School of Electrical Engineering, Computing and Mathematical Sciences

A Practical Approach for Coordination of Plugged- In Electric Vehicles To Improve Performance and Power Quality of Smart Grid

Sara Deilami

This thesis is presented for the Degree of
Doctor of Philosophy

Curtin University

August 2019

DECLARATION

To the best of my knowledge this thesis contains no material previously published by any other person, except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma at any university. The co- authors of the publications in this thesis have acknowledged my contribution as stated in Appendix A.

Sara Deilami
August 2019

ACKNOWLEDGEMENTS

ABSTRACT

This PhD research is undertaken by supplication and includes 14 peer reviewed published articles over seven years of research at Curtin University as the body of this thesis. Further, additional publications by candidate relevant to the thesis have also been included and used in introduction, discussion and future recommendations sections. This thesis offers a thematic narrative for the publications included in this body of work. The subject of the publications covers Plug- in Electric vehicles (PEVs) and their contribution in Smart Grid and future Microgrids (MGs) with incorporation of Renewable Energy Resources (RERs) and Switched Shunt Capacitors (SSCs). I would like to emphasize that this PhD study has been undertaken over seven years of research work and investigations at Curtin University. The candidate's publications represent her research outputs over these few years, acknowledging that, there has been significant development and changes in the field of Smart Grid and Microgrid and EVs over this time. The area of research remains dynamic reflecting innovations and changes to fill in the existing technological and system's needs. This piece of work tries to gather the previous research and present the existing gap to address number of priority issues and provide solutions and recommendations for further development.

Smart Grid technology with the inclusion of EVs have increased significantly in the past decade. The manufacturers continue to introduce new technologies with each new EV generation. These new generations of EVs represent a continued improvement to address limitations and market demands. As an example, Nissan Leaf introduced a new EV that can incorporate a modern lithium – acid battery as its source of power. Nissan Leaf EV battery chargers, Chevrolets, Mercedes Benz or Tesla are available in different type and level with different capacity, charging speed, harmonic contents and efficiency. Due to this large deployment of EVs, the electric utilities are becoming more concern about the impact of these new electric appliances on the performance, productivity, reliability and stability of the grid

especially with the integration of RERs. In response to the many negative impacts on power grids and control systems that are associated with uncontrolled EV charging, controlled centralized and decentralized methodologies for the basis of current innovations have been introduced.

This PhD study focuses on a real- time EV charging coordination with the inclusion of EV charger harmonics and tries to address utilities' concerns of grid power quality and performance with the application of SSCs dispatching. This body of work starts with proposing a real-time PEV coordination algorithm in published paper 1 and tries to enhance and modify the algorithm throughout this research to include the nonlinearities of charger harmonics as shown in publications of chapter 2 with the integration of RERs. In chapter 3, the incorporation of SSC dispatch in the real- time coordination approach has been shown. Chapter 4 presents further power quality improvement with the application of Active Power Filters (APFs) in the area of Smart Grids. In addition, a new method has been introduced in MicroGrids for power quality improvements.

LIST OF PUBLICATIONS INCLUDED IN THE THESIS

1- **Deilami. S,** Amir S. Masoum, Paul Moses, and Mohammad A.S. Masoum. 2011. "Real-time Coordination of Plug-in Electric Vehicle Charging in Smart Grids to Minimize Power Losses and Improve Voltage Profile." *IEEE Transactions on Smart Grid* 2(3): 456-467.

2- **Deilami. S,** Amir S. Masoum, Mohammad A.S. Masoum, and Ahmed Abu-Siada. 2013. "Performance of Heuristic Optimization in Coordination of Plug-In Electric Vehicles Charging." *IBIMA Publishing Journals, International Journal of Renewable Energy and Biofuels.* USA. 1-15, Article ID 898203, DOI: 10.5171/2013.898203.

3- **Deilami. S.** 2018. "Online Coordination of Plug-In Electric Vehicles Considering Grid Congestion and Smart Grid Power Quality. "*Energies.*1-17, Vol. 11, Issue 9, Article ID-36962, DOI: 10.3390/en11092187.

4- Panahi. D, **Sara Deilami,** Mohammad A.S. Masoum, and Syed. M. Islam. 2015. "Forecasting Plug-In Electric Vehicles Load Profile using Artificial Neural Networks." *Australasian Universities Power Engineering Conference (AUPEC 2015)*, Wollongong, NSW, Australia, 1-6.

5- Naghibi. B, Mohammad A.S. Masoum, and **Sara Deilami.** 2018. "Effects of V2H Integration on Optimal Sizing of Renewable Resources in Smart Home based on Monte Carlo Simulations." *IEEE Power and Energy Technology Systems Journal* 5 (3): 73 – 84. DOI: 10.1109/JPETS.2018.2854709.

6- **Deilami. S**, and Mohammad A.S. Masoum. 2013. "Optimal Dispatch of LTC and Switched Shunt Capacitors in Smart Grid with Plug-In Electric Vehicles." *IEEE Power Engineering Society General Meeting PES GM,* Vancouver, British Columbia, Canada, 1-7.

7- **Deilami. S,** Amir S. Masoum, Nasim Jabalameli, and Mohammad A.S. Masoum. 2013. "Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid with Electric Vehicles and Charging Station." *8th International Conference on Electrical and Electronics Engineering (ELECO 2013).* Bursa, Turkey, 162-166.

8- **Deilami. S.** 2015. "LTC and Shunt Capacitor Switching in Smart Grid: Sensitivity to Plug- In Electric Vehicle Forecasts." *International Journal of Electrical, Electronics and Data Communication,* ISSN: 2320-2084 3(2).

9- **Deilami. S,** Mohammad A. S. Masoum, Ahmed Abu-Siada, and Syed M. Islam. 2014. "Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid Concerning Overnight Charging of Plug-in Electric Vehicles." *Applied Engineering Sciences, ed. Wei Deng,* 65-70. London UK, CRC Press is part of The Taylor & Francis Group: CRC Press, 2014. **(Book Chapter).**

10- **Deilami. S,** Bahman Naghibi, and Keyhaneh Janfeshan. 2014. "LTC and Switched Shunt Capacitor Scheduling in Smart Grid with Electric Vehicles and Wind Distributed Generation Systems." *Australasian Universities Power Engineering Conference (AUPEC),* Perth, WA, 1-6.

11- **Deilami. S.** 2018. "Online Coordination of Plugged- in Electric Vehicles and Optimal Rescheduling of Switched Shunt Capacitors in Smart Grid Considering Battery Charger Harmonics." *IEEE Power and Energy Technology Systems Journal* 5(4): 1- 9. DOI: 10.1109/JPETS.2018.2880762.

12- **Deilami. S,** Mohammad A. S. Masoum, and Moayed Moghbel. 2016. "Derating Active Power Filters Considering Network and Bus Voltage Total Harmonic Distortions." *IEEE EEEIC 2016.* Italy, Florence, 1-6. DOI: 10.1109/EEEIC.2016.7555858.

13- Moghbel. M., Mohammad A. S. Masoum, Alireza Fereidouni, and **Sara Deilami.** 2017. "Optimal Sizing, Siting and Operation of Custom Power Devices with STATCOM and APLC Functions for Real-Time Reactive Power and Network Voltage Quality Control of Smart Grid", *IEEE Transactions on Smart Grid* 9(6): 5564 – 5575. DOI: 10.1109/TSG.2017.2690681.

14- Kermany. S.D, Mahmood Joorabian, **Sara Deilami**, and Mohammad A. S Masoum, 2017. "Hybrid Islanding Detection in Microgrid with Multiple Connection Points to Smart Grids using Fuzzy-Neural Network." *IEEE Transactions on Power Systems* 32(4): 2640 – 2651. DOI: 10.1109/TPWRS.2016.2617344.

ADDITIONAL PUBLICATIONS BY CANDIDATE RELEVANT TO THE THESIS

1. Masoum Amir S., **Sara Deilami,** Mohammad A. S. Masoum, Ahmed Abu-Siada, and Syed M. Islam. 2014. "Overnight Coordinated Charging of Plug-In Electric Vehicles based on Maximum Sensitivities Selections", *Applied Engineering Sciences,* ed. Wei Deng, 65-70. London UK, CRC Press is part of The Taylor & Francis Group: CRC Press.

2. Masoum Amir S., **Sara Deilami**, Ahmed Abu-Siada, Mohammad A. S. Masoum. 2015. "Fuzzy Logic Approach for Online Coordination of Charging Plug-In Electric Vehicles in Smart Grids," *IEEE Transactions on Sustainable Energy*, 6(3):1112-11121.

3. Derakhshandeh S.Y., Amir S. Masoum, **Sara Deilami,** Mohammad A. S. Masoum, and M. E. Hamedni Golshan. 2013. "Coordination of Generation Scheduling with PEVs Charging in Industrial Microgrids*." IEEE Transactions on Power Systems,* 28(3):3451-436.

   DOI: 10.1109/TPWRS.2013.2257184

4. Masoum Amir S., **Sara Deilami**, Paul Moses, Mohammad A.S. Masoum, and Ahmed Abu-Siada. 2011. "Smart Load Management of Plug-In Electric Vehicles in Distribution and Residential Networks with Charging Stations for Peak Shaving and Loss Minimization Considering Voltage Regulation." *IET Proceedings on Generation, Transmission and Distribution* 5(8):877-888.

5. Jabalameli Nasim, Mohammad A.S. Masoum, and **Sara Deilami.** 2017. "Optimal Online Charging of Plug in Electrical Vehicles Considering Voltage Unbalance Factor." *IEEE PES General Meeting,* Chicago, IL, USA, 1-5, July 16-20.

6. Moghbel Moayed, Mohammad A.S. Masoum, and **Sara Deilami**. 2016. "Optimal Placement and Sizing of Multiple StatCom in Distribution System to Improve Voltage Profile." *Australasian Universities Power Engineering Conference (AUPEC 2016),* Brisbane, Australia, 1-6, Sep. 25-28.

7. Panahi. Delshad, **Sara Deilami**, and Mohammad A.S. Masoum. 2015. "Evaluation of Parametric and Non-Parametric Methods for Power Curve Modelling of Wind Turbines." *9th International Conference on Electrical and Electronics Engineering (ELECO 2015),* Bursa, Turkey, 142-146, Nov.26-28.

8. Zargham Nejad Arash, **Sara Deilami,** Mohammad A.S.Masoum, and N. Haghdadi. 2015. "Map-Based Linear Estimation of Drive Cycle for Hybrid Electric Vehicles." *Australasian Universities Power Engineering Conference (AUPEC 2015),* Wollongong, NSW, Australia, 1-5, Sep. 27-30.

9. Masoum Amir S., **Sara Deilami**, Ahmed Abu-Siada, and Mohammad A.S.Masoum. 2015. "Fuzzy Logic Approach for Online Coordination of Charging Plug-In Electric Vehicles in Smart Grids." *Power Tech 2015 Conference*, Eindhoven, The Netherlands, 1-6, June 29-July 2.

10. Masoum Amir S., **Sara Deilami**, Mohammad A.S. Masoum, Ahmed Abu-Siada, and Syed. M. Islam. 2014. "Overnight Coordinated Charging of Plug-In Electric Vehicles Based on Maximum Sensitivities Selections." *International Conference on Applied Engineering Sciences (ICAES 2014),* Los Angeles, USA, July 23-24, 2014.

11. Naghibi. Bahman, and **Sara Deilami.** 2014. "Non-Intrusive Load Monitoring and Supplementary Techniques for Home Energy Management." *Australasian Universities Power Engineering Conference (AUPEC 2014),* Perth, WA, Australia, 1-5, Sep. 28-Oct. 1.

12. Janfeshan. Keyhaneh, Mohammad A.S. Masoum, and **Sara Deilami. 2014.** "V2G Application to Frequency Regulation in a Microgrid Using Decentralized Fuzzy Controller." *The 6th International Conference on Modelling, Identification and Control (ICMIC 2014),* Melbourne, Australia, 1-5, Dec. 3-5.

13. Masoum Amir S., **Sara Deilami**, Mohammad A.S. Masoum, Ahmed Abu-Siada, and Syed. M. Islam. 2014. "Online Coordination of Plug-In Electric Vehicle Charging in Smart Grid with Distributed Wind Power Generation Systems", *IEEE PES General Meeting,* Washington, USA, 1-5, July 27-31.

14. Jabalameli. Nasim, **Sara Deilami**, Mohammad A.S. Masoum, and Masoud Abshar. 2014. "Rooftop PV with Battery Storage Solar Smoother." *IEEE PES General Meeting,* Washington, USA, 1-5, July 27-31.

15. Jabalameli Nasim, **Sara Deilami,** Mohammad A.S. Masoum, and Farhad Shahnia. 2013. "Rooftop PV with Battery Storage for Constant Output Power Production Considering Load Characteristics", *8th International Conference on Electrical and Electronics Engineering (ELECO 2013),* Bursa, Turkey, 142-146, Nov.28-30.

16. **Deilami. Sara**, Amir S. Masoum, Paul. S. Moses, Mohammad A.S. Masoum. 2010, "Voltage Profile and THD Distortion of Residential Network with High Penetration of Plug-in Electrical Vehicles." *IEEE ISGT Europe 2010 (Innovative Smart Grid Technologies Europe) Conference,* Gothenburg, Sweden, October 10-13.

17. Moses Paul S., **Sara Deilami**, Amir S. Masoum and Mohammad A.S. Masoum. 2010. "Power Quality of Smart Grids with Plug-in Electric Vehicles Considering Battery Charging Profile." *IEEE ISGT Europe 2010 (Innovative Smart Grid Technologies Europe) Conference*, Gothenburg, Sweden, October 10-13.

18. Masoum Mohammad A.S., **Sara Deilami,** Syed M. Islam. 2010. *"Mitigation of Harmonics in Smart Grids with High Penetration of Plug-In Vehicles." IEEE Power Engineering Society General Meeting,* Minneapolis, USA, July.

19. Masoum. Amir S., **Sara Deilami**, Paul S. Moses, and Ahmed Abu-Siada. 2010. "Impact of Plug-in Electrical Vehicles on Voltage Profile and Losses of Residential System.*" Australasian Universities Power Engineering Conference (AUPEC 2010),* Christchurch, New Zealand1-6, Dec. 5-8, 2010.

20. Masoum. Amir S.**, Sara Deilami**, Paul S. Moses, and Ahmed Abu-Siada. 2010. *"Impacts of Battery Charging rates of Plug-in Electric Vehicle on Smart Grid Distribution Systems", IEEE ISGT Europe 2010 (Innovative Smart Grid Technologies Europe) Conference*, Gothenburg, Sweden, 1-6, October 10-13.

21. Masoum Mohammad A.S., Paul S. Moses, and **Sara Deilami.** 2010. *"Load Management in Smart Grids Considering Harmonic Distortion and Transformer Derating*", IEEE ISGT 2010 conference, the first IEEE PES Innovative Smart Grid Technologies, Gaithersburg, Maryland, USA, 1-7, Jan. 19-21.

STATEMENT OF AUTHOR CONTRIBUTION

The nature and extent of the intellectual input by the candidate and co-authors has been

approved by all authors and can be found in Appendix A.

LIST OF ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
AI	Artificial Intelligent
ANN	Artificial Neural Network
APF	Active Power Filter
APLC	Active Power Line Conditioner
ASD	Adjustable Speed Drive
BSS	Battery Storage System
CPD	Custom Power Devices
CS	Charging Station
DC	Current
DCFC	DC Fast Charging
DHPF	Decoupled Harmonic Power Flow
DG	Distributed Generation
DR	Demand Response
EV	Electric Vehicle
FACTS	Flexible AC Transmission System
GA	Direct Genetic Algorithm
HEMS	Home Energy Management System
H2G	Home to Grid
H-LMA	Heuristic Load Management Algorithm
ICT	Information and Communication Technologies
KCL	Kirchhoff Current Law
LTC	Transformer Load Tap Changer
LV	Low Voltage
MAS	Multi- Agent System
MSS	Maximum Sensitivity Selection
NOL-MSSCA	Nonlinear Online Maximum Sensitivity Selection based Charging Algorithm
MG	Microgrid
MAS	Multi-Agent System
MV	Medium Voltage
PCC	Point of Common Coupling
PEV	Plugged-in Electric Vehicle
PFC	Power Factor Correction
PHEV	Plugged-in Hybrid Electric Vehicle
PLCC	Power Line Carrier Communication
PPF	Passive Power Filter
PSO	Particle Swarm Optimization
PV	Photovoltaic
PWM	Pulse Width Modulation
RERs	Renewable Energy Resources
RDGs	Renewable Distributed Generations
SCADA	Supervisory Control and Data Acquisitions Systems
SG	Smart Grid
SSC	Switched Shunt Capacitor
STATCOM	Static Synchronous Compensator

THD	Total Harmonic Distortion
THDi	THD of Current
THDv	THD of Voltage
V2G	Vehicle to Grid
V2H	Vehicle to Home
VFD	Variable Frequency Drive
VSD	Variable Speed Drive
WA	Western Australia
WDG	Wind Distributed Generation
WT	Wind Turbine

Table of Contents

Table of Figures

1 CHAPTER 1 INTRODUCTION

1.1 Electric Power Grid

Power system was originally an isolated and localised system that was first created by Thomas Edison in early 1882 and then was promoted all across the country. At that time, there was a battle between two different types of systems: Direct Current (DC) and Alternating Current (AC). Thomas Edison was a proponent of DC systems and was competing with Nicolas Tesla who was promoting the AC system. In DC technology, the flow of electrons (current) is in one direction from generator to the load through a complete circuit. However, AC technology enables the flow of current to switch forth and back (The electricity grid, 2012; the war of the Currents, 2014). The main and major advantages of AC system could be the possibility of transmitting power in high voltage (HV) and convert it to low voltage (LV) to distribute the power more efficiently at lower levels. This can be done through step down transformers. In addition, AC system can transfer power not only through 3 wires but also through 1 wire to reduce the total network losses. Therefore, Due to abovementioned main advantages, the so-called DC system has been quickly replaced by AC system in early 1900 (The electricity grid, 2012).

The present electrical grid is an interconnected network to deliver electric power from the utilities/ producers to consumers. The main components of the conventional/current electric grid are: very high voltage (HV) AC plants generation stations, high voltage AC/ DC transmission lines (e.g., 400kV), medium voltage (MV) distribution systems (e.g., 20kV) and consumers. The generated power from generation side is carried and delivered through HV transmission lines and distribution network to the individual consumers of electric powers including industry, service sector and low voltage (LV) residential users. The control and monitoring of this traditional electric grid would be possible by mainly considering the

intelligence in the main locations and partly in substations. Remote loads in these conditions are nearly passive. This power grid might be more stable, operative, reliable (less power outage) and flexible with the use of two- way communication and information flows and enabling distributed intelligence systems in local electricity production (Colak et al, 2015, Liserre et al, 2010)

In general, the challenges/ drawbacks of the traditional power grids are (Basu 2015):

- For the so-called power grid, a centralised supervisory control is introduced to transfer and distribute the electricity and monitor the power system with almost no visibility on the substations.

- In traditional power grid, supply always needs to follow the demand. If electricity demand increases, the supply needs to respond in a timely and efficient manner. With increase demand this may lead to the installation of more power generators/stations (infrastructure) and therefore increase the electricity costs.

- Integration of smart appliances such as PEVs and RERs requires load balancing, overcoming the energy fluctuations and maintaining a stable power supply.

Therefore, a modernized/smarter electricity grid is required for the future industry to address the issues and limitations caused by the advanced technology (Amin et al, 2005).

1.2 Smart Grid

The future electric grid is broadly known as Smart Grid which requires a complicated two-way communication backbone, to support bi-directional electric flows between smart apparatus, advanced telecommunications and computer technologies. This is to facilitate innovations in grid operation and control strategies by implementing demand side management. The term Smart Grid reflects more than just the generation, transmission and consumer side of a power grid. Smart Grid is being pushed "to be modernized' or "smarter" to deliver the required electric

power in a reliable and efficient manner to reduce the power/frequency outages and system losses as well as managing the power consumption and costs associated with the grid (Grid modernization, 2007). Smart Grid is also offering electrical energy storage for load balancing purposes as well as overcoming electric power variations created by renewable distributed generations (RDGs). Smart Grid is able to prevent extensive power network failures/outage and grid perturbations and allow the integration of Plugged-in Hybrid (PHEV) and Plugged- in Electric Vehicles (PEV). Smart Grid is environmental friendly and quite helpful in dealing with energy and reducing greenhouse gas emissions. It also reduces carbon emissions from the transportation and provides storage to dynamically provide a balance between the generation and load levels. This transformation of the electric power grid to a 'smarter grid' and therefore this modernization leads to great prospects and challenges to improve the present power system's infrastructure to fulfil the delivery of electricity which requires strategic and controlled approaches and plans (Grid modernization, 2007). Overall, there are various challenges and great opportunities. Some of the Smart Grid challenges are listed below (Pierluigi 2014, Fang et al, 2012, Vardakas et al, 2017, Vrba et al, 2014, Bera et al, 2015):

- Large-Scale Integration of Renewable Distributed Generations (RDGs).
- Control and optimization of Microgrids, Minigrids and Smart Houses.
- Dynamic Demand Response (DR) and Decentralized ICT-Based Control.
- Distributed Energy Storage Systems and PEVs.
- Advanced ICT Infrastructures and Solutions.
- Multi-Agent Systems (MASs).
- Cyber-attacks and Security of Data.

There are also great opportunities with the new smarter power grid (Smart Grid Challenges and Opportunities, 2011, 20):

- "More efficient grid".

- "Enable electricity markets to flourish".

- "Higher penetration of intermittent power generation's sources".

- A clean power.

To summarize, not only utilities but also consumers and government are eagerly seeking for the great opportunities of new Smart Grid. Utilities are looking for more integration of load shedding tools such as smart appliances, PEVs/PHEVs, RERs, with new real- time and efficient management strategies. The new Smart Grid is expected to enable the required transformation and infrastructure. The consumers are also hoping to have less utility costs with the existing educational programs/strategies and two-way communication options in Smart Grid. The government tries to provide a secure network which can handle any possible issue (Smart Grid Challenges and Opportunities, 2014).

1.3   Smart Grids Resources

Technologies within Smart Grids provide an extensive opportunity for the development of advanced applications for power use optimization. Such technologies have the capacity to improve RDGs, energy storage and PEVs as well as Microgrids (MGs), smart buildings and homes with smart appliances and generation units such as rooftop PVs and rooftop wind turbines (Amin and Wollenberg, 2005, Mauri et al, 2009, Bruno et al, 2009). PEVs are becoming more popular due to their positive impact on greenhouse gas emissions and environment pollution. However, many electric utilities are concerned about the risks and impact of random (poorly predicted) PEV charging on the performance, stability, reliability, power quality and efficiency of the power grid (Su et al, 2012, Clement et al, 2010, A. Masoum et al, 2011, Deilami et al, 2010).

