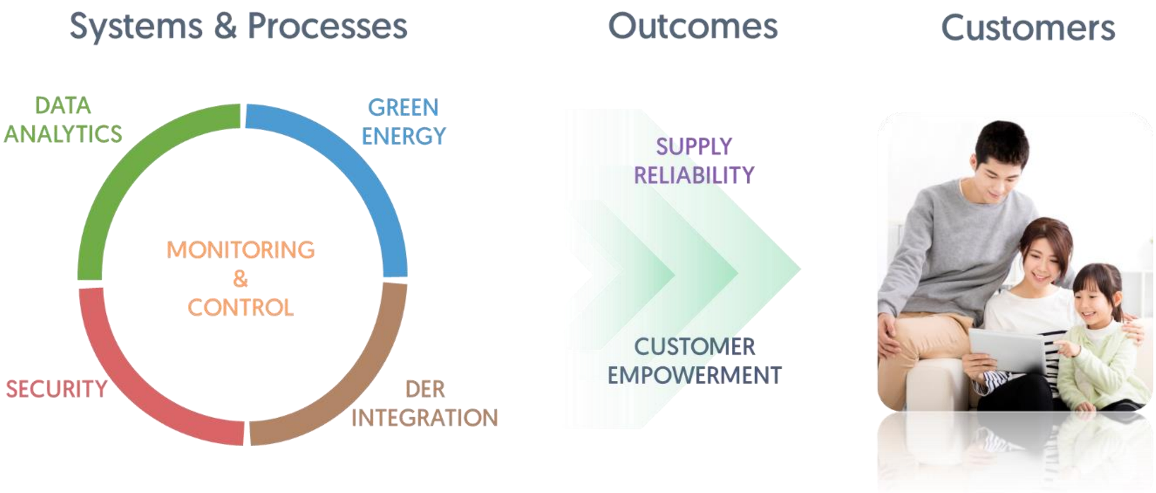

Figure 1: Delivering value to customers through a smart grid

2.1 Monitoring & Control

SCADA is commonly used by utilities for data acquisition, monitoring and control of the entire transmission and distribution network. The SCADA system plays a significant role in power system operations.

As the network becomes increasingly complex, a real-time network view and dynamic decision-making capabilities have become crucial for optimizing resources and managing the network, creating the need for DMS. A collection of various applications, the DMS acts as a decision support mechanism assisting the control room and field operating personnel. The DMS can process real-time data and provide vital information at the control centre in an integrated manner. In some utilities, DMS is taken to the next level, commonly known as ADMS, to include automatic fault location, isolation and supply restoration capabilities, and an integrated outage management system in the event of network failure.

2.2 Data Analytics

Data analytics is employed to improve operation, maintenance and asset management.

AMI is an integrated system of smart meters, communications networks and meter data management systems. These smart devices enable grid operators to monitor status of low voltage networks, which are typically not monitored under SCADA.

The implementation of AMI will lead to a huge increase in the volume of data collected. Advanced data analytics is therefore crucial for a smart grid to analyse the data and produce useful results. Utilities can use data analytics to improve their understanding of customer behaviour, consumption patterns, network reinforcement and asset renewal needs.

2.3 Supply Reliability

Supply reliability is still a key feature that utilities are expected to deliver under all circumstances. SAIDI and SAIFI are widely accepted reliability indices. Two broad ways to improve supply reliability are prevention and containment.

2.4 DER Integration

DER refers to solar PVs, wind turbines and ESS connected to the electrical distribution network. Due to their intermittent nature, the mass installations of solar PV, for example, are typically accompanied with ESS and flexible loads to solve the problem of variability. DERs bring flexibility into the electricity market allowing customers to have more choices and control over their energy consumption. Nonetheless, integration of DERs into the grid remains challenging in a smart grid development.

With the rapid growth of DERs, industrial standards and procedures for DER integration should be transparent and made available to all users. Tools, such as capacity hosting map should also be published and updated regularly. In this way, DER integration throughout the network will be facilitated consistently towards a smarter grid. Utilities must be able to manage integration of DERs without jeopardizing network stability. For example, DERMS, together with modern communications sensors, data platforms and artificial intelligence can be employed to effectively manage DERs.

