International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 10 (2015) pp. 27023-27030

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# Load Voltage Regulation of Grid Connected Wind Energy Conversion System Coupled With Fuzzy Controlled D-Statcom

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## Abstract

In a balanced power system, receiving end voltage will be as same as sending end voltage through which load voltage can be sustained for various load conditions. The major issue to be considered in wind power generation is fluctuation in output voltage frequency which results in poor power quality, stability and reliability of the system. To address the above issues, this paper will deal with the implementation of Fuzzy controlled D-STATCOM to provide robust control of voltage through VAR compensation. A model of a D-STATCOM using Fuzzy Logic control is used to regulate the voltage profile and frequency within the permissible limit is modelled in MATLAB/SIMULINK.

**Keywords:** Wind Energy Conversion System (WECS), D-STATCOM, Fuzzy Logic Control (FLC).

## Introduction

In recent years, the need for renewable energy is becoming more significant with wind energy playing a predominant role. The wind energy model converts mechanical energy to electrical energy. The model comprises of wind turbines connection to the grid at low, medium and high voltages. Practically, the turbines are connected at medium voltage to the grid. The main components for conversion are turbine rotor, gear box and generator. Generator can be of Synchronous or Asynchronous and the gear box facilitates the synchronization of rotor speed to the generator speed. The wind turbines can be classified as fixed speed or variable speed.

In fixed speed wind turbine, the turbine can be connected directly to the grid through transformer, whereas in variable speed wind turbine, the turbine cannot be directly connected to the grid it needs a power electronic interface. In addition to this, excitation plays a vital role in this type of configuration which is provided by either external capacitor or from grid. On this, any fluctuation in the wind will consequently result in generator output fluctuation i.e. output voltage frequency and leads to power quality issues. High power rating needs installation of separate substation but this paper deals with medium power rating which does not necessitate installation of substation. Secondly, there will be low voltage power quality due to unnecessary reactive power loading. This reactive power loading may be due to load imbalance causing additional stress on the networks, excess voltage imbalance resulting in over stress on supplementary loads connected to the same network. To resolve this issue shunt compensation is necessary which can be accomplished by FACTS device.

This paper proposes D – STATCOM with fuzzy control logic providing faster response, less loss and also takes care of loading making it more advantageous than the conventional methods [2]. The fuzzy logic control has more significant features to deal with uncertainties and non-linearity effectively which complements it over other classical controls. It can be of two types viz. Mamdani and Takagi Suguno. Most familiar mamdani type fuzzy logic controller is used in this paper which employs fuzzy set in subsequent part of the rules and it describes the control action.

## System Modelling

**Wind Energy Conversion System:**
In this paper, wind energy conversion system is designed with fixed speed wind turbine with pitch angle control. Since this is constant speed type, preferred one is Squirrel Cage Induction Generator which has simple construction and mechanical torque as follows

Mechanical power output from turbine can be determined by the formula:

$$P_{mech} = \frac{1}{2}\,\rho\, A\, C_P V_w^3\,.$$

In which, $\rho$ is air density in kg/m$^3$, area swept by the blade of the turbine is denoted as A in m$^2$,$V_w$ be the wind speed (m/s) and Cp is the Coefficient of performance i.e. Function of tip speed ratio.

Tip speed ratio= $w_r\cdot {R}/{V_w}$.

R be the radius of the turbine blade (m) and $w_r$ is the angular speed (rad/sec).

**D-STATCOM:**
D- STATCOM is a shunt reactive power compensating device. This it provide a control over the shunt reactive admittance and generates AC voltage which in turn injects the current through shunt transformer. This current which is injected is kept in quadrature with the load voltage and the desired regulation is achieved. This D-STATCOM also has an advantage of acting as a coupled bidirectional converter which injects tolerable level of reactive power to increase power quality represented as voltage at the Point of Common Coupling (PCC). It entails a Voltage Source Converter (VSC) to regulate the voltage at PCC using power electronic devices like

IGBT and it is force commutated to synthesis the transformer secondary side voltage from DC voltage source.

