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ANALYSIS OF GENERATOR RATINGS ON INERTIA AND FREQUENCY RESPONSE IN POWER SYSTEMS

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ANALYSIS OF GENERATOR RATINGS ON INERTIA AND FREQUENCY RESPONSE IN POWER SYSTEMS

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A dissertation submitted in partial fulfilment of the requirements for the degree of Master of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

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2018

DECLARATION

I declare that this thesis entitled "Analysis of Generator Ratings on Inertia and Frequency Response in Power Systems" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....

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Date : 18/9/2018

APPROVAL

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of scope and quality for the award of Master of Electrical Engineering (Industrial Power).

Signature : ....

Name : Dr. Norhafiz Bin Salim

Date : 18/9/18

DEDICATION

I dedicate my dissertation work to my family and all my friends who help me to get my master. A special feeling of gratitude to my loving parents, Fatimah Hizam and Ahmed Qaid whom words of encouragement and a push for tenacity to improve myself throughout all my walks of life. Thank you for giving me a chance and supporting me since I was child till now. Without you, I could not have gone that far, therefore, I will be forever grateful to you and I love you.

I also dedicate this dissertation to my beloved son Ahmed, and all my brothers have supported me through my study. I always miss and cherish the memories that we had. I love all of you.

Finally, and most importantly, a lovely thanks to my best friend and beloved wife, Lamia Abdulaghani, for always being for me. Arriving at this point would not have been possible without the stability and love she provided me. Her patience is the meaning of love, kindness and gentle soul, and thus, I love you and I will be grateful forever to you.

ABSTRACT

The increasing share of renewable generation integrated in the traditional power systems network has brought new challenges to the utility. More specifically, the high penetration of solar energy in the network will reduce the total system inertia which could jeopardize the system's stability during contingency. The lack of inertia in the power system will increase the rate of change of frequency (ROCOF). Moreover, the primary frequency response (PFR) should react fast after the contingency event and if it happens the PFR should response to prevent system blackout. In this dissertation the effects of generator ratings on inertia and frequency response in power systems have been analysed and discussed. Moreover, the impact of increasing solar photovoltaic (PV) penetration level on the frequency stability and response has been illustrated. The IEEE 9 bus test system and IEEE 39 bus New England system have been utilized in this dissertation to model the system's inertia response under various contingency scenarios. The results show that the small rating of generators can achieve higher inertia response as compared to the case with larger generator rating. This implies that system with small rating generator can better recover the system frequency than the large-scale generators of similar total rating. Furthermore, the results suggest that the increasing share of solar generation in the generation mix will result in the reduction of total system inertia. Hence the system becomes more susceptible to disturbance and contingency events. The presented study also shows that the system will collapse during the worst case contingency situation when the solar PV penetrations are over 40% of the system's generating capacity.

ABSTRAK

Peningkatan peningkatan tenaga diperbaharui ke dalam rangkaian system kuasa konvensional memberi suatu cabaran kepada pihak utiliti. Secara khususnya, dengan kapasiti masukkan yang tinggi daripada tenaga solar ke dalam rangkaian kuasa, kesannya ia akan mengurangkan jumlah inertia sistem serta menjejaskan kestabilan sistem semasa berlakunya kontigensi. Pengurangan sistem inertia secara tidak langsung mengakibatkan peningkatan kadar perubahan frekuensi. Selain itu juga tindakbalas utama frekuesi seharusnya bertindak pantas sejurus berlakunya kontingensi dan akan cuba untuk mengelakkan berlakunya kehilangan sistem secara total. Di dalam disertasi ini, kesan kadaran penjana terhadap inertia dan respon frekuensi di dalam sistem kuasa telahpun dibincang dan dianalisa. Di samping itu, impak peningkatan penggunaan tenaga solar telah diambil kira terhadap kestabilan frekuensi dan dipaparkan sewajarnya. Penggunaan sistem rangkaian IEEE 9 bas dan IEEE 39 bas telah digunapakai untuk pemodelan sistem tindakbalas inertia untuk beberapa senario kontingensi. Keputusan akhir menunjukkan bahawa saiz penjana yang kecil akan memberikan inertia yang lebih tinggi berbanding dengan saiz penjana yang besar walaupun mempunyai tahap kadaran yang sama. Selain itu, keputusan kajian ini mencadangkan bahawa peningkatan bahagian penjanaan solar dalam campuran penjanaan akan mengakibatkan pengurangan inertia keseluruhan sistem. Oleh itu sistem menjadi lebih terdedah terhadap gangguan dan kontigensi. Kajian juga menunjukkan bahawa sistem akan jatuh untuk kes paling teruk apabila kadar partisipasi solar PV melebihi daripada 40% jumlah kapasiti penjanaan sistem.

