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Transactive Energy System

By

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Author's Declaration

I declare that this thesis is my account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

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Abstract

The rising of distributed energy resource (DER) e.g. rooftop PV solar system, wind system and energy storage system, and load demand response bring both opportunities and challenges to the power grid. Coordinating decentralised DERs is important. The purpose of transactive energy (TE) system is to coordinate DERs at the distribution level and encourage consumers and prosumers to participate in electricity market by providing economic incentives. TE system enables customers and prosumers to sell the surplus energy to their neighbours. This thesis represents research on TE system in aspects of structure, technology, economics and participants. The impact of TE system in Australia's electrical standard and electricity business mode is also explored. Moreover, based on research findings, a TE system model for Australia is proposed. The key findings of this project are:

- TE System is a method to relieve electricity congestion.

- The power flow (distribution level) and transaction in TE system are bidirectional.

- TE system is customer-oriented and offers more choices to customers/prosumers.

- The new distribution system operator (DSO) plays a key role in coordinating DERs and end-users.

- Undertaking a TE system demonstration project in Australia is suggested.

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List of Abbreviations

AEMO	Australian Energy Market Operator
CEMS	Comprehensive Energy Management System
DER	Distributed Energy Resource
DLMP	Distribution Location Marginal Price
DMS	Distribution Management System
DR	Demand Response
DSO	Distribution System Operator
GHG	Global Greenhouse Gas
IEC	International Electrotechnical Commission
ISO	Independent System Operator
LMP	Location Marginal Price
MCC	Marginal Congestion Cost
MEC	Marginal Energy Cost
MLC	Marginal Loss Cost
SGAM	Smart Grid Architecture Model
TE	Transactive Energy

1.0 Introduction

1.1 Project Motivation

Nowadays, the involvement of advanced information technology, demand response (DR) and the growth of Distributed Energy Resource (DER) in particular bring both opportunities and challenges to electricity network transformation. DER comprises not only renewable generation such as solar system (rooftop solar) and wind turbine, but also some flexible loads and storage. The increasing number of DERs can improve the power system of a building or a microgrid resiliency by reducing single failure point. However, it can also make coordination and interoperability more complicated, which may cause reduced reliability (Ambrosio 2016). In other words, poor interoperability and cooperation on DERs introduce negative influence on power quality. A transactive energy (TE) system is a method to help the power system address these issues. The TE System can coordinate the different components to provide high-quality electricity by establishing distributed information system architecture. Also, a uniform signalling mechanism between the system components is applied in TE system to improve interoperability (Ambrosio 2016). Moreover, TE system encourage the consumers and prosumers to participate in electricity market by selling their surplus energy to their neighbours.

1.2 Project Objectives

The objectives of this thesis project are to:

1. Undertake a detailed research about the concept of transactive energy system;
2. Undertake a literature review to explore transactive energy system in aspects of technology and economics;
3. Undertake a literature review to identify the participants in transactive energy system and their relationship;

4. Explore the impact of transactive energy system in future power grid transformation of Australia

5. Develop a transactive energy system model for Australia

2.0   Background Information

2.1   Distributed Energy Resource

The energy report of the International Energy Outlook 2009 (IEO) indicates that from 2006 to 2030 world energy demand has an increase of 44%, and 77% in the net electricity generation worldwide (EIA, 2009). The conclusion of the report is that the proportion of fossil fuel used to generate electricity would be 80% in 2030 (Akorede, Hizam, and Pouresmaeil 2010). Global greenhouse gas (GHG) will increase significantly due to the dependence on fossil fuel.

It is well known that GHG emission is damaging to the environment, e.g. global warming and rising of sea level. A practical method to reduce the dependence of fossil fuel and GHG emission is adopting distributed generation technologies (DG) widely in power systems, which can produce a reliable, clean energy (Akorede, Hizam, and Pouresmaeil 2010). Instead of being connected to the bulk power transmission systems, distributed energy resource (DER) is electricity generation resources that are connected to the medium voltage and low voltage distribution directly (Akorede, Hizam, and Pouresmaeil 2010). DER is comprised of two main parts, which are distributed generation (DG) technologies and energy storage technologies. Figure 1 shows that DG technologies have fuel cells, micro-turbine, photovoltaic, wind turbine etc., and energy storage technologies include batteries, flywheels, superconducting magnetic energy etc. In this thesis report, DER about PV, wind turbine and batteries will be discussed.
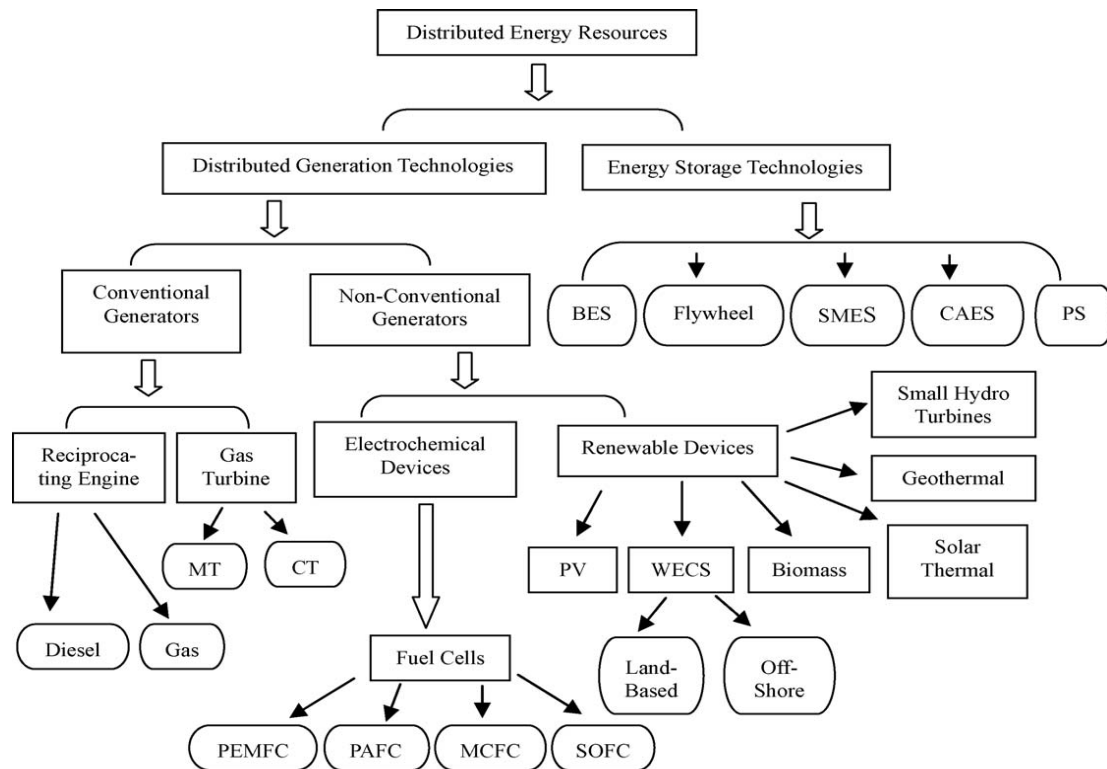
Figure 1 DER technologies (Akorede, Hizam, and Pouresmaeil 2010)

2.1.1   Photovoltaics Systems (PVs)

The function of a PV system is to convert solar energy into electricity without GHG emission. It could be stand-alone or connected to the grid. Figure 2 displays global solar capacity had a significant growing trend from 2011 to 2015, and total solar capacity could reach about 300 GW in 2016. In Australia, installed solar capacity is around 4500MW and ranks 6th in the world (ESAA n.d.). It is worth pointing out that Australia's penetration of household solar PV in Australia leads the world. Up until 2015, more than one-seventh of Australian households had installed solar PV (ESAA n.d.).
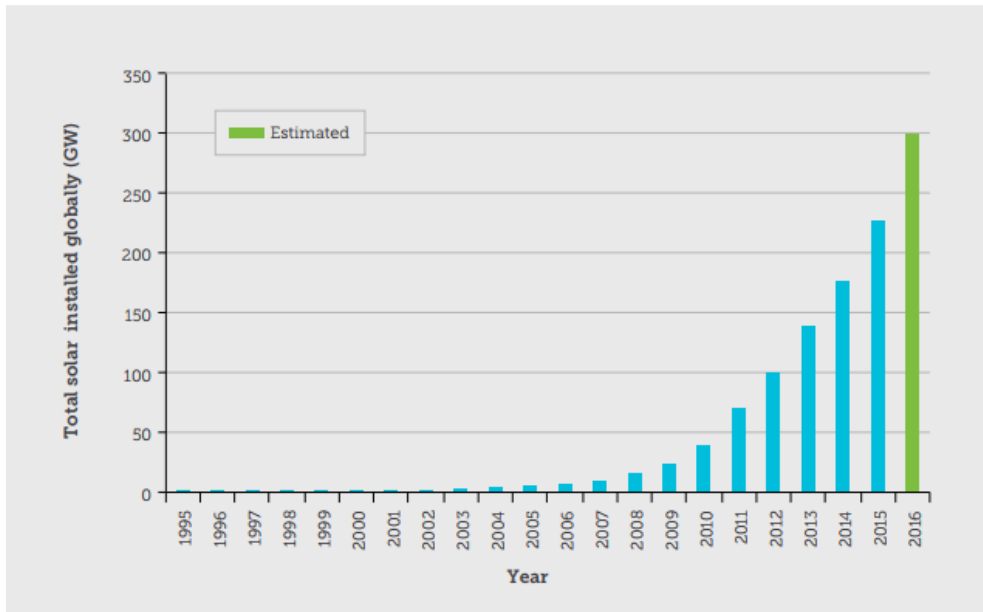
Figure 2 Global solar capacity (Climate Council, 2016)

2.1.2   Wind Energy Conversion System

Wind turbines can convert the kinetic energy of wind to electric power. Wind energy is an essential part of renewable energy. During the last two decades, the energy output of the wind turbine experienced an upward trend during from 20 kW in 1970 to 4 MW now (Lins et al. 2014). Meanwhile, the capacity of wind power in the world had an upward trend from 17 GW into 318 GW in 2013 (Figure 3). Currently, the installed wind capacity in Australia is 3800 MW and ranks 11th in the world (ESAA n.d).
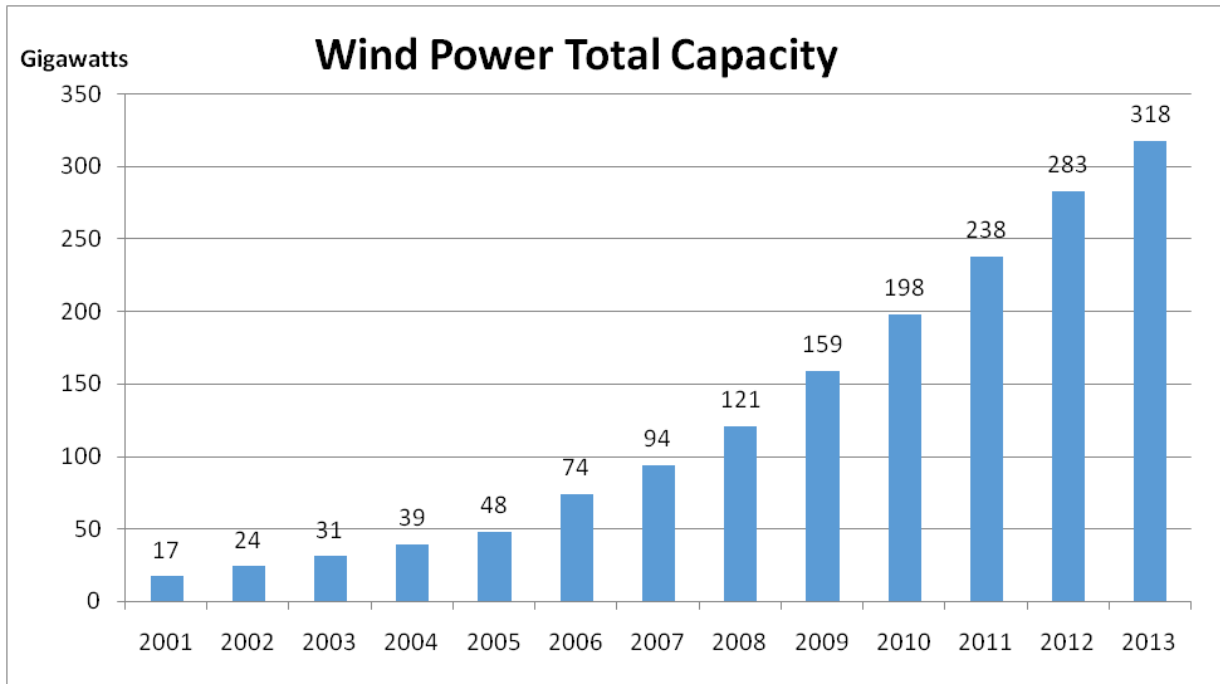
Figure 3 Wind power total world capacity (Lins et al. 2014)

2.1.3   Battery Energy storage system

Battery energy storage system (BESS) can provide spinning reserve when the power plant or transmission line equipment fails. For example, the installed battery can back up stand-alone PV system when the weather is cloudy, and PV system cannot produce enough electricity. Besides, batteries play an important role in load levelling and voltage controlling, VAR, and frequency (Akorede, Hizam, and Pouresmaeil 2010). Various battery materials have been used and proposed include lead-acid, nickel-metal hydride (NiMH), lithium-ion, and lithium polymer (Akorede, Hizam, and Pouresmaeil 2010). When installing batteries, production cost and life cycle should be taken into considerations.

2.2   Demand Response

The definition of demand response is that customers have the ability to respond to either a reliability trigger or a price trigger from their utility operator, load-serving entity or other demand response providers by reducing their power consumption (FERCS 2010). There are two types of demand response. Dispatchable demand response refers to planned changes in consumption that the customer agrees to make in response to direction from someone other than the customer. It includes three approaches to achieve demand response. Firstly, some appliances with controllable loads, such as air conditioning and water heating can be pre-set by customers based on their preference and tariff. Secondly, directed reductions in return for lower rates (called curtailable or interruptive rates) are used. The third method is a variety of wholesale programs provided by different system operators that compensate participants who decrease demand when directed for either reliability or economic reasons (FERCS 2010). The other type is non-dispatchable demand response refers to programs and products offered to customers who decides whether and when to reduce consumption according to various retail design over time. In non-dispatchable demand response with dynamic pricing programs, customers can choose to reduce demand load and sell electricity to the grid during high-demand hours (FERCS 2010).

2.2.1   Relationship between Demand Response and Smart Grid

Demand response is essentially linked with the smart grid in many areas of applications. The purpose of the smart grid is to enable real-time coordination of information from generation supply resource, demand resource, and distributed energy resource (Commission 2009). Many of the benefits linked with the asset in the smart grid are demand response actions. For example, the core of the smart grid is providing a better consumer management of electricity usage in response to price or signals from grid operators (TFERCS 2010).

3.0   Literature Review

3.1   Introduction

The literature review is one part of the thesis report, which has been published by various organisations and persons as a part of other projects related to the TE system and contributes much valuable information to this report. The relevant articles, project reports and journals included in literature review provide readers with information about TE system structure, economics, technologies, players and their relationship in TE system and the opportunities of TE system in Australia. Based on researching on TE system, TE system is an emerging technology, and the exploration of TE system for large-sale application in the future is still undergoing. Hence, in order to help readers to understand principle behind TE system, some of the demonstration projects of TE system and reports will be discussed as a part of literature review.

3.2 Transactive System Review

3.2.1 Structure of TE system

TE system combines technical communication between electrical infrastructure and exchange of market information in different players to achieve interoperability of the future electrical grid. A model was developed by the Grid Wise Architecture Council (GWAC) to represent the organisational, information specific, and technical aspects, which can be divided into eight categories(Melton 2013). As can be seen from Figure 4, three broad grouping of GWAC Stack elements of TE system can be defined.
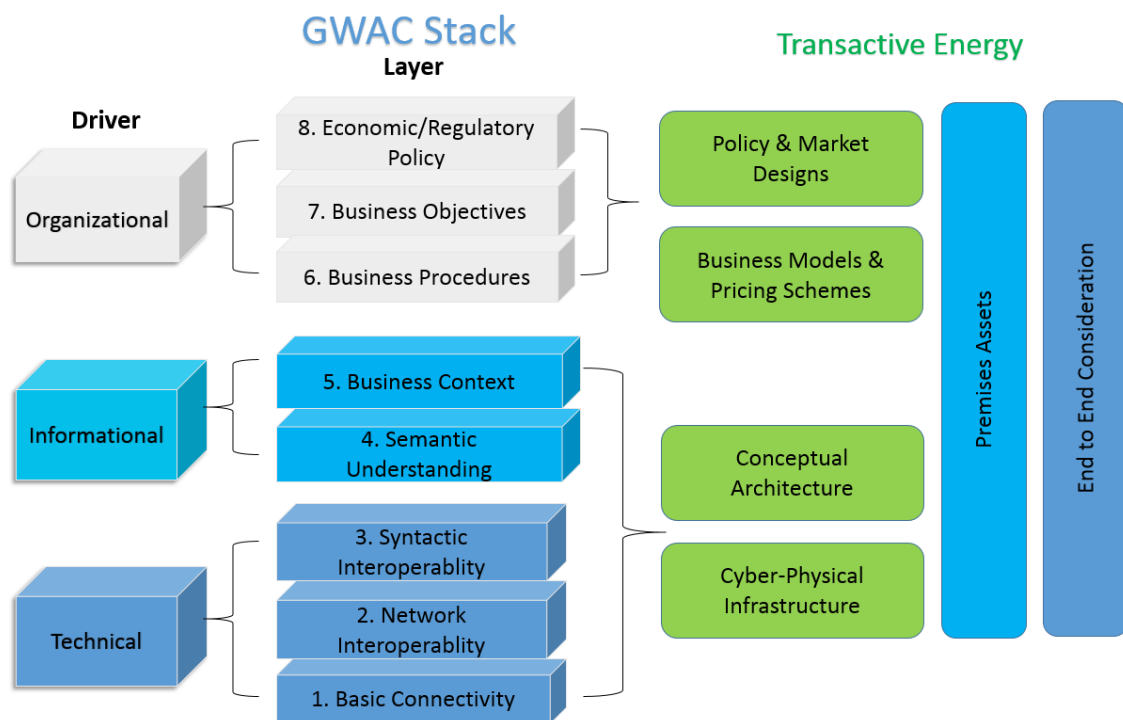
Figure 4 GWAC Stack with elements of transactive energy

Some reports and journals were published to simplify the structure of the TE system. A dominant structure called Smart Grid Architecture Model (see Figure 5) summarised eight categories into five interoperability layers including business, function, information,

communication and component layers (Trefke et al. 2013). The descriptions of these five layers are (Bruinenberg et al. 2012):

Business layer: Identify the macro level impacts of changes to electricity sector on different business. In the business layer, business roles and actors, business functions, business service, and business process are defined.

Function Layer: Describe the key options for a solution to meet the business case, which is independent of information, communication and physical components layers. The purpose of function layer is to describe the functional elements of a system and their relationship independent from physical implementation, applied technology or assigned actor.

Information Layer: Represents the type of information that is being passed to achieve the required function. The data model is an essential role in information layer and can be drawn easily onto the SGAM planes. Besides, integration technology, interfaces and logical interfaces are necessary for this layer.

Communication Layer: Describe protocols and mechanisms for exchanging objects specified in the information layer. It is also for the interoperable exchange of information, functions, service or data between components.

Component layer: Represents the physical distribution of all participating components including power system assets, protection, connecting and computers.

