D-STATCOM BASED TRANSIENT STABILITY IMPROVEMENT OF FUEL CELL POWER SYSTEM

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ABSTRACT

Fuel cells are one of the cleanest and most efficient technologies for generating electricity. Since there is no combustion, there are none of the pollutants commonly produced by boilers and furnaces. For systems designed to consume hydrogen directly, the only products are electricity, water and heat. Fuel cells are an important technology for a potentially wide variety of applications including on-site electric power for households and commercial buildings; supplemental or auxiliary power to support car, truck and aircraft systems; power for personal, mass and commercial transportation; and the modular addition by utilities of new power generation closely tailored to meet growth in power consumption. These applications will be in a large number of industries worldwide.

As a promising renewable energy source, fuel cell can play an important role to meet the increasing power demand worldwide. A detailed analysis of MATLAB/SIMULINK based fuel cell generation has been modeled in this proposed methodology. Along with this generation topology power electronics based flexible AC transmission system (FACTS), D-STATCOM, is introduced. The purpose of the D-STATCOM is to improve the transient stability of the fuel cell system. Different fault case scenarios are tested with the model system in order to verify the effectiveness of D-STATCOM. The stability enhancement using this control strategy has been verified by the time domain simulation model developed in MATLAB/SIMULINK

Keyword: - *D-STATCOM, Fuel cell.*

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1. INTRODUCTION

Fuel cell systems offer clean and efficient energy production and are currently under intensive development by several manufacturers for both stationary and mobile applications. The viability, efficiency, and robustness of this technology depend on understanding, predicting, and controlling the unique transient behavior of the fuel cell system. In this thesis, we employ phenomenological modeling and multivariable control techniques to provide fast and consistent system dynamic behavior. Moreover, a framework for analyzing and evaluating different control architectures and sensor sets is provided.

Two fuel cell related control problems are investigated in this study, namely, the control of the cathode oxygen supply for a high-pressure direct hydrogen Fuel Cell System (FCS) and control of the anode hydrogen supply from a natural gas Fuel Processor System (FPS). System dynamic analysis and control design is carried out using model-based linear control approaches. A system level dynamic model suitable for each control problem is developed from physics-based component models. The transient behavior captured in the model includes flow characteristics, inertia dynamics, lumped volumemanifold filling dynamics, time evolving spatially-homogeneous reactant pressure or mole fraction, membrane humidity, and the Catalytic Partial Oxidation (CPOX) reactor temperature.

The goal of the FCS control problem is to effectively regulate the oxygen concentration in the cathode by quickly and accurately replenishing oxygen depleted during power generation. The features and limitations of different control configurations and the effect of various measurement on the control performance are examined. For example, an observability analysis suggests using the stack voltage measurement as feedback to the observer-based controller to improve the closed loop performance.

The objective of the FPS control system is to regulate both the CPOX temperature and anode hydrogen concentration. Linear multivariable system analysis is used to identify the limitation of a decentralized controller and to design a model-based multivariable controller with significantly improved performance in CPOX temperature regulation. Further analysis unveils the critical controller cross-coupling term that contributes to the superior performance of the multivariable controller

Energy harvesting from conventional energy sources is creating a lot of problems nowadays. Besides, environmental issues have been a concern for the future power generation. The depletion of fossil fuels has compelled the researchers to go for new energy sources. Among the renewable energy sources fuel cells are considered as clean energy sources or green energy as the fuel cell energy is waste free.

Fuel cells are static conversion devices that convert the chemical energy of fuel to produce electrical current. But one big consideration of these devices is the stability issue. Fuel is not available all the time and fault always creates instability. The problem of efficient boost up of the power from other energy sources is caused. During fault conditions also, the achievement of the desired voltage level becomes so difficult for fuel cells that we need a restorer system that gives stored energy to the fuel cells during the fault time.

Voltage sags are created due to the sudden fault appearance into the system [1]. Voltage sags can be minimized and power quality can be improved by cost effective restorer systems likeDynamic Voltage restorer (DVR), Distribution Static Compensator (D-STATCOM) etc. These restorer systems provide additional energy to the main system when fault occurs.

2. THEROTICAL STUDY

2.1 D-STATCOM

A D-STATCOM consists of a dc energy storage unit, a two stage voltage source converter, a coupling transformer connected in shunt with the distribution network. The voltage source converter is essentially a dc to ac converter which converts the dc voltage of the energy storage device to three phase ac voltage. These ac voltages are in phase and coupled with the ac system through a coupling transformer [8].

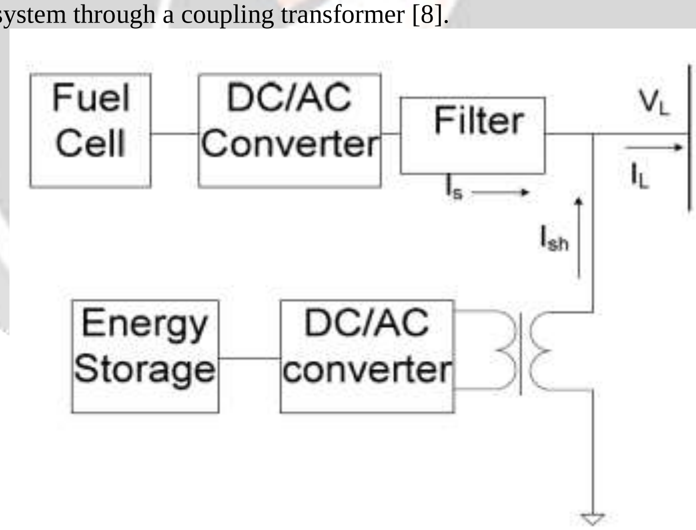

Fig-1: D-STATCOM acting on the ac system

The shunt current Ish corrects the voltage sag by adjusting the voltage drop across the system impedance Zth. The shunt current in figure 1 can be written as

$$I_{sh} = I_L - I_s = \frac{V_{th} - V_L}{Z_{th}}$$

$$I_{sh}\angle\eta = I_L\angle-\theta - \frac{V_{th}}{Z}\angle(\partial-\beta) + \frac{V_L}{Z_{th}}\angle-\beta$$