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TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	**i**
ABSTRAK	**ii**
ACKNOWLEDGMENTS	**iii**
TABLE OF CONTENTS	**iv**
LIST OF TABLES	**vii**
LIST OF FIGURES	**ix**
LIST OF APPENDICES	**xii**
LIST OF ABBREVIATIONS	**xiii**
LIST OF PUBLICATIONS	**xv**
CHAPTER	
1 INTRODUCTION	**1**
1.1 Research Background	1
1.2 Problem Statements	4
1.3 Objectives of Research	6
1.4 Scope of the Study	6
1.5 Contributions of Research	7
1.6 Structure of the Thesis	7
1.7 Summary	8
2 LITERATURE REVIEW	**9**
2.1 Introduction	9
2.2 Literature Studies	9
2.3 Power System Stability	12
2.3.1 Frequency Stability in Power System	13
2.3.2 Frequency Metrics	15
2.3.2.1 Frequency Nadir	15
2.3.2.2 Frequency Nadir Time	16
2.3.2.3 Settling Frequency	16
2.4 Frequency Response on the Power System	17
2.4.1 Inertial Response (Inertia Constant, H)	19
2.4.1.1 Primary Frequency Response	20
2.4.1.2 Secondary Frequency Response	22
2.5 Inertia in Power System	23
2.5.1 Inertia in Renewable Energy Sources	25
2.5.2 Virtual Inertia	27
2.6 Impact of RES on Frequency Stability in Different Countries and Systems	28
2.6.1 Nordic System	28
2.6.2 United Kingdom System	29
2.6.3 Ireland Region System	30
2.6.4 North America System	31
2.6.5 Great Britain System	31
2.6.6 Australia System	33

2.6.6.1 South Australia 35
2.7 Summary 38

3 **MODELLING AND SIMULATION** **39**
3.1 Introduction 39
3.2 Swing Equation 39
3.2.1 Inertia Constant 41
3.2.2 The Rate of Change of Frequency (ROCOF) 42
3.3 Research Process 43
3.4 Simulation Tool 45
3.5 IEEE 9 bus Test System Model 45
3.6 IEEE 39 bus New England Test System Model 47
3.7 Model Parameters for Stability Analysis in DIgSILENT PowerFactory 48
3.7.1 Modeling of Loads 49
3.7.2 Modelling of Generators 49
3.7.3 Modelling of Controller 52
3.7.3.1 Automatic Voltage Regulator (AVR) 53
3.7.3.2 Power System Stabilizer (PSS) 56
3.7.3.3 Governor 59
3.7.4 Modeling of Transmission Lines 64
3.7.5 Modelling of Transformers 65
3.7.6 Solar Photovoltaic Generation Modelling 66
3.8 Simulations and Calculation for the IEEE 9 Bus System 69
3.8.1 Load Flow Calculation 69
3.8.2 Performing Load Flow Calculation 70
3.8.3 Result of Load Flow Analysis 70
3.8.4 Stability Studies RMS Simulation 72
3.9 Results Validation of DIgSILENT IEEE 9 & 39 Bus Systems with IEEE Society 73
3.10Frequency Response Analysis After Losing A Generation 76
3.10.1 Effects of Generator Rating in Inertia and Frequency Response After Losing Generation on IEEE 9 Bus System 77
3.10.2 Impact of Replace Generators with the Solar PV on Frequency Response 79
3.10.2.1 Replacing the IEEE 9 Bus System Generators with Solar PV 79
3.10.2.2 Replacing the IEEE 39 Bus System Generators with Solar PV 81
3.11Summary 83