Business Layer

Function Layer

Information Layer

Communication Layer

Component Layer
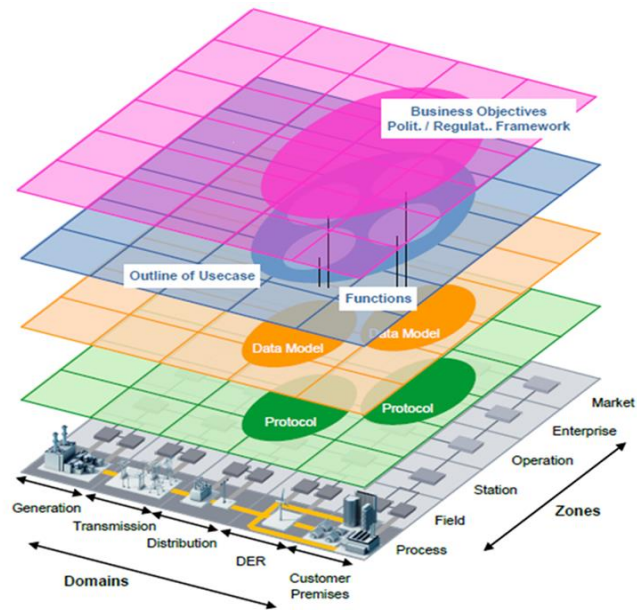
Figure 5 Smart Grid Architecture Model (SGAM) visualisation (Trefke et al. 2013)

In this structure, the categories of economic/regulatory policy and business objectives are summarised into business layer. Information layer is related to business context and semantic understanding. Syntactic interoperability and network interoperability are included in communication layer. Function layer and component layer are corresponding to business procedures and basic connectivity respectively (Bruinenberg et al. 2012). The other TE system structure will be introduced in next section.

3.2.2   Prosumer-Based Smart Grid Architecture

Nowadays, the increasing number of distributed renewable energy sources, storage and demand response allows the customers to produce and store energy. This new raising electrical entity is defined as "prosumer" (Grijalva and Tariq 2011). Based on Smart Grid Architecture Model (SGAM), a Prosumer-based Smart Grid Architecture that is remarkably flexible and scalable, which would ultimately enable a "flat" business paradigm across the industry is proposed (Grijalva and Tariq 2011). The Prosumer-based Smart Grid Architecture is simpler than SGAM. Figure 6 displays a Prosumer-based Layered Architecture containing four layers (Grijalva and Tariq 2011):

Device Layers: This layer describes the electrical components and devices in the grid. It is noticeable that "dumb" devices cannot provide sophisticated interfaces to the local control layer, but smart devices can provide mechanisms for local control and beyond.

Local Control Layer: This layer represents some devices have control mechanisms such as the exciter of a generator and battery charger of an electrical vehicle. The function of the local controller is a reaction to local information from the devices. In addition, it must arrange for interfaces for interactions with the system control layers.

System Control Layer: This layer describes meeting the functional and performance system level objectives such as loss minimization, economic and secure operation requires coordinated control. The system control layer plays a role that monitors the system devices and keeps track of the system state, which takes all the information from local controls and determines a set of commands.

Market Layer: The market layer takes advantage of all the system control information and utilises advanced economic and financial applications such as LMP calculation, load and price forecasting to generate control actions for the system control layer or price signals for the external world.
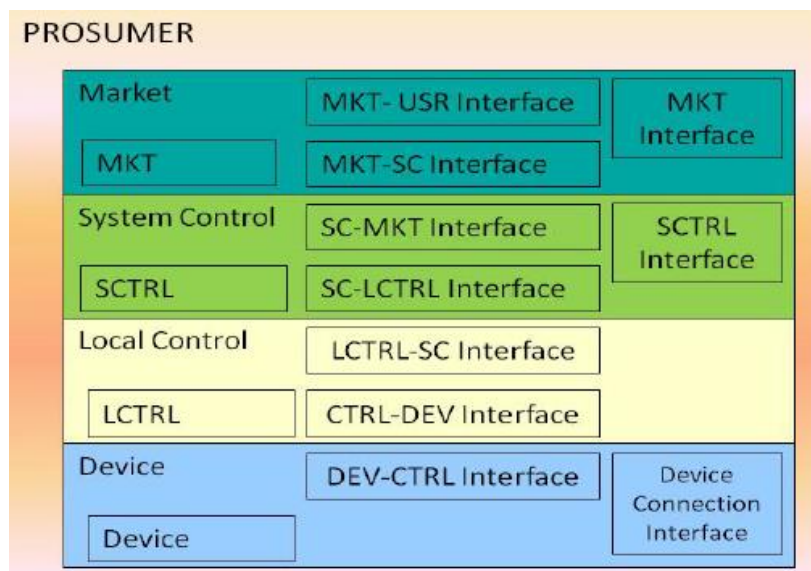
Figure 6 Prosumer-based layered architecture(Grijalva and Tariq 2011)

3.3   Opportunities and Challenges of TE system

Scientists and engineers are encouraged to explore TE systems because it presents many opportunities. "TE systems are a scalable, flexible approach to designing and implementing efficient, reliable, and resilient electrification systems, both large and small scale" (Ambrosio 2016). Although TE systems bring many opportunities to electrical grid, some challenges need to be overcame. The most of opportunities and challenges are linked with economics and technical aspects. The main opportunities and challenges will be listed and discussed briefly below:

Opportunities:

- Intelligent grid-edge devices, DERs, microgrids and building management can deliver the grid services needed at the bulk power levels and distribution system operation (Rahimi and Ipakchi 2016).

- One of the TE systems functions is coordinating the activity of the increasing number of distributed energy resource, which provides an approach to maintain the reliability and security of the power system while increasing efficiency (Melton 2013).

- In TE systems, economic entities such as asset owners and system operators who participate in the generation, transmission, and customers all have a stake in the reliable efficiency power system (Melton 2013). End-users with DERs and intelligent electrical devices are motivated to participate in power system management and make profit in TE systems.

Challenges:

- The level of bulk power needs a higher level of ancillary service to mitigate large variations in intermittent renewable energy resources (Rahimi and Ipakchi 2016).

- TE system challenges the traditional methods of bulk power system operations, planning and real-time operation based on the use of confirming load distribution

factors because the variability of DERs is invisible to bulk power system operators (Rahimi and Ipakchi 2016).

- Lower energy sales and the need for another source of income to meet the distribution system revenue requirement that challenges traditional business model (Rahimi and Ipakchi 2016).

3.4 Techniques of Implementing TE System

3.4.1 Standardization of a Hierarchical Transactive Control System

Improvements to the transactive control approach that has been generalised and formalised to make it practicable for any set of demand assets and many grid objectives are necessary (Hammerstrom et al. 2009). These improvements for increasing the applicability of control approach and making the approach more amenable to standardisation are shown below (Hammerstrom et al. 2009):

1. Enforce a hierarchical communication structure

2. Create an initialisation and maturation plan

3. Formalize generalised transactive inputs, outputs, and behaviours

4. Require a forecast time horizon

3.4.2 Multi-Agent based Transactive Energy Framework for Distribution System with Smart Microgrids

To reduce the aggregated complexity induced by microgrids in the distribution system, Kumar and Dipti proposed an agent-based transactive energy management framework with a Comprehensive Energy Management System (CEMS) (Nunna and Srinivasan 2017). The purpose of this framework is that microgrids sell or buy the energy in the transactive market, which is an inner microgrid auction based electricity market, to manage the excess supply or residual demand.
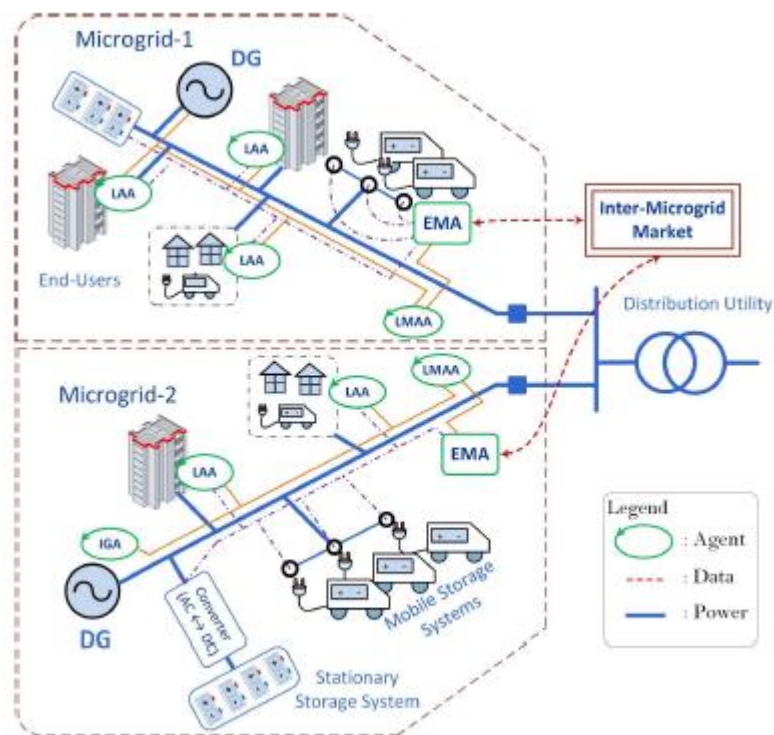
Figure 7Agent-based architecture of the proposed transactive energy framework(Nunna and Srinivasan 2017)

As can be seen from Figure 7, five kinds of agents are in the framework, which are Intermittent Generation Agents (IGAs), Load Aggregator Agents (LAAs), Energy Management Agents (EMAs), Local Market Auctioneer Agents (LMAAs), Transactive Energy Market (TMA).

IGAs and LAAs stand for distributed generators and load aggregators or loads respectively. There are two phases, viz. primary and secondary phase carried out by CEMS for energy management. "CEMS manages energy imbalances in microgrids by optimally configuring the DR and DESSs in primary phase while the mismatches leftover combined with forecast deviations are addressed using transactive energy in the secondary phase" (Nunna and Srinivasan 2017).

3.4.3   Transactive Home Energy Management System

It is necessary to develop a technique that can be used by the customers to control their utilities directly. An advanced Home Energy Management System (HEMS) operating within a transactive energy market is proposed, which can help meet needs of residential customers and utilities. The principle of the advanced HEMS participating in TE system is reacting to an energy price signal and returning information to transactive node issuing the price signal, such as power profile forecast; and automatically acting on behalf of the homeowner (Pratt et al. 2016).
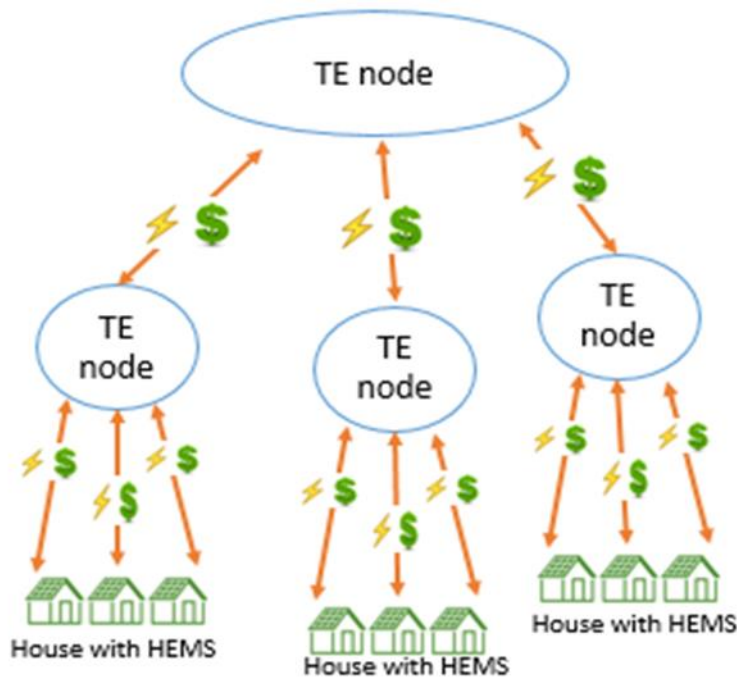
Figure 8 House with HEMSs participating in TE system(Pratt et al. 2016)

The advanced HEMSs in houses take part in a TE system by exchanging price signals and power profile forecasts with transactive energy nodes at a higher level (see Figure 8). The approaches to develop model and solution algorithms of HEMSs are based on a model predictive control (MPC) framework that accounts for price, weather, and renewable energy generation forecasts as well as the impact of storage components within in the houses (Pratt et al. 2016). Figure 9 displays that an advanced HEMS manages the operation of devices within the houses in response to consumer pre-set and price, weather, and distributed energy generation forecasts.
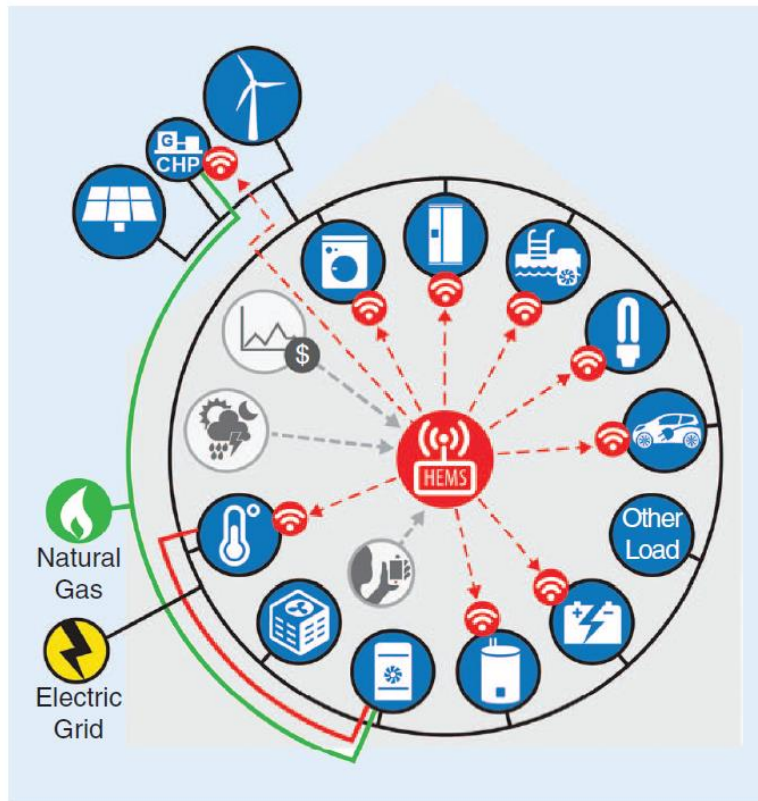
Figure 9 An advanced HEMS schedules the operation of the devices in a house(Pratt et al. 2016)

3.5 Economics of TE System

3.5.1 Distribution LMP-Based Economic Operation for future Smart Grid

Locational marginal price (LMP) is an approach to calculate the marginal price for energy and transmission at nodes on the grid, which reflects the incremental cost to supply the next unit of demand at a specific node (Orfanogianni and Gross 2007). Distribution LMP is an analogue of transmission LMP. Meng and Badrul propose a new method for calculating the distribution locational marginal prices (D-LMP) with distributed multi-agent paradigm (Meng and Chowdhury 2011). In this method, DLMP is used as a control signal for economic dispatch optimization. Figure 10 shows that how D-LMP is calculated in a distributed methodology.
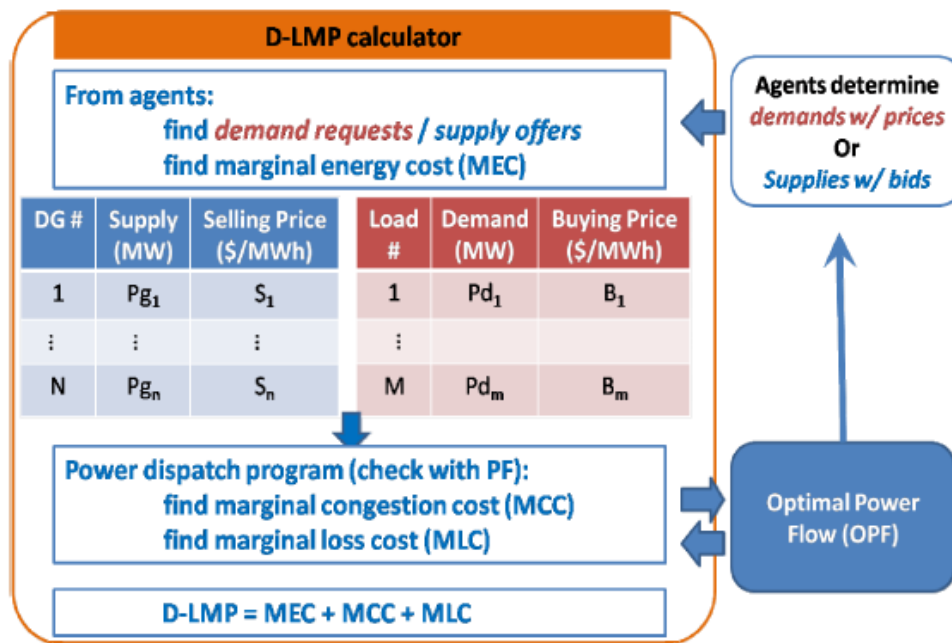
Figure 10 Agent-based D-LMP calculation paradigm (Meng and Chowdhury 2011)

Each load or supply entity is represented by an agent. Firstly, agents exchange offer/bid and create dispatch priority list indicating dispatch generations from lowest offer price to serve loads with highest bid prices. Meanwhile, Optimal power flow (DCOPF and ACOPF) check started dispatch to find marginal energy, loss and congestion cost. If the power flow is out of constraint, the system will re-dispatch based on offer/bid record until all demands are cleared. The job of each agent is to aggregate DLMP from OPF result, and then calculate individual payment/benefit (Meng and Chowdhury 2011).

3.5.2 Transactive Energy Market in Distribution Systems: A Case Study of Energy Trading Between Transactive Nodes

Distribution locational marginal price (DLMP) is generated by distribution system operator for transactive nodes (TNs), and DLMP for TNs considering losses is calculated by using the method of backwards-forward load flow (Sajjadi et al. 2016). Transactive node is defined as an electrical distribution system site. Firstly, DSO computes day-ahead hourly DLMP that is based on the forecasted load and running AC optimal power flow (ACOPF) considering losses. Then, TNs will send transactive incentive signal (TIS, $/MWh) and the transactive feedback signal (TFS, MW) based on their generation and cost of their device to DSO. Finally, TNs that have surplus energy update their TIS for those TNs need power. Energy transaction will complete if updated transactive incentive signal is less than DLMP. This approach assumes that PV is the only renewable energy source (RES), electrical vehicle and demand response are not taken into account (Sajjadi et al. 2016).

