MODELING AND SIMULATION OF GRID-CONNECTED SOLAR PHOTOVOLTAIC SYSTEMS WITH D-STATCOM AND DVR TO IMPROVE STABILITY IN DISTRIBUTION SYSTEM

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Special dedication to my beloved parents,

Abd Rashid bin Ahmad, Anis binti Iberahim

My honorable supervisor,

Dr. Siti Amely binti Jumaat

My fellow friends

Thank you

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ABSTRACT

Electrical utilities face problems such as the rising cost of electricity, aging equipment, increasing demand for electricity, regulating frequency, and the difficulties of incorporating renewables into the grid. The accumulated global photovoltaic (PV) particularly the installation of Grid-Connected Solar Photovoltaic (GCPV) systems has been exponentially expanding around the world. However, as the PV penetration and global PV market have recently grown, there are challenges to the utility companies regarding the power quality and the reliability of the system. This is because the integration of power electronics has raised concerns about the safe operation and protection of the equipment. Hence, the feasible solution to solve these problems is installing Distributed Flexible AC Transmission System (D-FACTS) devices to the distribution grid through the point of common coupling (PCC). The purpose of this project is to model and simulate 100 kW and 250 kW solar PV systems that are connected to the utility distribution system with and without Distribution Static Synchronous Compensator (D-STATCOM) and Dynamic Voltage Restorer (DVR) under normal and faults condition in MATLAB/ Simulink. The test systems consist of a PV array that is connected in series and parallel modules, a DC-DC Boost Converter, Maximum Power Point Tracking (MPPT) control, DC-AC inverter, inverter control, filter, three-phase load, distribution transformer, and grid equipment. The grid operates test systems I and II at the nominal three-phase line to line voltage of 260 V, supplied from 100 kVA and 250 kVA 25/ 0.26 kV distribution transformer. The test system I and II are tested with the Perturb and Observe technique. The simulation results showed that the installation of D-STATCOM and DVR in GCPV systems improved 80-90% of the output power from the PV systems, and stabilized the level of the RMS voltage and current within 5% of its nominal value at the distribution feeder under normal and fault conditions. The implementation of D-FACTS devices in GCPV systems will be beneficial for future power system stability studies in the distribution system.

ABSTRAK

Utiliti elektrik menghadapi masalah seperti kenaikan kos elektrik, kerosakan peralatan, permintaan elektrik yang meningkat, kekerapan mengatur, dan kesukaran memasukkan tenaga boleh diperbaharui ke dalam grid. Fotovoltaik global terkumpul terutamanya pemasangan sistem penyambungan grid solar fotovoltaik telah berkembang pesat di seluruh dunia. Namun, peningkatan dan pemasaran fotovoltaik pada peringkat global baru-baru ini berkembang, terdapat cabaran bagi syarikat utiliti berkenaan dengan kualiti kuasa dan kebolehpercayaan sistem. Ini kerana penyambungan elektronik kuasa telah menimbulkan kesulitan mengenai operasi dan perlindungan peralatan yang selamat. Oleh itu, penyelesaian yang dapat dilaksanakan untuk menyelesaikan masalah ini ialah memasang peranti Sistem Transmisi AC Fleksibel Terdistribusi ke grid pengedaran melalui titik gandingan biasa. Tujuan projek ini adalah untuk memodelkan dan mensimulasikan sistem PV solar 100 kW dan 250 kW yang disambungkan ke sistem pengagihan utiliti dengan dan tanpa D-STATCOM dan DVR dalam keadaan normal dan kerosakan dalam MATLAB/ Simulink. Sistem ujian terdiri daripada array PV yang disambungkan secara bersiri dan modul selari, DC-DC penukar rangsangan, kawalan MPPT, penyongsang DC-AC, kawalan penyongsang, penapis, beban tiga fasa, pengubah distribusi , dan peralatan grid. Grid mengoperasikan sistem ujian I dan II pada voltan talian fasa tiga hingga nominal 260 V, yang dibekalkan dari 100 kVA dan 250 kVA 25 / 0.26 kV pengubah pengedaran. Sistem ujian I dan II diuji dengan teknik “Perturb and Observe”. Hasil simulasi menunjukkan bahawa pemasangan D-STATCOM dan DVR dalam sistem GCPV meningkatkan 80-90% kuasa output dari sistem PV, dan menstabilkan tahap voltan dan arus RMS dalam lingkungan 5% dari nilai nominalnya pada pengedaran pengumpan dalam keadaan normal dan kesalahan. Pelaksanaan peranti D-FACTS dalam sistem GCPV akan bermanfaat untuk kajian kestabilan sistem kuasa masa depan dalam sistem pengagihan.