Moreover, the amplitude and temporal variability of the operation of distribution networks and voltage profiles attributed to uncoordinated PEV charging is further complicated by the installation of RDGs such as distributed solar and wind generators. The main concerns are related to the reliability issues in modern power grid with the inclusion of renewable resources. As an example, the unpredictability of wind energy resources and the changeability of solar energy resources due to climate changes and sunlight availability have negative effect on grid reliability (Moslehi Khet et al, 2010). The interaction between the different stochastic power profiles of both PEV charging and the utilisation of RDGs means that optimal power distribution solutions are required.

The possible approaches to resolve this problem could be performing an improved/enhanced coordination of smart appliances, implementation of new PEV charging strategies, improving infrastructure and optimal sizing and control of RDGs. (Chen et al, 2017) have discussed that the coordinated PEV charging by itself could successfully minimize the operational risks and improve the efficiency of the grid. The automatic temporally coordinated PEV charging activities to optimize grid load profile control through, advanced customer demand management have also been widely reported (Rahimi et al, 2010 and Clement-Nyns et al, 2010). In addition, many authors (Han et al, 2010, Sortomme et al, 2011 and Pillai et al, 2011) have investigated the possibility of vehicle to grid (V2G) operation by offering ancillary services (frequency/voltage regulations) in order to improve the performance of Smart Grids. (Deilami et al, 2010) and (Masoum et al, 2011) presented an optimal PEV charging strategy in a multi-tariff environment that included low and medium voltage residential and distribution networks as well as the application of industrial and residential nonlinear loads. As PEV adoption and utilization are expected to grow within the next few years, it is necessary to continue to develop new online PEV coordination/optimization strategies. Such strategies aim to improve the grid performance as well as the power quality of the network. This is to enhance

the grid reliability with the integration of RDGs while keeping the total harmonic distortions of voltage (THDv) of the overall system within the standard threshold of 5%. However, in Smart Grids with large scale PEV deployment, the growing risk of the negative impact of PEV charging activities is more difficult to coordinate with an optimal online strategy. Uncoordinated PEV charging methods are not only costly to the power grid but also a risk "to the reliability and generation adequacy of the grid" (Zhaoyang 2014, p1). Also, the future infrastructure may not have the capacity for high penetration of PEVs if most of recharging happens during peak hours for example when PEV owners return home from work (Zhaoyang 2014).

To overcome this increased complexity, it is proposed that the application of Load Tap Changers (LTCs) and Switched Shunt Capacitors (SSCs) in the online PEV coordination be investigated. Further, it is important to consider injected current harmonics by EV chargers or industrial loads and their impact on power quality of Smart Grid. The harmonic distortion affected by these nonlinear loads may result in mal-operation and further reduction in power quality of the grid (Deilami 2018). Solutions to harmonic problems may be the installation of capacitor banks, passive filters, optimal scheduling of LTCs and SSCs and even active power filters (APFs). These solutions have already been discussed and introduced in many recent publications (Singh et al, 1999; Masoum et al, 2010; M.A.S. Masoum et al, 2015 and Sun et al, 2016) and the benchmark standard permissible current and voltage harmonic distortion levels in electric power systems has been defined by International standards (IEEE Std 519-1992-1993).

1.3.1 PEV and EV Battery Chargers

The popularity of PEVs may be due to their reduced fuel usage and greenhouse emissions (Yilmaz et al, 2013). Due to the advanced technology, the connection of PEVs to the grid may lead to more opportunities such as load balancing, reactive power compensation or storing

energy; however, their complications such as high cost involved, battery cycle life cannot be neglected. In general, PEV is a battery-operated vehicle compare to the conventional fuel-based cars. Many manufacturers are now producing different types of electric or hybrid electric vehicles such as Nissan Leaf, BMW i3, Chevrolet Volts, Mitsubishi i-MiEV, Toyota Prius and Tesla (Wikipedia, 2017). These different types of EVs are introduced with different charger technologies and therefore, different charging infrastructure (Watson et al, 2015). The discussion is more about the EV battery chargers and the required infrastructure to ease the charging methods. Table I shows different EV technologies and their charging power levels (SAE Electric Vehicle, 2010-2017; Yilmaz et al, 2013).

Table I. Electric Vehicle Charging Technologies and Power Level.

Charging Level	Charger Location	Expected Charging Rate	Charging Time	Vehicle Technology	Typical Use of Method
Level 1 120 Vac (US)	On- board Single phase	1.4 kW (12 A)	4-11 hours 11-36 hours	PHEVs (5-15 kWh) EVs (16-50 kWh)	Home/Office
Level 2 240 Vac (US) 400 Vac (EU)	On- board single/three phase	4 kW (17 A) 8 kW (32 A) 19.2 kW (80 A)	1-4 hours 2-6 hours 2-3 hours	PHEVs (5-15 kWh) EVs (16-30 kWh) EVs (3-50 kWh)	Private/Public outlets
Level 3 (Fast Charging) 208- 600 Vac/Vdc	Off- board Three- phase	50 kW 100 kW	0.4-1 hours 0.2-0.5 hours	EVs (20-50 kWh)	Commercial, Analogous to a filling station

An Overview of EV Chargers- Electric cars may vary based on their charging infrastructure/ sockets for charging. Some types such as Nissan Leaf Mitsubishi have the facility of both AC charging and DC/fast charging. In other words, they are equipped with two types of sockets. Some others (for example Ford), do not have fast charging facility. The connections to the charging stations, the communications between the station and chargers and the rate of charging may also differ depends on the type of EVs and their charging methods (Watson et al, 2015).
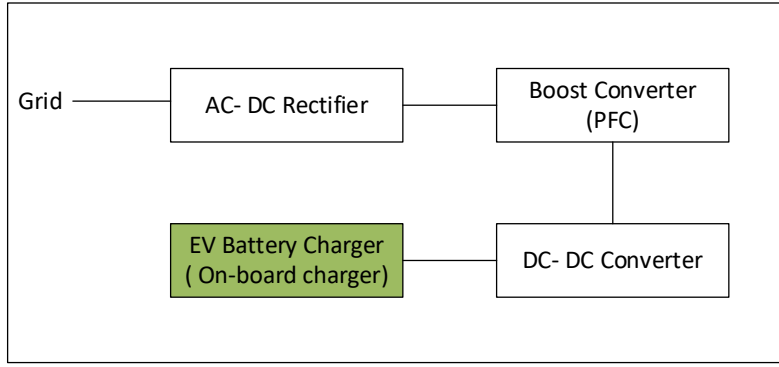
Fig.1. 1. Simple Schematic of EV Charging System

 The battery chargers' characteristics are important in developing EVs and their efficiency. In general, the operation of battery chargers is dependent on their infrastructure, charging and switching strategies (Yilmaz et al, 2013). EV battery chargers are classified within three charging levels of slow charging (Level 1), medium charging (Level 2) and fast DC charging (Level 3). PEVs can be plugged into an outlet and charged over night for a low charging at home. However, the primary charging method is known as Level 2 charging where a 240 V outlet is required. Level 3 or DC fast charging are considered for commercial and public usages (Yilmaz et al, 2013). Many researchers investigated the EV chargers' infrastructure with different charging levels and their associated harmonic current and voltage spectrums. Such research studies show that different type of EV battery chargers have totally different harmonic spectrums and the THD level of current and voltage vary with their level of charging and required voltages.

As studies show, when an EV is connected to the power grid, the current absorb by the grid is not purely sinusoidal (Lorenzo 2014). Fig. 1.1 shows a simple topology of EV charging system. During the charging time, EV is connected to the grid via power electronic devices such as DC-DC converters or AC- DC rectifiers. These power electronic equipment, create additional harmonics to the voltage and currents and therefore, this harmonic distortion will be transferred to the grid. When chargers connect to the charging station and starts drawing current, they act as a nonlinear load causing distortion depending on the type of charger and the charging rate.

Therefore, the injected current drawn from utilities and its harmonic distortion varies based on the percentage of its individual harmonic current spectrum. In order to study this harmonic propagation, the EV chargers have been widely modelled and tested (Lorenzo 2014). For example, for Nissan Leaf the harmonic components for charging rates of Level 1, Level 2 and Level 3 charging are different (Steady State Vehicle Charging Fact Sheet, 2015). In all cases with different charging level, the 3rd harmonic is the dominant harmonic component as shown in Fig. 1.5 Due to the growth of EV demand, the injected harmonic current by EV battery chargers can have a detrimental impact on power quality of the grid. Power quality is an important factor for distribution network and their reduction may cause severe consequences such as voltage deviations, increasing power losses lack of continuous service to the consumers (Bass et al, 2013). It is necessary to keep the distortion level low to improve the power quality of the system and comply with the standard limits of IEEE standard 519. According to Nissan Leaf's manufacturer' report in 2015, "as the vehicle charger rate decreases" its 'characteristics may also decrease such as: efficiency, power factor, and total harmonic distortion. Although the power factor reduction can be ignored, the decrease in efficiency and increase in total harmonic distortion cannot be underestimated nor neglected but should be avoided when possible (Steady State Vehicle Charging Fact Sheet, 2015). Figs.1. 2- 1.4 show the efficiency, power factor and THDi for Nissan Leaf (24 kWh).
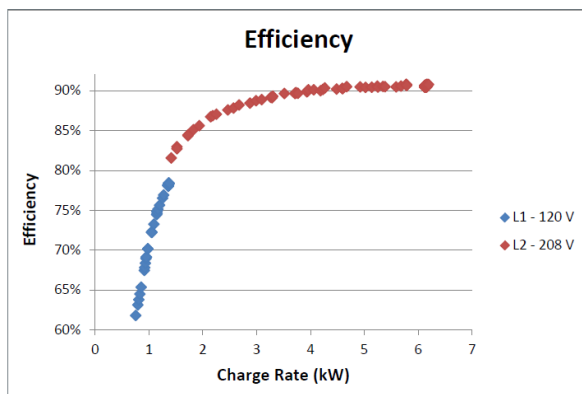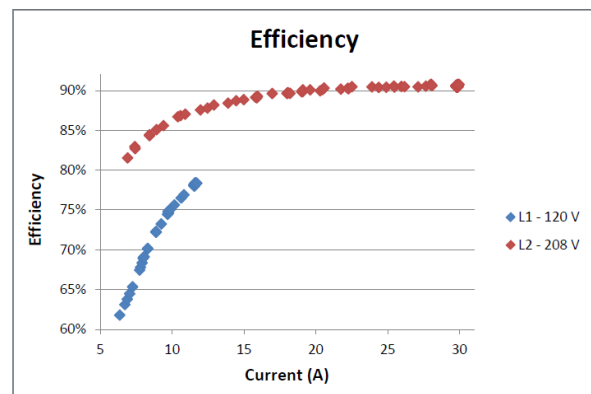
a)   b)

Fig.1. 2. Efficiency of EV for a) level 1 charging (120 V) and b) level 2 charging (208 V) for Nissan Leaf (24 kWh).
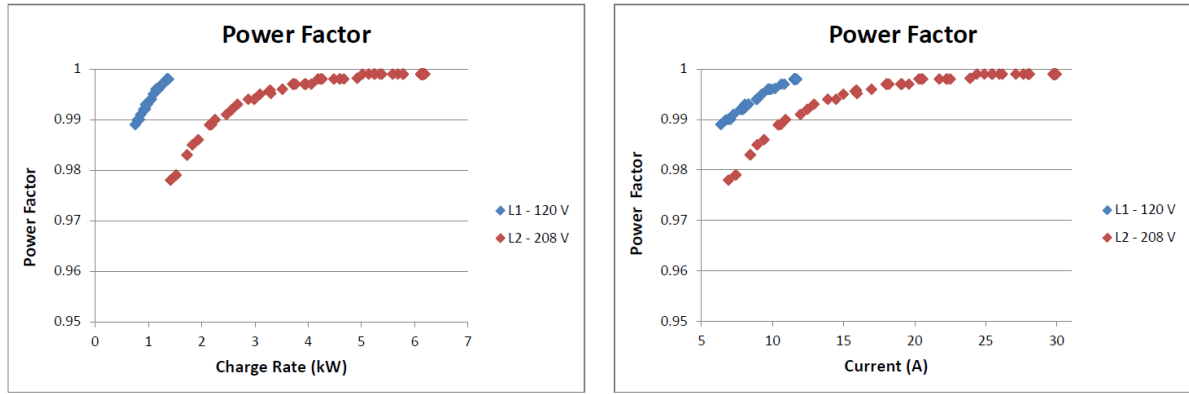
a)

b)

Fig.1. 3. Power Factor of EV for a) level 1 charging (120 V) and b) level 2 charging (208 V) for Nissan Leaf (24 kWh).
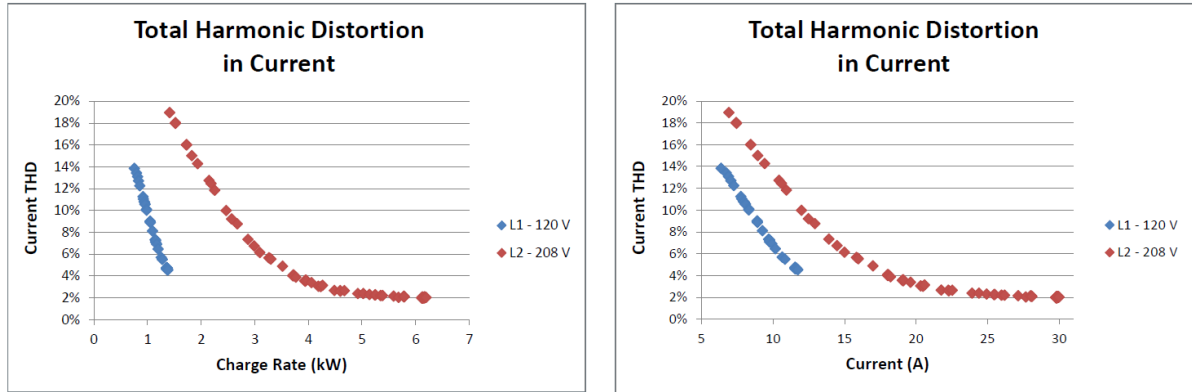
a)

b)

Fig.1. 4. THDi of EV for a) level 1 charging (120 V) and b) level 2 charging (208 V) for Nissan Leaf (24 kWh).
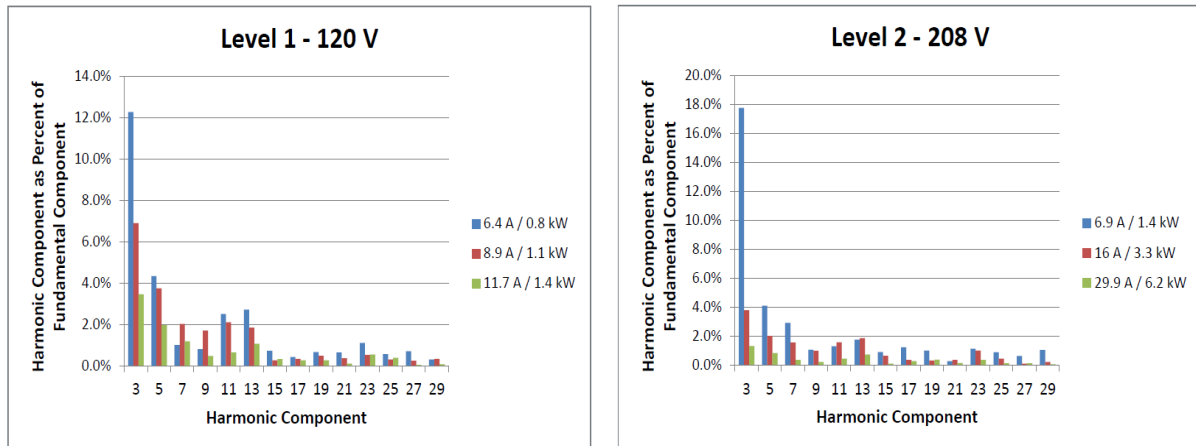
a)

b)

Fig.1. 5. Harmonic Components of three charging rates for a) level 1 charging (120 V) and b) level 2 charging (208 V).

1.3.2 **PEV Charging Approaches**

As discussed earlier, it is necessary to consider the impact of PEV charging activities on the operation of Smart Grids. The incorporation of PEVs as well as RERs into the developed Smart Grid necessitate new and proper design/ preparation. In preparation of the new design, the effect of PEV charging/discharging objectives, strategies, penetration rates and charging durations on grid performance as well as power quality conditions needs to be investigated. It can be observed that medium and moderate PEV penetrations can cause operation, reliability, stability and efficiency issues on both residential and distribution networks. Particularly, the negative impact of moderate PEV penetrations and their EV charger harmonics on LV residential and distribution networks and their power quality conditions need to be considered. Many investigations (Clement et al, 2010, Deilami et al, 2011, Masoum A.S. et al, 2011and Yilmiz et al, 2013) show that the random/uncontrolled PEV charging with moderate penetrations can lead to unacceptable increase in total power system losses, voltage variations and harmonic distortion especially during rush hours when PEV owners return home after work and wish to charge their EVs to get ready for their next trip early in the morning. (Kong et al in 2016) have discussed about the classifications of PHEV and PEVs and charging schemes in Smart Grid. Fig.1.6 shows an overview of charging schemes in Smart Grid (Kong et al, 2016).
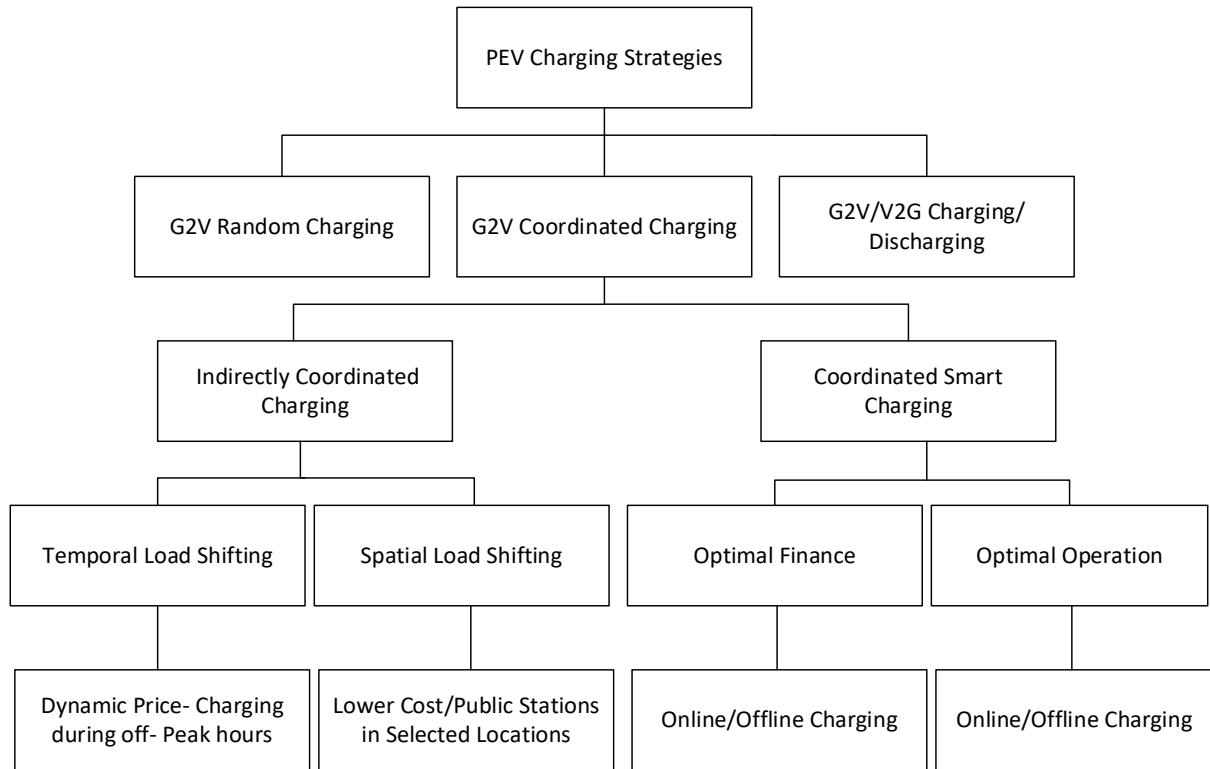
Fig.1. 6. PEV Charging Schemes/ Strategies

- **Uncontrolled/Uncoordinated PEV Charging Strategy**

As discussed earlier, uncoordinated or random charging defines as plugging in the EVs and start charging straight away without any delay or create a fixed delay by the EV owner and start after the delay and continue until the EV is disconnected (Yilmiz et al, 2013, Van Vliet et al, 2011 and Galus et al, 2010). This type of charging is mostly in Level 1 charging and may cause some severe issues by increasing the load especially during peak hours. The investigations have shown that even with low PEV penetrations, random or uncoordinated charging may lead to voltage variations, increasing power losses, overloading in distribution transformers and reliability issues.

To overcome these issues, different controlled/ coordinated offline and online strategies are introduced. This coordinated approach is based on educating the PEV customers to shift their electric vehicle charging loads to off peak hours by introducing coordinated charging schemes and defining charging zones with different tariffs. Therefore, the PEV owners are motivated to

12

charge their vehicles with a low tariff. Further, the use of time- variable tariffs by EV owners with Level 2 and 3 charging might be of helpful in this strategy (Yilmiz et al, 2013).

- **Controlled/ Coordinated Charging Strategy**

It has been discussed that this type of charging strategy is a smart charging strategy that seek reducing the cost of generating energy, and electricity bills, time management as well as increase customer satisfaction by optimizing the power demand and demand side management (Yilmaz et al, 2013).

Generally, there are two different strategies for PEV coordination techniques: centralized PEV charging or decentralized (distributed) PEV charging (Vandael et al, 2013). In Decentralized PEV charging, PEV customers can decide about the time and rate of the charging for their own vehicles. In this scenario, the system operator has no direct control over the PEV charging. However, it is still possible to motivate the owners by offering dynamic pricing to delay their PEV charging activities to off peak hours when the tariffs are in low price (Zhongjing et al, 2013, Vandael et al, 2013). On the other hand, centralized PEV charging allow the existing aggregator to perform and decide the charging time and rate for PEVs considering both PEV owner and system operators' conditions and preferences (Zhongjing et al, 2013, Vandael et al, 2013, Jin et al, 2013, and Foster et al, 2013). The data is provided by smart meters and their real time information about PEVs charging status, their arrival and departure time. This scenario can be implemented based on a dynamic or static coordination. In dynamic charging strategy, the PEVs are plugged in at any time and this is the aggregator which decides when to start the charging based on the updated information. However, the static charging needs the PEV charging schedules to be provided in advance.

Over the last few years, many studies have been carried out to investigate different PEV coordination techniques. (Jin et al., 2013) propose a PEV charging that will optimize the cost associated with the aggregator and generation as well as customer demand. (Geng et al, 2015)

introduce a dynamic aggregator for optimizing the cost associated with PEV charging activities. Further, a three-step approach is proposed by (Vandael et al, 2013) to investigate the demand side management of PEVs charging loads. (Linni et al, 2013) and (Gan et al, 2013) discuss about two different schemes for flattening the daily load curve: i) centralized charging ii) iterative decentralized charging. Some researchers also propose an optimal PEV coordination considering a day- ahead tariff with V2G and ancillary services (Chenrui et al, 2013, Rotering et al, 2011). (Deilami et al, 2010) and (Richardson et al, 2012) consider PEV charging activities with random and coordinated strategies and look into voltage improvement and performance of the LV residential networks.