3.5.3 Optimal Transactive Market Operations with Distribution System Operators

The uptake of DERs and microgrids in distribution networks makes power systems and electricity market more complicated. A day-ahead TE market framework has been proposed, which includes end-to-end power system participants starting from the bulk power ISO and ending at DSO (Renani et al. 2017). DERs is considered as a local distribution area (LDA), and the day-ahead transactive scheduling of LDA is modelled as a MILP and solved using the CPLEX solver (Renani et al. 2017). The proposed framework for day-ahead transactive market scheduling is displayed in Figure 11.
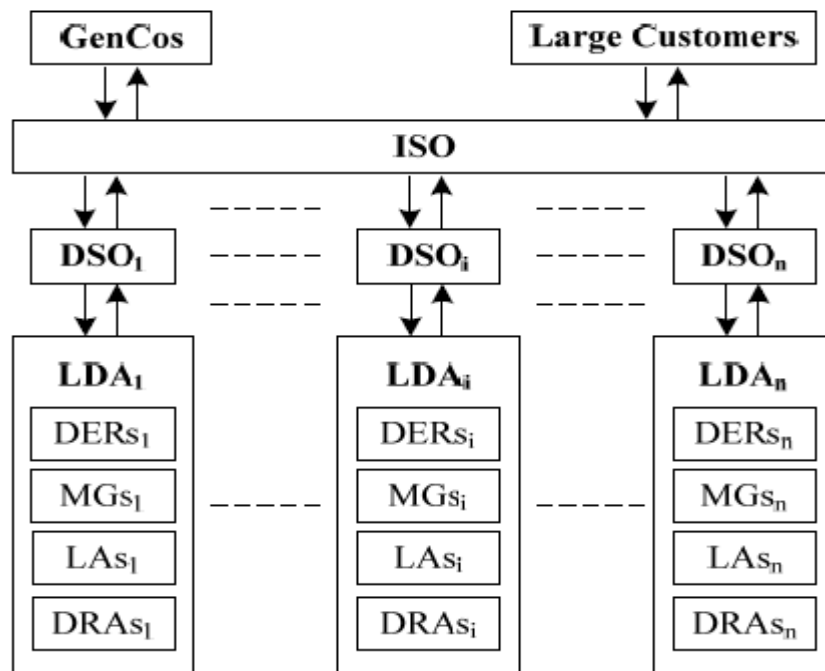
Figure 11Proposed framework for the day-ahead transactive market scheduling(Renani et al. 2017)

This framework provides opportunities for the operator of distribution system to participate in the wholesale electricity market, and enable all consumers with DERs and intelligent electrical device to make profits by participating in the electricity market. All energy resources in power systems can bid and benefit from competitive transactive electricity market (Renani et al. 2017).

3.6   Players of TE System

The emergence of TE systems changes the electrical markets by bringing in some new participants, especially prosumers and prosumer aggregators that can supply electric service to the market. The participants of TE system and their relationship are shown in Table 1 and Figure 12.

TE Participants	Definition	Value Proposition
Prosumers	End-use electricity consumers both buy and sell electricity while interconnected to distribution system. They can generate power through distributed generation.	Result in an electric system that is lower cost, more resilient and cleaner. The design of the TE marketplace determine who benefits as a direct customer of the prosumer.
Distributed Energy Storage	A category of prosumer whose primary resource is energy storage.	Reduce costs and increase the reliability of electric service to prosumer. It also can provide a flexible resource balancing electricity and demand on the distribution grid.
Prosumer aggregators	Combine the resources of different prosumer to get a better deal as part of a larger group and take a fee for this service	Ensure correct payment and knowledgably relieve the prosumer of any administrative burdens.
Virtual Power Plant (VPP) Operators	Coordinate dispatch of disparate prosumer resources. May also create value that maybe recognized through a capacity payment.	Greater value can be received by being part of a VPP for owners or operators of DER. The VPP can provide reliable wholesale power products competitive with those of real power plants.
Microgrids	Combine a group of interconnected loads and supply and demand resource clearly-defined electrical boundaries that operate as a unified system. It is operated as an integrated system and able to operate both grid-connected and island mode.	Customers in microgrid will have more reliable and resilient electricity.
Transaction Platform Provider	An electronic platform to communicate buy and sell offers in the markets as well as record the transactions among the parties, including payments.	Provides a convenient and cost-effective electronic venue to find buyer and seller counterparties on the distribution grid, make and record transactions with them.
Market Maker	An independent entity provides market clearing and settlements to parties that buy and sell in transactive marketplace.	Payment by buyers to sellers is assured and possibly later liquidity and risk management may be also ensured in a peer-to-peer market.
Distribution System Operator (DSO)	Similar to the ISO or RTO in an wholesale electric market. This is a regulated entity that would be funded based on fees charged to market participants.	Operate the TE market and other functions assigned to it in a equal, transparent and effective manner that will benefit all those who buy and sell in the TE marketplace.
Distribution System Owner (DO)	Plans, owns, operates and maintains the distribution system in market designs where the DSO does not also own the distribution system.	Conduct business serving customers in a fair, effective and least-cost manner as regulated by state public utility commissions.

Table 1Transactive energy participants(Cazalet et al. 2016)
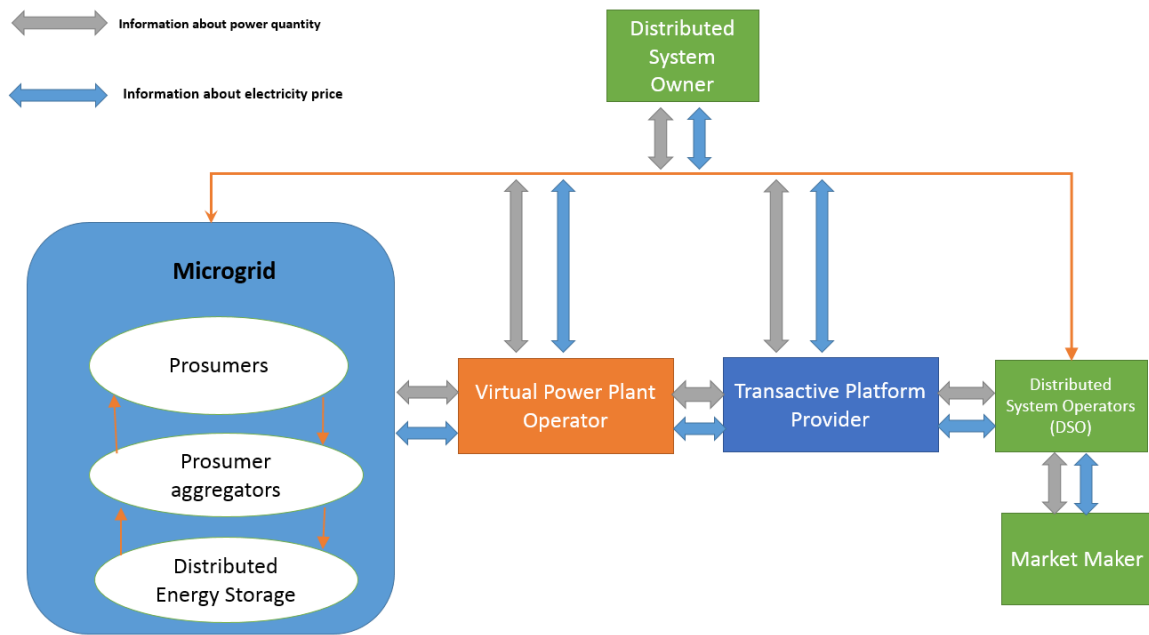
Figure 12Relationship between participants in TE system

3.7   Demonstrated Projects of TE Systems

3.7.1   Olympic Peninsula Demonstration

Located on the Olympic Peninsula of Washington state, the United States Olympic Peninsula Project is Pacific Northwest National Laboratory (PNNL) conducts the first proof-of-concept TE project. The Pacific Northwest Gridwise Tested Demonstration project aims to demonstrate that residential electric water heaters and thermostats, commercial building space conditioning, water pump loads, and several distributed generators can be coordinated through the two-way communication of load status and electricity price signals (Hammerstrom et al. 2008). As shown in Table 2, based on Smart Grid Architecture Model, the descriptions of Olympic Peninsula are:

Layers	Description
Business Layer	Utility provides the market with supply bids, and the 5-min market determined the clearing price for energy and broadcast that to the market participants. Each pump, diesel generators, residential demand-response equipment operate based on if their bid was higher or lower than the market-clearing price.
Function Layer	By using energy-information technologies, distributed electric load can be made to actively take part in the grid control, protection functions and real-time economic interactions.
Information Layer	Market information (bids and clearing prices) is the main signal that interconnects different layers

Communication Layer	IBM Internet Scale Control System(iCS), a Web-SphereTM Based middleware software is used for communication
Component Layer	Four large municipal water pumps, two backup diesel generators, and residential demand response from electric water and space heating systems in 112 homes

Table 2 Olympic Peninsula Project description in five layers (Hammerstrom et al. 2008)

3.7.2   Pacific Northwest Smart Grid Demonstration

The U.S. Department of Energy (DOE) found the Pacific Northwest Smart Grid Project (PNWSGD) in 2009. The purpose of PNWSGD included improved reliability, energy conservation, improved efficiency, and demand responsiveness (Melton 2015b). The description about PNWSGD is presented in Table 3.

Layers	Description
Business Layer	One or more electrically connected resource and utilities are represented as transactive-node. Information about the quantity of energy estimated to produce or consumed and the cost of that energy is exchanged between neighbouring nodes. Exchanging information among the nodes is iterated for each operation's time step until the difference in incentive price and energy exchange between each neighbour converges.
Function Layer	Asset systems that were installed can conserve energy or to improve efficiency and responsive to demand response signals from the

	transactive system of the project as well as provide more reliable service to distribution customers.
Information Layer	Make Information about dispatch practices, history, and most complete and accurate.
Communication Layer	The information from Aclara Two-Way Automatic Communication System (TWACS) meter and other system components are sent to TWACS power-line-carrier signals.
Component Layer	Electricity system of supply, transmission, distribution, and end users. Cooperation from multiple electric utilities including rural electric co-ops and investor-owned, municipal, and another public utility.

Table 3 PNWSGD description in five layers (Melton 2015b)

This section introduces two TE system demonstration projects. Olympic Peninsula Demonstration project discovered whether the TE system is feasible in customers/prosumers at the distribution level. Olympic Peninsula project demonstrated that "local marginal retail price signals, coupled with the project's communications and the market clearing process, successfully managed the bidding and dispatch of loads and accounted quite naturally for wholesale costs, distribution congestion, and customer needs" (Hammerstrom et al. 2008). Pacific Northwest Smart Grid Demonstration project is carried out in the large-scale grid and try to demonstrate the feasibility of TE system replacing the current power system. The project showed the region-wide connection from the transmission system down to individual premises equipment can be completed, and asset at end-users can respond dynamically on a wide scale (Melton 2015b).

3.8   The Opportunities of TE System in Australia

3.8.1   Solar PV in Australia

The line chart below shows the annual installed capacity of solar PV in Australia from 2007 to 2016. The year from 2009 to 2012, Solar PV capacity increased dramatically, followed by a downward trend from over 1000MW in 2012 to about 800MW in 2016. Nevertheless, total solar PV capacity kept growing from 2007 to 2016. "Australia has the highest penetration rates of the rooftop solar photovoltaic system on the planet; is a global 'test bed' for energy storage market entrants" (ENA and CSIRO, 2015). Hence, Australia need to coordinate these rooftop solar PV systems and has great potential to develop TE system.
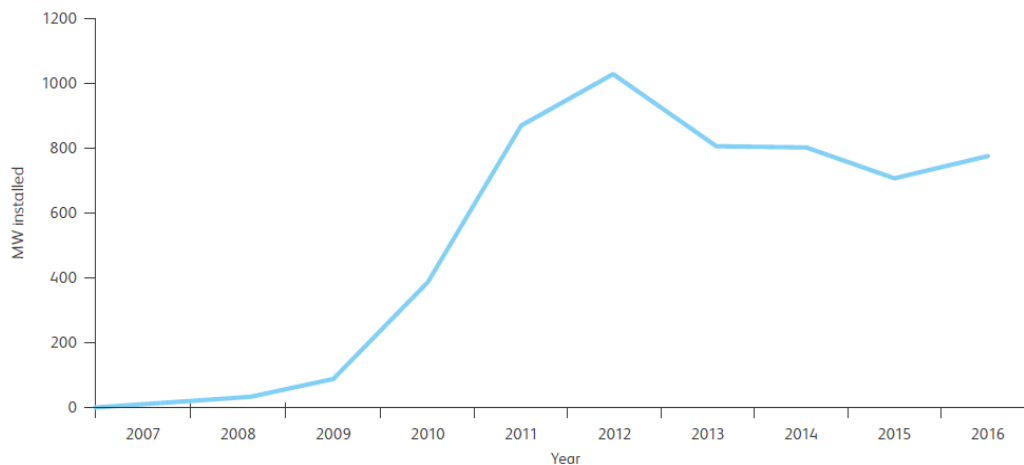
Figure 13Annual installed capacity of solar PV (MW) (Clean Energy Council, 2016).

3.8.2   Wind Energy in Australia

Figure 14 below displays cumulative installed wind capacity in Australia from 2000 to 2016. The total wind capacity has a steady growth from 2000 to 2016. As a lowest-cost form of new large-scale energy generation, wind energy in Australia will become an important contributor to the national Renewable Energy Target (RET) (Clean Energy Council, 2016).
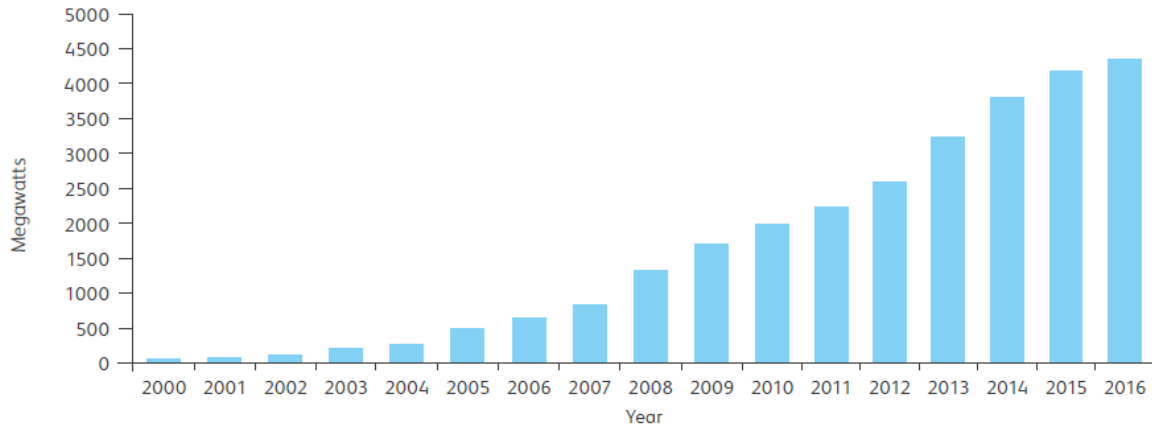
Figure 14 Cumulative installed wind capacity in Australia (Clean Energy Council, 2016).

3.9   Summary

As discussed above, although SGAM can be applied to guide the construction of TE system in the future, but it does not discuss too many details about guiding end-end interoperation. On the contrary, the TE system is customer-oriented, which means the five interoperable layers should consider the operation between end-users. The prosumer-based smart grid architecture is a practical idea to develop TE system on a large scale, but it is difficult for current information technology to model large-scale utility as prosumers.

The technique of Multi-Agent based transactive energy framework is appropriate for Australia to develop TE system. The number of agents can be reduced because DSOs can be the centre of TE systems and combine the functions of some agents. HEMSs play a role as the end-users' terminal communicating with the agents in various levels.

The DLMP is an important factor to influence the electricity price in the TE market. The DLMP at TE market must interact with ISO at the wholesale market. However, the methods to determine the agents-based DLMP mentioned above did not consider the relationship between DLMP and LMP in the wholesale market.

4.0   Methodology

The purpose of this section is to outline the methods and analytical tools used to complete the project objectives. As this is a research-based honours thesis project, exploring the number of articles about developing TE system and multiple TE system case studies play an essential part in the 'methodology' of this thesis project. The main purpose of this thesis project is to understand the new concept of TE system in various aspects and discuss the impact of TE systems in Australia. TE systems are researched and discussed in the aspects of architecture, participants, technique and economics (Figure 16). Firstly, the architecture is found to identify the elements of TE systems. The research on technologies and economic schemes behind the TE systems is carried out to understand the how TE systems work. Then, the roles of participants and their technical and economic relationship in TE systems are identified.
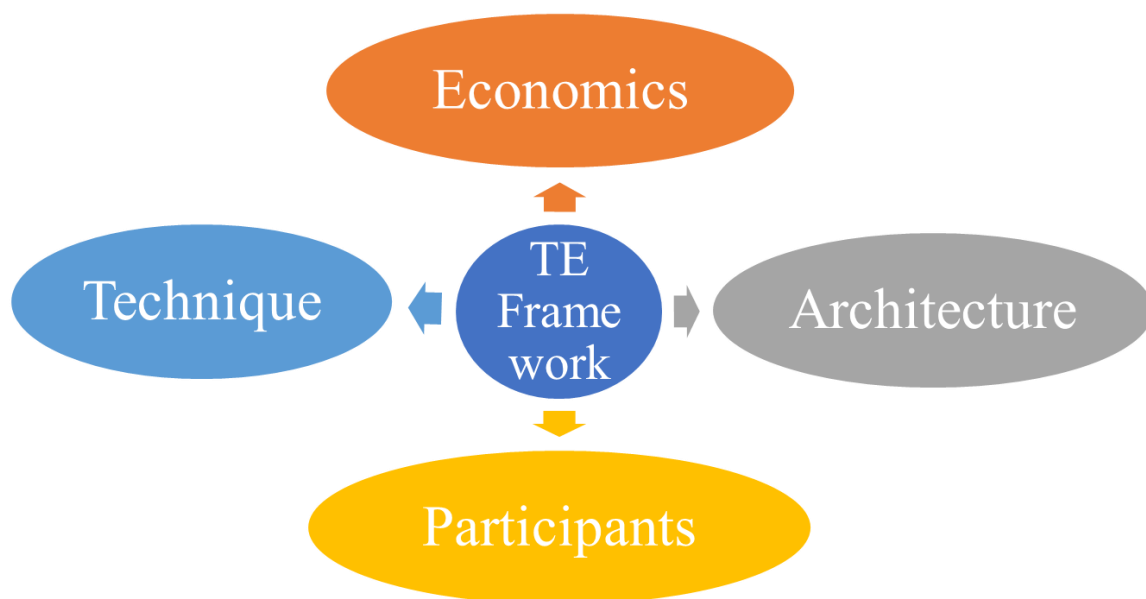
Figure 15 *TE* system in different aspects

From the literature Review (section 3.2), there are two types of TE system structures. One type of the structure is the Smart Grid Architecture Model (SGAM), which divides TE systems into five different layers. The other is Prosumer-Based Smart Grid Architecture that contains four layers. Consumers/prosumers play a key role in TE systems. Three techniques for

implementing TE systems are found from researches, which helps readers to understand the operation principle in TE system. Principles and feasibility of these three techniques are considered. Also, three economic schemes for establishing the TE market are discussed and compared.

According to the understanding of TE system, the impact of TE system in Australia is discovered. The research about the trend of electricity network transformation in Australia is needed to identify the potential of TE system in Australia, which mainly includes distributed energy resource and demand response. Some challenges for developing TE system in Australia are discussed. Moreover, application of TE system will also have an influence on current electricity market in Australia. In this report, the transformation of electricity business mode is discussed. Also, new electrical standards and regulation of TE system are explored. Lastly, a TE system model for Australia is proposed by applying techniques and economics principle from the Literature Review.