4 **RESULTS AND DISCUSSION** **84**
4.1 Introduction 84
4.2 Frequency Response Verification in IEEE 9 Bus System After Losing Generation85
4.2.1 Frequency Response After Losing Largest Generator Capacity 86
4.2.2 Frequency Response After Losing the Smallest Generator Capacity 88
4.3 Frequency Response Verification in IEEE 39 Bus After Losing Generation 89
4.3.1 Frequency Response After Losing the Largest Generator Capacity 91
4.3.2 Frequency Response After Losing the Smallest Generator Capacity 92
4.4 Effect of Generator Rating on Inertia and Frequency Response After Losing A Generator in IEEE 9 Bus Test System 94
4.4.1 Scenario 1 95
4.4.2 Scenario 2 98
4.4.3 Scenario 3 100

4.5 Impact of Replacing Conventional Generators with Solar PV System on the Frequency Response After Losing Generation 103
4.5.1 Replacing the IEEE 9 Bus System Generators with Solar PV System 104
4.5.2 Replacing of the IEEE 39 Bus System Generators with Solar PV System 106
4.6 Summary 109

5 CONCLUSION AND FUTURE WORKS 111
5.1 Conclusion 111
5.2 Significance of Research Findings 115
5.3 Recommendation for Future Works 115

6 REFERENCES 117
7 APPENDIX A 128
8 APPENDIX B 131
9 APPENDIX C 134

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Inertia constant, H for different generator turbine (Musau et al.,2017)	19
2.2	Previous events of complete loss of the Heywood Interconnector due to generation disconnection in SA illustrate the inertia decline (AEMO, 2017)	38
3.1	IEEE 9 bus system load demand	49
3.2	Generator data in the PowerFactory model based on their rated power	50
3.3	Generator Data for Inertia Calculation	51
3.4	Different values of generators rating for IEEE 9 bus system with inertia, H	52
3.5	Description of the parameter for the AVR IEEE type 1	54
3.6	Parameter definition for PSS control (DIgSILENT, 2015)	56
3.7	Description for steam turbine governor IEEE Type 1 parameters	60
3.8	Description of hydro turbine governor IEEE Type 3 parameters	62
3.9	Transmission line data in PowerFactory model (DIgSILENT, 2015)	64
3.10	Data of Transformers used in IEEE 9 bus system (DIgSILENT, 2015)	66
3.11	Static solar PV generator technical data (DIgSILENT, 2015)	67
3.12	IEEE 9 bus system generators dispatch (DIgSILENT, 2015)	72
3.13	Generators validation of DIgSILENT 9 bus system versus IEEE standard	73
3.14	Bus validation of DIgSILENT 9 bus system versus IEEE standard	74

3.15 Generation summary results validation of DIgSILENT 9 bus system versus IEEE standards 74

3.16 Generation summary results validation of DIgSILENT 39 bus system versus IEEE standards 75

3.17 Power and inertia data used in scenarios for each generator 79

3.18 Data of the generator replaced with solar PV system in IEEE 9 bus system 80

3.19 Scenarios of replacing generators with solar PV in IEEE 9 bus system 81

3.20 Data of the generator replaced with solar PV system in IEEE 39 bus system 81

3.21 Scenarios of replacing generators with solar PV in IEEE 39 bus system 82

4.1 Results of Scenario 1 96

4.2 Results of Scenario 2 99

4.3 Results of Scenario 3 101

4.4 Results of inertia & injected power after losing G2 in IEEE 9 bus system with different solar PV penetration 106

4.5 Results of the frequency response after losing G2 in the IEEE 9 bus system with different solar PV penetration 106

4.6 Results of inertia & injected power after losing G9 in IEEE 9 bus system with different solar PV penetration level 108