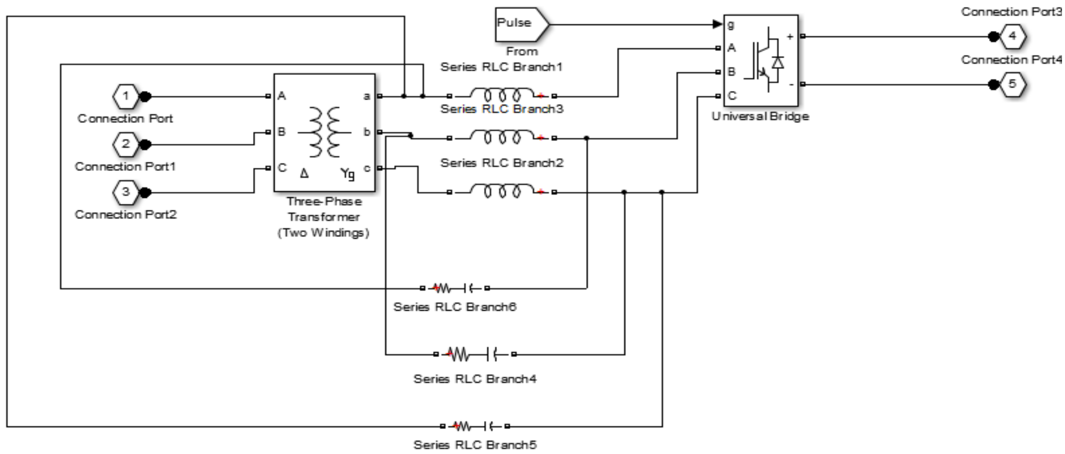


**Figure 2.2.1:** Simulation Diagram of D – STATCOM

**Load System**

A RL load is modelled in such a manner that it opens and closes with respect to time through circuit breaker. This paper uses two fluctuating loads and one constant load.

Figure 2.3.1 shows an 11kV distribution line in which, at the point of common coupling we have wind model and Fuzzy controlled D – STATCOM model followed by fluctuating load.

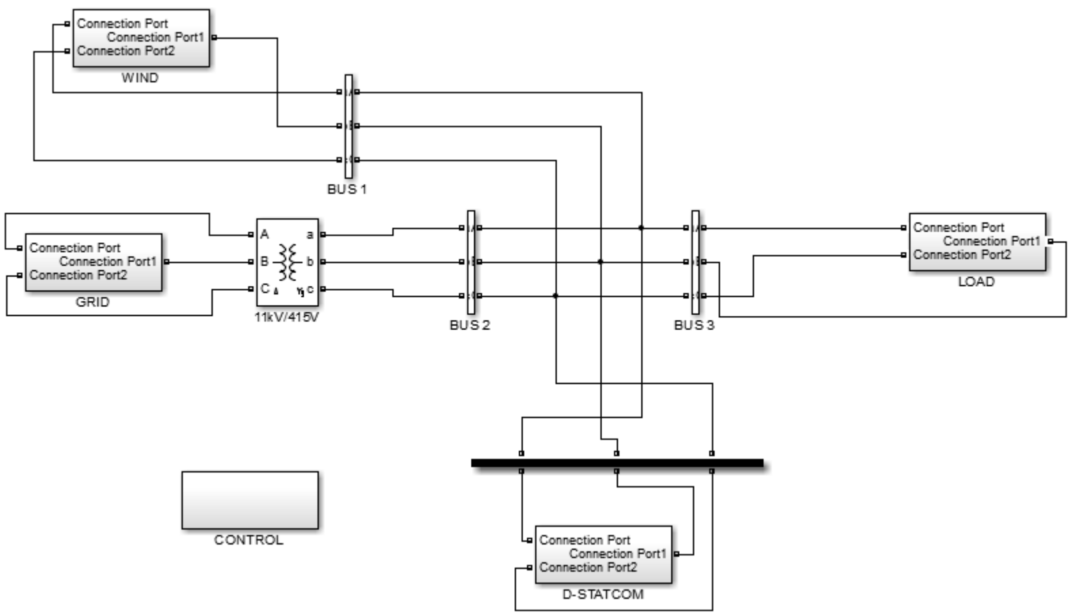


**Figure 2.3.1:** Simulation Diagram of entire system model

## D-Statcom Control

The voltage and current are taken form PCC whereas DC voltage is from DC link capacitor. This paper uses Phase Locked Loop (PLL) to produce a phase, equivalent to input signal phase ($V_{abc}$) which will find the voltage and current in dq frame of reference. AC and DC voltage regulator will generate $i_d$ and $i_q$ reference to sum up with the previous current reference which will be the output from the current regulator providing control voltage in dq axis. PWM generator (2 level) takes this control voltage as a reference signal and takes care of rest of the switching actions. The output from PWM is synchronized with PCC through transformer.