5.0 Analysis of Transactive Energy System

5.1 Transactive Energy System Architecture Analysis

5.1.1 SGAM Interoperability Layers

Interoperability is known as a critical attribute of the smart grid. The definition of interoperability is the "ability of two or more devices from the same vendor, or different vendors, to exchange information and use information for correct cooperation" (Bruinenberg et al. 2012). This concept can be displayed in Figure 17. Based on this idea, the GridWise Architecture Council introduced eight interoperability categories (Figure 2).
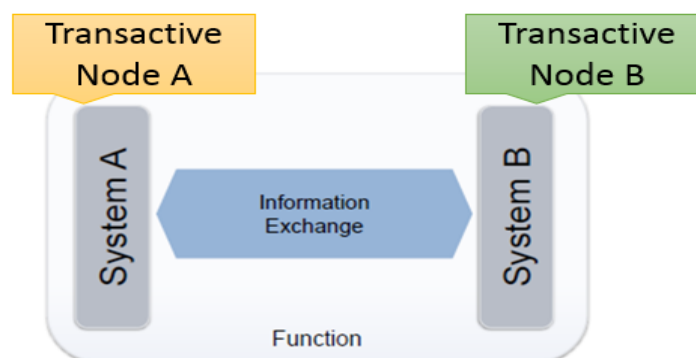
Figure 16Definition of interoperability-interoperable systems performing a function (Bruinenberg et al. 2012)
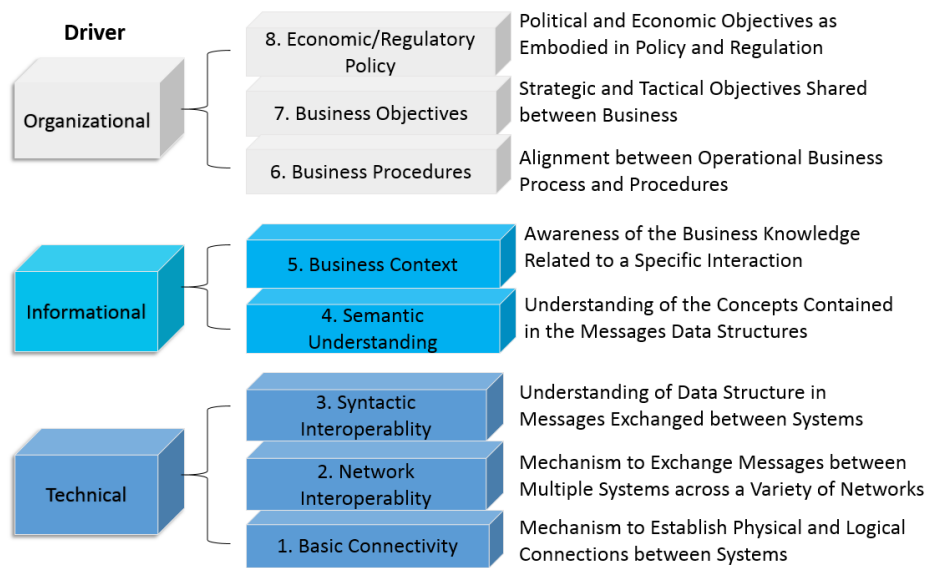
Figure 17 Interoperability Categories defined by GWAC (Melton 2015a)

These eight interoperability categories can be aggregated into five abstract interoperability layers. How the five layers are corresponding to the interoperability categories of TE system is presented in Figure 18. The five layers of SGAM framework represent business objectives and processes, functions, information exchange and models, communication protocols and components. The description of the five layers is displayed in section 3.2.1.
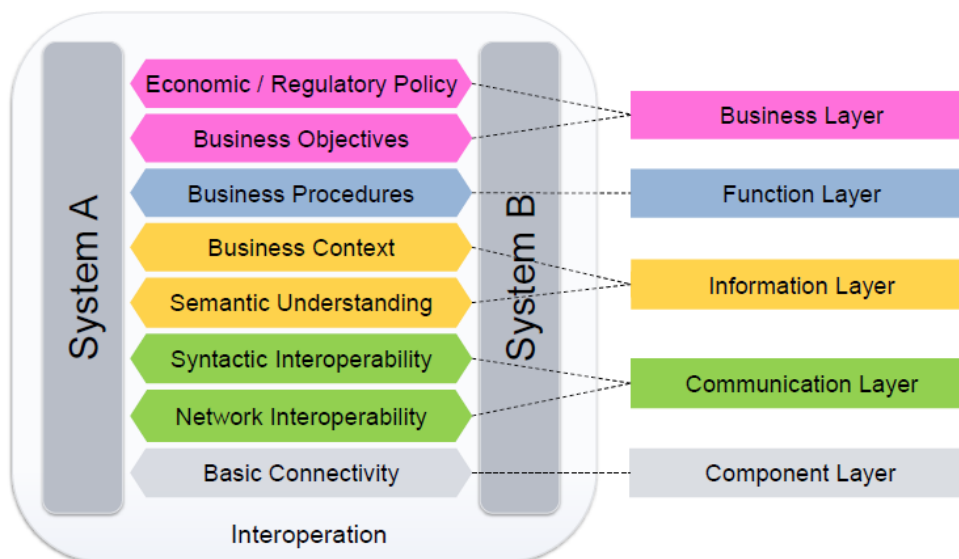
Figure 18 Grouping into interoperability layers (Bruinenberg et al. 2012).

5.1.2   Smart Grid Plane of SGAM

Electrical network management distinguishes electrical process from information management viewpoints. These viewpoints can be divided into the physical domains of the electrical energy chain and the hierarchical zones. The smart grid plane (see Figure 20) was designed to allow the representation on hierarchical zone or levels of power system management interactions between physical domains (Bruinenberg et al. 2012).

Physical domains are related to electrical grid including Energy Generation, Transmission, Distribution, DER, and Customer Premises, which is scheduled based on electrical energy conversion chain. The description of the SGAM domains is shown in Table 4.

The hierarchical levels of power system management are represented by SGAM Zones (Bruinenberg et al. 2012). Two important concepts of aggregation and functional separation in power system management are applied in SGAM Zones that reflects a hierarchical model (Bruinenberg et al. 2012). The process, Field, Station, Operation, Enterprise and Market compose SGAM Zones (See Table 5).

SGAM framework is built by applying the concept of interoperability layers. As a result, there are three dimensions in SGAM framework, which are Domain, Interoperability and Zone.
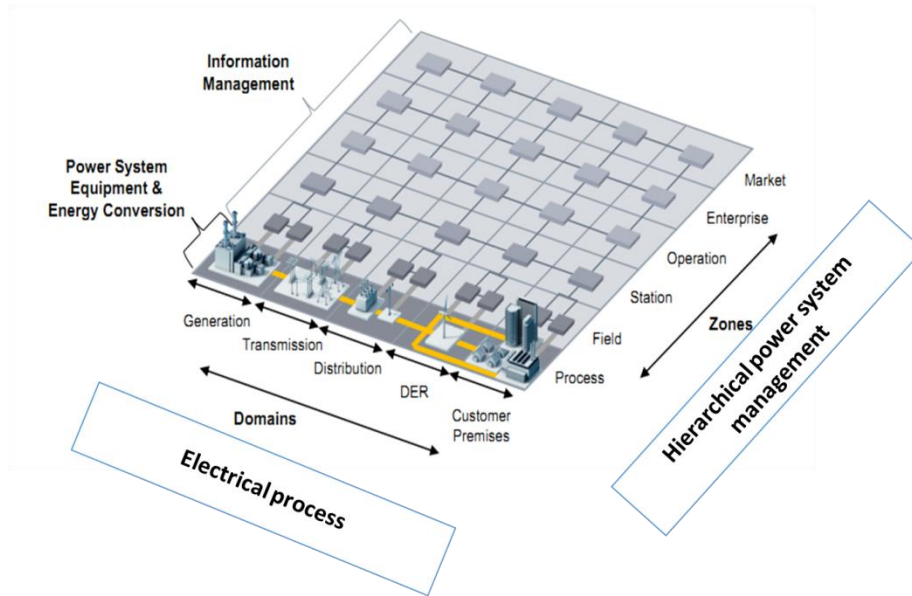
Figure 19 Smart Grid plane- physical domains and hierarchical zone (Bruinenberg et al. 2012).

Bulk generation	Transmission	Distribution	DER	Customer Premises
Generating electricity in bulk quantities such as fossil, nuclear and hydropower plants	The infrastructure and organisation that transports electricity over long distances	The infrastructure and organisation that distributes electricity to customers	Distributed electrical resources directly to the public distribution grid, using small-scale power generation	Both end users and producers of electricity. Including industrial, commercial and home facilities. Generation in the form of such as PV generation, electric vehicles storage, batteries and so on.

Table 4 SGAM domains description (Bruinenberg et al. 2012).

Process	Field	Station	Operation	Enterprise	Market

Different transformations of energy (e.g. electricity, solar, heat…) and the physical equipment directly involved (e.g. generators, transformers, circuit breakers…).	Represent equipment to protect, control and monitor the process of the power system, e.g. protection relays, bay controllers, intelligent electronic devices that can acquire and use process data from the power system	Describe the areal aggregation level for field level such as data concentration, functional aggregation, substation automation, local SCADA system…	Power system control operation in the respective domain, e.g. distribution management systems, energy management systems in generation and transmission systems, microgrid management systems…	commercial and organisational processes, services and infrastructures for enterprise (utilities, service providers, energy traders…).	Include the market operations possible along the energy conversion chain, e.g. energy trading, mass market, retail market.

Table 5 SGAM Zones description (Bruinenberg et al. 2012).

5.2   Prosumer-Based Smart Grid Architecture

5.2.1   Relationship to SGAM Framework

Prosumer-Based Smart Grid Architecture is proposed to enable a flat, sustainable electricity industry (Grijalva and Tariq 2011). The Prosumer-based architecture is compatible with the framework proposed by GWAC, and it is an evolution to make the SGAM framework more flexible. It is known that energy flow in the traditional electrical network is in one direction, where the current is from bulk generation through transmission and distribution to the end users. The main aim of Prosumer-based architecture is to allow two-directional physical flow at the

distribution level (Grijalva and Tariq 2011). End customers can not only sell any excess of energy to the utility, they can also buy electricity from the bulk market.

5.2.2   Prosumers

In the Prosumer-based architecture, the definition of prosumer is broad. In addition to the end users, prosumer can represent other electric systems, e.g. Electric Interconnection, Independent System Operator (ISO), Utility, Microgrid, Industrial Facility, Commercial Building and a House (Grijalva and Tariq 2011). In other words, any system can be represented as a prosumer (See Figure 21). The symbol ⟨∿↓⟩ stands for a prosumer. In this architecture, all the prosumers would interact at the same level by applying common interfaces.
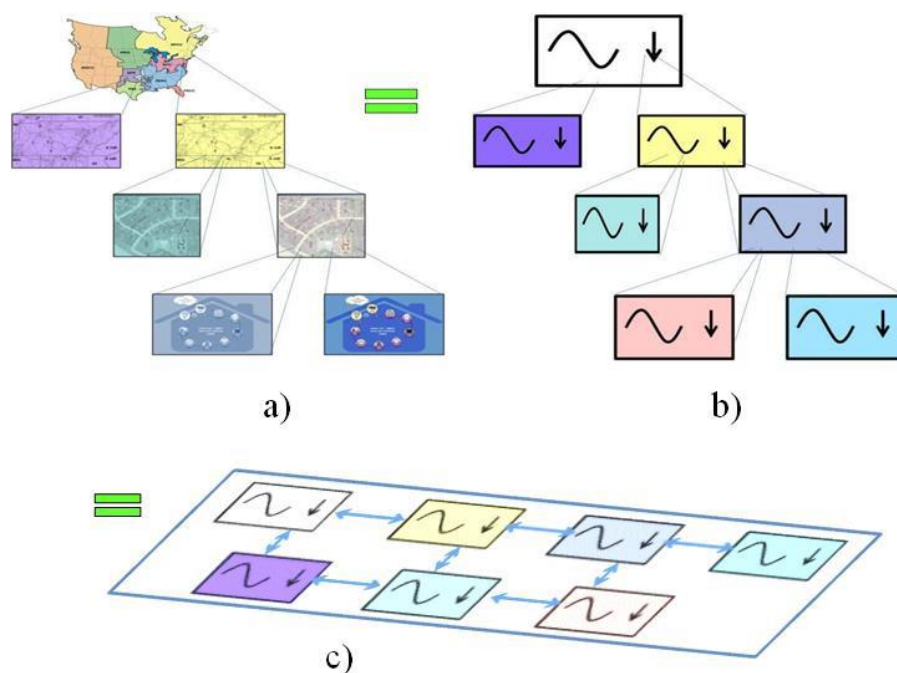
Figure 20 Logical equivalence of electric power systems a) Existing hierarchical industry paradigm, b) All power systems modelled as prosumers, c) Prosumer seen as same level entities (Grijalva and Tariq 2011).

5.2.3   Prosumer Service and Interface

The Prosumer-based architecture layers are described in section 3.2.2. The interface among the layers is essential to achieve interoperability. A Web Service-based Service Oriented Architecture (SOA) infrastructure is introduced. Service Oriented Architecture (SOA) is prevalent in the domain of enterprise computing because of the agility and adaptability it provides. "SOA is a design philosophy which aims at developing systems which are loosely coupled, flexible, reusable, and adaptable" (Grijalva and Tariq 2011). Web Service is the most popular technology for developing SOA based solutions because the standards of Web Service have full acceptance.

Some capabilities, e.g. transaction, reliable messaging and security provided by web service-based SOA could cope with the adaptability and reliability requirements of the future electricity grid. Web services-based SOA can improve the development process for new applications by using entity-based services and handle the interoperability issues among various vendors and different entities. Moreover, it allows easy upgrade and deployment of solutions through the composition of web service and provides support for adaptability to change management needs. The prosumer is the primary entity in the smart grid software infrastructure of this architecture. The prosumer is a web service, so are prosumers in local control, system control and market control layers. Then the definitions of service interfaces for local control, system control and market control built. The examples of service interfaces are attached in Appendix 1. The important parameters in power system such as voltage, active and reactive power are contained in messages applied in the definition (Grijalva and Tariq 2011).

5.3　Collaboration of Participants in TE System

5.3.1　Controlling Power System under Constraints

5.3.1.1Process of Reactive Power Controlling

An important objective of TE systems is to ensure the power system delivers energy to customers under some specific constraints, e.g. security of supply, system stability and power quality. Providing stable and high-quality electricity to the customer is the critical constraint for power systems. This section will provide analysis on how TE systems monitor and control voltage level on the distribution side. The collaboration of actors in the TE system can monitor voltage level in distribution grid, control the reactive power of DER unit and perform volt/var control of distribution. TE system participants that have been mentioned in section 3.6 can be summarised into a few of actors in this section (Table 6).

All Participants	Actor	Actor Type	Actor Description
Prosumers aggregators & Virtual power plant operators & Distribution system owner	Distribution-IED	Device	"Intelligent Electric Device (IED) is a communications-enabled controller to monitor and control automated devices in distribution which communicates with Distribution SCADA or other monitoring/control applications, as well as distributed capabilities for automatic operations in a localized area based on local information and on data exchange between members of the group. Operations such as such as tripping circuit breakers if they sense voltage, current, or frequency anomalies" (Bruinenberg et al. 2012).

Prosumer & Distributed energy storage &Microgrid	Distributed Generation	Device	Distributed generation is also called Distributed Energy Resources (DER), which is a part of Demand/Response programs and may be dispatchable resources (Bruinenberg et al. 2012).
Prosumer aggregators & Virtual power plant operators &Microgrid& Transaction Platform & Distribution system operator	Distribution Data Collector	Device	It can bring data from multiple source and put it into different from factors (Bruinenberg et al. 2012).
Prosumer aggregators & Virtual power plant operators $ Market Maker & Distribution system operator	Distribution Stabilize and Optimize	Application	Carried out by actors to ensure the network is operating under required tolerance in the system. Information is collected to make control decisions that ensure reliable, stability and optimization (Bruinenberg et al. 2012).
Transaction platform provider & Market Maker & Distribution system operator	Distribution Management	Application	The application software for minting and controlling the distribution system device based on computer-aided applications, market information, and operator control decision (Bruinenberg et al. 2012).
Distribution system operator & Distribution system owner & Transaction platform provider	Network Operations Reporting and Statistics	Application	Reporting actors archive on-line data, and performing feedback analysis about system efficiency and reliability (Bruinenberg et al. 2012).

Table 6 Summarise Participants of TE system into Actors

There are five steps to control voltage level and reactive power on the distribution side, which includes Data Acquisition, Supervisory Control and Data Acquisition (SCADA), Voltage/Var Control, DER Control and Audit. These five steps are described as follow (Bruinenberg et al. 2012):

1. Data Acquisition: The result of voltage measurement is exchanged periodically among the grid, distribution IED, distribution data collectors, and distribution management system. The process of transmitting information about voltage is displayed in Figure 6:

Figure 21 Process of communicating information about voltage

2. SCADA: DMS collect data from grid periodically and provide information about voltage measurement, location and topology to Network operations reporting & Statistics, Distribution Stabilize and Optimize.

3. Voltage/Var Control: After data is collected and received by all actors, the Voltage/Var Control would judge and react to the information about voltage level. The steps of Voltage/Var control are shown in Table 7:

Step #	Triggering Event	Actor	Description of the Activity	Information Producer	Information Receiver	Information exchanged
1	Voltage Measurement over threshold	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize application detects a threshold violation of voltage	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize	Violation information

2	Threshold Violation	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize application starts Voltage/Var calculation	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize	Start of voltage/Var calculation
3	Start voltage Var calculation	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize application calculates control value and identifies equipment to be controlled and transmits value to DMS	Distribution Stabilize and Optimize	DMS	control value, equipment ID

Table 7 The steps of Voltage/Var control (Bruinenberg et al. 2012).

4. DER control: The purpose of DER control is to make all devices and distribution generation work under required voltage constraints. The steps of DER control is shown below:

Step #	Triggering Event	Actor	Description of the Activity	Information Producer	Information Receiver	Information exchanged
1	Control value, equipment ID, received	DMS	DMS reformats control value and equipment id and transmits controllable setpoint to Distribution Data Collector	DMS	Distribution Data Collector	Controllable setpoint
2	Controllable setpoint received	Distribution Data Collector	Distribution Data Collector device forwards information to Distributed Generation device	Distribution Data Collector	Distributed Generation	Controllable setpoint
3	Controllable setpoint received	Distributed Generation	Distributed Generation device updates its operation parameters according to setpoint	Distributed Generation	Distributed Generation	Operation parameter
4	Operation parameter update	Distributed Generation	Distributed Generation device verifies updated operation mode and acknowledges parameter change	Distributed Generation	Distribution Data Collector	Acknowledge information
5	Acknowledge information received	Distribution Data Collector	Distribution Data Collector device forwards information to DMS	Distribution Data Collector	DMS	Acknowledge information

Table 8 The Steps of DER control (Bruinenberg et al. 2012).

5. Audit: The aim of Audit is collecting and documents records of control action. The steps of Audit is displayed in Table 9:

Step #	Triggering Event	Actor	Description of the Activity	Information Producer	Information Receiver	Information exchanged
1	Control action	DMS	DMS application posts control action to Network Operations Reporting & Statistics application	DMS	Network Operations Reporting & Statistics	Control action
2	Control action	Network Operations Reporting & Statistics	Network Operations Reporting & Statistics application documents control action	Network Operations Reporting & Statistics	Network Operations Reporting & Statistics	Control action

Table 9 The Steps of Audit (Bruinenberg et al. 2012).

