# MATHEMATICAL MODELLING OF WIND FARM AND HYBRID SOURCE POWER QUALITY IMPROVEMENT USING STATCOM

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**ABSTRACT**

*Power quality in terms of harmonics and voltage fluctuations is an important aspect for power generation companies. Various techniques are available for mitigation of harmonics fluctuations for single power source. Here this paper proposes a technique of Statcom to mitigate harmonics fluctuation when three different renewable energy sources are connected together to generate power and synchronized in grid. Technique to merge three different sources power is shown in implementation. Statcom is device which is used for harmonics mitigation. DC to AC conversion method also shown and boost converter is used to boost the level of voltage.*

**Keyword:** - *Hybrid power, Statcom, photo voltaic, wind farm, fuel cell*

## 1. INTRODUCTION

Energy generation and utilization with quality of power transmission is great demand in world. Industry as well residential equipment's needs harmonics free power. Source of power may vary depending upon locations natural resources and availability. Power is being generated by various natural and conventional sources. Natural sources are from wind, solar, sea waves and fuel cell etc. Conventional source of energy are coal, gas, petroleum etc. Natural sources like wind speed and solar radiation may vary during day, month and year depending upon weather condition. Wind farm/wind mill is used to generate power from wind and photo voltaic cell or plant is used to generate power from solar irradiation. One of the new concept is fuel cell. It used water as its fuel which is available from natural resources. Fuel cell also generates power. Output of PV cell is DC and it is converted into AC three phase supply using Inverter. DC link provides little bit harmonic reduction and ripple free operation. Fuel cell also generates DC supply and similarly it uses inverter to convert into AC. Wind farm directly generates three phase AC which is stepped down using transformer to fed into grid. But all this sources contains harmonics and it may damage customer side equipment's. Harmonic reduction techniques are used to reduce it. Many a times when load changes or fault occurs in line, line may trip or voltage or current dip may be observed. So, power quality also needs to improve. Statcom is a device which does multiple operation like harmonic reduction and power quality improvement.

## 2. MATHEMATICAL MODELLING OF PV CELL

Converting some hardware device into equivalent mathematical equation is called modelling, and before doing actual experiment on hardware, it is good enough to do some experiment on mathematical equations and to observe the behavior of a system and then to proceed further. This will reduce the risk of a hardware failure and a researcher will able to do analysis by using different methods and uncertain inputs. Uncertainty is one kind of disturbance or variation in either input or parameters of system itself. In PV panel variation in light intensity is varying parameter and we can call it as uncertainty.

**PV current**

$I = \{(I_{ph}N_p) - I_d - I_{sh}\}$

**Phase current equation**

$I_{ph} = T_{rr}(I_{sc} + K_i(T_{op} - T_{ref}))$

**Shunt current equation**

$I_d = I_sN_p(e^{\frac{(\frac{V}{Ns}+\frac{IRs}{Ns})}{nVtC}} - 1)$

$I_s = (\frac{Top^3}{Tref} Irs)*(e^{(\frac{-1}{Tref}+\frac{1}{Top})(\frac{1.12q^2}{Kn})})$

**Reverse saturation current equation**

$I_{rs} = \frac{Isc}{e^{\frac{Vocq}{KCTopn}})-1}$

**Diode current equation**

$I_{sh} = \frac{(V+Irs)}{Rp}$

$V_t = \frac{K\,Top}{q}$

**2.1 PV PANEL INPUT PARAMETERS**

| | |
|---|---|
| $V_{oc} = 21.1$ | C = 36 |
| $q = 1.6 \times 10^{-19}$ | $I_{ro} = 1000$ |
| $K_i = 2.2 \times 10^{-3}$ | $N_s = 1$ |
| $I_{sc} = 3.8$ | $N_p = 1$ |
| $K = 1.38 \times 10^{-23}$ | $V = V_{pv}$ |
| $I_{rr}$ = G = radiation intensity | $R_p$ = 360.002 ohm |
| $T_{op} = 25 + 273.15$ | n = 1.36 |
| $R_s = 0.18$ | Tref = 25+273.15 |