2.5 Green Energy

In December 2015, 195 nations signed the Paris Agreement, pledging a long-term global action plan to reduce greenhouse gas emissions and limit the increase in global average temperature [3]. Renewable energy resources are deemed to be the most promising solution to reduce greenhouse gas emission from electricity generation. Electricity generated from both customer-owned and utility-owned renewable energy resources can supplement power generation by conventional power plants. Therefore, the penetration rate of renewable energy is a measure of sustainable development.

Electric vehicle is another promising solution to reduce greenhouse gas as the emission is better controlled at the generation plants. Utilities can promote EV utilization by transforming their service fleet to EV, installing charging infrastructures for the public and offering ToU tariff for EV charging. ToU plans for EV charging will encourage customers to charge their vehicles during off-peak hours when the electricity demand is low. This can help to reduce the peak load demand, thus deferring capital investments and reducing carbon footprint.

2.6 Security

Physical, network and cyber are the three aspects of security that must be managed. Network security is a basic planning criterion. No utility will publish their physical security measures. Therefore, we only include cyber security in our framework.

Many organisations, including utilities, around the world have suffered from cyber-attacks. Utilities must exercise extreme caution to deal with cyber threats as more IoT devices are deployed in the network. Security of the grid, particularly the telecommunications, operation and control systems should always be a top priority; stringent cybersecurity measures and management should be adopted to safeguard against malicious attacks. Appropriate cybersecurity measures, including compliance to cyber security standards for both IT and OT systems, are crucial for secure operation of the grid.

2.7 Customer Empowerment & Satisfaction

In today’s electricity system, consumers can also be producers. The smart grid provides customers flexible choices to buy from and sell electricity to the grid. AMI enables utilities to provide customers with real-time energy consumption data and pricing information. This would create greater awareness for customers about their energy usage and enable them to manage their consumption and lower energy costs.

Regardless of how complex the energy landscape may evolve, customers continue to expect safe, reliable, resilient and affordable electricity. It is good practice to conduct regular customer satisfaction surveys and publish the results to show commitment to satisfying customers’ needs.

2.8 Assessment Method

Specific questions are designed for the seven dimensions to assess the performance of the grid. Scores are given based on the answers to the questions. The assessment is relatively simple, yet adequate to measure dominant attributes of a smart grid. The questions are constructed based on selected proxies in each dimension so that they can be answered using publicly available information.

The status of the smart grid's systems and processes, and the outcomes achieved are assessed. The SGI can serve as a guide for smart grid development and the benchmarking results can be used to measure the progress and set targets for continuous improvement. Utilities can also leverage on the index to gain stakeholders buy-in and justify their business plans for smart grid development.

3. BENCHMARKING RESULTS

We have completed a SGI benchmarking study for more than 40 utilities, across the globe. Using a star rating system, we grouped the utilities in terms of their grid smartness level, ranging from one to five stars, with five stars being the most advanced (See Table 1). We have excluded utilities that do not have adequate data publicly available for evaluation. We also identified examples of utilities with the best practices for each dimension to serve as references for utilities to level up and learn from one another. (See Table 2).

TABLE 1
BENCHMARKING RESULTS OF UTILITIES AROUND THE WORLD

Utility	Country	Grid Smartness Rating
Pacific Gas & Electric	USA	*****
Commonwealth Edison	USA	****
Consolidated Edison	USA	****
Duke Energy	USA	****
e-distribuzione (Enel italia)	ITA	****
EDP Distribuição	POR	****
Innogy	GER	****
San Diego Gas & Electric	USA	****
Southern California Edison	USA	****
UK Power Networks	GBR	****
Ausgrid	AUS	***
Chubu Electric Power	JPN	***
China Light and Power	HKG	***
CitiPower	AUS	***
DEWA	UAE	***
Eandis	BEL	***
Enedis	FRA	***
Florida Power & Light	USA	***
Helen	FIN	***
Hong Kong Electric Co	HKG	***
Hydro Ottawa	CAN	***
Kansai Electric Power Co	JPN	***
Korea Electric Power Corp	KOR	***
Liander (Alliander)	NED	***
Radius Elnet (Ørsted)	DEN	***
SEMPC (Shanghai)	CHN	***
SP Group	SIN	***
State Grid Beijing	CHN	***
Stedin	NED	***