5.3.1.2 Collaboration of Different Layers

This section will introduce a example that illustrates how a use case can be mapped to the SGAM framework. In this example, the process of controlling reactive power (section 5.3.1.1) is applied. Firstly, the actors are mapped to domains and zones of SGAM plane (section 5.1.2). Then, the technical collaboration that controls reactive power among the five layers will be described.
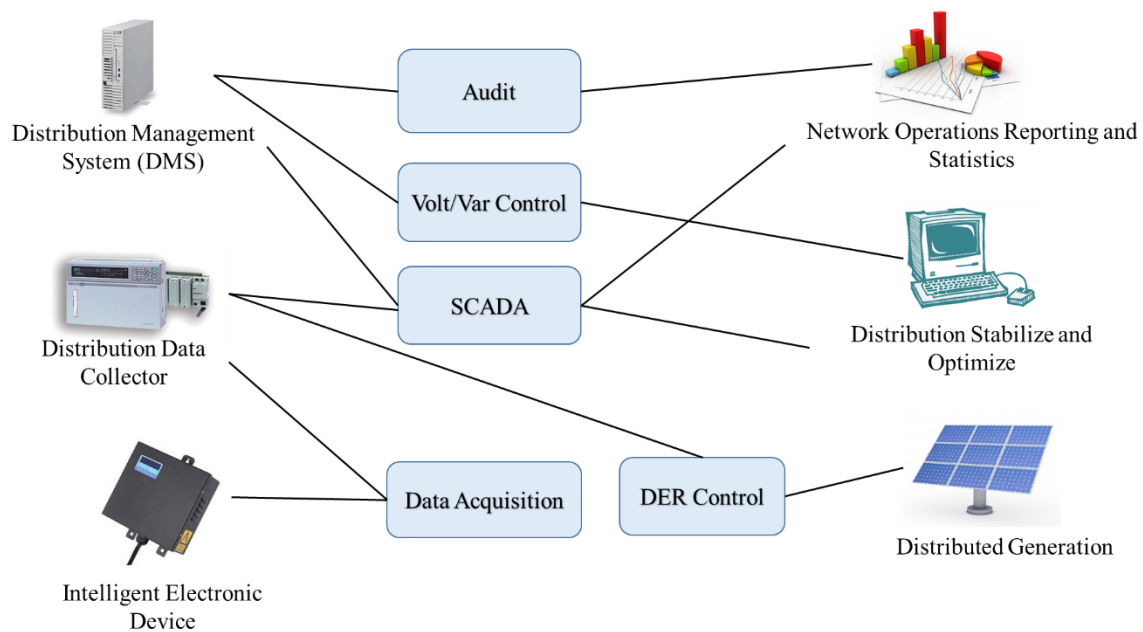
Figure 22 Technological collaboration of among the actors

Figure 23 displays the actors in TE systems are taking the five steps to control the reactive power and voltage level. Referring to the SGAM plane (section 5.1.2), the actors "DMS", "Network Operations, Reporting and Statistics" and "Distribution Stabilize and Optimize" can be placed in the Distribution Domain. DMS, "Distribution Stabilize, and Optimize" are in the Operation Zone, while "Network Operations, Reporting and Statistics" is in the Enterprise Zone. "Distribution Data Collector" can be placed in the Distribution Domain and Station Zone, land Distribution-IED is in the Distribution Domain and Field Zone. Distributed Generation is located at the DER Domain and Field Zone.

In component layer (Figure 24), the actors are in the form of hardware, which is used to provide the function of controlling reactive power and voltage level. The job of Customer Relationship Management (CRM) computer in the enterprise zone and DMS computer in the operation zone is hosting the application type actors and dedicated automation devices in field and station zones. To complete this job, installing the common communication infrastructure is necessary (Bruinenberg et al. 2012).
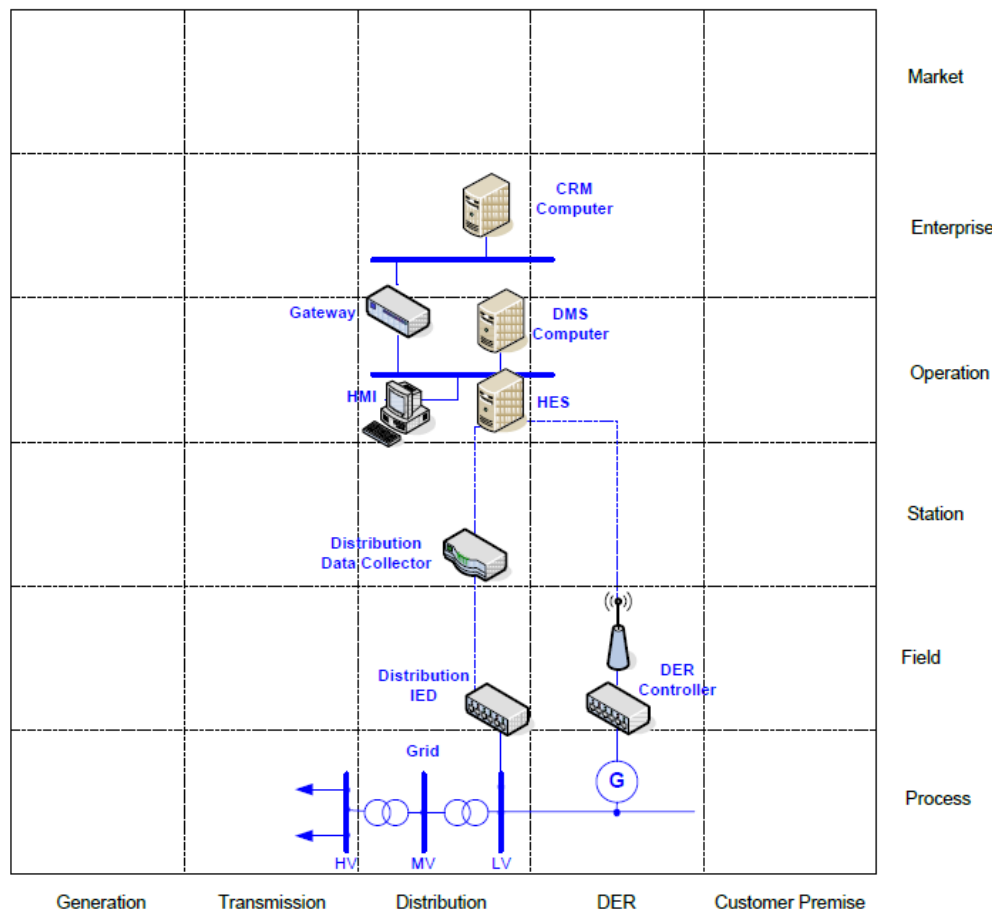
Figure 23 Component Layer "Control reactive power of DER unit"(Bruinenberg et al. 2012).

In the Business layer, business process, services and organisations are hosted, which include the business objectives, economic and regulatory constraints. All business entities should be located in the domain and zone appropriately (Figure 25). The yellow area in Figure 25 is affected by the use case and correspondingly influenced by latent business objectives and economic and regulatory constraints (Bruinenberg et al. 2012).
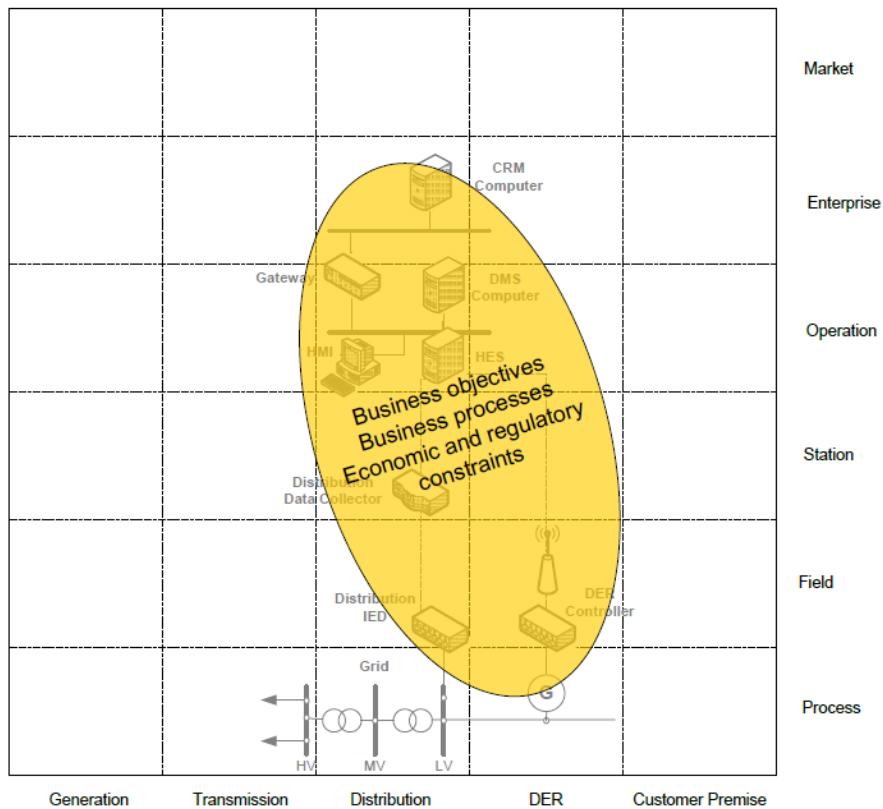
Figure 24 Business Layer "Control reactive power of DER unit" (Bruinenberg et al. 2012).

The function layer aims at representing functions and their interrelations concerning domains and zones. In this example, the process of controlling reactive provides the service of use case. Figure 26 shows the functions "Volt/Var Control "and SCADA are typically located in Distribution /Operation. The function "Audit" is in Distribution/Enterprise. The functions "Data Acquisition" and "DER Control" reside in Distribution/Field and DER/Field correspondingly (Bruinenberg et al. 2012).
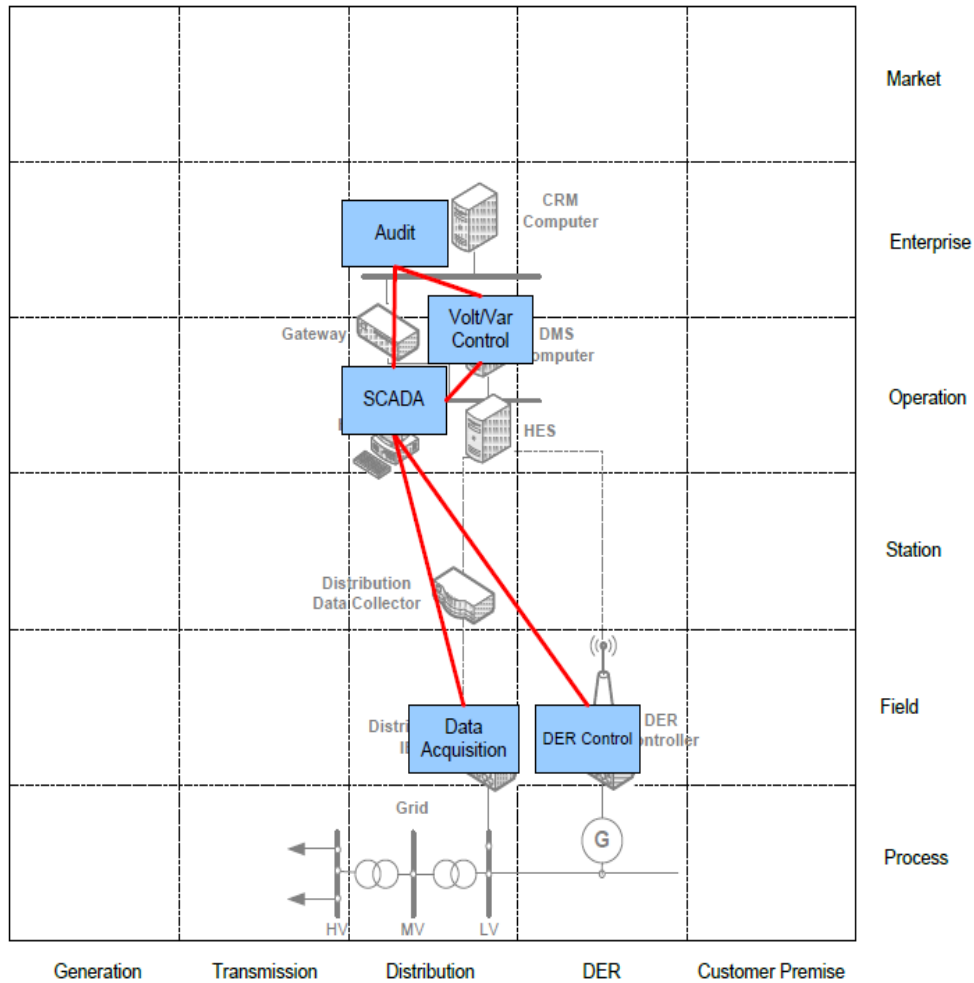
Figure 25 Function Layer "Control reactive power of DER unit" (Bruinenberg et al. 2012).

In the Information layer, underlying canonical data model standards can provide information objects. In the reactive power of DER controlling (Figure 27), there is three canonical data model including CIM standard (IEC 61968-4), IEC 61580-7-4 and IEC 61850-7-420. CIM standard is an appropriate basis for exchanging information objects in the enterprise and operation zone. IEC 61850-7-4 is a basis of data objects incompatible node classes and data object types, and IEC 61850-7-420 is a basis of data objects in distributed energy resource nodes (Bruinenberg et al. 2012).
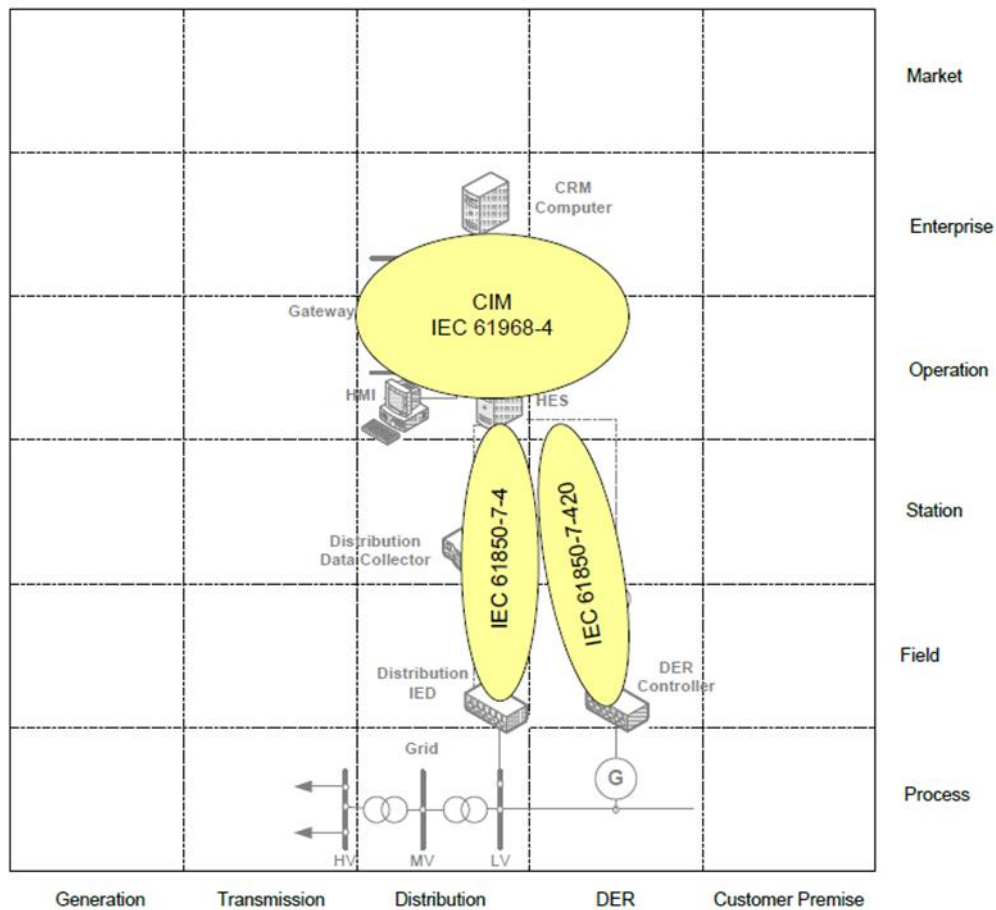
Figure 26 Information layer "Control reactive power of DER unit" (Bruinenberg et al. 2012).

The object of the communication layer is to describe protocols and mechanisms for the interoperable exchange of information between actors. Figure 28 displays that communication layer describes the communication protocols for data exchange of the necessary information between the components. IEC 61980-100 can exchange CIM data objects in the enterprise and operation zone. In power system automation, IEC 61850 is the state-of-the-art communication protocol which can be located in different lower layers, e.g. Ethernet, PLC or wireless communications (Bruinenberg et al. 2012).
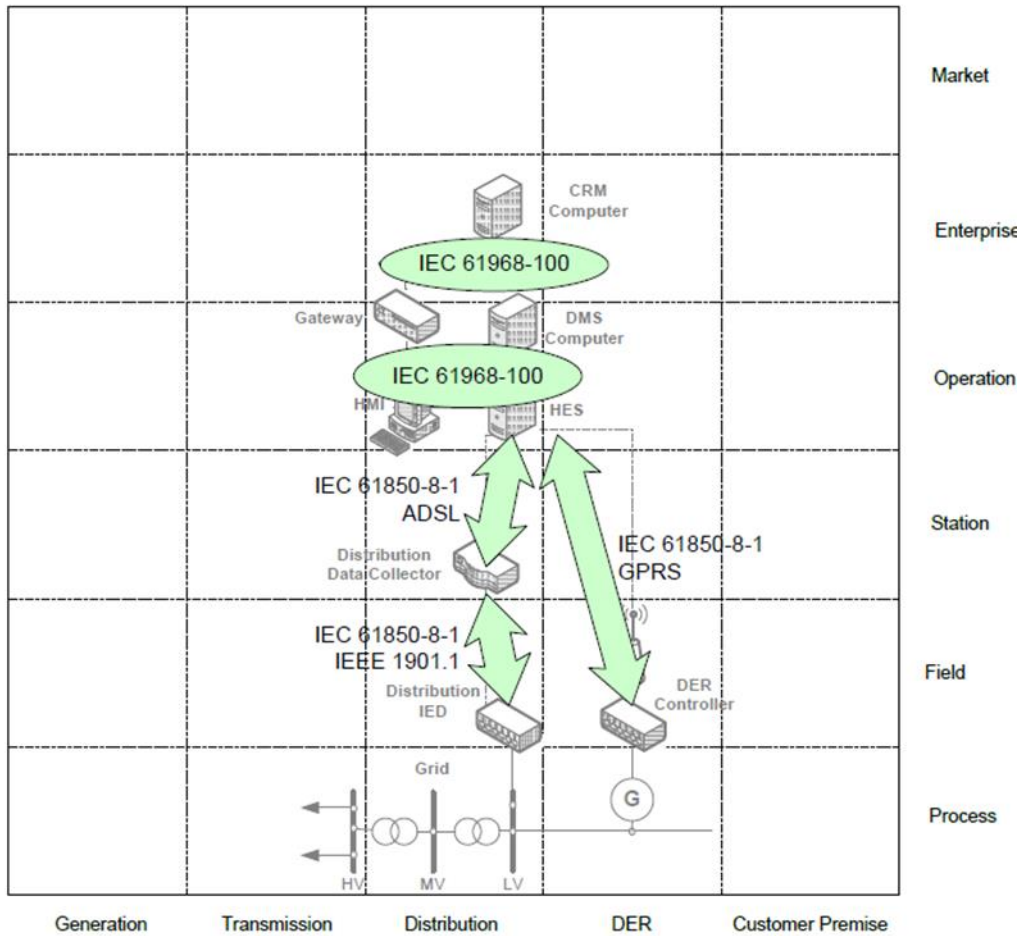
Figure 27 Communication layer "Control reactive power of DER unit" (Bruinenberg et al. 2012).