The complex power injected from the D-STATCOM can be written as-

$$S_{sh} = V_L I_{sh}^*$$

The control scheme for the D-STATCOM follows the same principle as for DVR. When the shunt current Ish is kept in quadrature with VL, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of Ish is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system [8].

2.2 Fuel cell

The first fuel cell was demonstrated in the middle of the 19th century by a scientist named William Grove. In a fuel cell a reaction takes place where hydrogen and oxygen recombine into water and thereby releasing electrical energy. The chemical formula of the reaction is seen in equation 1 [1].

A fuel cell consists of two electrodes, anode and cathode, with a layer of electrolyte between them, Figure 2. The electrodes are normally made flat and porous to achieve good contact between the electrolyte and the gases. The layer of electrolyte is made thin for the purpose to allow ions to pass through it without too much ohmic losses [1].

$$2H_2 + O_2 \rightarrow 2H_2O + Energy$$

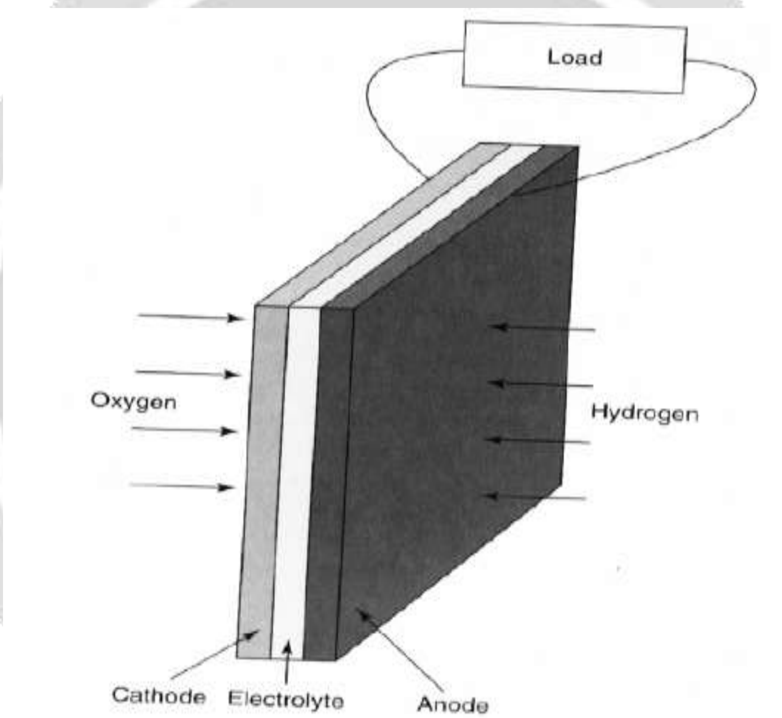

Fig-2: Basic structure of a fuel cell

3. PROPOSED METHODOLOGY

3.1 Simulation model without D-STATCOM

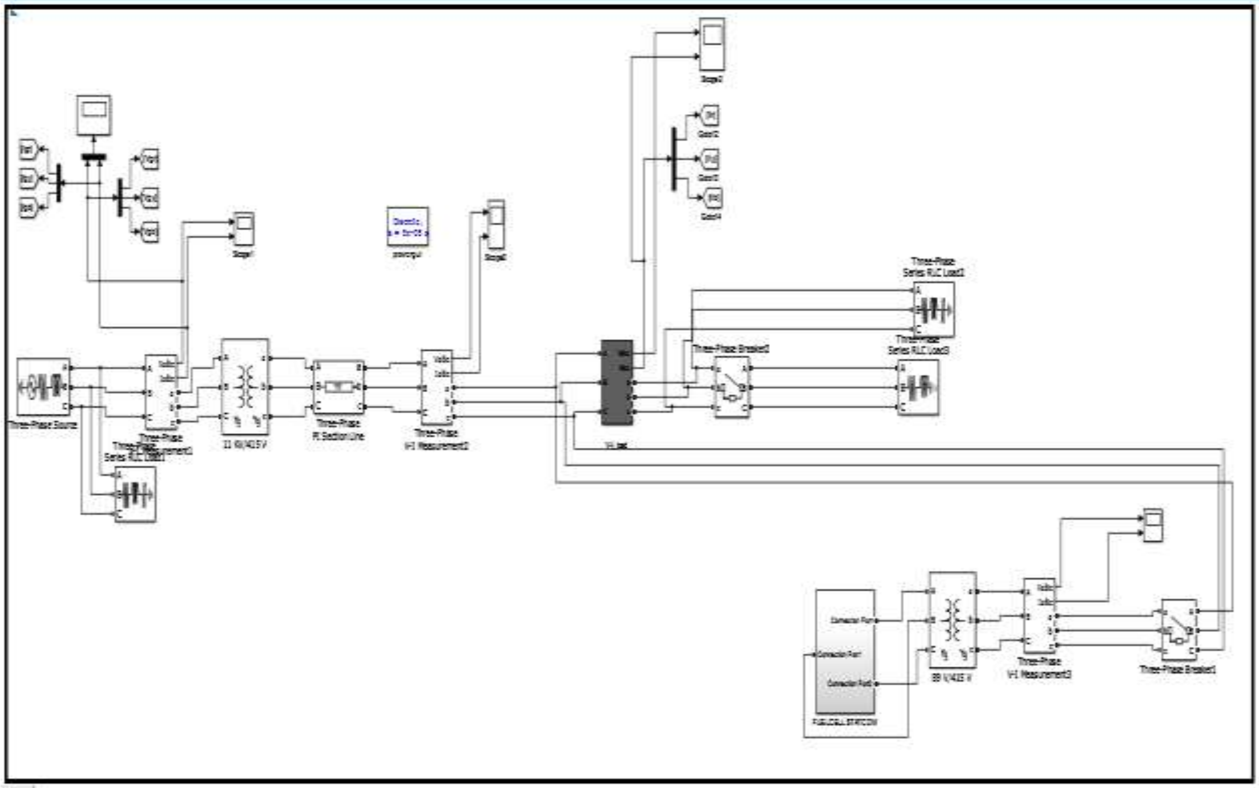

Fig-3: Main fuel cell based power system model without D-STATCOM using MATLAB Simulink

Table-1: Main fuel cell power system MATLAB Simulink model block parameter specification

Sr No.	MATLAB Simulink block	Parameter specification
1	Three phase source	Phase to phase rms voltage = 11Kv; Phase angle of phase A = 0 Degree; Frequency = 50Hz; Internal connection = star connected with ground; three phase short circuit level at base voltage (VA)= 415 VA; Base voltage (phase to phase) = 230 V; X/R ratio = 7