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LIST OF SYMBOLS AND ABBREVIATIONS

ω	–	Resonant Frequency
K_p	–	Proportional Gain
K_i	–	Integral Gain
i_L	–	Load Current
i_s	–	Source Current
i_f	–	Injected Current
V_s	–	Voltage Source
V_{dc}	–	DC-Link Voltage
AC	–	Alternate Current
DC	–	Direct Current
PV	–	Photovoltaic
DG	–	Distributed Generation
RMS	–	Root Mean Square
DVR	–	Dynamic Voltage Restorer
PCC	–	Point Common Coupling
PWM	–	Pulse Width Modulation
VSI	–	Voltage Source Inverter
CSI	–	Current Source Inverter
MPPT	–	Maximum Power Point Tracking
FACTS	–	Flexible AC Transmission System
VSC	–	Voltage Source Converter
VSG	–	Virtual Synchronous Generator
SVC	–	Static VAR Compensator
PSO	–	Particle Swarm Optimization
RCC	–	Ripple Correlation Control
PLL	–	Phase-Locked Loop
KCL	–	Kirchoff Current Law

IGBT	–	Insulated Gate Bipolar Transistor
GCPV	–	Grid-Connected Photovoltaic
UPFC	–	Unified Power Flow Controller
UPQC	–	Unified Power Quality Controller
MOSFET	–	Metal Oxide Semiconductor Field Effect Transistor
D-FACTS	–	Distributed Flexible AC Transmission System
D-STATCOM	–	Distributed Static Compensator

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Traditionally, large power plants use fossil fuels to generate electricity. Each power grid consists of three major parts which are generation, transmission, and distribution. Electric energy is generated by large generators, transmitted to load sites by the transmission system, and then distributed among loads by the distribution systems. The generation of electric energy typically is performed in large power plants that are located outside of cities. Then, the generated power is transferred to loads through long transmission lines. These power lines have many loops to increase reliability and carry large amounts of power to the distribution systems. Distribution systems consist of smaller lines that carry smaller amounts of power from distribution stations to the loads, ranging from small residential customers to large industrial factories. These systems usually take advantage of radial structures and act as the interconnection point between transmission systems and customers.

Recently, renewable energy systems have become more prominent in electricity production has been on the rise globally. Examples of renewable energy sources are wind, solar, biomass, geothermal, and hydroelectric. Among them, solar PV systems are one of the fastest-growing renewable energy-based distributed generators that are getting integrated into distribution networks [1]. Renewable energy systems offer several advantages over conventional energy sources such as natural gas or coal. Renewable energy systems are clean sources of energy found in most regions, emit no greenhouse gases, abundant, free, and generally not affected by political instability. Although the initial capital cost for most renewable energy sources is greater than conventional natural gas or coal power plants, renewables may be more cost-effective long term as compared to conventional sources because of lower operating and maintenance costs. However, renewable sources also have several disadvantages, including the primary disadvantages that they are commonly located in remote areas at great distances from large loads. The need for cleaner, greener energy has led to improvements in the capture of renewable energies to produce power. Most energy is produced and transmitted through power lines to the loads, it means great loss as well as the cost for operation and maintenance. Conversely, the theory that the end customer need not be a passive load but an active supplier of energy has produced the method of using distributed generation (DG) to the power systems. In this project, solar energy can be locally connected to the grid. Renewable energy sources cannot support the entire power demand, but they can be added to the main grids to help feed the loads.