Utility	Country	Grid Smartness Rating
Tata Power Delhi Dist	IND	***
TNB	MAS	***
TEPCO	JPN	***
Western Power Dist	GBR	***
CEM	MAC	**
Eskom	RSA	**
Vietnam Electricity	VNM	**
MEA	THA	**
Meralco	PHI	**
Moscow United Electric Grid Company (Rosseti)	RUS	**
PLN	INA	**
Tai Power	TPE	**
Vattenfall El distribution	SWE	**
Vector Limited	NZL	**
Western Power	AUS	**
Wien Energie	AUT	**

Grid Smartness Rating	*Score*
*****	*> 85%*
****	*70% - 84%*
***	*50% - 69%*
**	*25% - 49%*
*	*< 25%*

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TABLE 2
EXAMPLES OF UTILITIES WITH BEST PRACTICES

Utility	Best Practices
Enedis	Monitoring & Control
Tata Power Delhi Distribution	
e-distribuzione (Enel)	Data Analytics
Hong Kong Electric Company	Supply Reliability
SP Group	
Pacific Gas & Electric	DER Integration
Ausgrid	
Innogy	Green Energy
Commonwealth Edison	Security
Kansai Electric Power Company	Customer Empowerment
UK Power Networks	

The results indicate that the index is feasible for benchmarking utilities from various regions around the world. In general US utilities fare better than European utilities and both are ahead of Asian utilities. This could possibly be attributed to the US and European utilities facing disruption in their industry and regulatory intervention earlier than Asian utilities. The utilities in the study have all progressed in their smart grid development to attain at least a 2-star rating. Furthermore, the study shows that even a utility with a 2-star rating can achieve best practice in certain dimensions. Identifying good practices and learning from one another will aid utilities in their journey towards a smarter grid.

4. CONCLUSION

The SGI framework is designed for smart grid development to deliver value to customers. The SGI is a simple, quantifiable and yet useful tool for benchmarking of grid smartness using publicly available information. In this study, we benchmarked a large pool of power grids around the world and the results showed that the methodology is feasible. Using this SGI framework, utilities will be able to track development progress, set targets for further improvement to align with future energy landscape and customers' expectations. Furthermore, the SGI is constructed to measure not only the systems & processes implemented but also the outcomes achieved that deliver sustainability, reliability and satisfaction to the customers. From the benchmarking results, best practices from individual utilities can be identified, shared and acted upon in working towards a smarter grid.

In the fast-changing world today, technologies develop rapidly. New systems and processes of smart grids will continue to be developed. The assessment that is considered holistic today may not be regarded as comprehensive in future. The assessment methodology of the Smart Grid Index has thus to evolve with time by adopting new criteria to keep up with new technological development. One example is DERMS. With the increase in DER integration, DERMS will inevitably be an important component of a smart grid and cannot be ignored. However, our research showed that although many suppliers claim to offer DERMS, most projects are still pilot in nature. It is therefore not included as a measurable attribute in our current study. However, we are mindful that with the technological development DERMS will have to be seriously considered in future revision of the SGI.

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ACRONYMS AND ABBREVATION

ADMS	Advanced Distribution Management System
AMI	Advanced Metering Infrastructure
APRS	Automated Power Restoration System
DER	Distributed Energy Resources
DG	Distributed Generation
DMS	Distribution Management System
DERMS	Distributed Energy Resources Management System
ESS	Energy Storage System
EV	Electric Vehicle
IT	Information Technology
IoT	Internet of Things
NERC CIP	North America Electric Reliability Corporation - Critical Infrastructure Protection
OT	Operational Technology
PV	Photovoltaic
OMS	Outage Management System
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SGI	Smart Grid Index
ToU	Time of Use

DISCLAIMER

We have arrived at the findings, opinions and conclusion set out in this paper based on application of our methodology to materials and information which are publicly available, and we believe to be accurate and reliable at the time when we carried out the relevant research and study. Despite our best efforts, the materials and information may include inaccuracies and errors. The findings, opinions and conclusion will be construed solely as statements of opinion on the matters addressed in this paper including the degree of grid smartness ratings and shall not in any way represent authoritative assessment or judgment on any such matters. You assume the sole risk of making use and/or relying on the findings, opinions and conclusion made available in this paper. To the extent permitted by law, we disclaim liability to any person or entity for all and any liability, direct and indirect, special, consequential, incidental losses and damages whatsoever arising from or in connection with your access to or use of the findings, opinions and conclusion in this paper.