2	Three phase series RLC load 1	Load connection = Star connection; Nominal phase to phase voltage Vn (Vrms) =415V; Nominal frequency = 60Hz; Active power P=100W; Inductive reactive power QL = 100 Var; Capacitive reactive power Qc = 100 Var.
3	Transformer 11KV/415V	Winding 1 connection (ABC terminal) = Star connected with ground; Winding 2 connection (abc

		terminals) = Star connected with ground; Nominal power = 11KVA; Frequency = 60 Hz; Primary winding voltage V1 = 11KV; Primary winding resistance R1=0.002 pu; Primary winding inductance L1 = 0.08 pu; Secondary winding voltage = V2= 415V; Secondary winding resistance R2= 0.002; secondary winding inductance L2 = 0.08 pu; Mangetizing resistance Rm= 500pu; Magnetizing inductance Lm = 500pu.
4	Three phase PI section of line	Frequency used for RLC specification = 60 Hz; Positive sequence resistance r1 = 0.01273 Ohm/km; Zero sequence resistance r2=0.3864 Ohm/km; Positive sequence inductance l1=0.9337mH/km; Zero sequence inductance l2 = 4.1264 mH/km; Positive sequence capacitance C1=12.74N=Nf/km; Zero sequence capacitance C2=7.751 Nf/Km; Line length = 100km.
5	Three phase series RLC load2	Load connection = star with grounding; Nominal phase to phase voltage Vn = 415V; Nominal frequency fn = 50Hz; Active power P = 100W; Inducive reactive power QL=100 Var; Capacitive reactive power Qc = 100 Var
6	Three phase series RLC load3	Load connection = star with grounding; Nominal phase to phase voltage Vn = 415V; Nominal frequency fn = 50Hz; Active power P = 3000W; When capacitive load: Inductive reactive power QL=100 Var; Capacitive reactive power Qc = 10000 Var **When inductive load:**Inducive reactive power QL=10000 Var; Capacitive reactive power Qc = 0 Var