In conclusion, many possible approaches have been undertaken in order to prepare the future Smart Grid or even Microgrid for the deployment of PEVs and any other RERs. The approaches include any online coordination approach which leads toward more efficient, stable and reliable grid.

It is further discussed that online coordinated charging as part of smart charging, is often implemented/performed by defining an objective function as well as formulation of some operation conditions/constraints. In other words, an optimization algorithm is implemented to keep the performance and power quality of Smart Grid within the acceptable standard limits. The performance objective can be divided into optimal finance and optimal operation (Kong et al, 2016).

Under the optimal finance, there are various objective functions that can be considered and formulated. The related objective functions may include minimization of power losses subject to voltage deviations or charger output power or maximization of profit subject to the energy supply or the grid limitations. Different optimization techniques can be implemented such as integer linear programming, Quadratic or Heuristic programming. (Clement et al, 2009) investigated stochastic programming (linear Programming) in their studies. Linear

programming is a special optimization technique/ mathematical program to find out the maximum or minimum profit/cost. Quadratic programming is a simple form of nonlinear programming which optimizes a Quadratic objective function. (Clement et al, 2010) introduced and analyzed Quadratic and dynamic programming. The optimization methods applied for minimization of the objective function (losses of the system).

For optimal operation, minimization of load variation can be done by Genetic Algorithms or Quadratic programming. In addition, "maximizing fairness (avoiding overload)" is the second option that can be implemented by Heuristics programming (Alonso et al, 2014, Mets et al, 2010, Rezaei et al, 2014).

In this thesis, the online coordination strategy has been developed by defining required and relevant objective functions for optimal finance that have been solved by implementing few optimization techniques such as Maximum Sensitivity Selections (MSS), Genetic Algorithms (GAs) and Particle Swarm Optimization (PSO) according to their applications. The Maximum Sensitivity Selections (MSS) approach is one of the most practical and fast solutions for online PEV coordination and has been implemented and tested in few publications of this thesis. This strategy is theoretically defined/constructed based on the Jacobian matrices using power mismatch equations. (Khaldi, 2004) introduced a new vectorized approach to find out the sensitivity matrices to deal with reactive power (Q) control and voltage stability (V) in large power systems. Also, the analytical approaches for reactive power (Q) compensation and voltage control (V) presented based on sensitivity analysis). As noted previously, for Maximum Sensitivity Selection Approach of paper 1 in Chapter 2, the maximum sensitivity of system losses (the objective function of the problem) to the number of PEVs have been considered. This is done by temporary activation of PEVs in the Newton Raphson Power Flow of the proposed algorithm and considering system losses perturbations. The sensitivity of the system losses due to each PEV can be extracted from the entries of the Jacobian matrix of the

power flow and stored in MSS vector. The Jacobian matrix consists of the partial derivatives of the system power losses and reactive power to the voltage magnitudes and angles (Khaldi, 2004, Deilami, 2018):

$$J = \begin{vmatrix} Re\{\partial S/\partial\delta\} & Re\{\partial S/\partial V\} \\ Im\{\partial S/\partial\delta\} & Im\{\partial S/\partial V\} \end{vmatrix} \qquad (1)$$

In Chapter 3 (paper 11), the sensitivity of SSCs (reactive power) to the bus voltage profiles are also added to the original sensitivity approach of paper 1 Chapter 2. The MSS approach of paper 11 uses DHPF algorithm to include the nonlinearities of the EV chargers and therefore, the entries of the MSS vector are taken from the real parts and imaginary parts of Jacobian matrix of DHPF.

The equations for $MSS_{t,i}$ and $MSS_{ssc,i}$ are:

$$MSS_{ssc,i} = \partial Q_t/\partial V_i \, , i = 1, \dots, i_m \qquad (2)$$

$$MSS_{t,i} = \partial P_{t,loss}/\partial P_{PEV,i} \, , i = 1, \dots, i_m \qquad (3)$$

$MSS_{t,i}$ is the maximum sensitivity of system losses to the number of PEV d at node i at time t and $MSSssc,i$ is the maximum sensitivity of reactive power of the system to the bus voltage. i_m is the summation of all PEVs and $P_{PEV,j}$ is the power consumption at node i.

Genetic Algorithm (GA) is another optimization method that has been implemented and tested in few publications of this thesis mainly in Chapter 3. This algorithm is a simple and near optimal solution method and works based on an iterative process. GA starts with an initial/ random population. The population consist of individuals called chromosomes. The population (chromosomes) will undergo transformations to create new generation under an iterative process. In general, Genetic Algorithm initiates with a random population and tries to improve the population through a repetitive algorithm of mutation, crossover, inversion and selection

operator. (Ulinuha et al, 2008). In this thesis, the application of GA has been presented for minimization of the losses (objective function). The details of the objective functions, switching constraints and chromosomes have been discussed in Chapter 3.

Particle Swarm Optimization (PSO) is also one of the methods that has been used as a solution for optimal finance and has been implemented to solve the objective function of paper 5 in Chapter 2. This optimization is also a type of iterative algorithm and tries to improve the solution depends on the quality of the initial given data. PSO is a multi- objective optimization.

1.3.3 Optimal Dispatch of LTC and SSCs

In HV and large power systems, the electric power generation plants are responsible to produce and deliver energy and electricity to the consumers through transmission and distribution network. It is important to ensure the energy is delivered within the permissible and acceptable standard limits and voltage variations are minimized (Khaldi 2004). Reactive power compensation and therefore, the application of Switched Shunt Capacitors (SSCs) has been considered as one of the conventional approaches. This approach is able to deal with the effect of load variations on distribution networks such as poor voltage profiles, high power system losses, low efficiency, and low power quality considering harmonics. The most common control devices for coordinating reactive power are the transformers LTCs and SSCs. It is therefore essential to consider an optimal scheduling approach to control the switching operations of these control devices (Khaldi 2004).

Many studies have already discussed and investigated the application of transformers LTCs/SSCs and their optimal dispatch on power quality and performance of the grid. In this optimal dispatch program, both sinusoidal and non-sinusoidal operation of distribution systems have been considered. Due to the nonlinearity of the LTCs and SSCs, this optimal dispatch

program is very complicated (Ulinuha et al, 2008, Ulinuha et al, 2011, Deng et al, 2002, Liang et al, 2001, Liang et al, 2003, and Deilami et al, 2010).

(Deng et al, 2002) have presented the switching effects of SSCs on secondary bus voltage, lifetime of LTCs, and maintenance cost. The research shows an optimal solution to overcome the abovementioned issues related to the switching effects. The idea is to divide the daily load curve into several time intervals (four) to determine the best switching devices operating schedule. The main objectives of the optimal SSC scheduling are to minimize the total power system losses and control the voltage variations within the acceptable limits.

LTCs are responsible to control the secondary bus voltage at the substation transformers to keep them within the acceptable system limits under any disturbance. However, this is not an ultimate solution for voltage profile improvement as they are capable of changing the secondary voltage level and set the voltage. Therefore, installation of shunt capacitors can help with the voltage regulation by injecting reactive power during peak hours. These shunt capacitors are installed in the secondary side of substations and feeders (Baran et al, 1999, Liang et al, 2001, and Liang et al, 2003). Even though, the best solution is to simultaneously coordinate the two switching devices, this may complicate the optimization algorithm due to the nonlinearity of the process and objective function (Lu et al, 1977, Hsu et al, 1998 and Deng et al, 2001). To implement these optimal solutions, many clarifications and approaches have been developed over the past few years. The primary solutions ignored the nonlinearity of the problem and therefore, the solution was not quite accurate. Later, number of practical approaches were developed by implementing the artificial intelligent (AI) algorithms which were precise but time consuming (Liang et al, 2001, Grainger, 1985 and Wu et al, 1995). (Uluniha et al, 2008) proposed a GA optimization algorithm to simultaneously control LTC

and SSCs to minimize the system losses over 24 hours (objective function) and improve the voltage profile while satisfying the operational constraints.

- **Application of Optimal Dispatch Program in Smart Power Grid Considering Harmonic Distortion-**

With increasing the popularity of PEVs and integration of RERs in consumers' daily routine, an intelligent and modern power grid needs to be designed such that the efficiency and reliability of the grid are enhanced to meet not only the users' satisfaction but also to satisfy the utilities requirements and expectations. Such technology requires a highly smart and modern power grid to ensure efficient and safe operation of power system apparatus.

Obviously, there are many concerns about the utilization of new smart appliances including residential and distribution loads, PEVs, RERs such as wind and rooftop PV solar, PEV- CSs and Variable Speed Drives (VSDs). This is due to the application of variety of nonlinear loads and their injected current harmonics to the grid. Further, the capacity of the grid and, high demands and transformer over loadings need to be considered. Therefore, it is essential to consider the application of switching devices (LTCs/ SSCs) in the presence of harmonics to not only improve the voltage profiles and efficiency of the grid but also to control the harmonic distortion levels and power quality conditions. Many researchers have discussed the consequences of neglecting harmonic current injections which may lead to significant increase in power system losses and harmonic distortion levels (Uluniha et al, 2008; Ulinuha et al, 2011, Baghzouz et al, 2011, and Zobaa et al, 2004). The researchers also discussed the severity and complication of adding nonlinear loads and considering the harmonics in the optimal scheduling solutions (Uluniha et al, 2008, and Ulinuha et al, 2011). The recent researchers have already started to develop and create new simple and practical solutions to resolve the complexity of the inclusion of harmonic distortion (Deilami et al, 2013, and Singh et al, 2016).

On the other hand, to enhance the performance of the grid (increasing reliability, enhance voltage profile, reduce cost of generation and system losses) and power quality (control the THDv level according to the standards), it is essential to cover the inclusion of PEVs and RDGs and their coordination approaches in both distribution and residential networks. Moreover, it is also necessary to consider the effects of harmonic distortion associated with nonlinear loads including EV chargers. Although, the investigations and studies have started to look into the application of optimal LTC and SSC dispatch on the grid performance, the nonlinearity of EV chargers and nonlinear loads with their harmonics have not been included. Therefore, the impact of LTCs and SSCs dispatching including injected current harmonics by nonlinear loads and EV battery chargers needs to be investigated and is an area for further consideration. One practical solution to the harmonic distortion and voltage fluctuation may be the use of an optimization algorithm for both PEV coordination and SSC scheduling. In the literature, there have been new structural strategies for EV battery chargers such as the inclusion of Power Factor Correction (PFC) devices or smart control methods (Basu et al, 2004, Singh et al, 2016) to overcome the harmonic injection problems. On the other hands, new PEV coordination schemes have been recently introduced to enhance the Smart Grid performance and power quality simultaneously. The new PEV coordination strategies necessitate the inclusion of current harmonics caused by their battery chargers and other industrial loads and simplify the charging scheduling program. The inclusion of harmonics not only causes distortion in the system but also effect the charging protocols such that the PEVs have delayed charging. For moderate and high PEV penetrations, the control process fails to fully charge all PEVs for their next travel before 8am and this may result in owners' dissatisfaction. Therefore, an appropriate consideration should be taken to the application of SSCs scheduling in the online PEV charging coordination strategies to not only cover the power quality related issues but also the customer satisfaction in smart grid. The gap in the literature is the inclusion of nonlinearities of battery

chargers and large industrial products in the coordination strategies. This can be fixed by enhancing the scheduling programs to consider the harmonic distortion as well as the inclusion of day- ahead/ online SSC dispatch to improve the grid power quality and performance. This research first starts with introducing an online control strategy and then fills the existing gap by enhancing the recent online PEV strategies in the literature and proposing a simple and practical approach to ease both utilities and end users.

- **Application of Active Power Filters (APFs) and Custom Power Devices (CPDs) for Further Enhancement of Power Quality in Distribution Networks –**

According to many references, the installation of filters is one of the convenient solution approaches for mitigation of harmonics in a distorted system (Masoum et al, 2015). It is further discussed that different filters can be used to reduce the THD of the bus voltages based on their applications. Passive Power Filters (PPFs) are one of the common, simple and inexpensive filters that can be for harmonic mitigations. Although they are convenient to install, they can only compensate limited number of harmonics. Further, they are sensitive to nonlinear loads and network variations.   PPFs consists of a number of shunt connected branches. Each branch is tuned at a harmonic frequency (h=5, 7, 11, 13, 17). They can also help with power factor correction. (Masoum et al, 2015).

Active Power Filters (APFs) are another type of filters which are capable of injecting equal and opposite harmonics. APFs are quite accurate and reduce the THD to a very limited number. However, they are expensive, complicated and can only compensate harmonics locally. There has been some research on the application of APFs and how they can improve the power grid power quality (Masoum et al, 2015). The high cost involved with the installation of these devices however, has limited their application into local systems. It is suggested that the de-rating the size of APFs can resolve the cost related issues and therefore, further improvement of power quality can be achieved. By de- rating the size, we are using smaller APFs (as an

example we can de-rate an APF by 10% or 20%) and therefore save the cost and still control the THDv within the acceptable boundary and not completely eliminate the harmonics. This part of research will be discussed in chapter 4 of this thesis.

Other types of filters are Hybrid Power Filters consisting of APFs and PPFs. The idea is to tune a large PPF at lower order harmonic and use a small APF to compensate higher order harmonics. Therefore, this type of filter is less expensive than APFs alone (Masoum et al, 2015).

Another possible solution for harmonic compensation is Active Power Line Conditioner (APLC) which is a class of Custom Power Device (CPD). CPDs are active power controllers for distribution systems and act same as Flexible AC transmission Systems (FACTs) for transmission systems. CPDs are able to regulate the voltage and improve power quality of the power network (Sabin and Sannino, 2003). CPD is able to protect source from load by injecting reactive power and compensate harmonics. An example of this type of CPD is APLC which was very limited previously as the online data and system information was not accessible. However, this issue has been resolved by the installation of smart meters in Smart Grids (Moghbel et al, 2017). APLCs are similar to shunt APFs. They are able to improve the power quality of the entire power system or in other words, global harmonic compensation.

1.3.4 Power System Harmonics

Recent research studies have had a focus on design strategies to develop a smarter electric grid to accommodate large scale PEV penetrations. The incorporation of large- scale PEVs into distribution residential systems has been recognized as a factor that has the potential to disrupt both local and over all grid dynamics, reliability and responsiveness. Investigations to address the impact on the power grid due to different forms of PEVs deployment is a fertile area of ongoing research (Hernandez C. and Jorge E., 2015). The grid power quality and therefore, the

THD level is one area of specific research focus. The harmonic currents caused by EVs may have complications and negative impacts not only in large distribution systems but also in small residential communities. In addition to the residential impacts, nonlinear industrial loads inject harmonics into the system that can contribute to major power quality related issues such as increasing THDv level and power system losses, resonances, voltage variations, etc. Although the impact of non-linear industrial perturbations into the systems are recognized the potential for greater instability and potential risk lies with the unknown interaction from the residential utilization of mass EV use. For utilities to ensure a smooth power delivery without voltage variations and system losses, control and manage any harmonic distortion and power quality related issues is a growing point of concern.

As noted above, one practical solution to respond to the nonlinearities of EV chargers and industrial loads is modifying the online coordination algorithm and GA based- optimal dispatch program. The traditional newton- based power flow was originally used for the online PEV coordination. This power flow does not include the harmonic current sources and only considers the fundamental frequency for the calculation of fundamental voltage profiles and system losses. In order to include the harmonic frequencies, a harmonic power flow program is needed. This is to include in the main optimization program for both online PEV coordination and optimal dispatch algorithm to compute harmonic voltages and currents, THD levels and harmonic power losses. Obviously, the inclusion of harmonic into large scale distribution systems with nonlinear industry loads and EV battery chargers may increase the complexity of the program and optimization algorithm (Zobaa 2004 and Zobaa, et al, 2004). In other words, the harmonic power flow calculations are complex and very time consuming (especially when an online strategy is required. There are two scenarios for harmonic power flow calculations.

- **Coupled Harmonic Power Flow**

First scenario is the Coupled Harmonic Power Flow (Zobaa 2004 and Zobaa, et al, 2004). In this method, nonlinear loads and the coupling between their harmonic are exactly modelled. This harmonic calculation is very accurate as it considers the dependency and relation of harmonic voltages at each frequency on value of current (the magnitude and phase angle) at other harmonic orders. However, the computing time is very long resulting in a temporal lag response to the underlying perturbation. As a result, this solution is not a real-time solution for the optimal dispatch algorithm and online PEV coordination. The optimization algorithm for SSC scheduling and PEV coordination are a type of nonlinear iterative calculation and require a very fast and straight forward problem-solving scenario.

- **Decoupled Harmonic Power Flow (DHPF)**

The second category is a fast and simple method which considers the nonlinear loads as harmonic current sources injecting harmonics. This method is called Decoupled Harmonic Power Flow (DHPF). In this method, the couplings/ dependency between the harmonics are neglected and therefore, the computation time is fast comparing to the coupling method. The reference Baghzouz and colleagues, (1990) demonstrated that the accuracy of this method is also acceptable.

Many studies (Baghzouz et al, 1990, Ulinuha et al 2006, Ulinuha et al, 2007 and Yue et al, 2004) have widely used and implemented DHPF algorithm for power flow calculations of large scale systems with optimization program and achieving optimal solution where accuracy and speed are both important. The accuracy of this method has been tested and proved by many research works and resources (Ulinuha et al, 2008, and Zobaa et al, 2004). In order to implement this method, the power system distribution network is modelled by individual harmonic current sources and harmonic bus admittance matrices (Masoum et al, 2015).
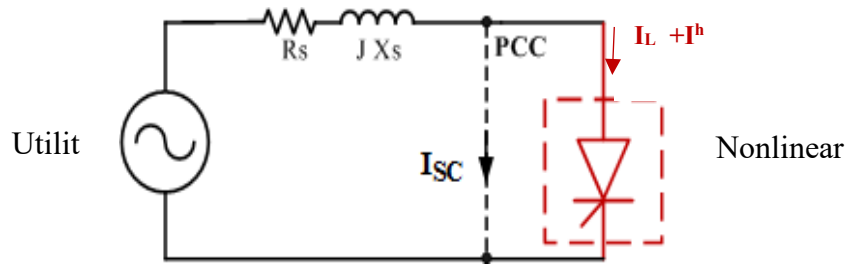
Fig.1. 7. Equivalent Circuit of a power system with a nonlinear load connected at PCC.

In this thesis, the DHPF method of previous researchers have been implemented and used for modelling the EV battery chargers and industrial nonlinear loads. The nonlinear loads are demonstrated (modelled and implemented in the design) as ideal current sources. These current sources inject harmonics into the system. The linear loads are also presented and designed as resistances. These resistances are shown in parallel with inductances. The whole system is modelled and works at fundamental frequency. In this method, it is first required to construct the harmonic bus admittance matrix at harmonic frequency.

- **Harmonic Bus Admittance Matrix**

The harmonic bus admittance matrices represent admittances at both fundamental and harmonic frequencies. This can be implemented by adjusting the admittances at fundamental frequency according to the harmonic order.

$$Y^{(h)}V^{(h)} = I^{(h)} \qquad (4)$$

The bus matrix is constructed by applying the famous Kirchhoff Current Law (KCL) at each node in the network to include all the bus voltages, currents, and branch impedances and admittances. (ECE530, Analysis Techniques for Large Scale Electrical Systems, Professor Hao Zhu, Department of Electrical and Computer Engineering, University of Illinois, August 2015.)

25

As above mentioned, the nonlinear loads (modelled as harmonic current sources) represent real power (P_i) and reactive power (Q_i) . The harmonic voltages are calculated by running the DHPF. Losses and THDv levels of system.

$$I_i^{(1)} = \left[(P_i + jQ_i)/V_i^{(1)}\right]^* \tag{5}$$

$$I_i^{(h)} = C_{(h)}I_i^{(1)} \tag{6}$$

Where, *C(h)* is the ratio of the hth harmonic current to the fundamental current, *P* is real power, *Q* is reactive power, and *V(h)* is the harmonic voltage.

The details and formulation of DHPF are also discussed and explained in the body of papers in (Chapter 2 and Chapter 4) of this thesis.

- **Standard Limitations for Current and Voltage Distortions (IEEE Standard- 519)**

According to IEEE- 519, there are two criteria to evaluate and determine the permissible limits for harmonic distortions. First, current harmonics limits that is measured based on harmonic current and refers to the allowable current harmonics that users can inject into network. It is measured by the following formulation:

$$\boldsymbol{THD_i} = \left[\sqrt{\sum_{h=2}^{H}(I^h)^2}\right]/I^1 \tag{7}$$

Where, I^h is the hth harmonic current, *H* is the highest harmonic order and *I* is the fundamental current.

Second, voltage harmonics limits that is measured in terms of harmonic voltage and refers to the allowable voltage harmonics limit that utility needs to supply for users. This term is defined based on following equation:

$$\boldsymbol{THD_v} = \left[\sqrt{\sum_{h=2}^{H}(V^h)^2}\right]/V^1 \tag{8}$$

Where, v^h is the hth harmonic voltage, H is the highest harmonic order considered and V is the fundamental voltage.

In order to set the permissible limits, the ratio of short circuit current at PCC to rated fundamental load current is calculated:

$$Rsc = |I_{SC}|/|I_L| \qquad\qquad (9)$$

According to IEEE 519 standard, it is consumers' responsibility to control the use of nonlinear loads such that THDi is within the acceptable limit. Then, utilities are required to control network harmonic voltages and keep the THDv within the acceptable standard limit of 5%.

1.4   Micro Grids (MGs) and Power Quality

It has been discussed in the literature that smarter grid is moving towards networked Microgrids. Microgrids are capable to maintain the loads in service when utilities fail during power outages, increase reliability, reduce energy costs and save money in long term. Microgrids are defined as a group of interconnected loads and RERs with limits and boundaries that can be connected or disconnected to the grid. Microgrids, with or without any connection to the main grid, are widely used to service isolated or rural power networks. Microgrids are able to work with connection to the main electric grid. They can have single or multiple connection to the main grid. On the other hand, Microgrids can be disconnected from the grid and operate independently. In other words, they can work as "grid- connected" or "island mode" respectively (Hirsh et al, 2018). Microgrids are now being considered not only to improve the reliability of the grid but also to enable addition of RERs to have a clean power energy and deliver electricity in rural areas where there is no centralized power related infrastructure (Hirsh et al, 2018). Many investigations discussed and studied different techniques for improving the power quality, stability and performance of Microgrids. There

27

have been different solutions such as real time power management of networked Microgrids by cyber communications networks (IEC- 61850) or hybrid islanding detection techniques for protection of Microgrids with single or multiple connections to the main power grid. The optimal placement/operation of standalone Microgrids in remote areas is a growing area of future research. In the loss of power or any rural emergency, Microgrids can be islanded (isolated). This strategy can be adopted by utilities that are under pressure to maintain reliable services and therefore islanding detection is one of the important part of interconnecting Microgrids research and development. This technique can be implemented remotely or internally based on real-time or predicted signals from either the main Smart Grid or Microgrid. (Darvish et al, 2017, Yin et al, 2004, Khamisa et al, 2013 and Li et al, 2014). The remote islanding detection modes are expensive but beneficial for large Microgrids. For example, Supervisory Control and Data Acquisitions Systems (SCADA) (Darvish et al, 2017, Khamisa et al, 2013) and Power Line Carrier Communication (PLCC) methods (Darvish et al, 2017, and Li et al, 2014) are common for remote approach. On the other hand, there are different local islanding strategies of passive, active or hybrid methods "by measuring the Smart Grid parameters such as voltage, frequency, current and harmonic distortions" (Darvish et al, 2017, 1). In order to consider the power quality and reliability of Microgrids with multiple connections to the grid, a recent published paper (Darvish et al, 2018) proposes a new approach considering passive, active and communication islanding detections based on wavelet transformations. The required signals are measured at the Smart Grid side through a hybrid ANN- fuzzy algorithm process. The details and the contributions of this proposed technique have been discussed in the body (Akhlaghi et al, 2014, and Darvish et al, 2017) and discussions of this thesis (Chapter 4, Paper 14).