Power electronic based flexible AC transmission systems (FACTS) have been developed to enhance control of active and reactive power transfer on feeder lines. FACTS components are the most efficient and economical method to control power transfer in interconnected AC transmission systems. FACTS systems include a wide range of power electronic devices used in power systems to ensure secure power transmission in the AC system [2], [3]. The most well-known FACTS devices that are applied to distribution systems are D-STATCOM and DVR. Conceptually, D-STATCOM and DVR are power electronic devices based on a VSC principle. D-FACTS devices are placed between the renewable energy source and the distribution grid to coordinate power, stabilize voltage and current level, and improve power quality problems.

1.2 Problem statement

I. Currently, power suppliers face problems such as rising fuel prices, aging equipment, energy demand, frequency control, and the difficulty of incorporating renewables into the grid. The presence of PV in the grid has also dramatically increased in recent years. However, with the recent growth in PV penetration and the success of the global PV industry, there are some challenges for grid integration of PV systems [4].

II. Some of the main issues are the output power variations of solar PV power relies on solar irradiance and temperature. Since these variables vary based on environmental conditions, the output power of the solar PV systems would change and contribute to voltage and frequency fluctuations in the power grid. Second, high solar PV penetration also affected power system stability. Since the solar PV devices are connected to the grid through a static converter such as power converters without physical inertia. Third, distributed solar PV power generation results in power quality issues. For example, harmonics and flicker in power networks. The harmonics are generated with the solar PV systems which affect power quality in power grids as they are equipped with inverters. Another effect of an increased solar PV penetration is the voltage swells and sags in the distribution feeder. This is due to the intermittent solar PV power output that may contribute to the transients of the system.

III. Hence, there is a need to install D-FACTS devices in grid-connected solar PV systems because it would contribute to the improvement of PV systems and increased the stability margin of voltage and current level under normal and fault conditions that happen in the grid. The implementation of D-FACTS devices in grid-connected solar PV systems will be beneficial for future power system stability studies in the distribution system.

1.3 Objectives of the project

I. To model 100 kW and 250 kW solar PV systems connected to the distribution grid.

II. To analyze the simulation of test systems I and II with and without D-STATCOM and DVR under normal and faults conditions.

III. To investigate the stability performance of D-STATCOM and DVR on the output power from PV systems, and the level of RMS voltage and current at the distribution feeder through the point of common coupling.

1.4 Scopes of the project

I. The first test system is a 100 kW PV array consists of 66 parallel strings with 5 series-connected modules per string, DC-DC Boost Converter equipped with MPPT controller, DC-AC inverter, inverter control, filter, load, distribution transformer, and grid equipment. A 100 kW PV array is connected to a 25 kV grid through a DC-DC Boost Converter and DC-AC inverter. The grid operates at the nominal three-phase line to line voltage of 260 V, supplied from 100 kVA 25/ 0.26 kV distribution transformer. This test system is tested under the Perturb and Observe technique.

II. The second test system is a 250 kW PV array consists 87 parallel strings with 7 series-connected modules per string. A 250 kW PV array is connected to a 25 kV grid via a three-phase converter. The grid operates at the nominal three-phase line to line voltage of 260 V, supplied from a 250 kVA 25/ 0.26 kV distribution transformer. This test system is tested under the Perturb and Observe technique.

III. The test systems are analyzed with and without D-STATCOM and DVR under normal and faults conditions. The three cases of short-circuit faults that happen in the grid are single line to ground, double line to ground, and three-phase to ground fault. The test systems are simulated in the Simscape Power System tool of MATLAB/ Simulink.

IV. The installation of D-STATCOM and DVR are placed to the distribution transformer through the point of common coupling (PCC). The purpose of the installation of D-STATCOM and DVR to improve output power from PV systems and keep the level of RMS voltage and current stable under normal and faults conditions.

1.5 Outline of the report

This report is divided into five chapters. Each chapter discusses the different issues related to this project. The outline of each chapter is stated in the next paragraphs.