3.2 Simulation model with D-STATCOM

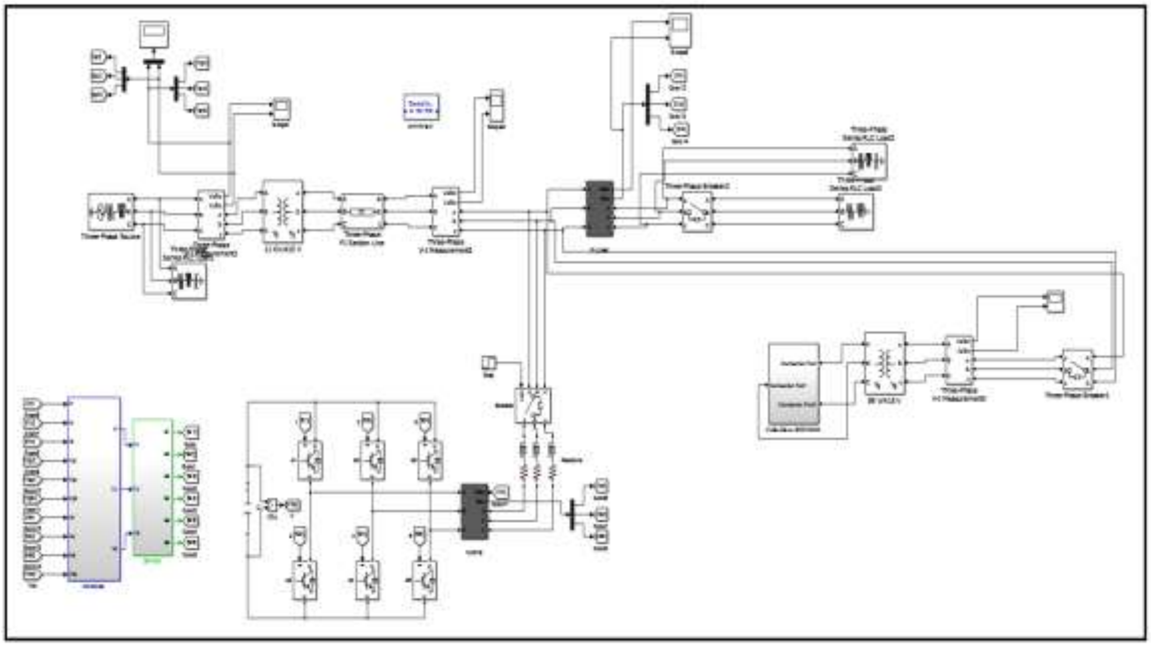

Fig-4: Main fuel cell based power system model with D-STATCOM using MATLAB Simulink