1.5 Aims and Objectives of the Published Papers

The main objectives of thesis are to implement a practical online PEV controlled strategy for improvement of the performance and power quality of Smart Grid while considering the harmonic distortions caused by industrial nonlinear loads and nonlinear EV chargers. This research initially started with proposing a very fast and precise online coordination approach where the PEV charging activities were considered in a large distributed network. The research model was extended by including the nonlinear loads and nonlinear EV battery chargers injecting current harmonics in the distribution and residential feeders, respectively. The effect of harmonic distortions and low power quality were successfully compensated by integrating the optimal rescheduling of SSCs. Further improvement was considered by allocating Active Power Filters (APF) to reduce the cost of generation and system losses and increasing the efficiency of the grid. The main objectives are:

- **Objective 1:** Online PEV Coordination Considering Harmonic Current Injections by EV Battery Chargers.
- **Objective 2:** Improving Performance and Power Quality of Smart Grid with Nonlinear PEV Charging and Nonlinear Loads by Rescheduling of SSCs.
- **Objective 3:** Further Power Quality Improvement by Siting and De-Rating of APFs or by the application of CPDs.

This body of work is presented as series of 14 peer reviewed publications. The individual aims and objectives for each paper are summarized as follows:

1. **Paper 1:**
Deilami. S, Amir S. Masoum, Paul Moses, and Mohammad A.S. Masoum. 2011. "Real-time Coordination of Plug-in Electric Vehicle Charging in Smart Grids to Minimize Power Losses and Improve Voltage Profile." *IEEE Transactions on Smart Grid* 2(3): 456-467.

Objective: to propose and develop a novel load management approach for online PEV coordination in Smart Grid. The proposed approach can successfully minimize the total cost of producing electricity and grid power losses.

2. **Paper 2:**

Deilami. S, Amir S. Masoum, Mohammad A.S. Masoum, and Ahmed Abu-Siada. 2013. "Performance of Heuristic Optimization in Coordination of Plug-In Electric Vehicles Charging." *IBIMA Publishing Journals, International Journal of Renewable Energy and Biofuels*. USA. 1-15, Article ID 898203, DOI: 10.5171/2013.898203.

Objective: To introduce a Heuristic Load Management (H-LMA) for controlled /coordinated PEV charging to minimize the network power losses by re- optimizing the system at certain time intervals as well as regulating the bus voltages profiles. The approach considers the PEV owners preference and substation transformer loading levels.

3. Paper 3:

Deilami. S. 2018. "Online Coordination of Plug-In Electric Vehicles Considering Grid Congestion and Smart Grid Power Quality. "*Energies*.1-17, Vol. 11, Issue 9, Article ID-36962, DOI: 10.3390/en11092187.

Objective: To include the harmonic distortions caused by nonlinear EV battery chargers in PEV coordination operation. Therefore, the current harmonics injected by EV charger will be included in the MSS based PEV coordination approach (Paper 1) to investigate their impact on overall grid operation and power quality conditions.

4. Paper 4:

Panahi. D, **Sara Deilami,** Mohammad A.S. Masoum, and Syed. M. Islam. 2015. "Forecasting Plug-In Electric Vehicles Load Profile using Artificial Neural Networks." *Australasian Universities Power Engineering Conference (AUPEC 2015),* Wollongong, NSW, Australia, 1-6.

Objective: To recognize the driving patterns and forecast the daily arrival of PEV and their load cycles using the historical data collected for each vehicle over the past two years. The forecasted daily load curves including their harmonic current spectrums are used for the next steps of this research.

5. Paper 5:

Naghibi. B, Mohammad A.S. Masoum, and **Sara Deilami.** 2018. "Effects of V2H Integration on Optimal Sizing of Renewable Resources in Smart Home based on Monte Carlo Simulations." *IEEE Power and Energy Technology Systems Journal* 5 (3): 73 – 84. DOI: 10.1109/JPETS.2018.2854709.

Objective: To propose optimal sizing of rooftop PV, Wind Turbine (WT) and Battery Storage Systems (BSS) in smart homes including PEVs with the help of Vehicle to Home (V2H) and Home to Grid (H2G) operations. For optimal sizing of RERs and BSS, a rule-based Home Energy Management System (HEMS), Monte Carlo simulations and PSO have been incorporated.

6. Paper 6:

Deilami. S, and Mohammad A.S. Masoum. 2013. "Optimal Dispatch of LTC and Switched Shunt Capacitors in Smart Grid with Plug-In Electric Vehicles." *IEEE Power Engineering Society General Meeting PES GM*, Vancouver, British Columbia, Canada, 1-7.

Objective: To investigate the inclusion of PEV charging activities in the optimal dispatch of LTC and SSCs to mitigate the detrimental impacts of uncoordinated PEV charging on voltage profile and network losses.

7. Paper 7:
Deilami. S, Amir S. Masoum, Nasim Jabalameli, and Mohammad A.S. Masoum. 2013. "Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid with Electric Vehicles and Charging Station." *8th International Conference on Electrical and Electronics Engineering (ELECO 2013).* Bursa, Turkey, 162-166.

Objective: To analyse and investigate the inclusion of PEV- CSs in the optimal GA rescheduling of SSCs program. The aim is to improve the performance of Smart Grid in the presence of PEV Charging Stations (CSs) by implementing the optimal SSCs dispatch algorithm.

8. Paper 8:
Deilami. S. 2015. "LTC and Shunt Capacitor Switching in Smart Grid: Sensitivity to Plug-In Electric Vehicle Forecasts." *International Journal of Electrical, Electronics and Data Communication,* ISSN: 2320-2084 3(2).

Objective: To assess the sensitivity to PEVs forecasts and their probable errors on the performance of LTC and SSCs.

9. Paper 9:
Deilami. S, Mohammad A. S. Masoum, Ahmed Abu-Siada, and Syed M. Islam. 2014. "Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid Concerning Overnight Charging of Plug-in Electric Vehicles." *Applied Engineering Sciences, ed. Wei Deng*, 65-70. London UK, CRC Press is part of The Taylor & Francis Group: CRC Press, 2014. **(Book Chapter).**

Objective: To investigate the behaviour of Charging Station activities and the impact of PEV charging activities on the THDv level, efficiency and losses especially during peak load hours. The aim is to analyse and compare different charging techniques including uncontrolled/ random PEV strategy, controlled online MSS based PEV charging and inexpensive overnight MSS based coordination on the performance of Smart Grid.

10. Paper 10:
Deilami. S, Bahman Naghibi, and Keyhaneh Janfeshan. 2014. "LTC and Switched Shunt Capacitor Scheduling in Smart Grid with Electric Vehicles and Wind Distributed Generation Systems." *Australasian Universities Power Engineering Conference (AUPEC),* Perth, WA, 1-6.

Objective: To assess the inclusion of RDGs in Smart Grid considering industrial nonlinear loads and PEVs which leads to a significant decrease in grid efficiency and the quality of electric power. In this study, the required grid energy at high PEV penetrations are being partially supplied by WDGs installed in distribution system.

11. Paper 11:
Deilami. S. 2018. "Online Coordination of Plugged- in Electric Vehicles and Optimal Rescheduling of Switched Shunt Capacitors in Smart Grid Considering Battery Charger Harmonics*." IEEE Power and Energy Technology Systems Journal* 5(4): 1- 9. DOI: 10.1109/JPETS.2018.2880762.

Objective: To assess the inclusion of nonlinear EV battery chargers and nonlinear industrial loads in SG and propose a practical solution to improve the power quality conditions and meet PEV owners' satisfaction by fully charging all PEVs before their next day trip.

12. Paper 12:
Deilami. S, Mohammad A. S. Masoum, and Moayed Moghbel. (2016). "Derating Active Power Filters Considering Network and Bus Voltage Total Harmonic Distortions." IEEE EEEIC 2016. Italy, Florence, 1-6.

Objectives: To present a simple practical approach for further improvement of power quality and mitigation of THDv considering de- rating APFs. The aim is to install APFs at the point of common couplings (PCCs) of nonlinear loads to compensate for the injected current harmonica at the PCCs and reduce the THDv of the whole network and keep the associated costs in minimum. This approach represents the idea of de rating the size of APFs to keep the THDv level within the acceptable limit recommended by IEEE- 519 standards instead of designing the APF to completely eliminating the injected current harmonics of nonlinear loads at their point of common couplings (PCCs).

13. Paper 13:
Moghbel. M., Mohammad A. S. Masoum, Alireza Fereidouni, and **Sara Deilami.** 2017. "Optimal Sizing, Siting and Operation of Custom Power Devices with STATCOM and APLC Functions for Real-Time Reactive Power and Network Voltage Quality Control of Smart Grid", *IEEE Transactions on Smart Grid* 9(6): 5564 – 5575. DOI: 10.1109/TSG.2017.2690681.

Objective: To present an online coordination approach with the application of CPDs with STATCOM and APLCs to regulate the voltage profile and improve the overall power quality of Smart Grid. A new particle swarm optimization (PSO) algorithm is proposed for optimal siting/ sizing and online control of multiple CPDs.

14. Paper 14:
 Kermany. S.D, Mahmood Joorabian, **Sara Deilami**, Mohammad A. S Masoum, 2017. "Hybrid Islanding Detection in Microgrid with Multiple Connection Points to Smart Grids

using Fuzzy-Neural Network." *IEEE Transactions on Power Systems* 32(4): 2640 – 2651. DOI: 10.1109/TPWRS.2016.2617344**.**

Objective: To propose a new hybrid islanding detection approach for Microgrids with connections to Smart Grids. This study proposes another avenue of power quality improvement in the area of Smart Grid. The proposed approach will be tested and implemented on Microgrid with Smart Grid connections by application of artificial neural network (ANN) and Fuzzy Logic algorithm. The idea is to prove that islanding detection of Microgrids can accurately detect and perform the islanding and improve the power quality of the grid.

1.6   Methodology

The abovementioned objectives are classified into different steps that need to be completed throughout this body of work.

- Objective 1 includes 3 steps (1- 3) and 5 papers (1-5).

- Objective 2 refers to step 4 and 6 papers (6-11) and

- Objective 3 refers to step 5 and 3 papers (12-14).

Fig. 1.8 shows the flow of the proposed algorithm including the steps, objectives and related papers.

The following steps are considered to complete the whole objectives of this thesis:

Prior to each stage the review of the current and contemporary literature on Optimal Dispatch of LTC and SSCs and PEV Coordination Strategies was undertaken.

Step 1: Online PEV Coordination to Minimise Generation Cost and Power System Losses.

Step 2: Inclusion of harmonic distortions such as the injected current harmonics by battery chargers and nonlinear loads in the online PEV coordination of Step 1.

Step 3: Forecasting/Prediction of the Residential Feeder Daily Load Curves and Their Current Harmonics Spectrums based on the Virtual PEV Coordination of Step 2.

Step 4: Improve Overall Power Quality of Smart Grid by Rescheduling of the Existing LTC and SSCs Considering the Forecasted Residential Feeder Loads of Step 3.

Step 5: Further Power Quality Improvement by Siting and De-Rating of APFs at the Worst Operating Condition and Control Operation of CPDs in Smart Grid.
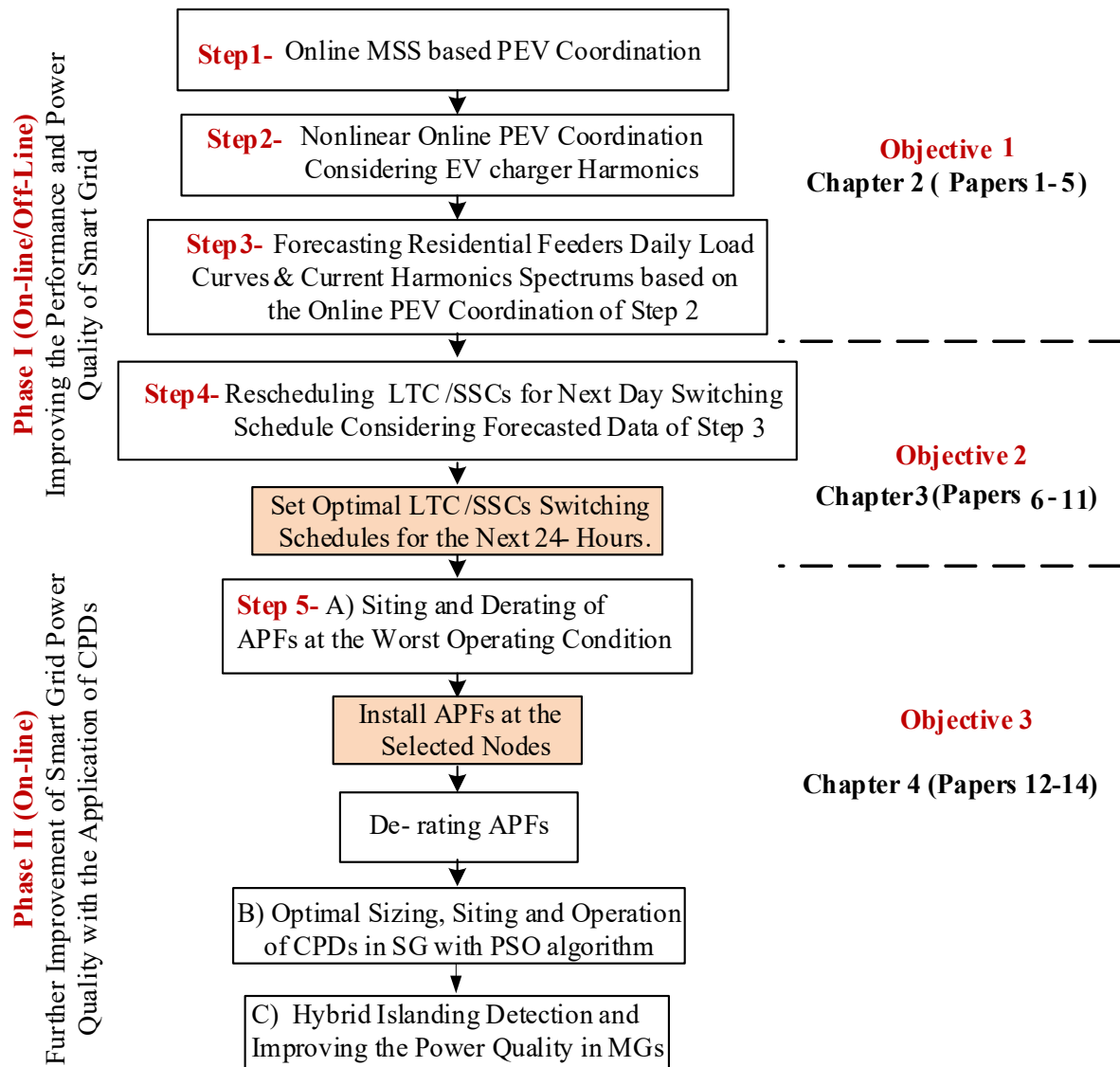

Fig.1. 8. The proposed algorithm for online PEV coordination to improve the performance and power quality of the Smart Grid with rescheduling of LTCS/SSCs and de- rating APFs considering nonlinear loads and EV chargers harmonics.

1.7   Thesis Outline

This thesis includes 6 chapters:

Chapter 1-This chapter provides the background, research history and current status of Smart Grid. It introduces the electric power grid from early stages and its enhancement throughout the past recent years to be adopted with the need and requirements of present environment. It demonstrates the necessity and intentions of governmental regulations to move towards more sustainable technologies such as hybrid and plug- in electric vehicles to reduce the emissions and environment pollutions. It also covers the innovative two-way communication backbone of Smart Grid which enables the rapid applications of renewable energy resources (RERs) and smart appliances especially PEVs. In addition, the challenges of the operation of PEVs and their charging activities on distribution and residential systems such as voltage variations, power losses, and harmonic distortions reducing efficiency of the power grids will be discussed and proposed solutions including online coordination of PEVs and application of LTC, SSC and APF will be investigated. A series of already peer reviewed and scientific publications will be referenced in this chapter.

Chapter 2- This chapter includes the **first objective** of this thesis and five related published papers (**Publications 1-5**) as presented in Fig. 1.8.

The aim is to perform PEV charging such that the costs associated with generation and losses are reduced without transformer overloading and voltage regulation issues while the overall and node total voltage harmonic distortions THDv are within the permissible limit of 5% (IEEE Std 519-1992, 1993). Paper 1 proposes and develops a new online strategy for PEV coordination in a large Smart Grid network including distribution and residential feeders. In second paper, a heuristic load management approach is also investigated. The main concern of

this paper is to seek the impact of system operation constraints and parameters such as time intervals and performance, accuracy and speed of PEV coordination to successfully reduce the burden on local distribution circuits as well as cost of premature failures of transformers. In paper 3, the proposed online MSS based approach of paper 1 (step 1) will be enhanced and modified to a nonlinear MSS algorithm to include the current harmonics injected by EV battery chargers to investigate their impact on power quality and performance of the grid. Paper 4 introduces the prediction and forecast of residential feeders' daily load curves by recognizing the driving patterns and forecasting the PEV load cycles on a daily basis. The required historic data gathered for PEVs over the past two years. This forecasted information of load demands is incorporated in the next steps of the thesis with the inclusion of their current harmonic spectrums. Paper 5, presents a new rule- based algorithm with Monte Carlo simulations and Particle Swarm Optimization algorithm to optimally include and size the RERs including rooftop PV, WTs, BSS and EVS in a home area network. This optimization minimizes the annual costs of household electricity. The analysis reveals different options such as eliminating BSS considering EVs and therefore, reduce the annual electricity costs.

Chapter 3- This chapter refers to the **second objective** of this thesis and includes six peer reviewed published papers (**Publications 6, 7, 8, 9, 10 and 11**). In general, the aim of this chapter is to reschedule the 24-hours switching of LTC and SSCs for simultaneous voltage regulations and harmonic current mitigations at the fundamental and harmonic frequencies, respectively. In this approach, the forecasted daily load curves and harmonic current spectrums are considered for rescheduling the existing LTC and SSCs. The first six papers (6- 11) demonstrate the application of LTC and SSC in Smart Grid with online PEV coordination without EV charger harmonics. The last paper presents the inclusion of EV charger harmonics and their impact on Smart Grid. Paper 6 studies the inclusion of PEV charging activities in the optimal dispatch of LTC and SSCs and compare the controlled and uncontrolled PEV charging

with and without the scheduled optimal SSCs dispatch on the performance of the grid. Paper 7 investigates the inclusion of charging stations (CSs) in the Smart Grid and the improvement of the grid performance by implementing the optimal dispatch of SSCs. Paper 8 demonstrates the sensitivity to PEVs forecasts and their probable errors on the performance of LTC and SSC. Paper 9 represents a comprehensive research on the PEV charging activities with different strategies including random/uncoordinated PEV charging, online MSS based PEV coordinated charging and an inexpensive overnight MSS based strategy. This publication represents a book chapter and includes a variety of possible scenarios to compare the impact of different strategies on the power quality and performance of the grid. Paper 10 assesses the inclusion of RDGs in Smart Grid considering industrial nonlinear loads and PEVs. Paper 11 investigates the application of optimal dispatch of SSC re-scheduling with the consideration of the sensitivity of the reactive power to the bus voltages in the nonlinear online MSS based algorithm in order to keep the harmonic distortion levels caused by nonlinear loads (nonlinear industrial and EV chargers) within the standard limits of 5%.