This example shows that a use case can be represented with existing infrastructures, functions, devices, business objectives and constraints and communication and information standards. SGAM framework can provides an appropriate structure to establish TE systems, which ensures that the electrical grid can work safely and reliably when end-users participate in power systems management and electricity market. The SGAM framework is appropriate for developing a TE system model for Australia.

5.3.2   Economic Relationship

5.3.2.1A Conceptual View of the major Relationships in the Retail Energy Ecosystem

In this section, an economic relationship from the viewpoints of customers will be discussed. Figure 29 displays a conceptual view of the significant relationships in the retail energy ecosystem, including wholesale market economics, DSO operations, DER economics, transformation and distribution (T &D) investments, utility rates, and customer investments and costs.
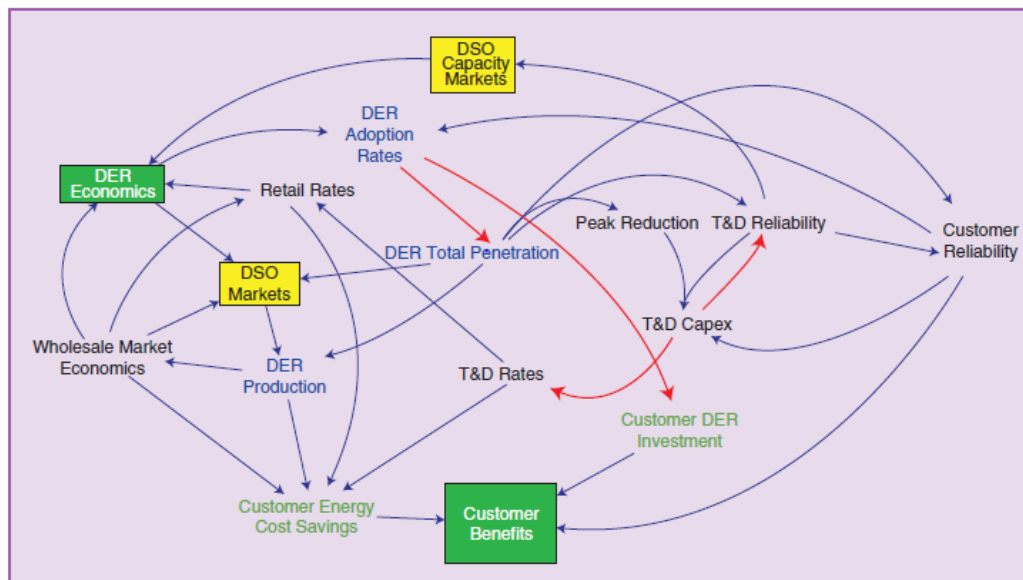
Figure 28 A conceptual view of the major relationships in the retail energy ecosystem (Masiello and Aguero 2016)

In Figure 29, the blue arrows mean "one variable influences another at any moment in time" (Masiello and Aguero 2016). The red arrows indicate, "one variable influences the rate of change of another variable" (Masiello and Aguero 2016). The impact of blue arrows could be quicker than the red arrows. For example, the DER adoption rate is affected by customer reliability in time. The higher customer reliability means that more customers could choose to install DERs, which can make DER adoption rates increase in a short period. DER adoption rates influence the rate of change of DER total penetration over a period of time. The market

maker needs to understand these relationships: feed-in tariffs, DER incentives, the application of real-time pricing, and how to operate the DSO capacity markets and energy and ancillaries' markets (if necessary) to improve overall customer and keep or improve reliability (Masiello and Aguero 2016).

5.3.2.2 Wholesale and Retail Markets

The wholesale market at the Independent System Operator (ISO) level allows energy trading between power plants, retailers and other financial intermediaries for both short-term trading and long-term trading. Retail market at the DSO level is a response to organised energy trading on the distribution side, which is important for TE system. In American, some states such as Hawaii and southern California have high PV penetration that brings some operational challenges such as voltage fluctuations and reverses flow. These states are trying to pursue the ability to limit total PV penetration on a given circuit. The measurement of restricting feed-in tariffs for PVs has been taken to reduce cross-subsidisation effects in T&D tariffs in some states (Masiello and Aguero 2016).

It is necessary for a DSO to organise the market and maintain reliability as well as to interact with the wholesale markets. The wholesale market has been developed for hundred years, so the mathematical framework, methodologies and other technologies are mature. From a simplistic perspective, the wholesale market only needs to "change "cost" to "price" in math and set up the mechanisms for power plant owners to bid into a market and settle the financial flows "(Masiello and Aguero 2016). The retail market that incentivises DER deployment has no case (except some small-scale demonstration projects) demonstrates integrated retail energy economics and reliable grid operation in real conditions (Masiello and Aguero 2016). There are some issues of how much it will spend to implement a DSO at scale and whether the benefits out weigh the cost.

According to the research of Masiello and Romero (Masiello and Aguero 2016) , the retail market at the DSO level needs to establish a capacity market (A capacity market would be for generation capacity and peak shaving) and a reliability market (A reliability market would be for reliability services such as voltage control or congestion management) (Masiello and Aguero 2016). Besides, ISO markets in a TE system should bridge the gap between long-term bilateral contracts for energy and the day-ahead markets. Market participants are investing in sophisticated software tools to cope with these issues (Masiello and Aguero 2016). Moreover, an alignment between the wholesale market products and the retail market products need to be considered. "Timing of biding, market submissions, and market closure/notification in the ISO and DSO markets have to be aligned to allow participants to make decisions and to allow the hierarchical markets to operate in an integrated way" (Masiello and Aguero 2016).

5.4   Techniques of Transactive Energy Framework

Technology	Range of Application	SGAM Layer	Description
Standardization of a hierarchical transactive control system	Power grid	Layers of Information, Communication, Business	1. Formalize a hierarchical node structure which defines the nodes and the functional signal pathways. 2. Generalize the input, output, and functional responsibilities of each node. 3. The new, generalised approach defines transactive signals including the predicted day-ahead future.
Multi-Agent based transactive energy framework	Distribution side	Layers of Component, Information, Communication, Function, Business	1. Local auxiliary resources such as Demand Response (DR) and Distributed Energy Storage Systems of the microgrids are optimally integrated into system operation to level off the forecasted energy imbalances in microgrids. 2. The operating configuration of the local auxiliary resources is adjusted in real-time along with transactive energy to address the imbalances leftover in the previous phase and forecast errors.
Transactive Home Energy Management Systems	End customers	Layers of Components, Information, Communication, Business	• Help meet the objectives of both residential customers and utilities • Participate in a transactive energy system by reacting to energy price signals; returning information to the transactive node issuing the price signal, such as a power profile forecast and preference of customers.

Table 10 Description of TE system techniques

Table 10 shows three available techniques that can be applied in TE systems. Standardization of transactive control system is necessary because this technology considers customers' preference. In the Olympic Penisula GridWise Project, thermostats were set to track current and future price signals and taking advantage of low-cost opportunities to pre-heat or pre-cool living spaces without requiring involving any explicit algorithm be applied for that purpose. Hence, the customer feel little discomfort because they can select temperature within some degree of freedom, and how much comfort they want to forego in exchange for incentive benefits (Hammerstrom et al. 2009). The purpose of this technique is to improve the transactive control approach which has been generalised and formalised to make it practicable for any set of demand assets and the grid objectives (Hammerstrom et al. 2009).

The increasing number of DERs and microgrids brings the aggregated complexity. The agent-based transactive energy management framework with CEMS can handle the energy imbalances in microgrids and reduce complexity induced by microgrids in distribution system efficiently. In a Multi-agent based TE system, microgrids can sell or buy the energy in the transactive market that is an inter-microgrid auction based electricity market to manage the surplus supply or residual demand (Nunna and Srinivasan 2017).

There is an increasing trend that people choose to install home automation products. For example, Home energy management systems (HEMS) are becoming popular, which can help to manage home energy costs. The customers can control their energy consumption and an electrical device such as thermostats and light through HEMS. HEMSs play a role as an interface between the customer and the devices. However, the most commercially HEMSs are currently limited, which has the function of monitoring and simple control over only a few appliances. Transactive Home Energy Management Systems with algorithms and optimisation approached can arrange the operation of residential appliances. The process of devices under control of transactive HEMS could respond to consumer preferences, price, weather, and distributed energy generation forecasts (Pratt et al. 2016).

5.5 Economic Scheme of Transactive Energy Framework

Economic Scheme	Subject	Description
Distribution LMP-based economic operation	Distribution LMP	• The DLMPs calculation is developed in MATLAB environment based on the optimal power flow solver form MATPOWER4.0b4 simulation package (Zimmerman, Murillo, Thomas, 2011). • Two Optimal Power Flow (OPF) models were applied to calculate the DLMP. • A distributed approach for calculating the D-LMPs without the presence of a centralised entity to supervise transaction is used.
Optimal transactive market operation with distribution system operators	Distribution system operators	• an independent entity without acquiring any biasing objectives • Responsible for the secure operation of local distribution systems and balancing supply and demand at distribution level • Link wholesale market and transactive retail market
Energy trading between transactive nodes	Transactive nodes	• TIS is the forecasted unit cost of electricity delivered in a TNs. • TFS is the is the forecasted aggregated power flow between two neighbouring TNs. • As transactive signals, TIS and TFS are exchanged between neighbouring TNs.

Table 11 Economic scheme description of TE system

As mentioned in section 3.5, three different economic schemes of TE system were found to establish the TE market. Table 11 compares these three economic schemes in aspects of subjects and principle of the economic schemes. Firstly, DLMP referred to transmission LMP, which reflects the incremental cost to supply the next unit of demand at a specific node. DLMP has three elements concluding marginal energy cost (MEC), marginal loss cost (MLC) and marginal congestion cost (MCC) (Orfanogianni and Gross 2007). DLMP is an essential economic signal for power dispatch and system control in a distribution microgrid and provides key information of network operating condition, e.g. congestion control, marginal generation/load allocation, energy storage operation. This information might be important for substation power schedule and infrastructure expansion (Meng and Chowdhury 2011).

New DSOs play a vital role in both power dispatch and retail transaction market. The traditional purpose of DSOs is to manage a local grid in the case of outages and ensure that local network be operated and maintain under system constraints. In TE system, DSOs are required for operation and the planning of distribution systems as prosumers who take part in real-time transactive markets and utilise dynamic pricing. In the transactive energy market, local distribution areas have their retail market and DERs are allowed to submit offers for transacting with wholesale energy market and prosumers. DSO is responsible for clearing this retail market, and it determine the optimum DERs' scheduling and the power interchanges with the wholesale market (Renani, Ehsan, and Shahidehpour 2017).

As mentioned in section 5.3.2, TNs represent electrical distribution systems, e.g. a consumer, microgrids and substations. As a major entity in the transactive retail market, the DSO calculates DLMP for all TNs by running AC optimal power flow (ACOPF) with consideration of losses during given time interval. Then, TN sends a TFS signal at the same time. During this time interval, TNs sell surplus energy to its neighbouring TNs. A new TIS will be calculated and updated by using ACOPF that consider the cost of losses of distribution feeder between the transactive TNs. It is demonstrated that TNs could achieve economic goal significantly by selling surplus energy to another TNs and satisfying their demand. Moreover, energy trading between TNs reduces the active power purchased from ISO and distribution losses (Sajjadi et al. 2016).

5.6   Discussion

The structure of TE system is mainly referred to the SGAM framework (section 5.1) that is decomposed into five interoperable layers because entities and infrastructures have to exchange information in real time. The information exchanged between various layers has two main types: energy dispatch and prices. The energy price and quantity depend on prosumers demand and surplus, which is not predictable. The most difficult issue for developing TE structure is to update appropriate device for controlling and communication and information technology. The system controlling and communication should make energy finish trading under grid constraints in real time, and information technology is responsible for expressing various real-time signals accurately and protecting customers' privacy. Participants in TE systems are collaborative. End prosumers and customers accomplish power trading through agents. The aims of technologies about TE system are to coordinate and aggregate the DERs at the distribution level. Economic scheme of TE system focuses on regulating customer offered by determining DLMP and organising an un-discriminative retail market. However, the economics in TE system is more complicated, and feasible transactive market in a real situation is still under exploration.

6.0 The Impact of TE systems on Australia's Grid

6.1 The Potential of TE systems in Australia

DERs are becoming more and more popular due to the increasing energy price and public awareness of reducing greenhouse gas emissions. Figure 30 shows how the household electricity price of Australia increased significantly by over 40 percent from 2002 to 2012 and was projected to keep increasing around 80 percent in 2014. In contrast with Australia, the rising trends of the electricity of other countries are smaller,for example, Japan even decreased around 10 percent in 2010.
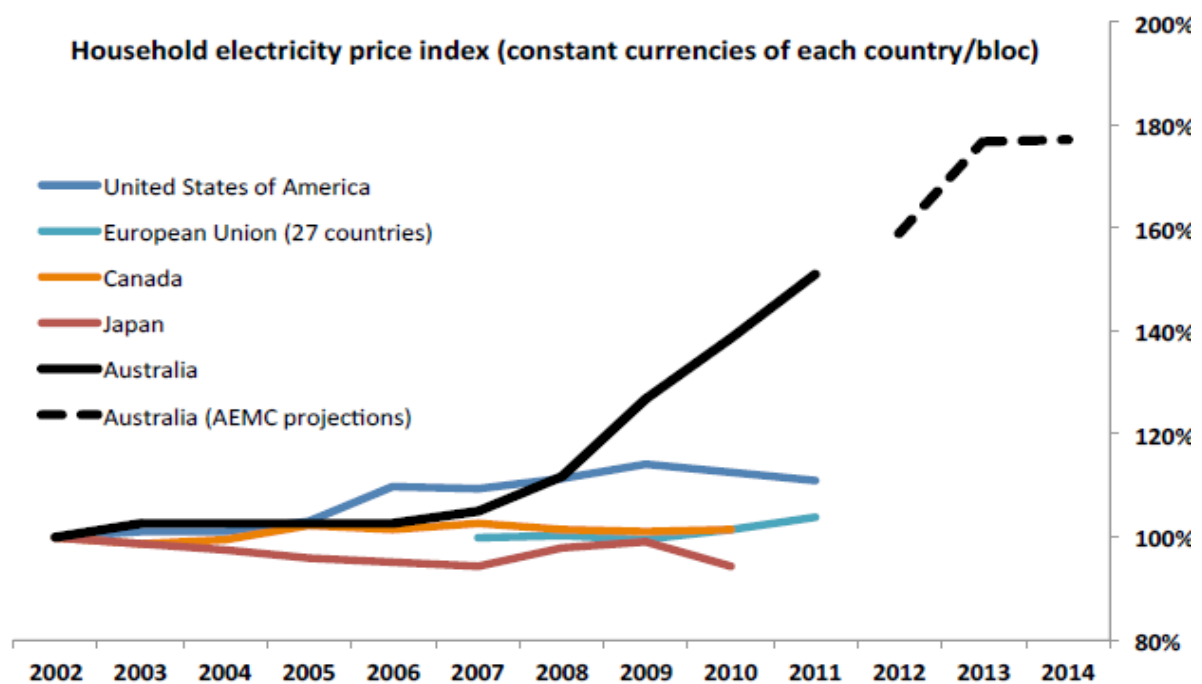
Figure 29 Household electricity price of Australia and other countries (Mountain 2012).

According to report from Department of Industry, Innovation and Science, the main reason causing electricity price increase is maintaining and upgrading the electricity network. By landscape, Australia with 7692024 km^2 is the world's sixth-largest country, but the population density is very low. As a result, Australia has the world's largest integrated electricity network,

which is costly to operate especially in some remote areas (Department of Industry, Innovation and Science, 2012). Therefore, DERs especially flexible rooftop solar systems have great potential in Australia. Table 12&13 indicate the number of solar panel systems and wind systems installations in Australia respectively. The year from 2007 to 2011 demonstrated a dramatic increase in the PV systems and wind systems. Number of installations of solar PV panel systems is much more than wind systems. Although annual installations of solar PV systems and wind systems experience a significant downward from 2011 to 2017, the total installations of DERs in Australia kept increasing from 2001 to 2017.
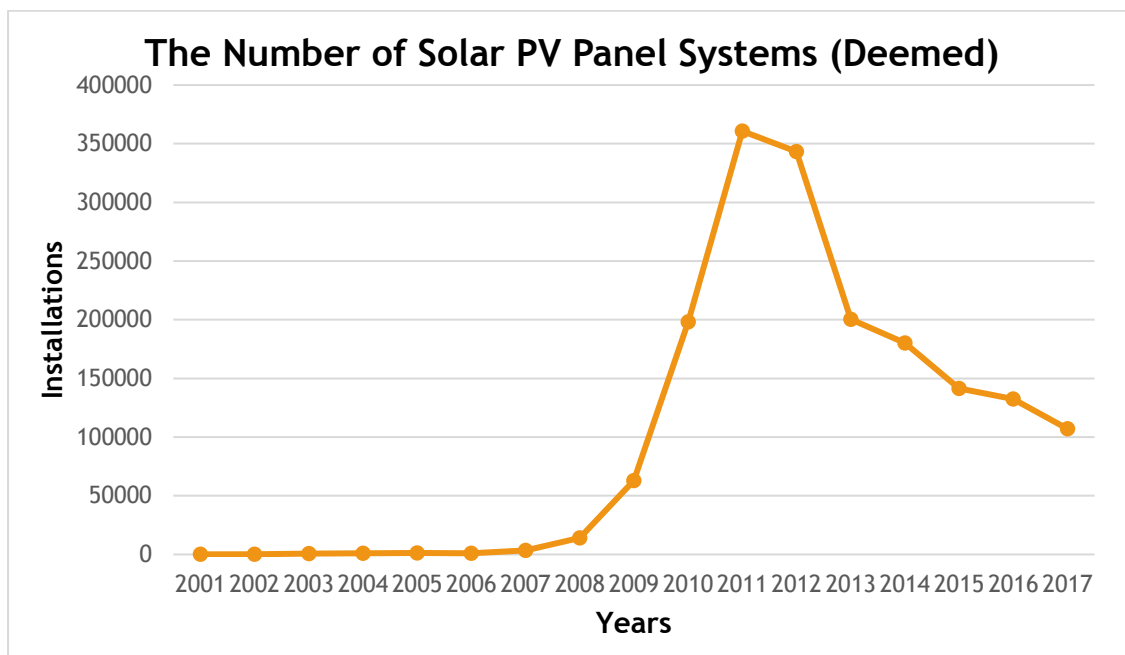
Table 12 The number of solar PV panel systems installations in Australia (Data source: http://www.cleanenergyregulator.gov.au/RET/Forms-and-resources/Postcode-data-for-small-scale-installations).