3.3 D-STATCOM controller subsystem

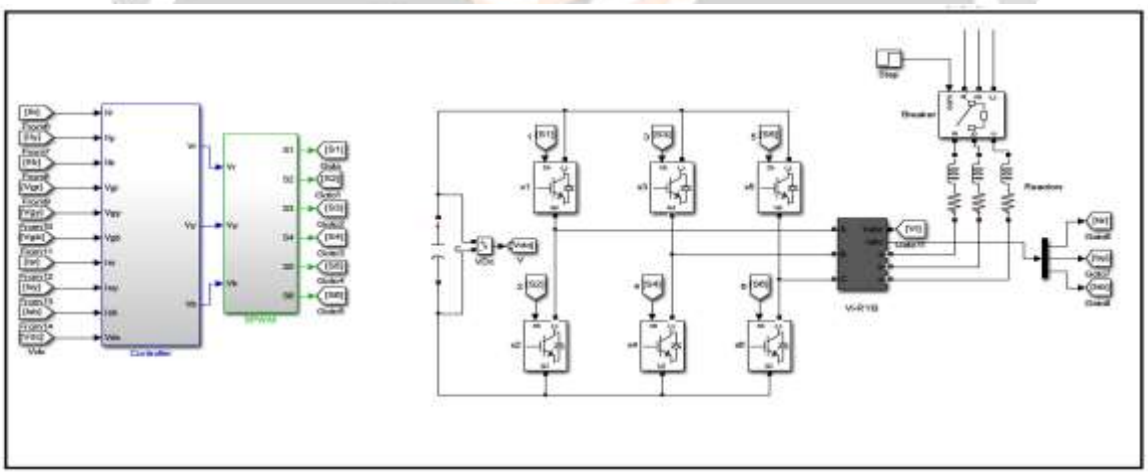

Fig-5: D-STATCOM subsystem model with controller subsystem

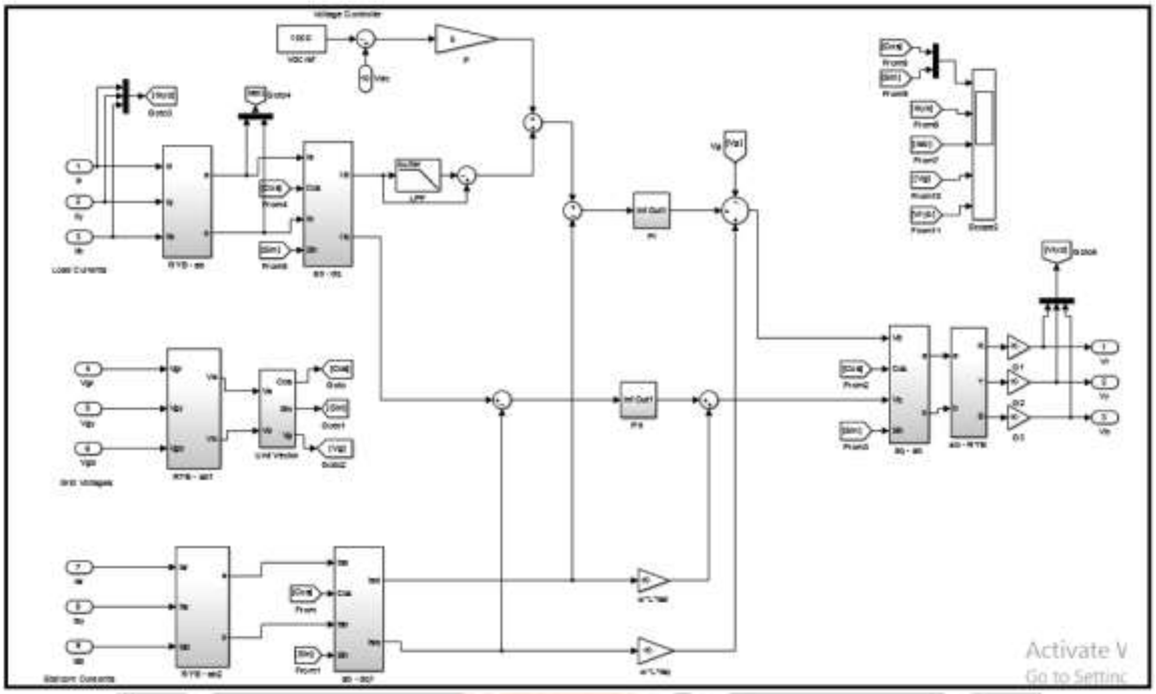

Fig-6: D-STATCOM controller subsystem

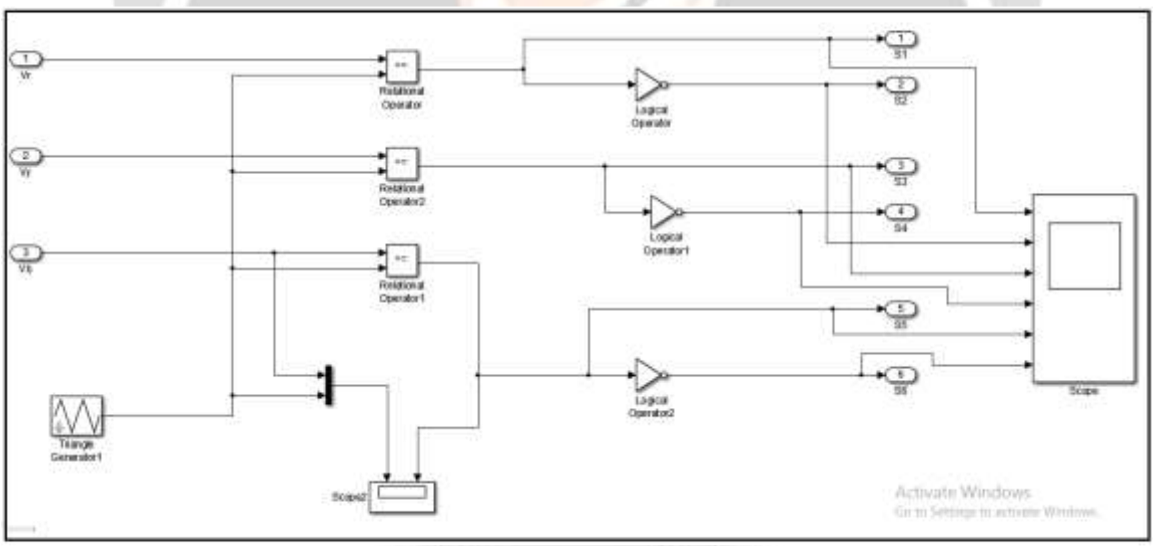

Fig-7: Pulse width modulation subsystem using MATLAB Simulink

3.4 Fuel cell subsystem with inverter

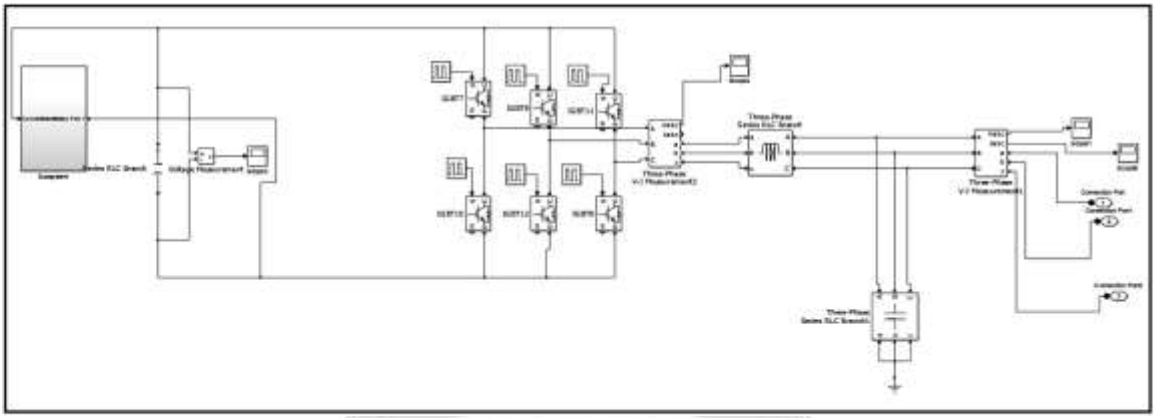

Fig-8: Fuel cell subsystem coupled with three phase IGBT based inverter MATLAB Simulink model