Chapter 4-This chapter investigates a new practical technique with the application of APFs for further power quality improvement of Smart Grid. It covers the **third objective** of this thesis (Fig.1.8) including three peer reviewed publications (**Publications 12, 13, and 14**). Papers 12 and 13 discuss that with increasing the penetrations of PEVS to moderate or high level, the second objectives of this study might not sufficiently improve the power quality of the Smart Grid. Therefore, they propose new strategies to further improve the power quality conditions of the grid with high penetrations of PEV charging and/or large numbers of nonlinear loads. Paper 12 proposes the installation of a number of APFs at selected buses while also reducing their ratings. This is to control the harmonic currents within the permissible limits of IEEE-519 standards rather that fully compensating them.
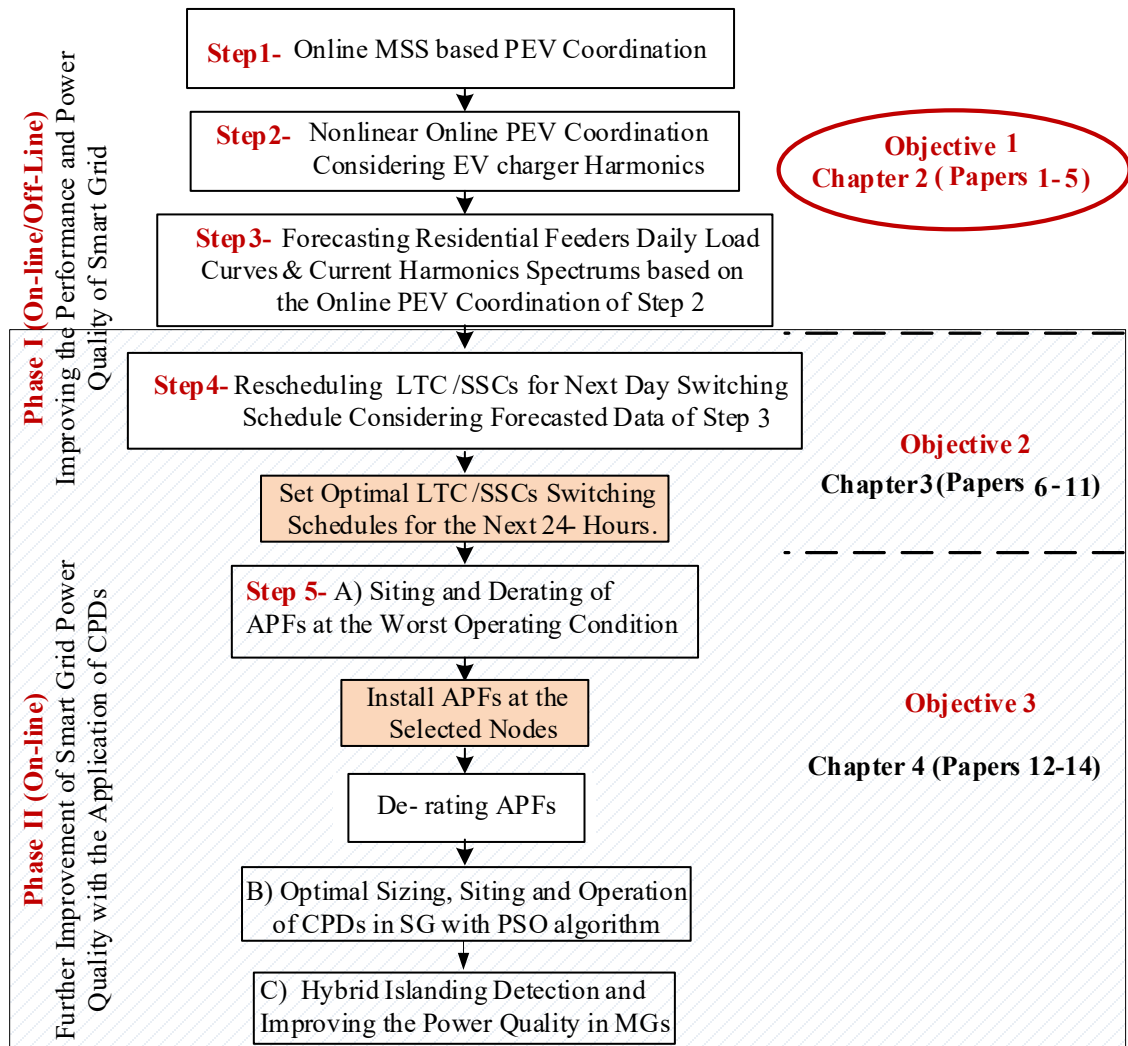
Paper 13 presents an online coordination technique with the application of CPDs with STATCOM and APLC to regulate the voltage profile and improve the overall power quality of Smart Grid. This is done by proposing two new particle swarm optimization (PSO) algorithms for optimal siting/sizing and online control of multiple CPDs. The first algorithm will determine the optimal locations/sizes of CPDs (for the worst operating condition) and the second one will compute the harmonic/fundamental reference currents to control and coordinate the CPDs by using the smart meter information. The simulation results show the improvement of THD of the voltages as well as voltage profiles.

Paper 14 includes a novel and new avenue for power quality improvement for Microgrids with Smart Grid connections. The approach considers the hybrid islanding detection method by the application of artificial neural network (ANN) and fuzzy logic algorithm.

Chapter 5-This chapter provide the summary and discussion of the thesis including the simulation results analysis, strength and gaps of the research to not only provide practical solutions for industry-based projects but also open avenues for continuing and developing the area of PEVs and their incorporation in future Smart Grids and Microgrids.

Chapter 6- The last chapter presents the conclusion and outcome of this research as well as the gaps and limitations of the research. It also provides future recommendations for continuing the subject of PEVs and their incorporations in future Smart Grid.

2 Chapter 2: Paper 1- 5

```
┌─────────────────────────────────────────────┐
│ Step1-  Online MSS based PEV Coordination   │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐          ╭──────────────────────╮
│ Step2-  Nonlinear Online PEV Coordination   │         (   Objective 1          )
│         Considering EV charger Harmonics    │         ( Chapter 2 ( Papers 1-5))
└─────────────────────────────────────────────┘          ╰──────────────────────╯
                      │
                      ▼
┌─────────────────────────────────────────────┐
│ Step3-  Forecasting Residential Feeders     │
│ Daily Load Curves & Current Harmonics       │
│ Spectrums based on the Online PEV           │
│ Coordination of Step 2                      │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│ Step4-  Rescheduling LTC /SSCs for Next Day │          Objective 2
│ Switching Schedule Considering Forecasted   │     Chapter3(Papers 6-11)
│ Data of Step 3                              │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│ Set Optimal LTC /SSCs Switching             │
│ Schedules for the Next 24-Hours.            │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│ Step 5- A) Siting and Derating of           │
│ APFs at the Worst Operating Condition       │
└─────────────────────────────────────────────┘
                      │
                      ▼                                   Objective 3
┌─────────────────────────────────────────────┐
│ Install APFs at the Selected Nodes          │     Chapter 4 (Papers 12-14)
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│ De- rating APFs                             │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│ B) Optimal Sizing, Siting and Operation     │
│ of CPDs in SG with PSO algorithm            │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│ C)  Hybrid Islanding Detection and          │
│ Improving the Power Quality in MGs          │
└─────────────────────────────────────────────┘
```

Phase I (On-line/Off-Line) — Improving the Performance and Power Quality of Smart Grid

Phase II (On-line) — Further Improvement of Smart Grid Power Quality with the Application of CPDs

2.1 Paper 1

Real-time Coordination of Plug-in Electric Vehicle Charging in Smart Grids to Minimize Power Losses and Improve Voltage Profile.

Deilami. S, Amir S. Masoum, Paul Moses, and Mohammad A.S. Masoum. 2011. "Real-time Coordination of Plug-in Electric Vehicle Charging in Smart Grids to Minimize Power Losses and Improve Voltage Profile*." IEEE Transactions on Smart Grid* 2(3): 456-467. DOI: 10.1109/TSG.2011.2159816.

The research study presented in this paper has been published by IEEE Transactions in Smart Grid in 2011.

All Authors of this article conceived the conception and design. I gathered and analysed the data with the guidance of the co- authors. I led the writing of the manuscript. All authors contributed to the drafts of the paper and gave the final approval for final submission and publication. This paper is the first section of chapter 2 and is a reproduction of the published manuscript by IEEE Transactions in Smart Grid. I also acknowledge that the system information and the EV data have been used in 2011 in my Master by research degree as part of input information only for another research study. This information is available in Chapter 5 pages 65-68 and 72-75. The data has been used because in 2011, there were limited types of EV battery chargers only to be used in this field of research.

This published paper develops a new real- time PEV coordination strategy in Smart Grid network including MV distribution and LV residential feeders. This new online strategy is based on MSS coordination and consider the maximum sensitivity of the system losses to the number of PEVs as well as customer priorities. The main contributions of the paper are improving the grid performance and minimizing the cost of generating energy and losses of the network. The simulation results show the effectiveness of the proposed control strategy in the improving of the losses and voltage profiles of the network. The system information and EV battery charger data were limited in 2011 and there were limited types of EVs. Recently, many different EVs have been launched by different manufacturers with variety of control strategies for battery chargers.

2.2   Paper 2

Performance of Heuristic Optimization in Coordination of

Plug-In Electric Vehicles Charging.

Deilami. S, Amir S. Masoum, Mohammad A.S. Masoum, and Ahmed Abu-Siada. 2013. "Performance of Heuristic Optimization in Coordination of Plug-In Electric Vehicles Charging." *IBIMA Publishing Journals, International Journal of Renewable Energy and Biofuels*. USA. 1-15, Article ID 898203, DOI: 10.5171/2013.898203.

The research study presented in this paper has been published by International Journal of Renewable Energy and Biofuels in 2013.

All Authors of this article conceived the conception and design. I gathered and analysed the data. I led the writing of the manuscript. All authors contributed to the drafts of the paper and gave the final approval for final submission and publication. This paper is the second section of chapter 2 and is a reproduction of the published manuscript by International Journal of Renewable Energy and Biofuels.

This paper presents a Heuristic Load Management algorithm (H-LMA) for coordinated PEV charging. The idea is to re- optimize the system at certain time intervals and not focusing on the improvement of the optimization algorithm. This research emphasises on the impact of the operation constraints as well as input parameters such as time intervals, speed and accuracy of the coordinated PEV charging loads. The main objectives and contribution of this paper are to reduce the costs and risks involved in the transformer premature aging and failures as well as lowering the burden on the load distribution circuits. In this strategy, the PEV owners' priorities and substation transformer loading levels are considered. The simulation results prove that the proposed management algorithm is able to regulate the voltage profiles and power system losses of the network.

2.3 Paper 3

Online Coordination of Plug in Electric Vehicle Considering Grid Congestion and Smart Grid Power Quality

Deilami. S. 2018. "Online Coordination of Plug-In Electric Vehicles Considering Grid Congestion and Smart Grid Power Quality. *"Energies*.1-17, Vol. 11, Issue 9, Article ID-36962, DOI:10.3390/en11092187.

The research study presented in this paper has been published by Energies in 2018.

I am the sole author of this paper. The contribution only belongs to the author for conception and design of methodology, writing the paper, submission and final approval. This paper covers the third section of chapter 2 and is a reproduction of the published manuscript in Energies.

This paper which has been recently published, aims at filling the existing gap of this research area of work. The coordinated strategies of the literature ignore the battery chargers and nonlinear loads' harmonics in the coordinated PEV charging activities. This study relies on the first paper of this research (paper 1) with the use of MSS coordination strategy and includes the harmonic distortions caused by nonlinear EV battery chargers and industrial loads in EV controlled strategy. The current harmonics injected by the EV chargers and nonlinear loads will be included in MSS coordination technique and therefore, a nonlinear PEV coordination approach will be presented. The main contribution is to investigate the impact of harmonics on overall system performance and power quality of grid considering large scale integration of PEVs. As shown by simulation results, the nonlinear online PEV coordination approach can control the THDv of the network while charging all the PEVs before their next day trip for low and medium PEV penetrations. However, it cannot satisfy the PEV owners' desire in fully charge their vehicles for high PEV penetrations. A simple strategy of installation of PPFs has been used to resolve the issue. However, a practical, global and simple solution needs to be considered. This solution has been proposed and implemented in the next chapter of the thesis.

2.4 Paper 4

Forecasting Plug-In Electric Vehicles Load Profile using Artificial Neural Networks

This paper has been published and presented in AUPEC Conference 2015.

I was the co- supervisor of the main author. All Authors of this article conceived the conception and design. I helped with the writing of the manuscript. All authors contributed to the drafts of the paper and gave the final approval for final submission and publication. This paper is the fourth section of chapter 2 and is a reproduction of the published manuscript in AUPEC conference.

This study covers a simple approach for prediction and forecast of residential feeders' daily load curves by recognizing the driving patterns and forecasting the PEV load cycles on a daily basis. In order to gather the PEV load data, the historical data for each vehicle has been collected for the past two years and used in the proposed algorithm. The main objectives of this paper are to predict the load cycles and clarifying the driving patterns of PEVs. An ANN algorithm has been implemented and applied to forecast the arriving rime and daily PEVs' travel distance. The forecasted results of this study can be easily used for other study purposes, management, and coordination and operation strategies for EVs in Smart Grid.

This forecasted information of load demands was required for the next steps of the thesis with the inclusion of their current harmonic spectrums.

2.5   Paper 5

Effects of V2H Integration on Optimal Sizing of Renewable Resources in Smart Home based on Monte Carlo Simulations

Naghibi. B, Mohammad A.S. Masoum, and **Sara Deilami.** 2018. "Effects of V2H Integration on Optimal Sizing of Renewable Resources in Smart Home based on Monte Carlo Simulations." *IEEE Power and Energy Technology Systems Journal* 5 (3): 73 – 84. DOI: 10.1109/JPETS.2018.2854709.
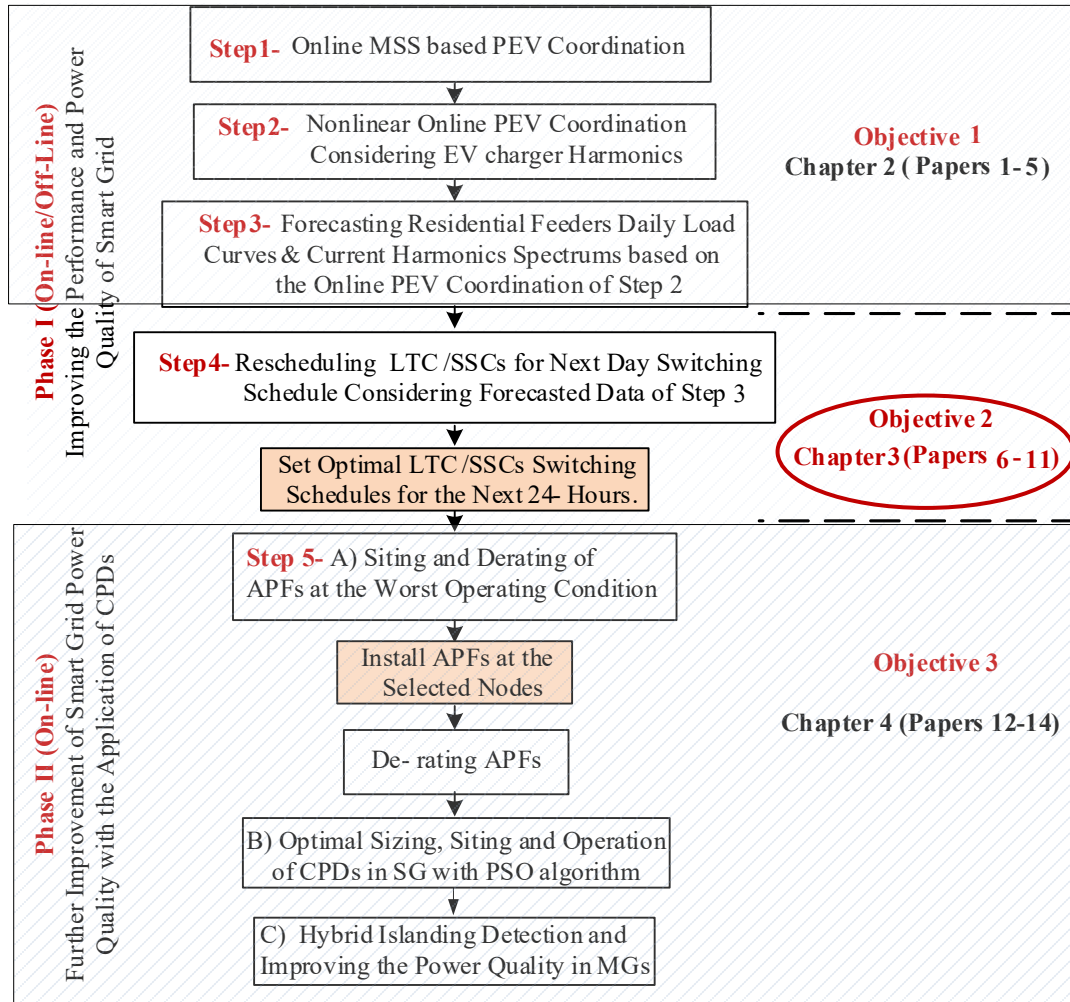
This paper has been published by IEEE Power and Energy Technology Systems Journals in 2018.

I was involved in this research study as the co- supervisor of the main author who was completing his HDR studies. All Authors of this article conceived the conception and design. I helped in writing of the manuscript. All authors contributed to the drafts of the paper and gave the final approval for final submission and publication. This paper covers the fifth section of chapter 2 of this thesis and is a reproduction of the published manuscript in IEEE Power and Energy Technology Systems Journals.

This study introduces a new strategy for optimal sizing and siting of RERs including rooftop PV, WTs, BSS and EVS in a home area network. To do this, a rule- based algorithm, a Monte Carlo simulation as well as PSO have been implemented in two steps to first find the optimal size of RERs in a home area and then site and operate. This optimization minimizes the annual costs of household electricity. Different case studies and options have been studied to find out the optimal combination of the RERs. The analysis and simulation result present different options such as eliminating BSS considering EVs and therefore, reduce the annual electricity costs.

3 Chapter 3: Paper 6-11

3.1   Paper 6

Optimal Dispatch of LTC and Switched Shunt Capacitors in Smart Grid with Plug-In Electric Vehicles.

Deilami. S, and Mohammad A.S. Masoum. 2013. "Optimal Dispatch of LTC and Switched Shunt Capacitors in Smart Grid with Plug-In Electric Vehicles." *IEEE Power Engineering Society General Meeting PES GM*, Vancouver, British Columbia, Canada, 1-7. DOI: 10.1109/PESMG.2013.6672609.

This paper has been published and presented in IEEE Power Engineering Society General Meeting PES in 2013.

As the main author, I was fully involved in the conception and design of the mythology of this paper. I led the writing of the manuscript. All authors contributed to the drafts of the paper and gave the final approval for final submission and publication. This paper covers the first section of chapter 3 of this thesis and is a reproduction of the published manuscript in IEEE Power Engineering Society General Meeting PES in 2013.

This study investigates the integration of PEV charging loads in the optimal dispatch of LTC and SSCs program. In order to include the PEV and daily residential loads, a forecast of residential feeders and PEVs were required. The residential loads were forecasted considering different PEV penetrations not only by random activities but also by the use of coordination technique of paper 1. Then this forecasted data has been used in the day- ahead optimal dispatch of SSC/LTCs. The aim is to show the impact of random/ uncontrolled charging and compare with the effect of MSS coordinated PEV charging with and without the scheduled optimal SSCs dispatch on the performance of the grid. The simulation results show the effectiveness of the proposed practical approach in improving the performance of the grid.

Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid with Electric Vehicles and Charging Station.

Deilami. S, Amir S. Masoum, Nasim Jabalameli, and Mohammad A.S. Masoum. 2013. "Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid with Electric Vehicles and Charging Station." *8th International Conference on Electrical and Electronics Engineering (ELECO 2013)*. Bursa, Turkey, 162-166. DOI: 10.1109/ELECO.2013.6713824.

This paper has been published and presented in 8th International Conference on Electrical and Electronics Engineering in 2013.

As the main author, I was fully involved in the conception and design of the mythology of this paper. I led the writing of the manuscript. All authors contributed to the drafts of the paper and gave the final approval for final submission and publication. This paper covers the second section of chapter 3 of this thesis and is a reproduction of the published manuscript in International Conference on Electrical and Electronics Engineering.

This paper is the continuation of paper 6 of this thesis and studies the inclusion of charging stations (CSs) in Smart Grid. In this study, the impact of SSCs and PEVs with different penetrations have been investigated for both uncontrolled and controlled charging activities. Then the effect of day ahead LTC/SSC scheduling on the performance of grid has been tested. For this purpose, the Charging Stations charging loads have been individually considered and first predicted to be added in in the optimal dispatch program. The simulation results show the improvement of the grid performance by implementing the optimal dispatch of SSCs.

3.3   Paper 8

LTC and Shunt Capacitor Switching in Smart Grid: Sensitivity to Plug- In Electric Vehicle Forecasts.

Deilami. S. 2015. "LTC and Shunt Capacitor Switching in Smart Grid: Sensitivity to Plug- In Electric Vehicle Forecasts." *International Journal of Electrical, Electronics and Data Communication*, ISSN: 2320-20843(2). http://www.iraj.in/journal/journal_file/journal_pdf/1-109-142286759810-14.pdf.

This paper has been published in International Journal of Electrical, Electronics and Data Communication in 2015.

I am the sole author of this paper. The contribution belongs to the author for conception and design of methodology, writing the paper, submission and final approval. This paper covers the third section of chapter 3 and is a reproduction of the published manuscript in International Conference on Electrical and Electronics Engineering.

This study presents the sensitivity to the PEV forecasts and the errors associated with the prediction of the daily residential feeders and random arrival of the PEV charging loads in the optimization program. The sensitivity of the PEV forecasting and their integration in the optimization program as initial input are assessed and their impacts on the performance of the day ahead optimal dispatch of LTC and SSCs are investigated. This research focuses on the GA optimization approach for optima dispatch program considering the forecasted input data. The simulation results show different case studies and the sensitivity of the system to the predicted data.

3.4   Paper 9

Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid Concerning Overnight Charging of Plug-in Electric Vehicles.

Deilami. S, Mohammad A. S. Masoum, Ahmed Abu-Siada, and Syed M. Islam. 2014. "Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid Concerning Overnight Charging of Plug-in Electric Vehicles." *Applied Engineering Sciences, ed.* Wei Deng, 65-70. London UK, CRC Press is part of The Taylor & Francis Group: CRC Press, 2014. **(Book Chapter).** http://hdl.handle.net/20.500.11937/42135.

This research work is a book chapter and has been published in Applied Engineering Sciences by Taylor & Francis Group in 2014.

As the main author, I was involved in the conception and design of the methodology. I led the writing of this paper. All authors contributed in the draft, submission and final approval. This research work covers the fourth section of chapter 3 and is a reproduction of the published book chapter in Applied Engineering Sciences by Taylor & Francis Group.

This book chapter investigates different approaches for coordination of PEV charging loads with different penetrations considering PEV CSs. The day- ahead optimal dispatch of LTC and SSCs are also included in order to improve the performance and power quality of the grid. In this study, the inclusion of industrial nonlinear loads in the distribution system and their harmonic spectrum is only considered in the optimal LTC and SSCs program and therefore, the PEV coordination program neglects the effects of harmonics in PEV charging activities. Further, the harmonic currents injected by EV battery chargers are neglected in both PEV coordination and GA optimal LTC/SSCs program. Different approaches have been presented and compared in this book chapter: First, random uncontrolled/ uncoordinated PEV charging strategy is tested. Then, the real- time MSS based coordination strategy is implemented. In the next step, the possibility of an inexpensive overnight coordination approach is investigated and compared with other methods. The simulation results can clearly show the different approaches and their impacts on the power quality, efficiency and system losses considering the behaviour of Charging Stations activities.

3.5 Paper 10

LTC and Switched Shunt Capacitor Scheduling in Smart Grid with Electric Vehicles and Wind Distributed Generation Systems.

Deilami. S, Bahman Naghibi, and Keyhaneh Janfeshan. 2014. "LTC and Switched Shunt Capacitor Scheduling in Smart Grid with Electric Vehicles and Wind Distributed Generation Systems." *Australasian Universities Power Engineering Conference (AUPEC),* Perth, WA, 1-6. DOI: 10.1109/AUPEC.2014.6966570.

This paper has been published and presented in AUPEC 2014.

As the main author, I was involved in the conception and design of the methodology. I led the writing of this paper. All authors contributed in the draft and final approval. This research work covers the fifth section of chapter 3 and is a reproduction of the published manuscript in AUPEC 2014.

In this paper, the integration of wind turbine in Smart Grid has been investigated. The Charging Stations and industrial nonlinear loads have also been included. In order to increase the efficiency and quality of the grid, the forecasted PEV charging loads (residential feeders) have been included in the optimal day- ahead schedule of LTC/SSCs. In this study, at high PEV penetrations, the grid energy has been partially supplied by WDGs. The simulation results show the negative impacts of uncontrolled PEV charging on the grid performance in the presence of harmonics and how the integration of the WDGs can help to improve the overall performance and efficiency of the grid.

"Publication has been removed due to copyright restrictions". The content can be accessed via

DOI: 10.1109/AUPEC.2014.6966570.

Online Coordination of Plugged- in Electric Vehicles and Optimal Rescheduling of Switched Shunt Capacitors in Smart Grid Considering Battery Charger Harmonics.