4.7 Results of the frequency response after losing G9 in the IEEE 39 bus system on different solar PV penetration level 109

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Global Photovoltaic System Capacity 2007- 2022	2
1.2	Evolution of Power System Grid (Tamrakar et al., 2017)	3
2.1	The Power System Stability Classification (Kundur et al., 2004)	13
2.2	Power System Frequency Ranges During Normal Operations and After Contingency Event (Eto et al., 2018)	15
2.3	Description Frequency Response Performance Metrics	16
2.4	Frequency Response Stage and Their Time Scale (Eto et al., 2018)	17
2.5	Inertia Constant for Conventional Generators	20
2.6	Delicate Balance Illustration Between Electricity Demand and Production, with Rotating Inertia as A Spooler with Certain Energy Stored	24
2.7	Annually Period Curves of The ROCOF at A High Renewable Scenario in Great Britain (Smith, 2015)	32
2.8	Annually Period Curves of the Inertia at A High Renewable Scenario in Great Britain (Smith, 2015)	33
2.9	Inertia Distribution of the South Australian Network (AEMO, 2013)	35
2.10	Frequency Response during the South Australian Blackout (AEMO, 2016)	36
3.1	Flowchart of Methodology for Analysing the Influence Contingencies on the Power Frequency Response	44

3.2	Single Line Diagram of IEEE 9 Bus Test System	46
3.3	Sigle Line Diagram of IEEE 39 Bus New England System	48
3.4	Inertia Constant in Different Power Rated MVA	51
3.5	Block Diagram for AVR IEEE Type 1 Excitation System	55
3.6	Block Diagram for Power System Stabilizer Model (DIgSILENT, 2015)	58
3.7	Block Diagram for Governor Steam Turbine Model IEEE Type 1	61
3.8	Block Diagram for Governor Hydro Turbine Model IEEE Type 3	63
3.9	Static Solar PV Generation Symbol in PowerFactory Network	67
3.10	Block Diagram of Solar PV Static Generator Model in PowerFactor	68
3.11	The IEEE 9 Bus Network Colour Standards After Load Flow Calculation	71
3.12	The IEEE 9 Bus System Generation Summary	74
3.13	The IEEE 39 Bus System Generation Summery	75
3.14	Losing of a Single Generator Contingency Event	77
3.15	IEEE 9 Bus Grid After Replacing Conventional Generators with Solar PV	80
4.1	IEEE 9 Bus System Frequency Behaviour in Steady State	85
4.2	IEEE 9 Bus System Active Power in Steady State	86
4.3	Frequency Response After Losing Generator G2	87
4.4	Active Power After Losing Generator G2	87
4.5	Frequency Response after Losing Generator G3	88
4.6	Active Power After Losing Generator G3	89
4.7	IEEE 39 Bus System Frequency Behaviour in The Steady State	90
4.8	IEEE 39 Bus System Active Power in Steady State	90
4.9	Frequency Response After Losing Generator G9	91
4.10	Active Power After Losing the Generator G9	92

4.11	Frequency Response after Losing Generator G10	93
4.12	Active Power after Losing the Generator G10	93
4.13	Result of Frequency Response for Scenario 1	95
4.14	Result of Inertia Constant in Scenario 1	97
4.15	Result of ROCOF in Scenario 1	97
4.16	Result of Frequency Response for Scenario 2	98
4.17	Results of Inertia Constant in Scenario 2	99
4.18	Results of ROCOF in Scenario 2	100
4.19	Result of Frequency Response for Scenario 3	101
4.20	Results of Inertia Constant in Scenario 3	102
4.21	Results of ROCOF in Scenario 3	102
4.22	IEEE 9 Bus System Frequency Behaviour in Steady State After Replacing the Conventional Generator with 49% Solar PV System	103
4.23	Frequency Response After Losing G2 in Different Solar PV System Penetration on IEEE 9 Bus System	104
4.24	Frequency Response After Losing G9 in Different Solar PV System Penetration on IEEE 39 Bus System	107