3.5 Fuel cell subsystem

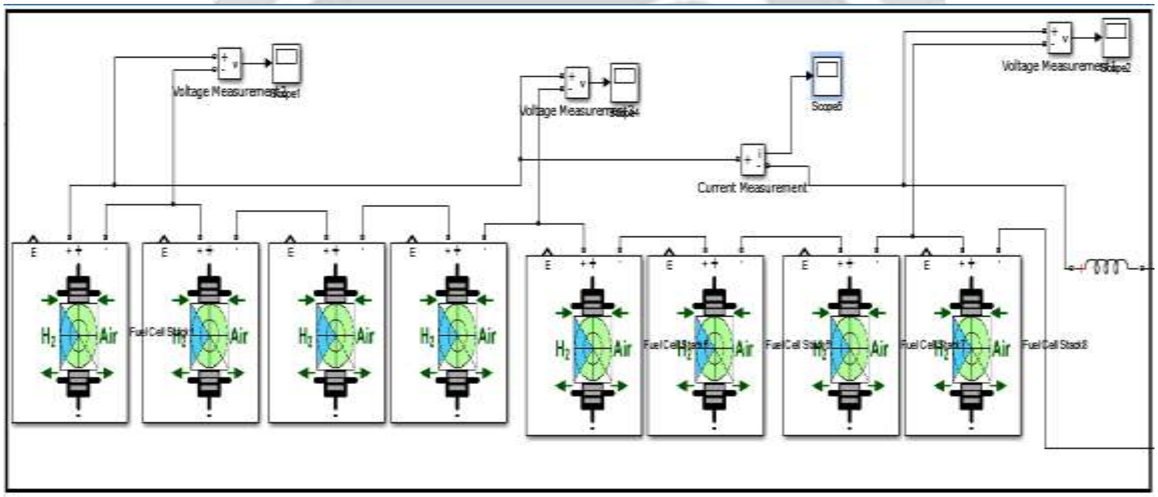

Fig-9: Fuel cell subsystem MATLAB Simulink model

4. SIMULATION RESULTS

4.1 Fuel cell based power system without D-STATCOM

Figure 10 shows the three phase voltage and current waveform for fuel cell coupled power system during voltage swell or leading load on power system behave as non-uniform load on power system during power system operation. During this operation D-STATCOM not connected with power system, we observe that after leading load connected with power system then voltage of power system increases called voltage swell and this voltage swell continue thorough the system and due to this voltage and current of main power system fluctuating nature.

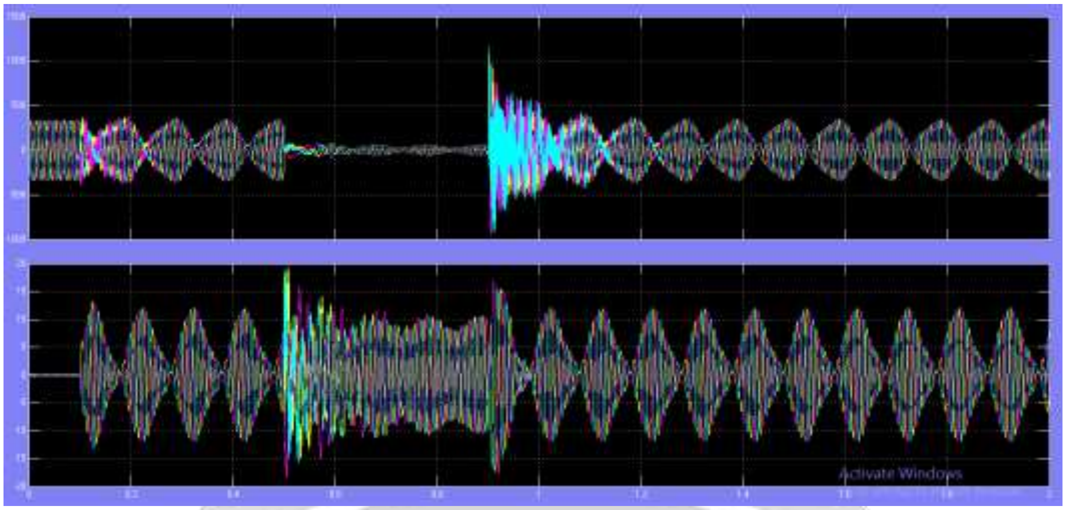

Fig-10: Fuel cell based power system transmission line three phase voltage and current during voltage swell without D-STATCOM

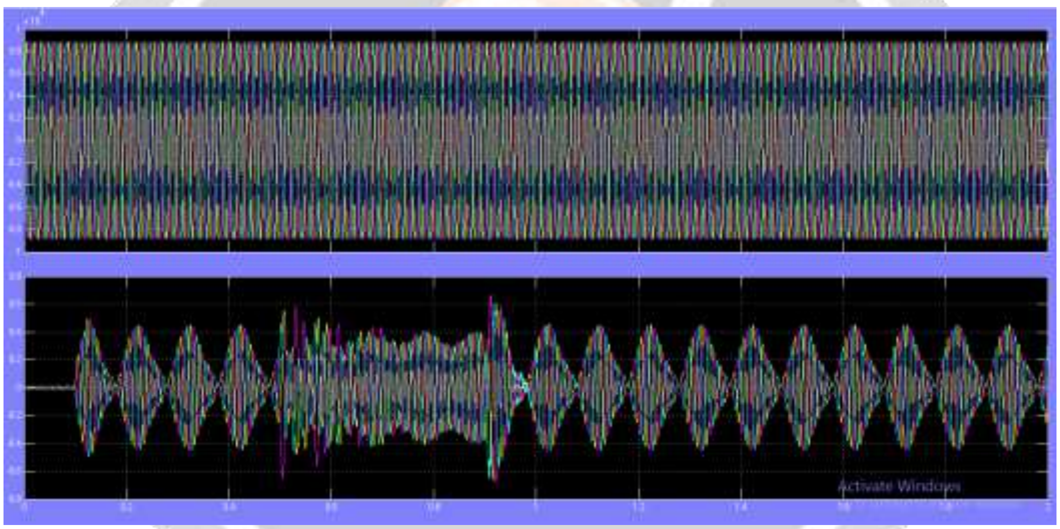

Fig-11: Fuel cell based power system three phase generator end three phase voltage and current waveform during voltage swell without D-STATCOM

In figure 11 shows that generated three phase AC voltage and current of fuel cell coupled power system without D-STATCOM connected in power system. In this we observe that, when leading load not in system then upto that time say 0.5 sec generated voltage of power system smooth. But first fuel cell system coupled with power system at 0.1 second duration then fuel cell system make fluctuations in current waveform then after leading load connected to this power system at 0.5 second then voltage of power system increases from rated voltage value. After that power system voltage fluctuating throughout the operation due to nonlinear nature of fuel cell output and leading load nature.