Deilami. S. 2018. "Online Coordination of Plugged- in Electric Vehicles and Optimal Rescheduling of Switched Shunt Capacitors in Smart Grid Considering Battery Charger Harmonics." *IEEE Power and Energy Technology Systems Journal* 5(4): 1- 9. DOI: 10.1109/JPETS.2018.2880762.

This paper has been recently published in IEEE Power and Energy Technology Systems Journal in 2018.

I am the sole author of this paper. The contribution belongs to the author for conception and design of methodology, writing the paper, submission and final approval. This paper covers the sixth section of chapter 3 and is a reproduction of the published manuscript in IEEE Power and Energy Technology Systems Journal.

This paper is the continuation of paper 3 of chapter 2 with the inclusion of the SSCs. In this study, the impacts of EV charger harmonics and nonlinear industrial loads harmonics are also considered in Smart Grids. The simulation results of paper 3 revealed that the inclusion of EV charger harmonics with high penetrations may lead to customer dissatisfaction. Although, the real- time PEV coordination approach can control the THDv of the system, it cannot guarantee the fully charge of PEVs before their next day trip in early morning. To solve the issue, not only the nonlinearities of EV chargers are included in online coordination strategy, but also, the rescheduling of SSCs are considered in the approach. To do this, the algorithm, includes the maximum sensitivity of losses to the number of PEVs as well as maximum sensitivity of the reactive power to the number of capacitors. This can be a practical and better solution for resolving the issue of customer satisfaction. The aim is to fully charge the PEVs before 8am. As indicated in the simulation results, the program can control THDv within the acceptable limit of 5% by postponing the charging schedules to off- peak hour and successfully charge all the PEVs before their next day trip. It is further discussed that the iteration process can resolve the issues associated with the forecasting errors and random PEV activities.

"Publication has been removed due to copyright restrictions". The content can be accessed via DOI: 10.1109/JPETS.2018.2880762.

4 Chapter 4: Paper 12-14
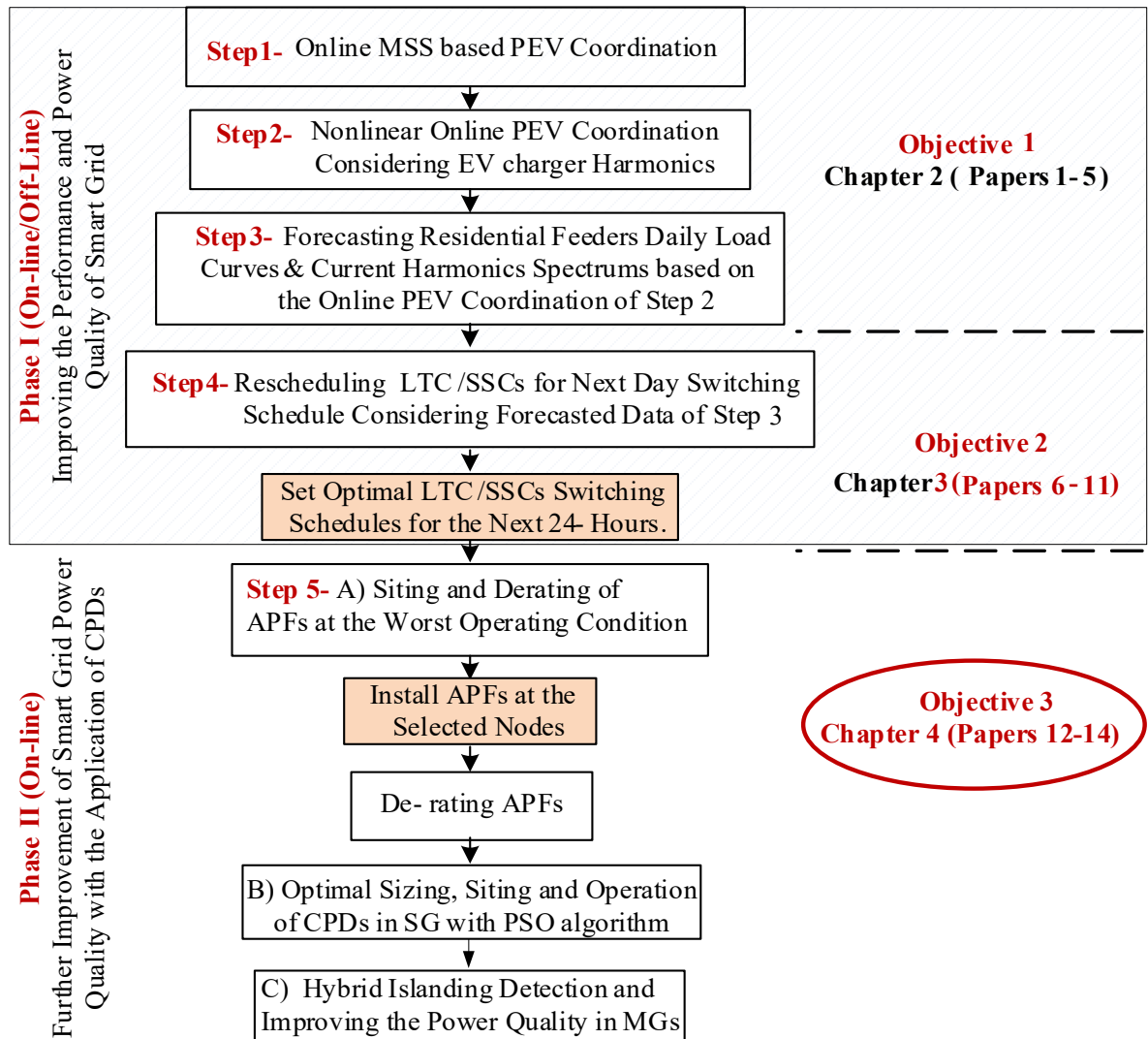
4.1   Paper 12

De-rating Active Power Filters Considering Network and Bus Voltage Total Harmonic Distortions.

This paper has been published and presented in IEEE EEEIC 2016.

As the main author, I was involved in the conception and design of the methodology. I led the writing of this paper. All authors contributed in the draft and final approval. This research work covers the first section of chapter 4 and is a reproduction of the published manuscript in IEEE EEEIC 2016.

This research study presents the new and simple idea of installation and de- rating of APFs at in distribution networks to not only reduce the THDv of the network but also to overcome the issues related to the cost of these devices. The APFs are very accurate and can compensate for the injected current harmonics at the point of common coupling (PCCs) however, they are really expensive. This paper investigates the practicality of installation of these devices considering de- rating the actual size. Simulation results indicate that this conventional approach, can fully compensate the THDvs; however, this is a very expensive strategy and may not be feasible especially for small systems. Further to this, they are not effective on regulating the voltage profiles of the system. As a future direction, CPDs are considered as an optimal solution. The application of CPDs are discussed in the next section of this chapter (paper 13).

"Publication has been removed due to copyright restrictions". The content can be accessed

via DOI: 10.1109/EEEIC.2016.7555858.

4.2 Paper 13

Optimal Sizing, Siting and Operation of Custom Power Devices with STATCOM and APLC Functions for Real-Time Reactive Power and Network Voltage Quality Control of Smart Grid.

Moghbel. M., Mohammad A. S. Masoum, Alireza Fereidouni, and **Sara Deilami.** 2017. "Optimal Sizing, Siting and Operation of Custom Power Devices with STATCOM and APLC Functions for Real-Time Reactive Power and Network Voltage Quality Control of Smart Grid", *IEEE Transactions on Smart Grid* 9(6): 5564 – 5575. DOI: 10.1109/TSG.2017.2690681.

This paper has been published in IEEE Transactions on Smart Grid in 2017.

This research work investigates the application of CPDs (STATCOM and APLC) for further improvement of the power quality and performance of the grid. The optimal sizing and siting of the CPDs have been done by implementing PSO algorithm to first size and locate the devices under worst operating conditions and then operate the algorithm and calculate both harmonic and fundamental reference currents. This has been done by the use of smart meter information and online voltage data. The simulation results show the effectiveness of the proposed approach.

4.3   Paper 14

Hybrid Islanding Detection in Microgrid with Multiple Connection Points to Smart Grids using Fuzzy-Neural Network.

Kermany. S.D, Mahmood Joorabian, **Sara Deilami**, and Mohammad A. S Masoum. 2017. "Hybrid Islanding Detection in Microgrid with Multiple Connection Points to Smart Grids using Fuzzy-Neural Network." *IEEE   Transactions   on   Power   Systems* 32(4):   2640 –   2651. DOI: 10.1109/TPWRS.2016.2617344.

This paper has been published in IEEE Transactions on Power Systems in 2017.

This paper investigates improving power quality and reliability in an advanced Microgrids network. This strategy considers Microgrids with multiple connections to the grid and presents a new hybrid islanding detection strategy that aims in further improvement of system power quality. To do this, an ANN and fuzzy logic optimization algorithm has been proposed and tested considering the new wavelet energy technique to perform better islanding and improve the power quality. The simulation results prove the effectiveness of the proposed strategy.

"Publication has been removed due to copyright restrictions". The content can be accessed via DOI: 10.1109/TPWRS.2016.2617344.

5 Chapter 5: Summary and Discussion

The main objective of this thesis is to propose a new practical approach for online PEV charging coordination while considering the power quality of Smart Grid. The inclusion of smart appliances such as PEVs and RERs and their coordination strategies create a significant impact on the grid performance and power quality of network. In recent years, researchers have investigated these negative impacts and tried to address the issues of harmonic distortion associated with EV chargers and nonlinear loads. However, these programs have never been included in the controlled PEV charging activities. This gap needs to be filled by inclusion of harmonic sources in the PEVs' control strategies to improve the efficiency, reliability and power quality of the grid by increasing the accuracy of the practical solutions. This thesis aims at filling this gap by developing the PEV coordination to also consider the harmonics created by EV chargers as well as nonlinear industrial loads. This research has been initiated by first proposing an online, accurate and very fast coordination technique to improve the grid performance and efficiency by reducing the costs associated by losses and generating energy. This study has been proposed and simulated in paper 1 of this research. To the best of my knowledge, this novel coordination technique has been the most effective and fast strategy over the past few years. Many other optimization methods have been tested and compared in literature by authors of this paper as well as other researchers. Even though, the proposed online MSS based optimization algorithm is not a global optimization technique to lead to a global solution, it is still a very effective and accurate strategy compared to other optimal solutions. This is due to the novelty of the load management approach for online controlled PEV charging in Smart Grid including MV distribution and LV residential feeders. This real-time control strategy considers the PEV owner preferred charging time frames (priority groups) and system operation constraints such as total system demands, voltage variations and system

power losses. The algorithm successfully reduces the cost of generating electricity and power losses and enhances the voltage profiles.

The research theme in paper continues with the content of the second paper. In this paper, a different management approach has been tested and implemented. The focus of this paper is not necessarily on the improvement of the optimization algorithm. This method introduces a heuristic strategy and seek for the impact of operation constraints and parameters such as time intervals, accuracy and speed of controlled PEV charging activities. This approach aims at reducing the burden on the load distribution circuits and costs/risks associated with the transformer premature failures.

Paper 3 tries to improve and modify the online PEV coordination strategy of paper 1 to include harmonic distortions created by nonlinear EV battery chargers as well as nonlinear industrial loads. The online MSS based optimization technique of paper 1, can successfully reduce the overall costs but ignores the impact of harmonics associated with EV chargers and nonlinear loads in the online controlled program and therefore, the impact of grid power quality were not included. The new idea is to consider harmonic current injections in coordination strategy. To do this, a harmonic power flow is required to calculate the harmonic voltage and currents, harmonic system losses as well as THDv of the entire system. As the power quality is an important factor in Smart Grid, an appropriate consideration needs to be taken. In this paper, the harmonics are modelled as individual current sources injecting harmonics and their coupling are neglected due to the complexity of the optimization algorithm. The so-called DHPF has been included in the process as a fast and relatively accurate harmonic power flow. This approach has been selected as the coordination algorithm is an online strategy and necessitate a fast and precise calculation. Therefore, a nonlinear online MSS based optimization algorithm (NOL- MSSCA) is introduced in this paper. As indicated in the

simulation results, the algorithm can manage to fully charge all PEVs at low and medium PEV penetration while controlling the harmonic distortion by controlling the THDv level within the acceptable limit of 5%. This is done by shifting the PEVs charging schedules to off- peak hours and therefore, not only the power quality problems are resolved but also the PEV owners are satisfied. However, at moderate and high PEV penetrations especially during rush- hours, the algorithm cannot achieve the customer satisfaction as PEVs may not be fully charged before 8am in the morning to be ready for their next day trip. As a simple approach for this issue, installation of PPFs at the worst voltage buses are proposed.

There are many practical solutions for resolving the issue of power quality and customer satisfaction such as considering APF, CPDs and SSCs. The recent researches have already started to investigate these different solutions and their challenges/ opportunities to enhance the power quality of the grid. However, the application of integrating these devices in to the coordination program and their impact on the charging schedules and customer satisfaction has never been investigated. This part of work starts with the installation of PPFs as a simple solution in this published paper and continue implementing other methods throughout next publications in the following chapters of this thesis. Inclusion of abovementioned devices may have complexity, significant impact on the grid and drawbacks. Therefore, a proper scheduling/ optimal solution may be required to effectively help the grid with saving energy and satisfying PEV owners' desire which has been discussed and covered in chapter 3 as the second objective of this PhD. As part of the practical strategy for grid performance and power quality improvement, rescheduling of SSCs and their integration in the online PEV algorithm is required.

The second objective of thesis, requires some input information and initial data such as PEV data and load demand history which has been provided by forecasting of PEV charging loads

in the first chapter. Paper 4 of chapter 2 introduces a forecasting method to predict the daily load pattern of randomly PEVs and distribution transformer loading. The proposed strategy aims at predicting the load cycles and identifying the driving patterns of PEVs. This is done by implementing ANN which is capable of forecasting the arrival time and daily PEV travel distance. ANN uses the historical data for each EV that is collected over the past two years. The forecasted results can be used for coordination, management and operation purposes.

Further to findings of the abovementioned publications, a novel optimal solution has been presented and implemented in paper 5 for integration of RERs in the home area network. As mentioned in the literature, the integration of RERs has been significantly increased and is one of the important factors that needs to be considered with the inclusion of PEVs. This research work has tried to apply a novel rule- based algorithm with the application of Monte Carlo simulations and PSO to come up with a balance between the RERs and PEVs in Smart Grid. This optimal strategy reduces the annual electricity costs of a household with presenting different options/sizes of RERs such as eliminating BSS and therefore, reducing the costs involved while considering PEV.

As discussed before, the proposed solution approach of this study for power quality improvement and customer satisfaction is to incorporate the online PEV charging coordination algorithm in an optimal SSCs dispatch program. This refers to the second objective of this thesis which is rescheduling of LTC and SSCs over 24-hours for voltage regulations and harmonic mitigations. It is challenging to consider both algorithms as the LTC/SSCs scheduling algorithm is an off- line problem that selects the LTC/SSCs switching for the next day where the PEV coordination is an on-line controlled charging. Therefore, this study offers a simple strategy to run the online PEV coordination algorithm and incorporate the forecasted load demands including the PEVs as the input of the existing LTC/SSCs scheduling program.

Paper 6 starts with the inclusion of PEV charging activities in the optimal dispatch program for LTC and SSCs to mitigate the negative impacts of uncontrolled PEV charging on the system losses and voltage profiles. As presented in the simulation results, the uncoordinated PEV charging especially without the inclusion of LTC and SSCs lead to severe voltage variations and system losses. Also, the results prove that the inclusion of PEV charging activities especially with the MSS based coordinated forecast, can significantly improve the voltage profile and system performance and reduce the system power losses.

Paper 7 also considers the same approach in the existence of PEV Charging Stations. In this study, the PEV charging stations and their load profiles are also forecasted and included in the SSCs dispatch program. The results show detrimental impact of uncoordinated charging on the grid performance in the presence of Charging Stations. Obviously, the optimal dispatch algorithm can successfully improve the grid performance considering controlled EV charging.

It has been discussed that the inclusion of forecast program in the optimization algorithm may lead to errors and probable issues associated with the forecasted daily load curves and random arrival of PEVs as the initial/ input data. Paper 8 of this thesis investigates the errors associated with the PEV forecasting and their incorporation as the initial input. To do this, the sensitivity of the optimization algorithm to the PEV forecast is investigated and assessed. In this paper, a GA optimization algorithm for LTC and SSCs rescheduling is implemented considering the forecasted PEV data and the sensitivity to this forecast on the performance of the LTCs and SSCs are investigated as shown in the simulation results.

Further to abovementioned research and assessments, this book chapter (paper 9) covers the idea of PEV coordination and optimal LTC/SSCs program considering Charging Stations and their charging activities as well as nonlinear industrial loads. In this chapter, the inclusion of nonlinear loads in the distribution network and their harmonic spectrum in the optimal LTC

and SSCs program is considered. However, the harmonic currents injected by EV battery chargers are neglected in both PEV coordination and GA optimal LTC/SSCs program. Different scenarios are considered and compared in this book chapter:

i) A random uncoordinated PEV charging strategy is tested.

ii) Online MSS based coordination algorithm (OL-MSSCA) is performed.

iii) An inexpensive overnight MSS based coordination algorithm (ON-MSSCA) is implemented.

This is a different approach for PEV charging coordination. The simulation results show the behaviour of Charging Stations activities and the impact of different techniques on the THDv level, efficiency and losses especially during peak load hours.

Perceptibly, ignoring the harmonics in the PEV online coordination may increase the forecasting errors. This is due to the fact that the harmonic spectrums initiated by nonlinear loads (EV chargers and industrial loads) are not considered in the coordination program and their generated PEV daily load curves. As a result, the forecasted PEV daily load curves generated by this algorithm ignores the harmonics and may cause discrepancy in the actual results.

According to the literature, RERs are becoming very popular in the new smart grid topology. This published paper (paper 10) assesses the inclusion of wind distributed generations in distribution systems considering the industrial nonlinear loads and PEV- Charging Stations. This could lead to a significant decrease in grid efficiency and the quality of electric power. Therefore, the optimal rescheduling of LTCs and SSCs in Smart Grid is performed. In this research, the required grid energy at high PEV penetrations are being partially supplied by WDGs installed in distribution system. The online MSS based PEV coordination algorithm of

paper 1 is performed while considering Charging Stations and low order odd current harmonics injected by nonlinear loads. The WDGs are considered as negative PQ loads. As indicated by results, the uncontrolled/uncoordinated PEV charging reduces the performance of the grid especially with the harmonic injection of nonlinear load. Therefore, the optimal dispatch of LTC and SSC can significantly improve the system performance, losses and voltage profile. Finally, the WDGs can improve the overall performance especially the system losses and cost of generating energy. Therefore, the application of SSC rescheduling is being tested once again.

So far, the application of LTC and SSCs scheduling has been tested in different conditions and scenarios such as including the industrial nonlinear loads, PEV- Charging Stations and even the WDGs. However, none of the abovementioned scenarios considers the impacts of EV battery charger harmonics on the performance and power quality of the grid especially with grid congestion. The inclusion of EV charger harmonics has been initially included in the online PEV controlled program by enhancing/modifying the MSS based algorithm of paper 1 in chapter 1. This was with the inclusion of DHPF algorithm in the online PEV coordination of paper 1. The modified version is called nonlinear MSS based PEV coordination and is previously thoroughly discussed, proposed and tested in published paper 3 of chapter 1. To complete and solve the main objective of this thesis, it is necessary to include the nonlinearities of EV battery chargers and industrial loads in the proposed online PEV controlled strategy and SSC rescheduling algorithm. In this scenario, the nonlinear online PEV controlled strategy is performed to generate the residential feeders' daily load curves populated with the PEVs and their harmonic spectrums as well as harmonics associated with the industrial nonlinear loads. In other words, the forecasted PEV load curves data also includes the harmonic spectrums. Paper 11 proposes a new online strategy for this nonlinear online PEV coordination and SSC rescheduling. In this approach not only the PEV coordination program but also the SSC dispatch algorithm includes the harmonic distortions created by EV chargers and nonlinear

industrial loads. This can be considered as a second and better option for solving the power quality and customer satisfaction issues. As discussed earlier in paper 3 (chapter 2), the nonlinear online PEV coordination approach can enhance the power grid performance and quality for low and moderate PEV penetrations by shifting the PEV loads to the off- peak hours. The idea of shifting the PEV charging activities to off- peak hours could be operational when the PEV penetrations are not high and therefore all PEV owners are still able to fully charge their vehicles before the designated time of 8am. In high PEV penetrations, the algorithm may not manage to charge all PEVs before their next travel at 8am. The simulation results of paper 3 (chapter 2) shows that with penetrations of 47% (high penetration), number of PEVs are left unchanged. Paper 3 of chapter 2 proposes PPFs installation to resolve the issues. However, paper 10 proposes the application of SSCs rescheduling considering harmonics and the inclusion of sensitivity of reactive power (Q) to the bus voltage. The proposed PEV coordination strategy of paper 3 was based on maximum sensitivity of system losses to the number of PEVs. In this paper, the sensitivity of the reactive power to bus voltages are also included. The switched capacitors are installed and switched according to their primary day-ahead schedules based on Genetic Algorithm optimization. This is to improve the bus voltages (grid enhancement) and the THDv (grid power quality). Therefore, the sensitivity of reactive power of the system can be investigated. It is further discussed that the iteration of the solution approach can resolve the issues associated with the forecasting errors and random PEV arrivals used as initial data for SSCs rescheduling optimization algorithm. It can be observed that the results are more accurate, and algorithm can successfully satisfy the PEV owners' desire.

The third objective of this thesis investigates a new practical strategy with the application of APFs to further improve the power quality of Smart Grid. As discussed before, with large PEV deployment and large number of nonlinear loads in residential and distribution feeders, even with the nonlinear approach of objective 2 cannot sufficiently reduce the THDv to the

acceptable boundary of 5%. A further consideration is required to safely accept the inclusion of smart appliances, RERs and industrial nonlinear load without the reliability, power quality and performance issues. Paper 12 proposes the new idea of installation and de- rating of APFs at selected buses to resolve the issues. The APFs can compensate for the injected current harmonics at the point of common coupling (PCCs) and therefore, reduces the THDv of the whole system. Although the conventional approach of installing APFs in all buses can fully compensate the THDv, this is a very expensive strategy and may not be feasible especially for small systems. Paper 12 proposes the new idea of de- rating of these devices under the worst operating condition. This simple practical approach de- rate the size of APFs to control the THDv level within the permissible limit. Such strategy designs the APFs to control the THDv of total network within the allowable boundary rather than fully eliminating the injected current harmonics of nonlinear loads at their PCCs. The simulation results show further improvement of power quality and mitigation of THDv.

In paper 13, the application of CPDs with STATCOM and APLC has been proposed for voltage regulations and power quality improvement of the grid. A new PSO based algorithm has been proposed for sizing/siting and online control of multiple CPDs. Two PSO algorithms have been used to first determine the optimal size and locations of CPDs under the worst operating conditions and second, to calculate the harmonic and fundamental reference currents to coordinate and control the CPD using smart meter information. The simulation results indicate the grid power quality and voltage profile improvement in Smart Grid.