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	The Technical Data Sheet for IEEE 9 & 39 Bus Test System	128
B	Result Validation of IEEE 9 & 39 Bus System with IEEE Society	131
C	Results Report of Load Flow and RMS Simulation from DIgSILENT 15.2 tool	134

LIST OF ABBREVIATIONS

AEMC	-	Australian Energy Market Commission.
AVR	-	Automatic Voltage Regulator
DIgSILENT	-	Digital Simulation and Electrical Network
DSL	-	DIgSILENT Simulation Language
ENTSO-E	-	European Network of Transmission System Operators for Electricity
ERCOT	-	Electric Reliability Council of Texas
FR	-	Frequency Response
GOV	-	Governors
GW	-	Gigawatt
Hz	-	Hertz
IEEE	-	Institute of Electrical and Electronic Engineering
IR	-	Inertial Response
MW	-	Megawatts
NERC	-	North American Electric Reliability Corporation
P	-	Active power
P.U	-	Per Unit
PES	-	IEEE Power and Energy Society
PF	-	Power Factory Software
PFR	-	Primary Frequency Response
PSDPC	-	IEEE Power System Dynamic Performance Committee
PSS	-	Power System Stabilizer

PV	-	Photovoltaic
Q	-	Reactive power
QSS	-	Quasi-Steady state
RES	-	Renewable Energy Source
RMS	-	Root Mean Square
ROCOF	-	Rate of Change of Frequency
SA	-	South Australia
SFR	-	Secondary Frequency Response
SOF	-	System Operability Framework

LIST OF PUBLICATIONS

1. Khaldon Ahmed Qaid, Chin Kim Gan, Norhafiz Bin Salim, Meysam Shamshiri, *"Effect of Generator Ratings on Inertia and Frequency Response in Power System"*, Postgraduate Research Conference *PReCON 2018, Melaka, Malaysia, 2018.*

   (Published)

2. Khaldon Ahmed Qaid, Chin Kim Gan, Norhafiz Bin Salim, Meysam Shamshiri, *"Impact of Large-scale Solar Photovoltaic Generation on Power System Frequency Response"*, *CEAT 2018* International Conference on Clean Energy and Technology, *Kuala Lumpur, Malaysia, 2018.*

   (Accepted)

CHAPTER 1

INTRODUCTION

1.1 Research Background

Worldwide fossil fuel power stations release around 10 billion tons of carbon dioxide CO_2 to the air annually (Quéré et al., 2016). This has led to the environmental pollutions and the pressing global warming. These challenges have brought together the governments around the world to establish common goals for reducing greenhouse gases emissions. One of the concerted initiatives is to increase the use of renewable energy sources (RES) in their electrical power networks (Dreidy, Mokhlis & Mekhilef, 2017). For instance, China has established a goal for generating over 15% of its total power from renewable energy sources by 2020 with 30 GW of biomass, 200 GW of wind, 50 GW solar photovoltaic (PV), and 420 GW from hydro. In terms of PV system, Chinese PV demand exceeded 34 GW of the installed capacity in 2016 and has reached to over 78 GW. It is interesting to note that the global PV installed capacity now tops 306.4 GW as reported in (Attia & Heggarty, 2017) and shown in Figure 1.1. The author of (National Grid, 2015) has reported that the growing number of renewable energy sources in the United Kingdom could decrease the inertia constant by up to 70% from 2013 to 2033. These strategies are critical to addressing the large rise in world energy demand while at the same time decreasing the quantity of pollutions. However, the reliability of the whole electrical system may decrease due to the high integration of intermittent RES which could cause short term network stability problem (Sawin *et al.*, 2012).

The fast expansion of RES is instigating the electrical power networks to go towards the inverter dominated power system from a rotational conventional generator dominated system, as shown in Figure 1.2. Solar photovoltaic systems and most modern wind turbines are connected to the main grid through inverters. The inverter-based generation does not provide any mechanical inertial response and hence compromises frequency stability, this is considered as advantageous from the harvesting RES point-of-view and disadvantageous from the stability point-of-view (Tamrakar *et al.*, 2017).