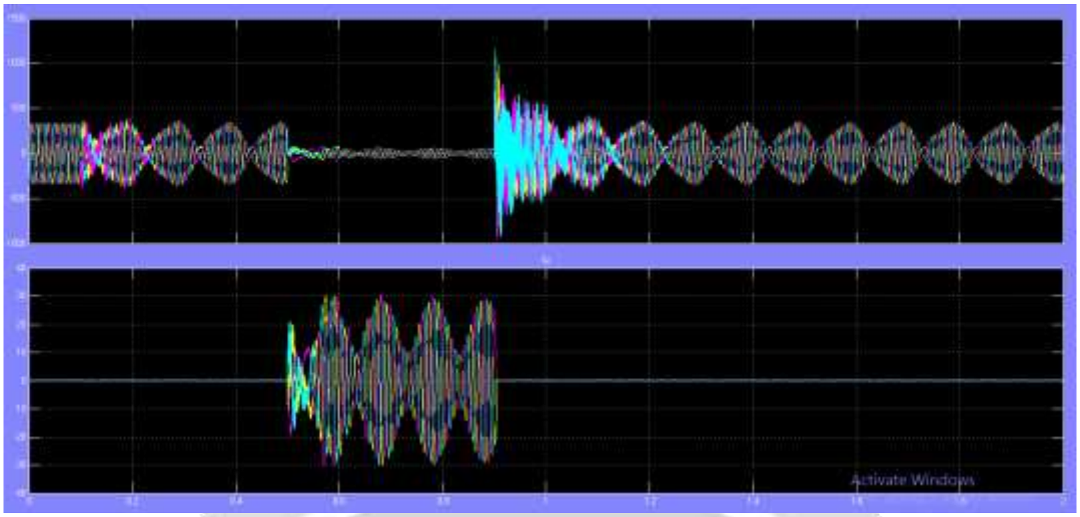

Fig-12: Fuel cell based power system load three phase voltage and current waveform during voltage swell without D-STATCOM

Figure 12 show that, three phase AC voltage and current of connected loads on power system. In this we observed that, when leading load connected to power system at 0.5 second then this load causes voltage swell in power system upto 0.9 second when leading load disconnected from power system.

4.2 Fuel cell based power system with D-STATCOM

Figure 13 show that, when D-STATCOM connected with fuel cell based power system then D-STATCOM removes the fluctuations occurs in three phase power system voltage and current during synchronization of coupling of fuel cell stack with main power system removes by controlling the reactive power of the system. In leading load or voltage swell condition voltage of power system absorb the reactive power from main power system by controlling the firing angle of thyristor based D-STATCOM controller using controller circuit.

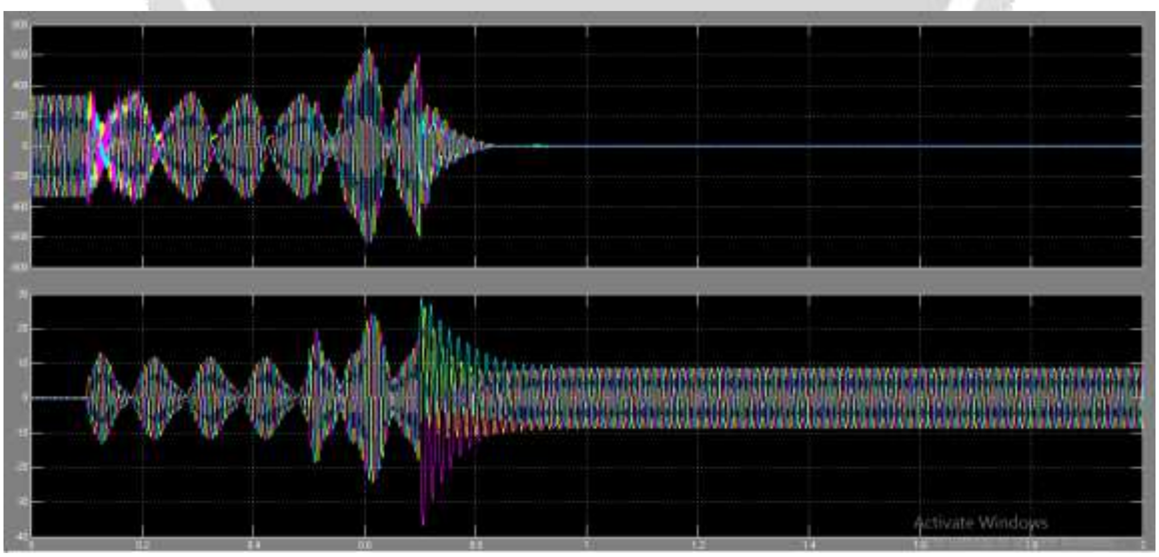

Fig-13: Fuel cell based power system transmission line three phase voltage and current during voltage swell with D-STATCOM