Paper 14 considers a slightly different topology and system network. The idea is to follow the advanced technology and investigate and assess the power quality improvement and reliability not only in Smart Grid but also on future Microgrids. This approach considers a Microgrid with connections to the Smart Grid and proposes a new hybrid islanding detection approach to further improvement of the power quality. In this study, the application of ANN and fuzzy

logic optimization algorithm has been tested to protect the Microgrids by the new hybrid islanding detection technique that is capable to perform islanding and improve power quality of the grid. This strategy works based on a combination of passive, active and communication islanding detections by the application of wavelet energy transform. In this study, the probability of islanding is measured in the Smart Grid side for a Microgrids with multiple connections to the grid. The contribution of this paper in comparison with the previous investigations are first in the consideration of multiple connections to the grid. Secondly, this method is performing limited number of active islanding detections in cases where one of the probability of islanding values higher than the defined limit. It is further discussed that the proposed method relies on the measured utility current and voltages signals. And more importantly the power quality of Microgrids is improved using the new wavelet energy transform technique. The simulation results assess the performance of the proposed approach.

6 Conclusion

In overall, the main contributions, limitation and future directions of this PhD thesis are concluded and thoroughly discussed in the three following sections:

6.1 Significance of Research and Contribution

This thesis presents the development of research productivities that highlights an innovative and practical approach to support the overall power quality and performance of the grid in both MV distribution and LV residential networks. This scheme mainly focuses on the transformation of the Smart Grid to a "Smarter Grid" and the infrastructure to enable the integration of smart appliances such as PEVs as well as RERs with an adaptive and intelligent control strategy/ optimization. This strategy aims at first integrating large- scale PEV penetrations and RERs into Smart Grid while considering system operation conditions and secondly offering grid energy storage for load balancing and mitigating energy power

variations caused by RERs. Thirdly, the proposed algorithm can optimally increase the customer (PEV's owners) satisfaction within the predefined power system constraints and limitations.

Overall, the main contributions of this body of work is to develop a practical, simple and novel strategy to keep- up with advanced technology and growth of PEVs. The aim is:

First- to develop and implement an online PEV controlled algorithm based on Maximum Sensitivities Selection (MSS) Optimization to minimize the cost of generating energy by integrating retail electricity prices and PEV owner priority charging selections/zones (grid performance) as presented in paper 1. The online PEV coordination algorithm of paper 1 is a novel strategy which is tested on a large scale modified IEEE Smart Grid system including LV residential feeders. The data for daily load curves and residential feeders are from a real suburb in WA. This innovative strategy has been compared with different optimization techniques in the literature and it is still one of the most practical, fast and accurate methods which have ever been proposed and implemented. The published paper has been cited and implemented in many studies and practical industrial works over the past few years. The part of the system information and system input data has been used not only in many transactions and peer reviewed articles but also has been the base of the whole research of the candidate throughout her academic activities. The system information and EV technical data of this paper has been also used in candidates' Master of Philosophy for another application and a different research objective (Deilami. S, 2010, pages 65-68 and 72-75). This online PEV coordination strategy is further developed and modified to consider the injected current harmonics by EV battery chargers and nonlinear loads in the real-time PEV coordination (paper 3).

Second- Now that the control strategy and algorithm is developed and tested, the PEV coordination approaches are included in both distribution and residential networks by optimal rescheduling of LTC and SSCs considering the forecasted residential feeders' load curves and

their current harmonic spectrums to enhance the performance, reliability and power quality of Smart Grid. The Optimal dispatch/rescheduling is implemented to minimize power system losses, voltage variations and total harmonic distortion (THD). Further, PEVs are also coordinated to minimize the cost associated with generating electricity and enhance the voltage profiles (node voltages) of the residential feeders over the 24 hours. According to this approach, the typical load profiles of the residential feeders with uncontrolled PEV charging as well as PEV- CSs and RDGs are forecasted (simulated) and then included in a Genetic Algorithm model. This Genetic Algorithm model is to implement optimal dispatch of LTC and SSC in the presence of harmonics in MV distribution networks as well as EV battery chargers in LV residential networks. The EV charging activities at charging stations not only affects the capacity of the grid but also the quality of the supply even at low PEV penetration during rush hours. The idea of implementing optimal dispatch program in the PEV coordination strategies, is very effective in improving the power quality of the Smart Grid. The switched shunt capacitors perform as passive filters and help in suppressing harmonic distortion. This strategy can be suggested as a cost- effective option compare to the expensive active power filters (APFs) or even to decrease active filters sizing to be used in future smarter grids.

Third - Further improvement of power quality by online PEV coordination with rescheduling of LTC/SSCs is proposed by de- rating of APFs considering harmonics.

This simple approach is to install APFs at the point of common couplings (PCCs) of nonlinear loads to compensate the injected current harmonics and reduces the THDv of the whole network to meet the permissible standard level and not by eliminating the THDv and therefore, the cost and size of APFs will be reduced.

The proposed control strategy is an industrial application that provides demand response and leads towards reducing the cost of energy and electricity bills as well as considering customer satisfaction. The improvement of power quality is also assessed and applied on isolated

Microgrids by implementing discrete wavelet transform using neural networks and fuzzy systems. The control operation of Microgrids, is a new avenue in the field of Smart Grids which has been started by researchers. This research paper represents a new and advanced version of Microgrids supported by Smart Grids and enables openings for future investigations and studies.

The contributions of thesis have been presented and assessed in series of peer reviewed publications listed in Table I. The research outputs of this thesis (peer reviewed publications in this thesis) have been continuously cited and in some special cases (for example paper 1), the citation is over 800 times as of November 2018. The input data of residential feeders are obtained from a real residential suburb in WA and the work was supported by industry (Western Power).

Further, there are more relevant publications of the author in the area and subject of this thesis that are not included in the body of this work but available in list of author's publications (Appendix B).

6.2 Limitations

It has been discussed that the area of Smart Grid or Smarter Grid is very vast and immense. In order to keep – moving up with the growth of technology, the researchers need to continue to fill the existing gaps and to provide and prepare the grid with enhanced efficiency, reliability and stability. This preparation provides the new Smart Grid for integration of large- scale smart appliances and RERs.

The aim of this thesis was looking into the gaps over the past few years especially considering industry needs in order to put this research into practice by proposing new control strategies that could successfully address their requirements. Obviously, the research can never stop and

needs moving on to cope with the growing technology. There are limitations and special needs in this body of work as it cannot cover all aspects of smart energy.

An appropriate consideration needs to be taken while considering this body of work. The first and important factor is the advanced smart technology itself that cannot be totally covered. Given the fact that the control strategy of paper 1 has been continuously cited and used over the past few years, it is important to consider number of limitations about this study. The system information about the size and type of batteries are related to the time of publishing this paper. Manufacturers have been rapidly come up with new type of PEVs with advanced specifications. As an example, there are new manufacturers with different types of EVs with new control strategies and power electronic control devices for Power Factor Correction. Therefore, it is important to update the data and this information accordingly. In addition, there are integrated EV battery types that can be used for industrial applications. Having said that the proposed online approach can still perform with the updated new PEV technology. One other limitation is the PEV charging levels that are not considered in this paper. Nowadays, the charging levels are different and therefore, the size, efficiency and charging methods are not considered. This paper focuses on the online coordination approach with a fixed PEV charging rate. It has been shown that PEVs can use different charging methods and can be charged in different stations (in their parking stations, shopping centers or charging stations). This limitation has been considered in paper 3 where a real PEV (Nissan Leaf) has been tested with level 2 charging.

Another limitation/gap of this thesis is the frequency response and the possible contribution of EVs to a dynamic frequency control strategy. The primary frequency response can also be considered by EV charging strategies with large scale penetrations of DERs to create a balance

between the load and the source. This research is currently under investigation by candidate and a paper is being finalized to be submitted to a journal articles.

Further, the variable charging is out of scope of this study and can be counted as a limitation that is not covered. In addition, the customer satisfaction is considered by the online coordination strategy and a separate constraint is not included. This is an area that could be added. In the literature, there are some publications which focus on variable charging and customer satisfaction factor.

In second part of the thesis (objective 2), the rescheduling of SSCs are considered. In this study, the SSCs scheduling is an off-line approach based on a day- ahead scheduling. This is one of the limitation to this research. The candidate considers this limitation and is currently investigating the practical approaches to solve this problem. Further, the switching constraint need to be considered as an important factor/constraint for online SSCs scheduling. This is important as the online switching may not be practical as it may reduce the switching life time need to be restricted.

In general, the research should continue to progress and cover a comprehensive aspect of this topic. Such research requires an applicable electricity market design and development for an advanced day-ahead scheduling to also incorporate the policies and financial aspects of the design. This is important to increase public awareness and encouragement to participate in smart charging activities. Further to this, the capital investment and government policy for this new growing technology is yet to be clearly identified (Hernandez C. Jorge E. 2015).

6.3 Future Directions

The nature of Smart Grid is intensely multidisciplinary and not only involves electric power systems and related engineering but also requires the integration of computer engineering,

economical/financial precautions as well as control engineering. This necessitates group of researchers from any related discipline to work together on both challenges and prospects to come up with innovative and adaptive approaches for the present Smart Grid to be prepared for any forthcoming and advanced technology. Therefore, one of the main future directions of this work could be the inclusion of computer-based control strategy with the IT and internet support to enhance the real- time coordination approaches of smart appliances. Further, it is important to consider the industry inputs and governmental financial purposes in the optimization approaches. These enhanced solutions can apply on new Microgrids with the inclusion of PEVs or Charging Stations to present/ implement solution for reliability and stability conditions. One example could be the recent publication of the author (Derakhshandeh. S. Y. et al, 2013). This research investigates a dynamic coordination approach for RERs and EVs in industrial Microgrids. The published paper uses dynamic optimal power flow for electricity and heat generation scheduling and EV coordination in industry considering solar PVs generation. The aim is reducing the overall cost of industry Microgrid in grid connected and standalone modes. In this approach, the nature of the scheduling algorithm has changed from a simple hourly power flow to an advanced dynamic version by the inclusion of PEVs' dynamic constraints.

Other future instructions may also be considered in the field of Smart Grid, Microgrid and power quality as listed below:

- **Application of Proposed Strategy in Smart Grid**

1- The NOL - MSSCA may also be modified to include coordinated G2V applications.

2- The proposed strategy of this thesis can also be adapted to consider THDi of EV charger harmonics. The THDv and THDi can be defined as new objective functions to cover more aspects of EV charger harmonics in power industry.

3- The proposed 4-Step approach for optimal dispatch of LTC/SSCs in distorted Smart Grid with PEVs charging loads can also be modified to simultaneously perform both online coordination of electric vehicle charging and optimal scheduling. This will definitely complicate the dispatch/controlled process, however, it may considerably improve the correctness and quality of the solution approach.

4- The proposed algorithm can also be improved to also maximize the EV owners' satisfaction without violating operation conditions. This could be a new load management strategy to also reduce the peak load demand. This may require modifications to model PEV charging patterns based on the stochastic behavior of vehicle owners.

5- Optimal Sizing/Siting of RDGs and Energy Storage Systems.

6- EV charging approaches for Primary Frequency Response.

- **Application of Proposed Strategy in Microgrid (MG)**

1- The nonlinear online PEV coordination algorithm should be enhanced and developed for Microgrid configurations with the integration of RERs and broader variety of loads such as entertainment technology, home security networks, home area systems and smart appliances. The main focus can be the improvement of performance, efficiency and power quality of Smart Grid connected to the Microgrids.

2- Considering Online Power Management of Networked Microgrids enabled by IEC-61850-Based Cyber Communication Network.

3- The NOL - MSSCA can be modified for optimal placement and operation of standalone Microgrids in remote areas.

References

1- Akhlaghi. S., A. A. Ghadimi and Akhlaghi. A. 2014. "A Novel Hybrid Islanding Detection Method Combination of SMS and Q-f for Islanding Detection of Inverter-based DG." in Proc. *IEEE Conf. Power Energy* Illinois, Champaign, IL, USA, 1–8.

2- Alonso. M, H. Amaris., J. G. Germain., and J. M. Galan. 2014. "Optimal Charging Scheduling of Electric Vehicles in Smart Grids by Heuristic Algorithms." *Energies* 7(4): 2449–2475.

3- Amin. S. and B. Wollenberg. 2005. *"Toward a Smart Grid: Power Delivery for the 21st Century." Power and Energy Magazine*, IEEE, 3(5):34–41.

4- Bass. R. and N. Zimmerman. 2013. "Impact of Electric Vehicle Charging on Electric Power Distribution Systems." *Oregon Transportation Research and Education Consortium,* Technical Report, OTREC-SS-731.

5- Baghzouz.Y and S. Ertem. 1990. "Shunt Capacitor Sizing for Radial Distribution Feeders with Distorted Substation Voltage*." IEEE Trans. on Power Delivery*, 5(2): 650-657.

6- Baran. M.E. and M.-Y. Hsu. 1999. "Volt/VAr Control at Distribution Substations." *IEEE Trans. on Power Systems,* 14:312-318.

7- Basu. M. 2015. "Optimal dispatch in Smart Power Grids with Partially Known Deviation. " Master of Science Degree Thesis in Electrical and Computer Engineering, the University of Iowa.

8- Basu. M., K. Gaughan and E. Coyle. 2004. "Harmonic Distortion Caused by EV Battery Chargers in the Distribution Systems Network and its Remedy. " *International Universities Power Engineering Conference* (UPEC).

9- Bera Samaresh, Sudip Misra, and Joel. J.p.c Rodrigues. 2015. "Cloud Computing Applications for Smart Grid: A Survey", *IEEE Trans on Parallel and Distributed Systems.* 26 (5):1477-1494.

10- Bruno Sergio, Silvia Lamonaca, S, M. L. Scala, Giuseppe Rotondo, and U. Stecchi. 2009. "Load control through smart-metering on distribution networks". In Proc. *IEEE Bucharest Power-Tech*, 1-8, Bucharest, August 2019. DOI: 10.1109/PTC.2009.5282256

11- Chen. H, Z. Guo, Y. Xin, Y. Zhao, and Y. Jia. 2017. "Coordination of PEV Charging across Multiple Stations in Distribution Networks Using Aggregate PEV Charging Load Model." *International Smart Cities Conference (ISC2).*

12- Chenrui Jin, Tang Jian, and Prasanta Ghosh. 2013, "Optimizing Electric Vehicle Charging with Energy Storage in the Electricity Market." *IEEE Trans. on Smart Grid*, 4(1): 311-320.

13- Clement-Nyns. Kristian, Edwin Haesen, and Johan Driesen 2009. ''Coordinated Charging of Multiple Plug-in Hybrid Electric Vehicles in Residential Distribution Grids,'' in Proc. *IEEE/PES Power Syst. Conf. Exposit.* (PSCE), Seattle, WA, USA, Mar. 1–7.

14- Clement-Nyns. Kristian, Edwin Haesen, and Johan Driesen. 2010. "The impact of charging plug-in hybrid electric vehicles on a residential distribution grid." *IEEE Transactions on Power Systems,* 25(1). 371-380.

15- Colak IIhami, Ersan Cabalci, GianlucaFulli, and StavrosLazarou. 2015." A Survey on the Contributions of Power Electronics to Smart Grid Systems." *Renewable and Sustainable Energy Reviews, Elsevier* 47: 562-579. https://doi.org/10.1016/j.rser.2015.03.031

16- Deilami Sara. 2010. "Optimal Dispatch of Shunt Capacitors and Load Tap Changers in Distorted Distribution Systems Using Ant Colony Algorithms", Master of Philosophy. Curtin University.
https://espace.curtin.edu.au/handle/20.500.11937/92.

17- Deilami Sara, Amir S. Masoum, Paul S. Moses, and Mohammad A.S. Masoum. 2010. "Voltage Profile and THD Distortion of Residential Network with High Penetration of Plug-in Electrical Vehicles." *IEEE ISGT Europe* 2010 *(Innovative Smart Grid Technologies Europe) Conference*. Gothenburg, Sweden.

18- Deilami. S, Amir S. Masoum, Paul Moses, and Mohammad A.S. Masoum. 2011. "Real-time Coordination of Plug-in Electric Vehicle Charging in Smart Grids to Minimize Power Losses and Improve Voltage Profile." *IEEE Transactions on Smart Grid* 2(3): 456-467.

19- Deng. Youman, and Xiaojuan Ren. 2001. *"Fuzzy Modelling of Capacitor Switching for Radial Distribution Systems."* in *IEEE Power Engineering Society Winter Meeting*, 2:830-834.

20- Deng, Youman, Xiaojuan Ren, Changcheng Zhao, and Dapu Zhao. 2002. "A Heuristic and Algorithmic Combined Approach for Reactive Power Optimization with Time-Varying Load Demand in Distribution Systems," *IEEE Trans. on Power Systems*. 17(4):1068-1072.

21- Fang, Xi, Satyajayant, Misra, Guoliang Xue, and Dejun Yang. 2012. "Smart Grid- The New and Improved Power Grid: A Survey", *IEEE Communication Surveys & Tutorials*, 14(4): 944-980.

22- Foster, Justin M., and Michael C. Caramanis. 2013. "Optimal Power Market Participation of Plug-in Vehicles Pooled by Distribution Feeder," *IEEE Trans. on Power Systems,* 28(3):2065-2076.

23- Galus, Matthias. D, Marek Zima, and Göran Andersson. 2010. "On Integration of PHEVs into Existing Power System Structures," *Energy Policy*, 38(11): 6736–6745.

24- Gan, Lingwen, Ufuk Topcu, Steven H. Low. 2013. "Optimal Decentralized Protocol for Electric Vehicle Charging." *IEEE Trans. on Power Systems*, 28(2):940-951.

25- Geng, Bo, James K. Mills, and Dong Sun. 2013. "Two-Stage Charging Strategy for Plug-in Electric Vehicles at the Residential Transformer Level," *IEEE Trans. on Smart Grid,* 4(3):1442-1452.

26- Global EV Outlook. 2017, *"International Energy Agency (IEA)"*. www.iea.org.

27- Grainger. J. J. and S. Civanlar. 1985. *"Volt/Var Control on Distribution Systems with Lateral Branches Using Shunt Capacitors and Voltage Regulators. Part I: The Overall Problem." IEEE Trans. on Power Apparatus and Systems*. 104(11):3278-3283.
DOI: 10.1109/TPAS.1985.318842

28- Grid Modernization and Smart Grid. 2007.
https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid.(Date accessed March 2018)

29- Han, Sekyung, Soohee Han, and Kaoru Sezaki. 2010. "Development of an optimal vehicle-to-grid aggregator for frequency regulation*." IEEE Transactions on Smart Grid. 1(1):65-72.*

30- Hernandez C. Jorge E. (2015)." Third Harmonic Management and Flexible Charging for The Integration of Electric Vehicles into the Grid" Doctor of Philosophy in Electrical and Computer Engineering in Georgia Institute of Technology.
https://smartech.gatech.edu/handle/1853/53495.

31- Hirsch, Adam, Yael Parag, and Josep Guerrero. 2018." Microgrids: A Review of Technologies, Key Drivers, and Outstanding Issues." *Elsevier Renewable and Sustainable Energy Reviews*, 90:402-411.

32- Hsu, Yuan-Yih and Feng Chang Lu. 1998. "A Combined Artificial Neural Network-Fuzzy Dynamic Programming Approach to Reactive Power/Voltage Control in a Distribution Substation." *IEEE Trans. on Power Systems*, 13:1265-1271.

33- IEEE Std 519-1992. 1993. Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.

34- Jin, Chenrui, Jian Tang. J and Prasanta Ghosh. 2013. *"Optimizing Electric Vehicle Charging: A Customer's Perspective,"* IEEE Trans. on Vehicular Technology, 62(7):2919-2927.

35- Kermany. S.D, Mahmood Joorabian**,** Sara Deilami, Mohammad A. S Masoum, 2017. "Hybrid Islanding Detection in Microgrid with Multiple Connection Points to Smart Grids using Fuzzy-Neural Network." *IEEE Transactions on Power Systems* 32(4): 2640 – 2651. DOI: 10.1109/TPWRS.2016.2617344.

36- Khaldi Mohamad R. 2004. "Sensitivity Matrices for Reactive Power Dispatch and Voltage Control of Large-Scale Power Systems".*izmir*2004."

37- Khamis, Aziah, Hossain Shareef, Erdal Bizkevelcic, and Tamer Khatib. 2013. "A Review of Islanding Detection Techniques for Renewable Distributed Generation Systems." *Elsevier Renewable and Sustainable Energy Reviews*, 28:483–493. https://doi.org/10.1016/j.rser.2013.08.025

38- Kong, Peng -Yong and George K. Karagiannidis. 2016. "Charging Schemes for Plug-In Hybrid Electric Vehicles in Smart Grid: A Survey." *IEEE Access*. 4: 6846 – 6875. DOI: 10.1109/ACCESS.2016.2614689

39- Li, Canbing, Chi Cao, Yijia Cao, Yonghong Kuang, Long Zeng, and Baling Fang. 2014. "A Review of Islanding Detection Methods for Microgrid." *Elsevier Journal Renewable and Sustainable Energy Reviews (*35): 211–220.

40- Liang, Ruey- Hsun, and Chen-Kuo Cheng. 2001. *"Dispatch of Main Transformer ULTC and Capacitors in a Distribution System." IEEE Trans. on Power Delivery* 16(4):625-630.

41- Liang, R.-H, and Y.-S. Wang. 2003. "Fuzzy-Based Reactive Power and Voltage Control in a Distribution System." *IEEE Trans. on Power Delivery* (18):610-618.

42- Liserre, Marco, Thilo Sauter,and John Y. Hung.2010. "Integrating Renewable Energy Sources into the Smart Power Grid through Industrial Electronics." *IEEE Industrial Electronics Magazine 4(1):18-37*. DOI: 10.1109/MIE.2010.935861

43- Linni, Jian, Xue, Honghong, Xu, Guoqing, Zhu, Xinyu, Zhao, Dongfang, and Z.Y. Shao. 2013. "Regulated Charging of Plug-in Hybrid Electric Vehicles for Minimizing Load Variance in Household Smart Microgrid." *IEEE Trans. on Industrial Electronics* 60 (8):3218-3226.

44- Lu, Feng-Chang, and Yuan- Yih Hsu. 1997. "Fuzzy Dynamic Programming Approach to Reactive Power/Voltage Control in a Distribution Substation." *IEEE Trans. on Power Systems* 12(2): 681-688.

45- Masoum, Amir. S., Sara Deilami, Paul Moses, Mohammad. A.S. Masoum, Ahmed Abu-Siada. 2011. "Smart Load Management of Plug-in Electric Vehicles in Distribution and Residential Networks with Charging Stations for Peak Shaving and Loss Minimization Considering Voltage Regulation." *IET Proceedings on Generation, Transmission and Distribution.* 5(8), 877-888.