The Number of Wind Systems (Deemed)
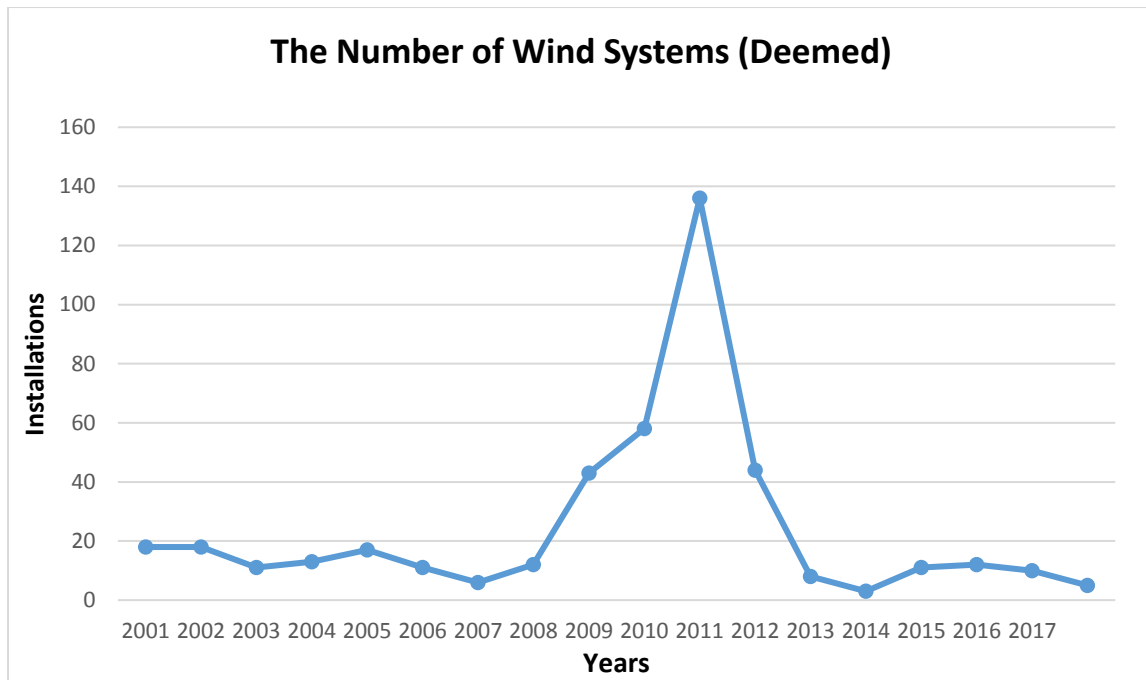
Table 13 The number of wind systems installations in Australia (Data source:
http://www.cleanenergyregulator.gov.au/RET/Forms-and-resources/Postcode-data-for-small-scale-installations).

Australia has the appropriate conditions to develop TE system. First of all, "Australia has the highest penetration rates of rooftop solar photovoltaic on the planet" (ENA and CSIRO, 2015). One of TE system's purpose is to coordinate DERs at the distribution level, which can relieve electricity congestion without upgrading the current components of networks. Hence, the electricity price in Australia could be reduced. Secondly, TE systems make the power grid flatter. In other words, TE system converts centralised power system to decentralised power systems, which can meet the need of Australia's low density population. TE system offers customers and prosumers more choices than traditional power systems. Customers and prosumers sell or buy energy based on their preference and the real-time price provided by the transactive retail market. Also, end-users can reduce the electricity fees by setting up their DR of devices like ACs to avoid high electricity price during peak time.

6.2   The challenge of developing TE system in Australia

The biggest challenge of developing TE system is bridging the gap between Independent System Operator (ISO) and Distribution System Operators (DSOs). The major ISO in Australia is Australian Energy Market Operator (AEMO) that is responsible for operating Australia's largest gas and electricity markets and power systems. Although the penetration of DER is increasing, AMEO still has the responsibility to maintain power system security and deliver information to support the efficient market. Therefore, the AEMO needs to have sufficient visibility to DERs, e.g. rooftop solar PV systems and energy storage. If the large number of DERs are installed behind the meter (BTM, meaning on end-users' houses), the ability of AMEO to quantify and manage the operational impacts of DER on power system will be affected due to the lack of visibility to the DERs (AMEO, 2017).

The invisibility of DERs directly influences two areas of power operations including prediction of load and response of load. In the past, AEMO can predict load accurately by analysing historical data with the consideration of variables such as weather, time of day, the day of the week, electricity prices (AMEO 2017). The data without penetration of DERs was stable and easy to predict. The DERs affect the demand patterns by changing the load behaviour and the ability to predict it. For example, the output of rooftop PV systems is affected by panel quality, location, orientation, solar irradiation, and temperature. As a result, the output power of each solar PV systems is different, which influence daily power profile and load forecasting. Also, some DERs like storage systems that cannot generate energy have the effect of shifting according to the end-users control signals. End-users could choose to charge the battery in the period when electricity price is low and use or sell the energy that has been storedin the battery during the peak time.

In addition to prediction of load, the large number of uncoordinated DERs makes load response inefficient and unreliable. Load response to system disturbances, e.g. frequency and voltage fluctuation is essential to manage power system security. "AEMO needs to understand how to load, in aggregate, will respond to these event" (AEMO, 2017). The DERs especially solar PV systems connect to the grid through inverters that are pre-set to disconnect from the grid in the case of voltage and frequency reaching certain thresholds. It is difficult for AEMO to have

appropriate plans and operations for contingency without visibility of how these DERs are pre-set to response (AEMO, 2017).

In TE system, DSOs that coordinate DERs must provide AEMO with enough visibility of DERs for bridging the gap between DSOs and ISOs. The data required by AEMO will vary among different types of technology. Broadly, AEMO needs two types of data from DERs. One is the static data on location, capacity, and the technical characteristics of systems, in particular, the inverters interface to the network. The other is at least five-minute real-time DER output data, which is aggregated at the connection point level for operational forecasts (AEMO, 2017). The main challenge of applying TE system in Australia is enabling visibility of DERs needs to upgrade information and technology technologies for exchanging and documenting the data quickly. Moreover, end-users need to install the energy management and control system in order to data to DSOs and receive feedback information from the DSOs.

6.3 The Impact of TE system in Electrical Standards and Regulations

Due to the penetration of DERs, the power systems are undergoing rapid changes. Electricity markets, consumer technologies, power systems operations and business models in TE system are different from the traditional network, and customer values are becoming the centre of electricity supply chain. It is necessary to make changes in current electrical standards and regulations in Australia. Some international engineering organisations such as International Electrotechnical Commission (IEC) have developed the standards that integrate the penetration of DERs. However, Electrical standards of electricity network in Australia do not take the penetration of DERs into account in the past few years (Standards Australia, 2017).

Today, Standards Australia develops a road map for standards that incorporate DERs. IEC standards and other related international standards are mirrored to Standards in Australia. The needs of change are mainly in the area of DERs coordination, cyber security, electrical operation, microgrids, terminology and framework and privacy (Standards Australia, 2017). The principle of new electrical standards must incorporate the DERs and protect the profits of

all participants especially the customers. The design principles for the standards framework are (ENA and CSIRO, 2015):

- Focused on long-term interests of customers

- Flexible and enabling for emerging technology, technology diffusion, new competition and marketplaces

- Able to align network incentives with long-term consumer value

- Proportional and bounded

- Non-discriminatory

- Consistent, coherent and knowable for all participants

- Independent and accountable

The make of new electrical standards is still undergoing. There are some suggestions referred to the IEEE standards that could be useful for the new electrical standards in Australia. First of all, the new standards should identify the requirements related to the performance, operation, testing, safety considerations, and maintenance of the interconnection between DERs and substations. Some general requirements, e.g. response to abnormal conditions, power quality, islanding, and test specifications and requirements for design, production, installation evaluation, commissioning should be included in new standards. It is also necessary for new standards to identify specification of the electrical devices such as power inverters, converters and batteries (Basso 2014). For example, the inverters of rooftop PV system is required to exchange the real-time information about output power, frequency and Volt/Var control with power grid at the distribution level.

Secondly, the new electrical standards should not only provide requirement about hardware but also need to consider software. In TE systems, high advanced software tools that manage the grid are required to establish the appropriate interface among five interoperable layers. Moreover, the new standards need to find design tables and classification of data flow characteristics, templates, which is to establish power perspective needs and identify and integrating information-communication technology protocols, and standards. These protocols and standards need to address reliability and cyber security.

6.4 The Impact of TE system in Electricity Business mode

6.4.1 Current Electricity Business Mode in Australia
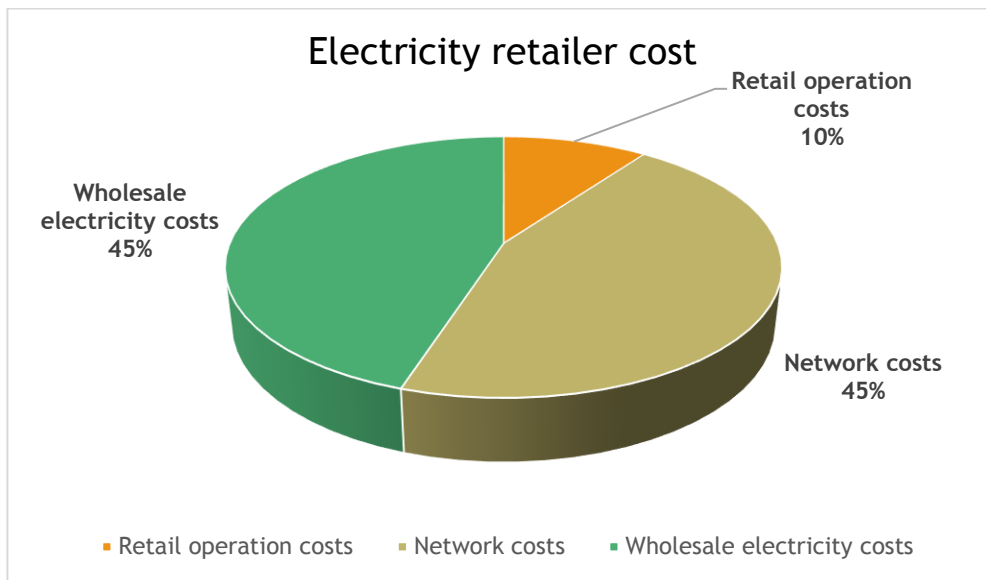
Figure 30 Three categories of retailer cost

Electricity price of Australian households and small business in most states of Australia is regulated and supervised. Electricity retailers sell electricity directly to the public. The factors influencing the cost of them can fall into three categories: retail operation cost, network cost and wholesale electricity costs. As can be seen from Figure 31, both the whole electricity costs and network costs occupy 45% respectively, and retail operation such as meter reading, billing and marketing typically makes up 10 % (Gardner, 2010).

Network costs mainly contain two parts: the transmission and distribution networks. The costs of transmission take up about 10% of retail prices, while distribution charges take up 35 to 50%. The network cost resets every five years, under significant regulation from government; the network cost resets every five years. Wholesale market in Australia is National Energy Market (NEM) where electricity retailers purchase bulk electricity. The prices of the wholesale costs update every five minute and are unregulated because wholesale electricity price is determined by the market (Gardner, 2010).
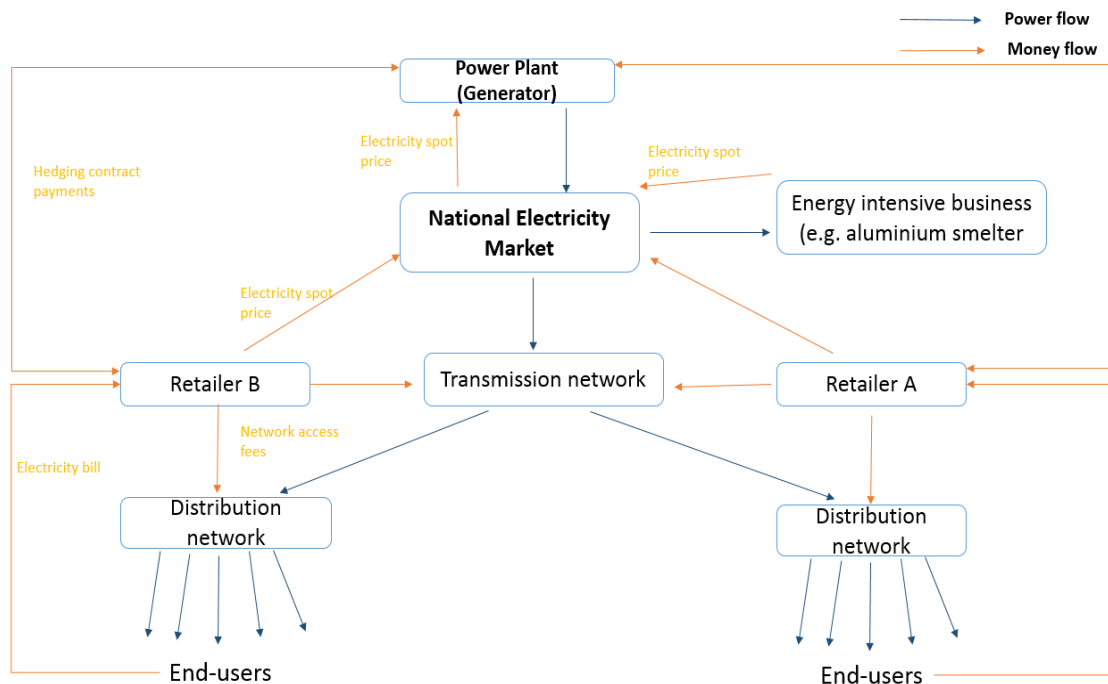
Figure 31 Current electricity business process in Australia (Gardner, 2010)

Current electricity business process is the single direction in which the money of the grid flows from ender users to retailers, NEM and generators. In the process, the retailers purchase the electricity generated by power plants from NEM to distribution points via a transmission network. In addition to electricity, retailers pay access fees to the networks for the use of their infrastructure. Some energy-intensive companies can purchase electricity directly from the NEM. All transactions among all players are undertaken at the variable spot prices settled through the AEMO. Fluctuations of electricity spot price are regulated by applying over the count (OTC) and trade derivative, which can protect the benefit of customers and ensure the electricity market works sustainably (Gardner, 2010).

6.4.2   Proposed Electricity Business Mode of TE System

The emergence of DERs changes the electricity business mode in which the energy trading is becoming bilateral. Prosumers can sell the surplus energy to their neighbours or the grid at

distribution level in TE system. The appearance of the end-to-end transaction needs a new electricity business mode. In the proposed business model, the DSO play a key role in providing an information technology platform that integrates suppliers, buyers, and retail market (Masiello and Aguero 2016). DSO-based business model is responsible for ranging bilateral and bid-based transactions and communicating the operational schedules to all transacting parties (Rahimi, Ipakchi, and Fletcher 2016).

The transactive paradigm of emerging TE system can be viewed as an extension of the existing wholesale market and demand side that has some new attributes and characteristics (Rahimi, Ipakchi, and Fletcher 2016). Energy transaction is happened among entities, e.g. traders, load serving and generation companies, while the participants of TE system paradigm are extended from the transactive entities to retail and grid-edge devices such as energy storage and solar PV systems. Besides, the current business model has limited or no visibility to the retail and end-user transaction. The DSOs in TE systems have the responsibility to provide sufficient visibility of these transactions to all participants.
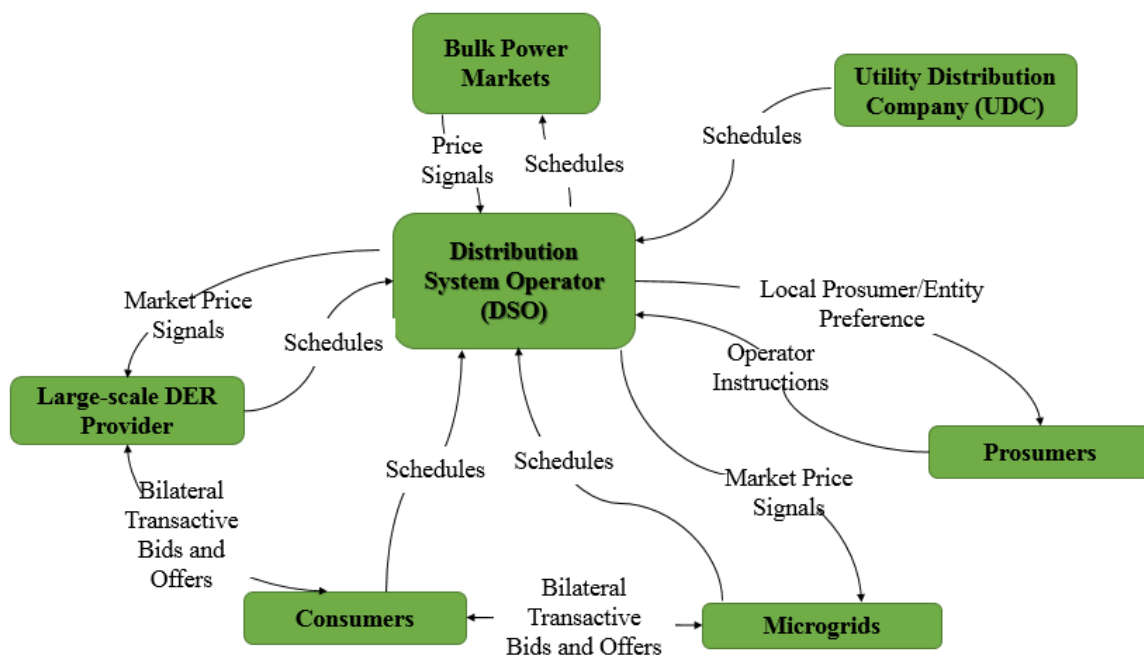

Figure 32Transactive agents and interaction (Rahimi, Ipakchi, and Fletcher 2016)

Figure 4 illustrates the new electricity business mode in which consumers, prosumers and microgrids are involved in electricity transaction. The transactive agents in TE systems provide the operational schedules with the quantity of active power and reactive power exported or imported to DSO. At the same, the DSO sends the market information to the participants and organise the trade among these transactive agents. For example, a prosumer who is planning to sell the surplus the power to other agents submits the quantity of exported electricity with bids to DSO. When DSO publishes this trading request on the trading platform, the potential buyers can compare this energy quantity and bids to another trading request and give the offers based on electricity quantity, price and distribution losses.

An important consideration in TE system business mode is to coordinate the relationship between the wholesale market and retail markets. The concept of distribution locational marginal price (LMP) is proposed to apply transactive exchanges between distribution/end devices and the wholesale market (Rahimi, Ipakchi, and Fletcher 2016). The DLMP can be viewed as the extension of LMP that is the foundation for energy pricing, payment, and cost allocation in the wholesale market. The DLMP could be calculated according to LMP in the wholesale market, local bids and offers, or combination thereof. Similar to LMP, the DLMP could be expressed in bids and offers, and ensure that energy trading is under power system operational constraints (Rahimi, Ipakchi, and Fletcher 2016).

6.5 Propose a Transactive Energy System Model for Australia

As mentioned in section 2.1.1, rooftop PV systems are the main type of DERs in Australia. Therefore, the design of TE system model in Australia should give priority to those two types. Considering Australia's vast territory with low population density, the establishment of TE system model may focus on the small-scale grid in a remote area. The proposed TE system model is customer-oriented, and provides two options for participating in TE markets: sell surplus energy produced by DERs and demand response of electrical devices. The TE system model is at distribution level, which interacts with the main grid and the wholesale market. The main grid plays a role in supporting industry production and the TE system model in case of

DER failing to meet the households demand. In this sector, the proposed TE system model will be described in aspects of technical and economic principle.