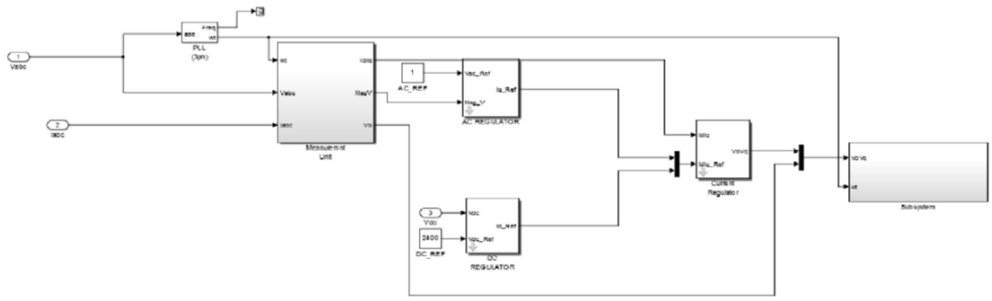


**Figure 3.1:** Simulation diagram of D –STATCOM control

## Fuzzy Logic Controller

Fuzzy consists of knowledge base, fuzzification interface, decision making logic and defuzzifier. The knowledge base consists of information about input and output fuzzy partitions followed by that fuzzification interface. This interface converts the variable into fuzzy linguistic variables which is later converted into logic i.e., this set of rules, provide the control variables which will be defuzzified.

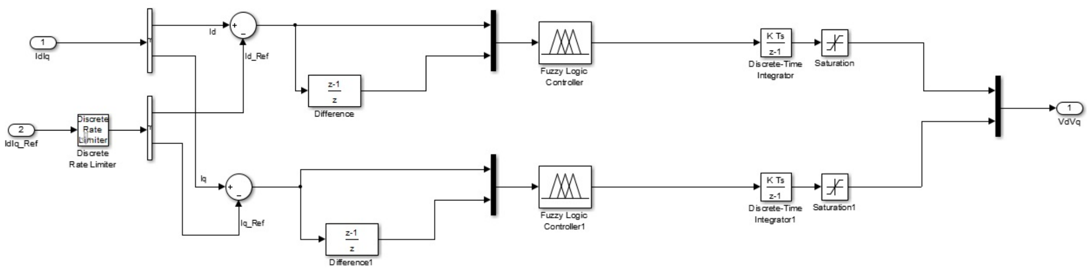


**Figure 4.1:** Simulation diagram of Fuzzy Logic Controller (Current Regulator)

Fuzzy logic control implemented in current regulator is as shown Figure 4.1. Same control strategy is considered for AC and DC voltage regulator. Two inputs given to the control strategy are error (e) and rate of change of error (e′). There are seven linguistic variables like Negative Large (NegL), Negative Medium (NegM), Negative

Small (NegS), Zero (ZO), Positive Large (PosL), Positive Medium (PosM) and Positive Small (PosS). The number of rules will be $7^2$i.e49. These rules are tabulated in Table 4.1. In this paper, we consider triangular membership function. The interface implemented is shown in Table 4.1. The Defuzzification is done through Centroid method.

**Table 4.1:** Fuzzy logic Rules

| e / e′ | NegL | NegM | NegS | ZO | PosL | PosM | PosS |
|---|---|---|---|---|---|---|---|
| PosL | ZO | PosS | PosM | PosL | PosL | PosL | PosL |
| PosM | NegS | ZO | PosS | PosM | PosL | PosL | PosL |
| PosS | NegM | NegS | ZO | PosS | PosM | PosL | PosL |
| ZO | NegL | NegM | NegS | ZO | PosS | PosM | PosL |
| NegS | NegL | NegL | NegM | NegS | ZO | PosS | PosM |
| NegM | NegL | NegL | NegL | NegM | NegS | ZO | PosS |
| NegL | NegL | NegL | NegL | NegL | NegM | NegS | ZO |

## Results

System voltage and frequency has to be maintained for stable operation under any kind of variations. Figure 5.1 shows the output voltage frequency of wind energy conversion system. The system frequency 50Hz has to be maintained but it is oscillating causing low power quality.