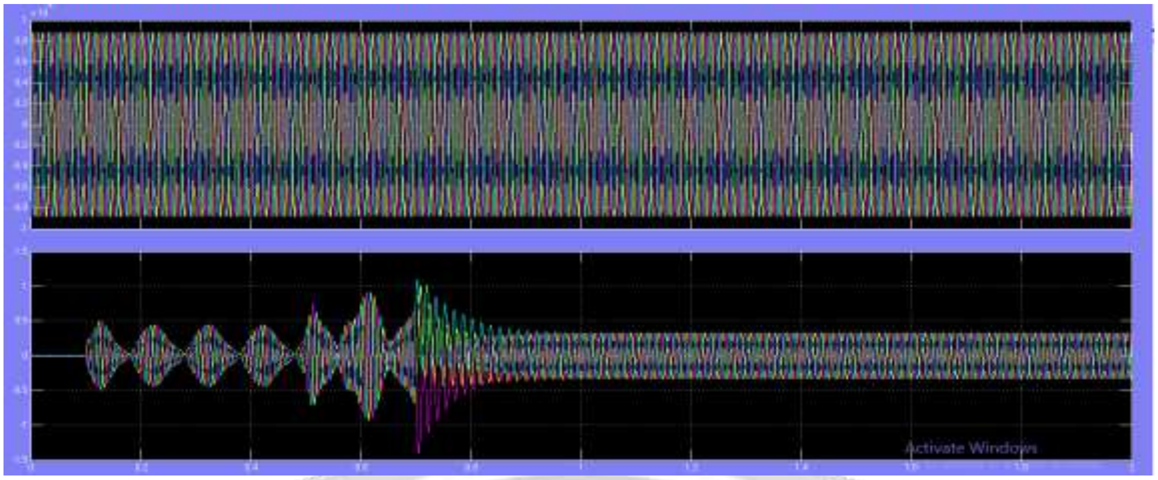

Fig-14: Fuel cell based power system three phase generator end three phase voltage and current waveform during voltage swell with D-STATCOM

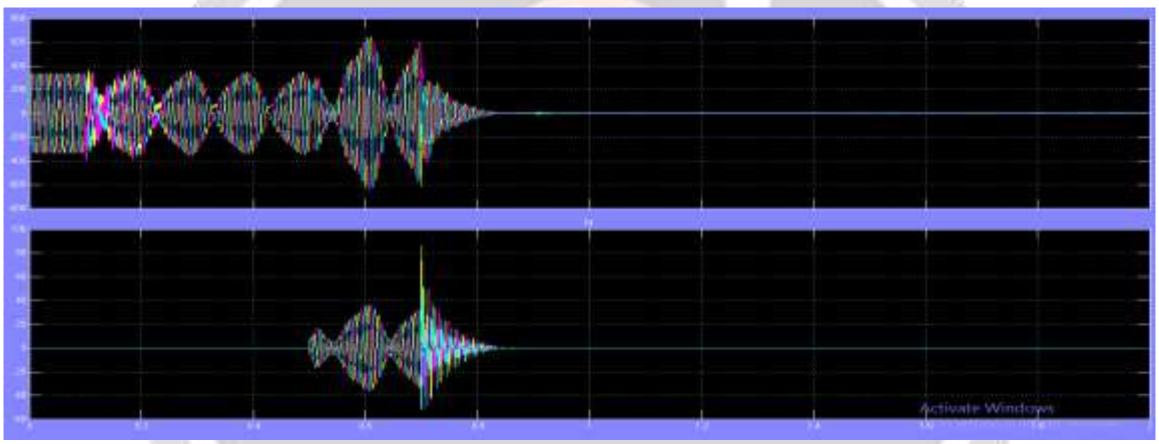

Fig-15: Fuel cell based power system load three phase voltage and current waveform during voltage swell with D-STATCOM

5. CONCLUSION

The stability of fuel cell system can ensure the continuous power supply alongside the conventional energy sources. Fuel cells have a promising demand in the field of renewable energy. However the stability enhancement has been the major concern. This stability can be achieved by using different FACTs devices which are costly stabilization schemes. This dissertation shows how the stabilization of the fuel cell system can be ensured using cost effective stabilization scheme DSTATCOM.

Use of D-STATCOM in fuel cell coupled power system removes the fluctuations from power system voltage and current during synchronization of power system with main power system. Also D-STATCOM remove the fluctuation or variations during abnormal loading conditions (voltage sag or swell) by controlling the reactive power of power system using charging capacitor or DC source of D-STATCOM.

The modeling and simulation of the fuel cell system including the fault analysis have also been focused within the limit of this paper. The future works will be focused on the comparison of different stabilization schemes and the feasibility.

A satisfactory transient behavior is one of the critical requirements of the fuel cell system for both automotive and residential applications. A well-designed control system is needed in order to provide fast and consistent transient behavior of the fuel cell system. The system consists of four main subsystems, namely, reactant supply, heat and temperature, water management, and power management subsystems. Additional complexities arise for the system with a hydrogen fuel processor that converts carbon-based fuel into hydrogen. Interactions among the subsystems lead to a complex control problem.

Two control problems related to the fuel cell system are presented in this thesis. The first problem is the control of the cathode oxygen reactant for a high-pressure direct hydrogen fuel cell system (FCS). The control goal is to effectively regulate the oxygen concentration in the cathode by replenishing fast and accurately the oxygen depleted during power generation. The second problem is the multi-input multi-output control of a low-pressure partial-oxidation based natural gas fuel processor system (FPS). The control objectives are to regulate both catalytic partial oxidation (CPOX) temperature and anode hydrogen concentration. System dynamic analysis and control design are carried out using the model-based linear control approach.

The stack voltage is calculated based on time varying load current, cell temperature, air pressure, oxygen and hydrogen partial pressure, and membrane humidity. The fuel cell voltage is determined using a polarization curve based on the reversible cell voltage, activation losses, ohmic losses, and concentration losses. Flow equations, mass conservation, and electrochemical relations were used to calculate changes in partial pressures and the humidity of the gas in the fuel cell stack flow channels. The FCS model contains nine states representing the masses of various gases inside the component volumes.

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