6.5.1 Technical Principle of Proposed Transactive Energy System
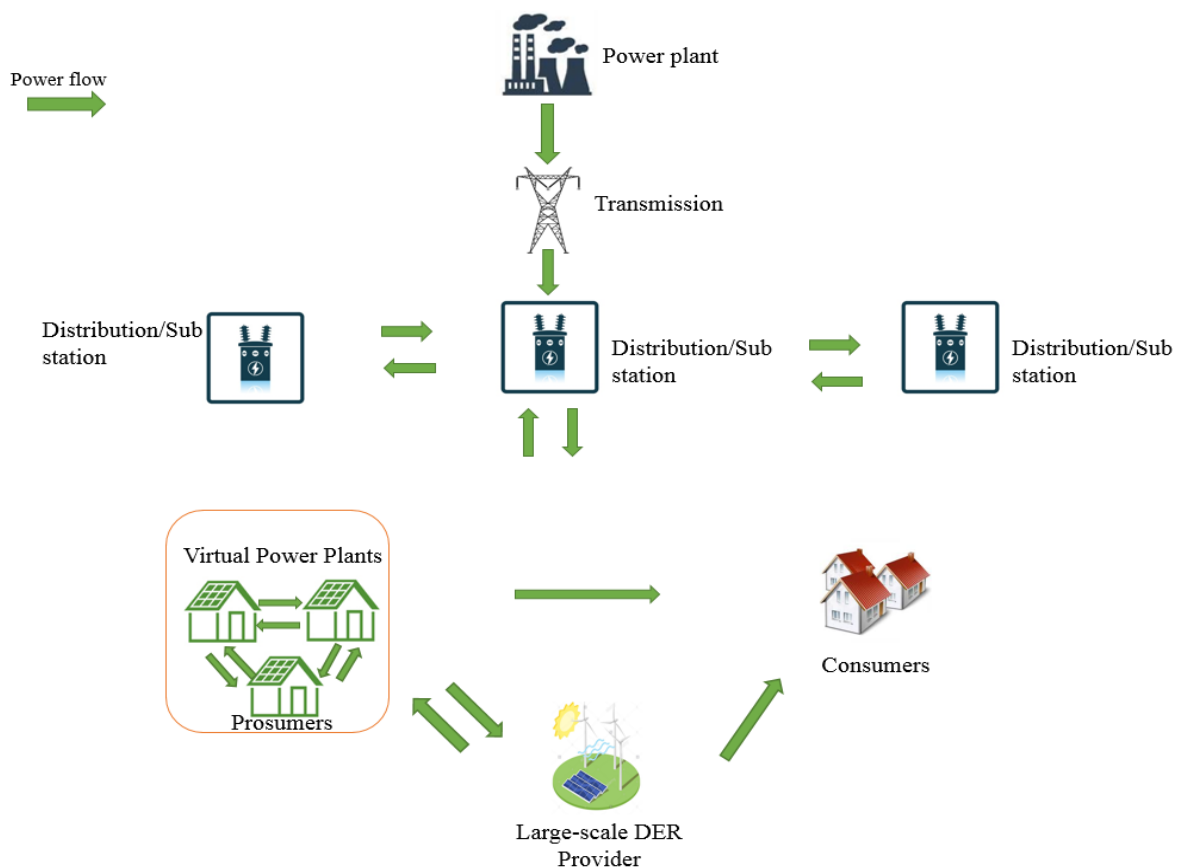
Figure 33Transactive energy system technical model

The figure above illustrates the proposed TE system model for Australia, which will not export the electricity to the grid at the long-distance transmission level. In this system, the prosumers are integrated into virtual power plants that can coordinate the DERs in households and organise power dispatch efficiently. By doing this, consumers have various choices to purchase electricity from the retailer, prosumers or large-scale DER provider based on electricity prices and quantity. On the other hand, prosumers, large-scale DER providers can exchange the

electricity in real time. Furthermore, the substation in can sell/buy electricity from other neighbour substations.

6.5.1.1 Control System of TE system Model

It is essential for TE systems to provide reliable and high-quality energy for end-users. The massive penetration of PV system and battery storage systems can bring some technical challenges that influence electricity quality. For instance, the output power from PV system in a day is highly dependent on the weather condition, which could cause the voltage and frequency fluctuation of the grid. Therefore, TE systems need to update the control system of the grid and apply the new information and communication technologies. New sensors, actuators, and distributed and centralised control elements must be deployed. The devices in the grid and house must support asynchronous information gathering and exchange. Coordinated DERs with the control elements have the function to response to the information of power quality from various operators and maintain the voltage and frequency automatically in real time. In addition, the TE system model will permit an operator at the highest level to send the signals to the various operators and entities running the grid, all the way to end-user premises where the customer or customer-programmed appliances can make decisions about whether to respond to the signal or not (Melton 2013).

As such, the TE system model will establish the multiple level control systems. Consumers and prosumers must install the smart meter and home energy management system (HEMS). The smart meter and HEMS is the end-user terminal sending the data of appliances status and receiving the signal from the operators in different levels. The HEMS orders the DERs and electrical devices to react to the signal based on customer/prosumer's preference and the power system constraints. The virtual power plants, large-scale DER providers and substations have the higher level of control system that is compromised by distribution management system and various sensors on grid device such as relays and transformers.

6.5.2   Hierarchy of Node Levels

Although the TE system model is at the distribution level, the operators at a high level must be involved in TE system control and management. The TE system at distribution level needs to interact with the main grid to ensure the safety and reliability of the power system. A hierarchy of physical and logical node level has existed in current power grid (Melton 2013). The current hierarchy nodes need transformation because the characteristics of the node in different levels must consider the involvement of TE system. The six-level of hierarchy nodes are shown below (Melton 2013):

- Regional Nodes

The level of regional nodes is the highest, which is responsible for balancing a region. The regional nodes stand for the largest-scale power plants and have the wholesale market with individual transaction architecture for energy, ancillary services and hedging. Each regional node is the origination point for wide-area TE messages. The ISO might focus a TE message on a specific area to reduce transmission congestion.

- Control Area Nodes

The next level is "control area node" that is a legacy control area with a control centre and its automatic generator controls (AGC) system. A control area would respond to TE transaction and send the signal regulating the voltage and frequency.

- Distribution Nodes

The next level down would be distribution nodes which make up control areas have a unique way of communicating with end-users through smart meters and HEMS via text message or a radio station. Distribution nodes have to translate TE transactions between other nodes into understandable message sending to various levels.

- Supply Nodes

Supply nodes cover all locations providing additional generation from any source with the range from 1 W to 3000 MW. The regional node or the control area node supervises these nodes.

- Building Nodes

The building nodesare the minimum element of the hierarchy level node represents all electrical appliance that is connected to overall systems. It includes all consumer/prosumers in the distribution system.

The table below identifies the characteristics and responsibility of the various types of nodes just mentioned.

Level	Transactive Energy Responsibility
Regional	1) Creating initial transaction 2) Securing transactions in an approved fashion 3) Transmitting transactions to an approved list of receivers 4) Receipt, verification, acknowledgement of downstream messages 5) Translation of downstream messages into information for the operators 6) Logging and auditing transactions
Control Area	1) Receipt, verification, acknowledgement of regional messages 2) Translating regional messages into messages for lower level nodes 3) Transmitting transactions to lower level nodes in a secure fashion 4) Receipt, verification, acknowledgment of downstream messages 5) Translation of downstream messages for transmission upstream 6) Transmitting downstream messages upstream in a secure fashion 7) Logging and auditing transactions

Distribution	1) Receipt, verification, acknowledgement of upstream messages
	2) Translating regional messages into messages for lower level node
	3) Transmitting transactions to lower level nodes in a secure fashion
	4) Receipt, verification, acknowledgment of downstream messages
	5) Translation of downstream messages for transmission upstream
	6) Transmitting downstream messages upstream in a secure fashion
	7) Logging and auditing transactions

Table 14 Characteristics and responsibilities of nodes (Melton 2013)

Level	Transactive Energy Responsibility
Supply	1) Receipt, verification, acknowledgement of upstream messages 2) Translating transactions into local action 3) Responding upward with actions taken or not taken 4) 4) Logging and auditing transactions
Building	1) Receipt, verification, acknowledgement of upstream messages 2) Translating transactions into local action 3) Responding upward with actions taken or not taken **Table 14 (continue)**

6.5.3   Economic Principle of the Proposed TE Systems

The electricity market based on TE system is different from the traditional market because the consumer/prosumer participates in the market and imposes an effect on electricity price directly. The purpose of the new electricity market is to provide the economic incentives for the consumers/prosumers and benefit all the participants. This sector will describe the new electricity market. The structure of the new market is an agent-basedtransactive energy management formwork with a Comprehensive Energy Management System (CEMS) in which multi-agents represent the market players and finish the energy transaction. DSO organises the day-ahead auction market and electricity spot market in the proposed TE market framework.
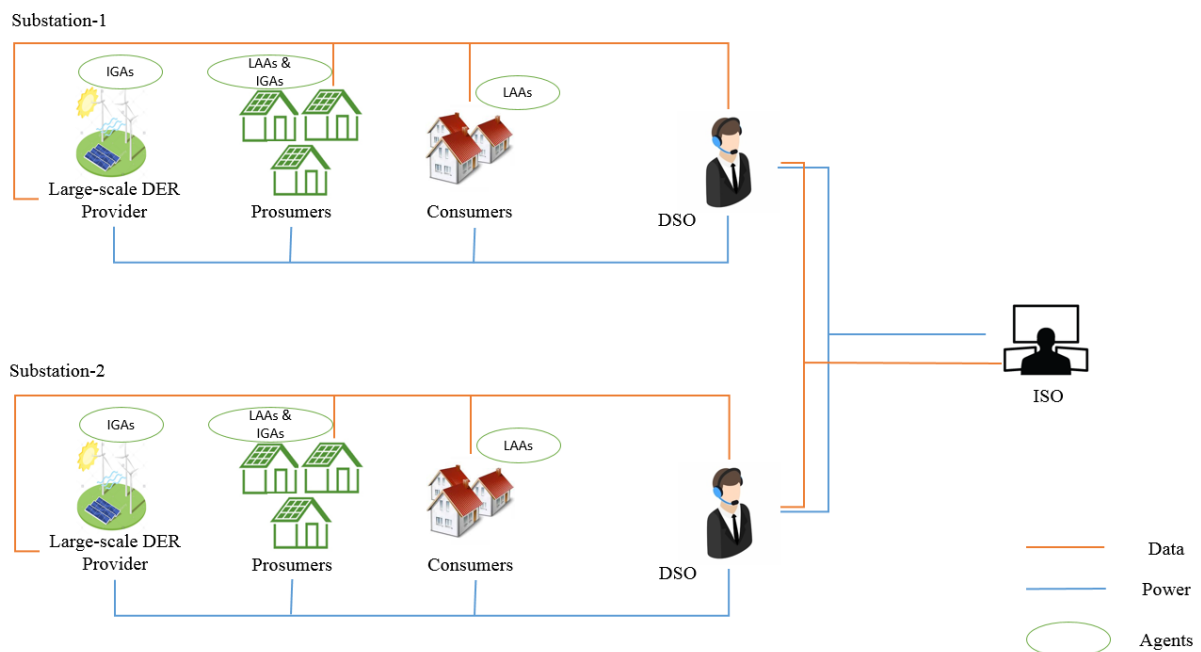
6.5.3.1The Transactive Energy Market Framework

Figure 34Agent-based architecture of the proposed transactive energy market framework

The architecture of the proposed transactive energy market framework is displayed in Figure 6. As shown in the architecture, there are five kinds of agents including Intermittent Generation Agents (IGAs), Load Aggregator Agents (LAAs), Distribution System Operators (DSOs) and Independent System Operators (ISOs). Among these agents, IGAs and LAAs represent the distributed generators and load aggregators or loads respectively. The aggregators and loads can communicate with HEMS installed by end-users to control the intelligent load, and HEMS can track the energy consumption patterns of prosumers/consumers and communicate with load aggregators.

As mentioned in Literature Review, CEMS carries out energy management in the two phases, Primary phase and secondary phase (Nunna and Srinivasan 2017):

1) Primary phase: In this phase, HEMS of end-users carries out day-ahead forecast about energy consumption and generation, and determine bids based on historical data and weather forecast. IGAs and LAAs collect and submit the day-ahead forecast and bids for each demand interval of the following the day to DSO. Then, DSO organises a day-ahead auction market and quantifies the energy mismatch in each interval of the following day according to the forecast data. DSO uses the forecasted mismatches and the bids provided by the end-users to calculate the electricity price. The detailed method to calculate electricity price is introduced in next section. DR load can be pre-set to avoid the high electricity price at peak time by putting threshold value based on the day-ahead forecast.

2) Secondary phase: In this phase, DSO organises a spot market where energy management and transaction occurs it occurs in real time, i.e. one demand interval ahead. In each interval, the information about real-time energy generation and consumption from IGAs and LAAs are reported to DSOs that quantifies the forecast error of real-time mismatches from the forecasted mismatches. Also, DSO carries out an inter-substation market in each time interval. The inter-substation market is a sub-hourly auction based electricity market where DSOs of the substations publish their secondary mismatches. If the mismatch value is positive, then the corresponding DSO

act as an energy supplier and the DSO with negative mismatch value act as energy consumers in the market.

According to the first price continuous double auction mechanism, DSO clears the market and identifies the least quoted seller (outstanding seller) and highest quoted buyer (outstanding buyer). If the price from the outstanding buyer is higher than or equal to the price quoted by the outstanding seller, an energy transaction will happen between the outstanding seller and buyer (Nunna and Srinivasan 2017). Moreover, the threshold value of DR load would change according to the end-users' preference and real-time electricity market.

6.5.3.2 The Method to Calculate Electricity Price

The agent-based D-LMP calculation is applied to determine the electricity price in TE market. Similar to LMP, DLMP reflects the incremental cost to supply next unit of demand at a specific node, and can be considered as an economic signal for power dispatch and system control in a substation. There are three parts making up DLMP: marginal energy cost (MEC), marginal loss cost (MLC) and marginal congestion cost (MCC)(Meng and Chowdhury 2011).
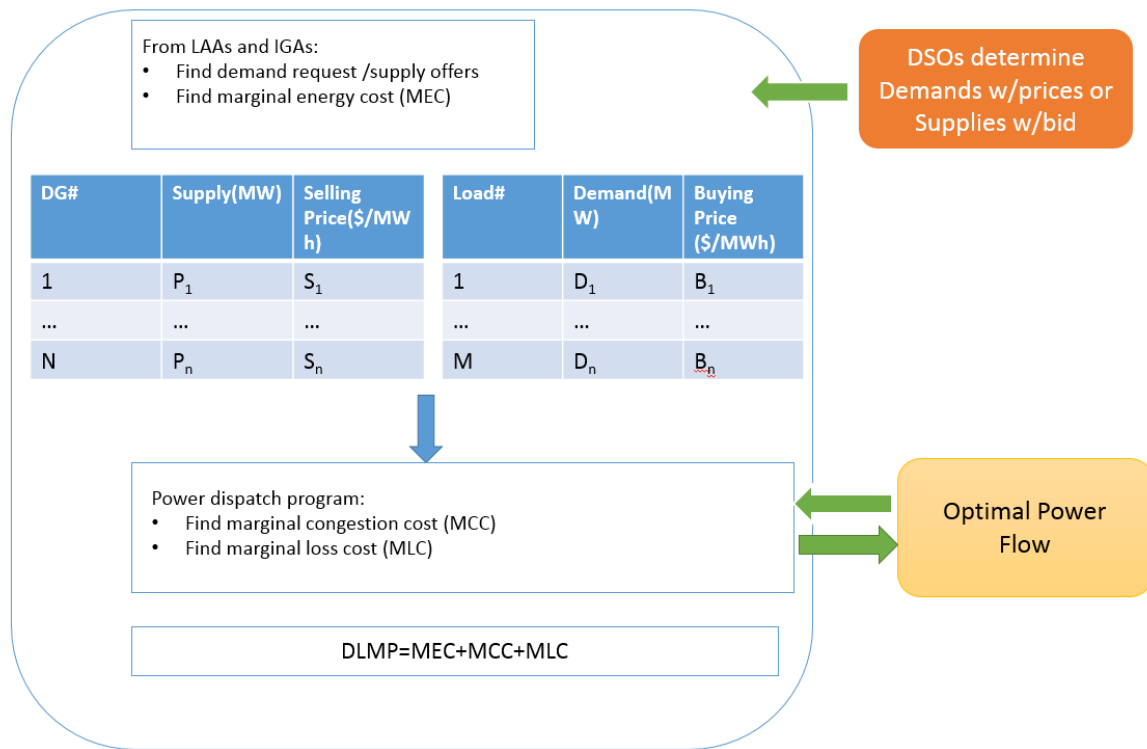
Figure 35 Paradigm of agent-based DLMP calculation

The flowchart representing the method to calculate the DLMP is shown in Figure 36.

1. LAAs and IGAs exchange offer /bids through the DSO and create dispatch priority list that dispatch generations from lowest offer price to serve loads with highest bid prices.

2. Optimal Power Flow (OPF) check the initial dispatch to find MCC and MCC. The system will re-dispatch based on offer/bid record until all demand are cleared if the initial dispatch beyond system constraints.

3. DSOs aggregate DLMP from OPF result, and then calculate individual payment/benefit and social surplus (Distribution LMP-based Economic Operation).

Besides, the DLMP price calculation must refer to LMP from ISO representing the wholesale market. The wholesale market LMP can be a reference value for DLMP calculation and limit the DLMP to keep a reasonable range. However, the specific arithmetic based on multi-agents to combine the LMP to DLMP has not been developed now.

7.0 Conclusion and Recommendation

This research provides a comprehensive analysis of TE systems in aspects of structure, economics, techniques, and participants. The structure of TE system has three dimensions: five interoperable layers, domains and zones. The economics of TE system concentrate on transforming the single direction energy transaction to the bidirectional energy transaction especially customer-to-customer energy business pattern. The current techniques of TE systems focus on coordinating decentralised DERs and DR load efficiently. The responsibility of participants especially DSO in the power system has changed due to the end users' participation in TE system, and DSO is essential for coordinating the resource from the end-users.

The development of proposed TE system model for Australia refer to techniques and economics principle mentioned in Literature Review and consider the impact of TE system is current electricity business model and electrical standards of Australia. Australia has the largest number of rooftop PV system in the world but has low population density. Hence, TE system in Australia should be PV system oriented and small scale.

The concept of TE system is just emerging, and many techniques and economic principle behind the TE system are still not mature. However, the following recommendations for developing the TE system further should be considered:

- TE system structure should be improved and add more details about guiding the technical and economic cooperation among end users.
- High advanced cybersecurity technology should be developed to protect the privacy of customer/prosumers.
- The government should establish specialised department to regulate and supervise the dynamic electricity price of TE market

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9.0   Appendix

```
  </operation>
  <operation name = "DescribeCapability">
    <input message="requestCapabilityMessage"/>
    <output message="giveCapabilityMessage/>
  </operation>
  <operation name = "GiveRealTimeStatus">
    <input message="requestRealTimeStatusMsg"/>
    <output message="giveRealTimeStatusMsg/>
  </operation>
  <operation name = "ReceiveRealTimeControl">
    <input message="sendRealTimeControlMsg"/>
    <output message="AckRealTimeControlMsg/>
  </operation>
</interface>
```

```
SYSTEM CONTROL SERVICE (SCTRL) INTERFACE
<interface name= "SCTRLInterface">
    <operation name = "SetOperatingPoint">
      <input message="SetNewProsumerStateMsg"/>
      <output message="AckNewPrsoumerStateMsg"/>
    </operation>
      . . .
</interface>
```

```
MARKET SERVICE(MKT) INTERFACE
<interface name= "MKTInterface">
  <operation name = "NegotiateNewPrice">
      <input message="SetNewPriceMsg"/>
      <output message="AckNewPriceMsg"/>
  </operation>
  <operation name="DeterminePriceForDownstream">
    <input message="GoalForNewPriceMsg"/>
    <output message="DownstreamNewPriceMsg"/>
  </operation>
    . . .
</interface>
```

Figure 36. Prosumer Interface(Grijalva and Tariq 2011)