46- Masoum, Mohammad A.S, and E.F. Fuchs. 2015. Power Quality in Electrical Machines and Power Systems. *Elsevier, Academic Press, USA, Second Edition.*

47- Masoum, Mohammad A.S, Sara Deilami, and Syed M. Islam. 2010. "Mitigation of Harmonics in Smart Grids with High Penetration of Plug-In Vehicles." *IEEE Power Engineering Society General Meeting,* Minneapolis, USA.

48- Mauri, Giuseppe, Diana Moneta, and C. Bettoni. 2009. "Energy Conservation and Smart Grids: New Challenge for Multimetering Infrastructures." *In Proc. IEEE Bucharest PowerTech*. 1-7.
DOI: 10.1109/PTC.2009.5282219.

49- Meng, Jian, Yunfei Mu, Jianzhong Wu, Hongjie Jia, Qian Dai and Xiaodan Yu.2015." Dynamic frequency response from electric vehicles in the Great Britain power system" *Journal of Modern Power Systems and Clean Energy, 3(2):203-211.*

50- Mets, Kevin, Tom Verschueren, Wouter Haerick, Chris Develder, Filip De Turck. 2010. "Optimizing Smart Energy Control Strategies for Plug-in Hybrid Electric Vehicle Charging.'' *in Proc. IEEE/IFIP Netw. Operations Manage.* Symp. Workshops, Osaka, Japan, 293–299.
DOI: 10.1109/NOMSW.2010.5486561.

51- Moghbel. M., Mohammad A. S. Masoum, Alireza Fereidouni, and Sara Deilami. (2017). "Optimal Sizing, Siting and Operation of Custom Power Devices with STATCOM and APLC Functions for Real-Time Reactive Power and Network Voltage Quality Control of Smart Grid", *IEEE Transactions on Smart Grid* 9(6): 5564 – 5575.
DOI: 10.1109/TSG.2017.2690681.

52- Moslehi, Khosrow, and Kumar Ranjit. 2010. "Smart Grid – A Reliability Perspective" Paper 10SG0068, *IEEE PES Conference on Innovative Smart Grid Technologies,* January 19-20, Washington, DC.
DOI: 10.1109/ISGT.2010.5434765.

53- Pillai, Jayakrishnan Radhakrishna, and Birgitte Bak-Jensen. 2011. "Integration of Vehicle-to-Grid in the Western Danish Power System." *IEEE Transactions on Sustainable Energy,* 2(1), 12-19.

54- "Plug-in Electric Vehicle", Available from:
en.wikipedia.org/wiki/Plugin_electric_vehicle.

55- Qi, Wei, Zhiwei Xu, Zuo- Jun Max Shen, Zechun Hu, and Yonghua Song. 2014. ''Hierarchical Coordinated Control of Plug-in Electric Vehicles Charging in Multifamily Dwellings.'' *IEEE Trans. Smart Grid* 5 (3):1465–1474.

56- Rahimi, Farrokh and Ali Ipakchi. 2010. "Demand Response as a Market Resource under the Smart Grid Paradigm." *IEEE Transactions on Smart Grid*. 1(1): 82-88.

57- Rezaei, Pooya, Jeff Frolik, and Paul D.H. Hines. 2014. ''Packetized Plug-in Electric Vehicle Charge Management.'' *IEEE Trans. Smart Grid* 5(2): 642–650.

58- Richardson, Peter, Damian Flynn, and Andrew Keane. 2012. "Optimal Charging of Electric Vehicles in Low-Voltage Distribution Systems," *IEEE Trans. on Power Systems* 27(1):268-279.

59- Rotering, Niklas, and Marija Ilic. 2011. "Optimal Charge Control of Plug-in Hybrid Electric Vehicles in Deregulated Electricity Markets," *IEEE Trans. on Power Systems* 26(3):1021-1029.

60- Sabin D. Daniel and A. Sannino. (2003). *"A Summary of Draft IEEE P1409 Custom Power Application Guide." IEEE PES Transmission and Distribution Conference and Exp*. 3: 931-936. http://grouper.ieee.org/groups/1409/0309_sannino.pdf.

61- J1772™ (2017).SAE J1772- SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler *J1772_201001*, 2010-2017.
https://saemobilus.sae.org/content/j1772_201710

62- Singh, Bhim, and Radha Kushwaha. 2016. "An EV Battery Charger with Power Factor Corrected Bridgeless Zeta Converter Topology." *7th India International Conference on Power Electronics (IICPE).*

63- Siano Pierluigi. (2014). "Demand response and smart grids—A survey." *Renewable and Sustainable Energy Reviews, Elsevier* 30 (2014): 461- 478.

64- Singh. B, K. Al-Haddad, and A. Chandra. 1999. "A review of Active Filters for Power Quality Improvement*." IEEE Transactions on Industrial Electronics*. 46(5): 960-971.

65- Sortomme, Eric, and Mohamed A. El-Sharkawi. 2011. "Optimal Charging Strategies for Unidirectional Vehicle-to-Grid*", IEEE Transactions on Smart Grid*. 2(1): 131-138.

66- Sarangi. Smruti. R, Partha Dutta, and Komal Jalan. 2012. ''IT Infrastructure for Providing Energy-as-a-Service to Electric Vehicles.'' *IEEE Trans. Smart Grid* 3(2): 594–604.

67- Su. Wencong, Habiballah Rahimi-Eichi, Wente Zeng, and Mo-Yuen Chow. 2012. *"A Survey on the Electrification of Transportation in a Smart Grid Environment." IEEE Transactions on Power Systems*. 3(1): 1-10.

68- Sun, Xiaofeng, Rujung Han, Hong Shen, Baocheng Wang, Zhigang Lu. Z and Chen. Z. 2016. "A Double-Resistive Active Power Filter System to Attenuate Harmonic Voltages of a Radial Power Distribution Feeder." *IEEE Trans. on Power Electronics*. 31(9): 6203-6216.

69- The Electricity Grid: A History; http://burnanenergyjournal.com/the-electricitygrid-a-history/.(Date accessed March 2018).

70- The War of the Currents: AC vs. DC Power https://www.energy.gov/articles/war-currents-ac-vs-dc-power. (Date accessed August 2019).

71- Torres. J. 2011. "Smart Grid: Challenges and Opportunities", Sandia National Laboratories, jjtorre@sandia.gov, https://www.osti.gov/servlets/purl/1120614.

72- Ulinuha. A, Mohammad A.S. Masoum. M.A.S, and Syed M. Islam. 2008. "Optimal Scheduling of LTC and Shunt Capacitors in Large Distorted Distribution Systems Using Evolutionary-Based Algorithms" *IEEE Trans. on Power Delivery* 23(1):434-441.

73- Ulinuha. A, Mohammad A.S. Masoum, and Syed M. Islam. 2011. "Hybrid Genetic-Fuzzy Algorithm for Volt/Var/THD Control of Distribution Systems with High Penetration of Nonlinear Loads." *IET Trans. on Generation, Transmission & Distribution* 5(4):425-439.

74- Ulinuha. A, Mohammad A.S. Masoum, and Syed M. Islam. 2006. "Decoupled Harmonic Power Flow for Large Power System with Multiple Nonlinear Loads," *The Seventh Postgraduate Electrical Engineering and Computing Symposium (PEECS),* Perth, Australia.

75- Ulinuha. A, Mohammad A.S. Masoum, and Syed M. Islam. 2007. "Harmonic Power Flow Calculations for Large Power System with Multiple Nonlinear Loads Using Decouple Approach." *The Australasian Universities Power Engineering Conference (AUPEC),* Perth, Australia.

76- Vardakas, John S., Nizar Zorba, and Christos V Verikoukis. 2017. "A Survey on Demand Response Programs in Smart Grids." *IEEE Communication Surveys & Tutorials17* (1):152- 178.

77- Vandael, Stijn, Bert Claessens, Maarten Hommelberg, Tom Holvoet, and Geert Deconinck. 2013. "A Scalable Three-Step Approach for Demand Side Management of Plug-in Hybrid Vehicles," *IEEE Trans. on Smart Grid* 4(2):720-728.

78- Van Vliet, Oscar, Brouwerb, Kuramochi. T.; van den Broek. M.; Faaij. A. *2011."* Energy Use, Cost and CO2 Emissions of Electric Cars." Power Sources 196: 2298–2310.

79- Verhoeven. B. 2002. *"Probability of Islanding in Utility Networks Due to Grid Connected Photovoltaic Power Systems." Int. Energy Agency*, Paris, France, Tech. Rep. PVPS T5–07.

80- Vrba. Pavel, Vladimír Mařík, Pierluigi Siano, Paulo Leitão, Gulnara Zhabelova, Valeriy Vyatkin , and Thomas Strasser. 2014. "Review of Agent and Service-Oriented Concepts Applied to Intelligent Energy Systems." *IEEE Trans. on Industrial Informatics*, 10(3): 1890 - 1903.

DOI: 10.1109/TII.2014.2326411

81- Watson. N. R., J. D. Watson, R. M. Watson. K. Sharma, and A. Miller. 2015. "Impact of Electric Vehicle Chargers on a Low Voltage Distribution System." *EEA Conference & Exhibition*, Wellington. http://hdl.handle.net/10092/12059

82- Wikipedia,https://en.wikipedia.org/wiki/List_of_modern_production_plug-in_electric_vehicles (Date accessed 2017).

83- Kane. M. 2014. "Sales of Mitsubishi MiEV in Japan Fell Off Sharply in 2013; Battery Production Constraints Probable Cause". https://insideevs.com/news/320759/sales-of-mitsubishi-miev-in-japan-fell-off-sharply-in-2013-battery-production-constraints-probable/ (Date accessed August 2019).

84- Cobb. J. 2016. "Global 10 Best- Selling Plug-In Cars Are Accelerating Forward". *https://www.hybridcars.com/global-10-best-selling-plug-in-cars-are-accelerating-forward/*. (Date accessed August 2019)

85- Wu. Z.Q., and K.L.Lo. 995. "Optimal Choice of Fixed and Switched Capacitors in Radial Distributors with Distorted Substation Voltage." *IEE Proceedings-Generation, Transmission and Distribution* 142(1): 24-28.

DOI: 10.1049/ip-gtd: 19951570.

86- Yilmaz. M., and PH. T. Krein. 2013. "Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles." *IEEE Transactions on Power Electronics* 28(5): 2151 – 2169.

DOI: 10.1109/TPEL.2012.2212917

87- Yin Jun, Liuchen Chang, and C. Diduch. 2004. "Recent Developments in Islanding Detection for Distributed Power." *in Proc. IEEE Conf.* Large Eng. Syst. Power Eng., 124–128. Halifax, NS, Canada 28-30 July.

DOI: 10.1109/LESCPE.2004.1356285

88- Yu, Xin- Mei, Xin-yin Xiong, and Yao-Wu Wu 2004. "A PSO-based Approach to Optimal Capacitor Placement with Harmonic Distortion Consideration." *Elsevier.* 27-33.

DOI: 10.1016/j.epsr.2004.01.002

89- Zhongjing Ma, Duncan S Callaway, and Ian Hiskens. 2013. "Decentralized Charging Control of Large Populations of Plug-in Electric Vehicles." *IEEE Trans. on Control Systems Technology* 21(1):67-78.

DOI: 10.1109/TCST.2011.2174059

90- Zoba Ahmed F., and Abdel Aziz. 2004. "LC Compensators Based on Transmission Loss Minimization for Nonlinear Loads," *IEEE Trans. on Power Delivery* 19 (4):1740-1745.

DOI: 10.1109/TPWRD.2004.835426.

91- Furukakoi Masahiro, Mir Sayed Shah Danish, *and* Abdul Motin Howlader. 2018.*"* Voltage Stability Improvement of Transmission Systems Using a Novel Shunt Capacitor Control." *International Journal of Emerging Electric Power Systems* 19(1).

DOI: https://doi.org/10.1515/ijeeps-2017-0112.
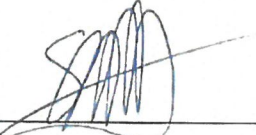
Appendix A   Attribution of Authors

Deilami. S, Masoum, A.S, Moses, P, Masoum, M.A.S (2011). Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile. *IEEE Transactions on Smart Grid* 2(3), 456-467.

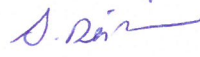|	Conception & Design	Acquisition of data & method	Data Conditioning & manipulation	analysis & statistical method	interpretation & discussion	Final Approval
Sara Deilami	X	X	X	X	X	
I acknowledge that these represent my contribution to the above research output. Signed. *J. Di* NOV. 26/11/18						
Amir S. Masoum		X	X	X		
I acknowledge that these represent my contribution to the above research output. Signed. *(am)* 16/11/2018						
Dr Paul Moses	X			X	X	
I acknowledge that these represent my contribution to the above research output. Signed. The co-author was not avaialble to sign. He has already approved his contribution electronically in 2015. Contributions as approved in 2015: Deilami: 50%, Amir: 20%, Moses: 20%, M.A.S. Masoum: 10%.						
Professor Mohammad Masoum	X				X	X
I acknowledge that these represent my contribution to the above research output. Signed. *Swf MaSm M A Z* Nov. 24, 2018						
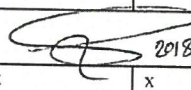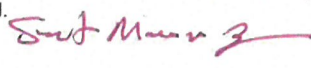
"Deilami. S, Masoum. A.S, Masoum. M.A.S, Abu-Siada. A. (2013). Performance of Heuristic Optimization in Coordination of Plug-In Electric Vehicles Charging. *IBIMA Publishing Journals, International Journal of Renewable Energy and Biofuels*. USA. 1-15, Article ID 898203, DOI: 10.5171/2013.898203."

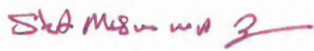|	conception & design	acquisition of data & method	data conditioning & manipulation	analysis & statistical method	interpretation & discussion	Final Approval
Sara Deilami	X	X	X	X	X	X
I acknowledge that these represent my contribution to the above research output. Signed. ⟨signature⟩ S. Dei─ Nov. 26/11/2018						
Amir S. Masoum		X				X
I acknowledge that these represent my contribution to the above research output. Signed. ⟨signature⟩ am 16/1/2018						
Professor Mohammad Masoum	X				X	X
I acknowledge that these represent my contribution to the above research output. Signed. ⟨signature⟩ Nov 24 2018						
A/Professor Abu-Siada	X				X	X
I acknowledge that these represent my contribution to the above research output. Signed. ⟨signature⟩ A. Jial..						

"Panahi. D, Deilami. S, Masoum. M.A.S, Islam. S.M. (2015). Forecasting Plug-In Electric Vehicles Load Profile using Artificial Neural Networks. *Australasian Universities Power Engineering Conference (AUPEC 2015)*, Wollongong, NSW, Australia, 1-6."

	conception & design	acquisition of data & method	data conditioning & manipulation	analysis & statistical method	interpretation & discussion	Final Approval
Delshad Panahi	X	X	X	X	X	X

I acknowledge that these represent my contribution to the above research output.

Signed. *Panahi* DELSHAD PANAHI 2018.11.13 08:43:31 +08'00'

Sara Deilami	X			X	X	X

I acknowledge that these represent my contribution to the above research output.

Signed. *S Dei* 26/11/18

Professor Mohammad Masoum	X				X	X

I acknowledge that these represent my contribution to the above research output.

Signed. *Syd Masoumes* Nev. 24, 2018

Professor Syed Islam						X

I acknowledge that these represent my contribution to the above research output.

Signed.

Naghibi. B, Masoum. M.A.S, Deilami. S. "Effects of V2H Integration on Optimal Sizing of Renewable Resources in Smart Home based on Monte Carlo Simulations", IEEE Power and Energy Technology Systems Journal.
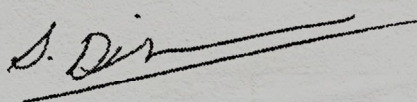
	conception & design	acquisition of data & method	data conditioning & manipulation	analysis & statistical method	interpretation & discussion	Final Approval
Bahman Naghibi	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed. _(signature)_ 2018 10 16						
Professor Mohammad Masoum	x				x	x
I acknowledge that these represent my contribution to the above research output. Signed. _(signature)_ Nov. 24, 2018						
Sara Deilami	x				x	x
I acknowledge that these represent my contribution to the above research output. Signed. _(signature)_ 26/11/18						

Deilami. S, Masoum. M.A.S. (2013). "Optimal Dispatch of LTC and Switched Shunt Capacitors in Smart Grid with Plug-In Electric Vehicles. "*IEEE Power Engineering Society General Meeting PES GM,* Vancouver, British Columbia, Canada, 1-7.

	conception & design	acquisition of data & method	data conditioning & manipulation	analysis & statistical method	interpretation & discussion	Final Approval
Sara Deilami	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed. ⟨signature⟩ Nov. 26/11/2018						
Professor Mohammad Masoum	x					x
I acknowledge that these represent my contribution to the above research output. Signed. ⟨signature⟩ Nov. 24, 2018						

Deilami. S, Masoum. A.S, Jabalameli. N, Masoum. M.A.S. (2013). "Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid with Electric Vehicles and Charging Station." *8th International Conference on Electrical and Electronics Engineering (ELECO 2013)*. Bursa, Turkey, 162-166.

	conception & design	acquisition of data & method	data conditioning & manipulation	analysis & statistical method	interpretation & discussion	final approval
Sara Deilami	x	x	x	x	x	x

I acknowledge that these represent my contribution to the above research output.

Signed. *S. Dei_____* NOV. 26/11/18

Amir Masoum					x	x

I acknowledge that these represent my contribution to the above research output.
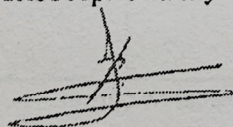
Signed. *(signature)* 16/11/2018

Nasim Jabalameli					x	x

I acknowledge that these represent my contribution to the above research output.

Signed. *(signature)* 13/11/18

Professor Mohammad Masoum	x					x

I acknowledge that these represent my contribution to the above research output.

Signed. *(signature)* NOV. 24, 2018
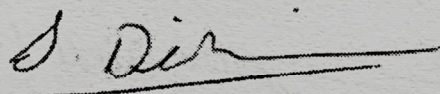
Deilami. S, Masoum A.S, Masoum. M.A.S, Abu-Siada A, Islam. S.M. (2014). Optimal Scheduling of LTC and Switched Shunt Capacitors in Smart Grid Concerning Overnight Charging of Plug-in Electric Vehicles. *Applied Engineering Sciences*, ed. Wei Deng, 65-70. London UK, CRC Press is part of The Taylor & Francis Group: CRC Press, 2014. (Book Chapter).
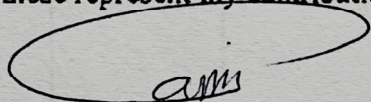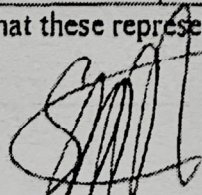
	conception & design	acquisition of data & method	data conditioning & manipulation	analysis & statistical method	Interpretation & discussion	Final Approval
Sara Deilami	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed. _S. Dei_____ NOV. 26/11/18						
Amir Masoum		x				x
I acknowledge that these represent my contribution to the above research output. Signed. _ams_ 16/1/2018						
Professor Mohammad Masoum	x				x	x
I acknowledge that these represent my contribution to the above research output. Signed. _Mr_ Nov. 24, 2018						
Professor Syed Islam	x					x
I acknowledge that these represent my contribution to the above research output. Signed.						
Associate Professor Abu- Siada	x				x	x
I acknowledge that these represent my contribution to the above research output. Signed. _A. Siada_						
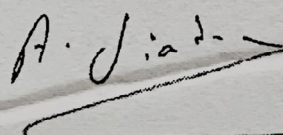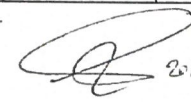
Deilami. S, Naghibi. B, Janfeshan. K. (2014). LTC and Switched Shunt Capacitor Scheduling in Smart Grid with Electric Vehicles and Wind Distributed Generation Systems. *Australasian Universities Power Engineering Conference (AUPEC 2014)*, Perth, WA, Australia, 1-6.
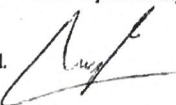
	conception & design	acquisition of data & method	data conditioning & manipulation	analysis & statistical method	interpretation & discussion	Final Approval
Sara Deilami	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed. $\quad$ S. Dei— 26/11/18						
Bahman Naghibi					x	x
I acknowledge that these represent my contribution to the above research output. Signed. $\quad$ 2018/10/16						
Keyhaneh Janfeshan					x	x
I acknowledge that these represent my contribution to the above research output. Signed. $\quad$ 11/11/18						

Moghbel. M., Masoum. M.A.S., Fereidouni. A., Deilami. S. "Optimal Sizing, Siting and Operation of Custom Power Devices with STATCOM and APLC Functions for Real-Time Reactive Power and Network Voltage Quality Control of Smart Grid."

	conception and design	acquisition of data & method	data conditioning & manipulation	analysis & statistical method	interpretation & discussion	Final Approval
Moayed Moghbel	x	x	x	x	x	x

I acknowledge that these represent my contribution to the above research output.

Signed. _[signature]_ 16/10/18

Professor Mohammad A.S Masoum	x				x	x

I acknowledge that these represent my contribution to the above research output.

Signed. _[signature]_ Nov. 24, 2018

Alireza Fereidouni	x				x	x

I acknowledge that these represent my contribution to the above research output.
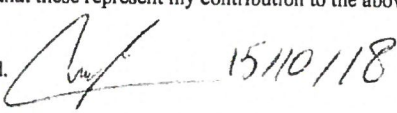
Signed. _[signature]_ 16/10/2018

Sara Deilami	x				x	x

I acknowledge that these represent my contribution to the above research output.

Signed. _[signature]_ 26/11/18

Deilami. S, Masoum. M.A.S, Moghbel. M. (2016). Derating Active Power Filters Considering Network and Bus Voltage Total Harmonic Distortions. *IEEE EEEIC 2016*.

	conception and design	acquisition of data & method	data conditioning & manipulation	analysis & statistical method	interpretation & discussion	Final Approval
Sara Deilami	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed. *S. D~~ 26/11/18*						
Professor Mohammad A.S Masoum	x					x
I acknowledge that these represent my contribution to the above research output. Signed. *Soft Mos~ MA 3 Nov 24, 2018*						
Moayed Moghbel					x	x
I acknowledge that these represent my contribution to the above research output. Signed. *15/10/18*						

Authors' contributions of: "Hybrid Islanding Detection in Microgrid with Multiple Connection Points to Smart Grids using Fuzzy-Neural Network"

Dear all,

Thanks! I really appreciate the time and effort you put into this article. It could not be done without your help.

Based on speaking with all, I reckon we can share contributions of this article as below:

Saman Darvish Kermany: 40%

Professor Mahmood Joorabian: 25%

Doctor Sara Deilami: 25%

Professor Mohammad A. S. Masoum: 10%

If you have any other idea please let me know.

This is my pleasure to write other articles together in future.

Best regards

Saman Darvish

Appendix B   Additional Publications by Applicant

"Publications have been removed due to copyright restrictions".