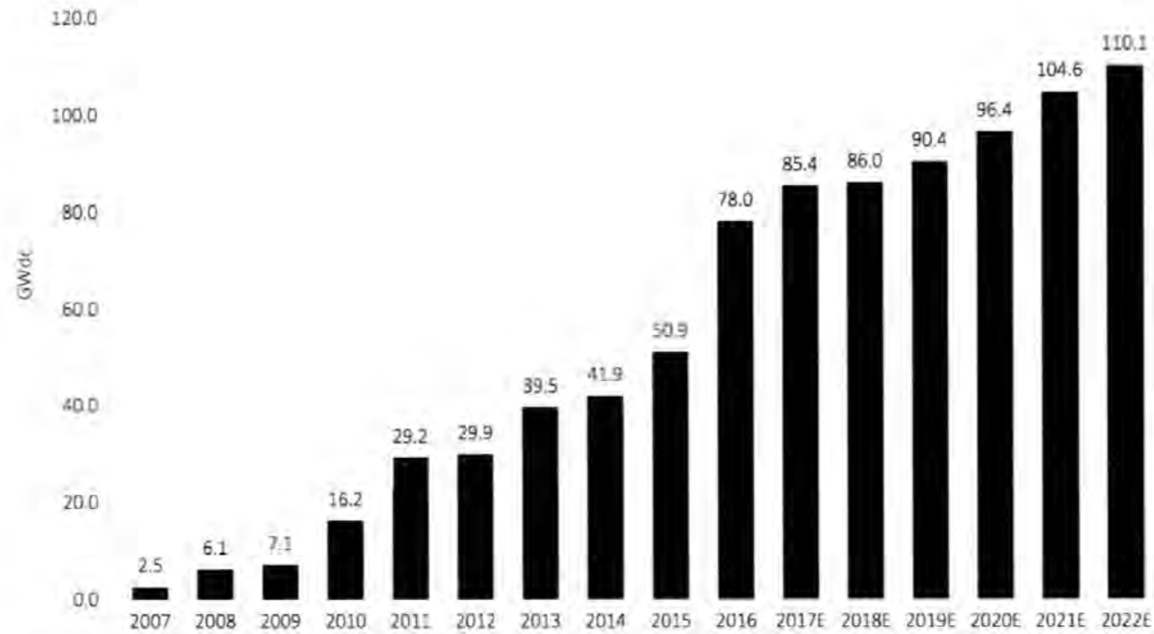

Figure 1.1: Global Photovoltaic System Capacity 2007- 2022 (Attia & Heggarty, 2017)

The critical frequency stability challenges will appear on very high RES penetration (Bevrani, Ghosh & Ledwich, 2010). This is because the inertial response in RESs is naturally low for wind turbines and non-existent such PV solar systems (Dehghanpour & Afsharnia, 2015). For instance, to effectively decouple the wind turbine inertia from relieving system transients, the wind turbine's unstable speed is normally linked to the electrical grid across power electronic converter device. In addition, there is no inertia response provides to the power system from the solar photovoltaic systems, that because there is no rotational part in the PV system. Consequently, the power grid total inertia will decrease when replacing conventional sources with the renewable energy resources.