In chapter 1, introduces the project presenting a background of the electrical grid, renewable energy sources, and D-FACTS devices, problem statement, objectives of the project, and scopes of the project.

In chapter 2, offers literature on the fundamental knowledge of grid-connected solar PV systems, power system stability studies, and working principle of D-FACTS devices in the distribution system.

In chapter 3, provides a planning framework of the project, test systems configuration analysis of grid-connected solar PV systems, and D-FACTS devices, steps on how to model, and simulate grid-connected solar PV systems, and D-FACTS devices.

In chapter 4, presents the simulation and discussion of the results of the test systems I and II under normal and faults conditions with and without D-FACTS devices.

In chapter 5, concludes the findings of this project, discusses the conclusion, and makes some recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter reflects on the existing literature of modeling for grid-connected solar PV systems with D-FACTS devices for stability analysis of the power system. Firstly, the chapter presents a review of different components and control techniques of grid-connected solar PV systems, such as MPPT algorithms, and inverters with voltage and current control strategies. Then, reviews the modeling of the solar PV systems suitable for stability analysis. Power system stability studies conducted with solar PV systems and the working principle of the D-FACTS devices are also reviewed in this chapter. The chapter ends with a summary based on the research gaps and key findings.

2.2 Previous research work

This section presents a review of few works of literature related to the electrical grid with renewable energy sources and D-FACTS devices for stability enhancement in the distribution network system.

In paper [5] suggested the improvement of the microgrid systems' power quality based on solar and wind power plant by using D-STATCOM. The finding of this study is D-STATCOM able to correct the poor power factor of the microgrid and also the fluctuation of the microgrid input voltage. Paper [6] proposed the D-STATCOM system to maintain power quality issues. The conclusion is the performance of D-STATCOM is a better compensating device for voltage fluctuation. In paper [7] investigated the voltage instability problems in distribution systems integrated with rooftop PV resources and presented a solution based on the incorporation of D-STATCOM. The conclusion of this study is the effectiveness of D-STATCOM to mitigate the voltage of the network at PCC have been verified to improve the voltage qualities. In paper [8] investigated an application of D-STATCOM to control power flow in the distribution line. The conclusion of this study is D-STATCOM based on the proposed power flow control strategy provided full or partial reactive power compensation to the distribution line. Paper [9] studied the performance of a D-STATCOM system for improving distribution system performance under all types of fault. The result showed that the charge and discharge of the capacitor are rapid through this new method and the response of the D-STATCOM is fast.

In paper [10] presented the performance of STATCOM delivered the required power to the system, maintains the frequency and voltage to be constant, and improves power quality in the system. The method used in this research is Fuzzy Controlled STATCOM along with a Battery Energy Storage System. The result of this research is the STATCOM can maintain the system parameters (V, f, P, Q) constant for different loading conditions. In paper [11] modeled and optimized a STATCOM for reactive power compensation of a microgrid and AC bus voltage regulation. The microgrid mode in this research is islanding mode. The conclusion of this study is control strategy responds to AC bus voltage fluctuations and configures the STATCOM to adjust dynamic reactive power accordingly. In paper [12] ensured stable fast-acting reactive power compensation within voltage regulation limits based on power flow in microgrids with feeders geographically spread out. The FACTS device used in this study is STATCOM. The conclusion of this study is the reactive power compensation with coordinated control of DGs and STATCOM with communication in the loop for a microgrid is improved. Paper [13] analyzed a STATCOM for voltage dip mitigation. The finding of this study is D-STATCOM provided more reliable and simple control in improving power quality. In paper [14] validated the performance of the FD-STATCOM system to mitigate power quality problems and improved distribution system performance under all types of system-related disturbances and system unbalances faults, such as line to line, and double line to ground fault and supplies power to sensitive loads under islanding condition. The conclusion is FD-STATCOM observed that the load voltage is very close to the reference value and the voltage sags are completely minimized. Also, the charge and discharge of the capacitor are fast. In paper [15] presented the improvement of power quality in grid-

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