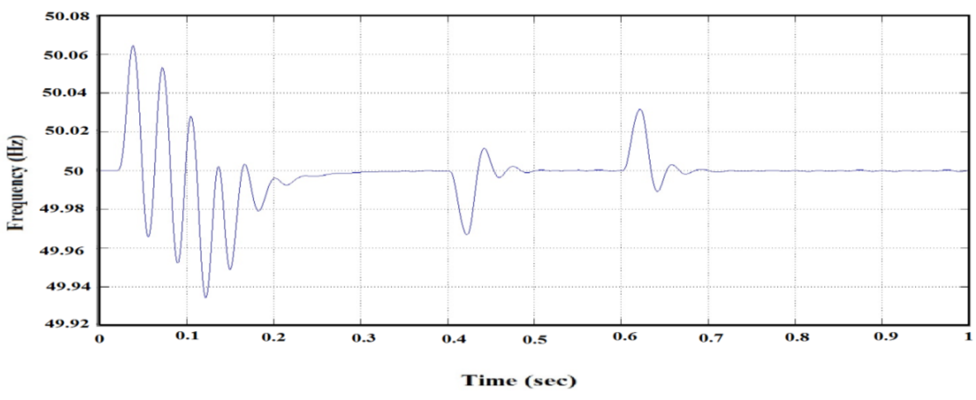


**Figure 5.1:** Output Voltage frequency of wind energy conversion system

The Figure 5.2 illustrates the output with and without D- STATCOM. The load fluctuates between 0.4 to 0.6 second causing drop in load voltage. The voltage is droped to 0.835pu without D-Statcom whereas 0.895pu with D-STATCOM. The spike with little less value indicates the output without D-STATCOM and the spike value little above the previous one and almost equal to 1 pu indicates the required output with D- STATCOM.

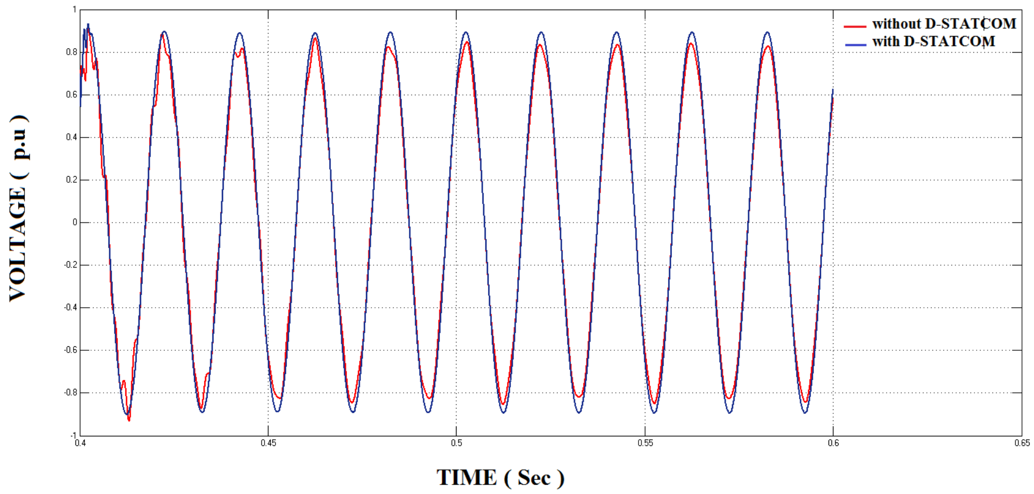


**Figure 5.2:** Voltage at the point of PCC

## Conclusion

Power quality improvement helps in proving an efficient dynamic performance which in turn is provided by fuzzy controlled D –STATCOM in this paper. Any system connected to dynamic load is continuously variable, the load voltage regulation and variable WECS output frequency should be maintained well within the limit. This paper clearly illustrates that WECS output frequency is within the tolerable limit but oscillatory leading to low power quality which is mitigated using Fuzzy Controlled D-STATCOM. The comparison with and without D-STATCOM for load voltage is clearly illustrated. This kind of controllers helps to damp out the power oscillations due to dynamic variations and hence increase the efficiency of the system.

## Appendix

| S. No | Component | PARAMETER | VALUES |
|---|---|---|---|
| **1** | **INDUCTION GENERATOR (SQUIRREL CAGE GENERATOR)** | KVA | 45 |
| | | V | 750 |
| | | Rs(pu) | 0.0197 |
| | | Ls(pu) | 0.0397 |
| | | Rr(pu) | 0.0191 |
| | | Lr(pu) | 0.0397 |
| | | Lm(pu) | 1.354 |
| | | INERTIA CONSTANT | 0.09526 |
| **2** | **WIND TURBINE** | P(nominal) | 130KW |
| | | Ws(base value) | 11.5m/s |
| | | Pmax(pu) | 1.35 |
| | | Wr(base value) | 0.85 |
| **3** | **LOAD** | Constant Load (RL Load 1) | 6 kW, I kVAR |
| | | Fluctuating Load (RL Load 2) | 55 kW, 25 kVAR |
| | | Fluctuating Load (RL Load 3) | 65 kW, 9 kVAR |

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