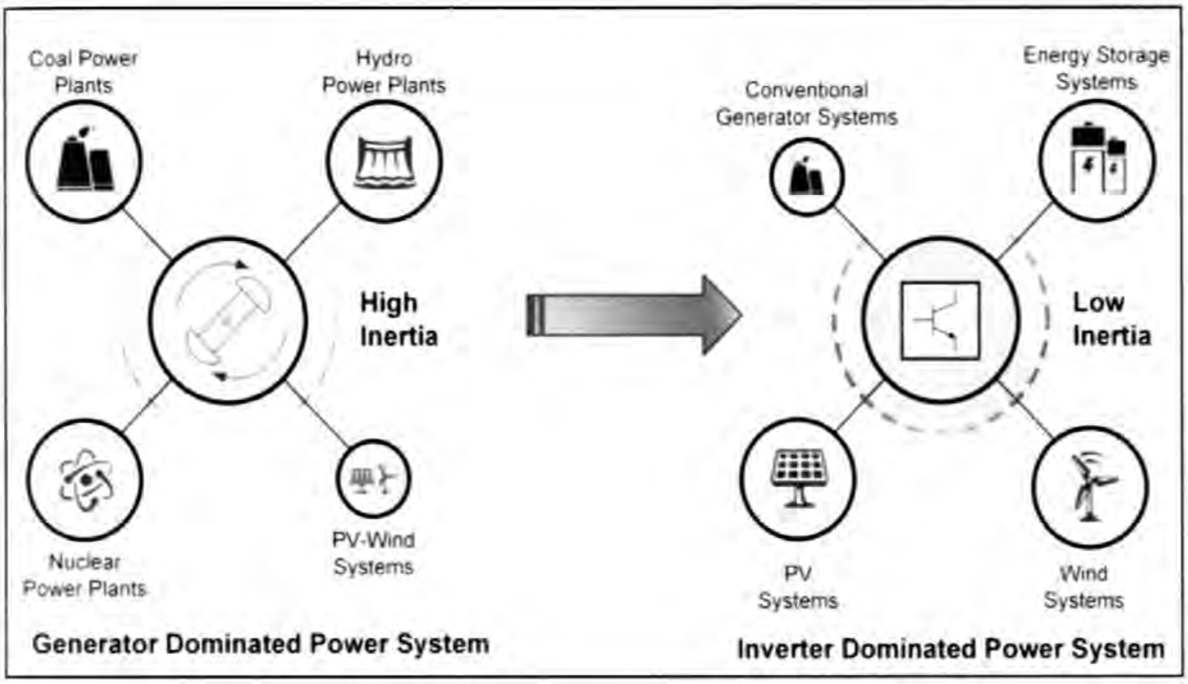

Figure 1.2: Evolution of Power System Grid (Tamrakar *et al.*, 2017)

In a power system which is characterised by low system inertia, the rate of change of frequency (ROCOF) will be sufficiently high to mal-trip the frequency relay in load shedding condition. Therefore, decreasing of system's inertia constant might cause system blackout during a contingency. As reported in (Jayawardena, *et al*, 2012), when the percentage of the installed capacity of RESs increases, the inertial constant will decrease. This will lead to the increase of ROCOF in the power system. Moreover, due to the increase in the penetration level of the RESs, the number of conventional generation units supplying reserve capacity power for primary and secondary frequency response will decrease, consequently, the frequency deviation will be increased. Therefore, the future RESs should incorporate some new forms of frequency control methods. This is to enable the contribution of frequency regulation service by the RES (Ulbig, Borsche & Andersson, 2014).

This dissertation presented the effect of generator rating on frequency stability and inertia constant after contingencies. In this regard, the IEEE 9 bus test system and the IEEE 39 bus New England system are modelled in DIgSILENT 15.2 tool to study the impacts of different generator rating on frequency response. Moreover, the effect of the integration of large-scale PV system in the frequency response and stability will be illustrated in this dissertation.

1.2 Problem Statements

The increased penetration of renewable energy resources with power electronics converters shows the marked impact on system stability. Subsequent a large contingency occurs in the grid such as generator losing or sudden loading, the reinstating force that brings the frequency of the affected network back to its nominal value is related to the synchronizing generators and the inertia interaction of the whole system. In the case of renewable resources based on power electronics devices, the electrical power produced is completely controlled by the converter device. After an electrical contingency event, the converter device rapidly controls the generation unit to return its power output to the nominal value same as before contingency, thus limiting the possible inertial response of the other generators from the network. Hence, with the increase of renewable energy resources penetration, the effective inertia of the system is noticeably decreased, thus, potentially affecting the system dynamic performance.

The inertia lack disturbs the power system network after a contingency event occurs in two ways: First, the kinetic energy stored in the whole system will decrease and the inertia time constant for each generator will decrease. Secondly, the rate of change of frequency