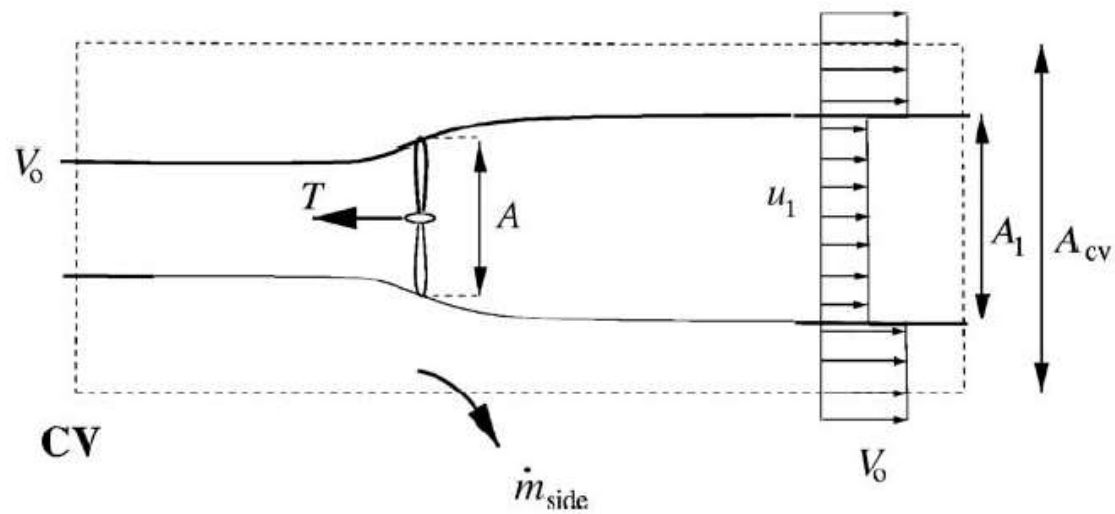
## 3. FUEL CELL PARAMETERS

Available hydrogen fuel cells are Proton Exchange Membrane hydrogen Fuel Cell, Solid oxide fuel cell and alkaline fuel cell.

FUEL CELL CHARACTERISTICS

| Proton Exchange Membrane hydrogen Fuel Cell | |
|---|---|
| Voltage at 0A | 900v |
| Voltage at 1A | 895v |
| Nominal operating Current | 80A |
| Nominal Operating Voltage | 625v |

## 4. ONE DIMENSIONAL MATHEMATICAL MODEL FOR WIND TURBINE DESIGN




**One Dimensional fluid mechanics of wind turbines**

**Application of Raynold's conservation theorem for linear momentum:**

$$(\text{momentum})_{out} - (\text{momentum})_{in} = -F_n \quad (1)$$

**Where,**

$F_n$ = Axial thrust on Rotor

$$(\text{Momentum})_{out} = \rho u_1^2 A_1 + \rho V_0^2 (A_{cv} - A_1) + \dot{m}_{side} V_0 \quad (2)$$

$$(\text{Momentum})_{in} = \rho V_0^2 A_{cv} \quad (3)$$

**Combining equation (1) to (3), gives**

$\rho u_1^2 A_1 + \rho V_0^2 (A_{cv} - A_1) + \dot{m}_{side} V_0 - \rho V_0^2 A_{cv} = -F_n$ (4)

**Application of conservation of mass**

$\rho A_1 u_1 + \rho (A_{cv} - A_1) V_0 + \dot{m}_{side} = \rho V_0 A_{cv}$ (5)

$\dot{m}_{side} = \rho A_1 (V_0 - u_1)$ (6)

Further,

$\dot{m} = \rho u A = \rho u_1 A_1$ (7)

$\frac{A}{A1} = \frac{u1}{u}$ (8)

**Combining equation (6),(7) and equation for conservation of momentum leads to:**

$F_n = \rho u A (V_0 - u_1) = \dot{m} (V_0 - u_1)$ (9)

Further, it can be shown that:

$u = 0.5 (V_0 + u_1)$ (10)

**<u>Alternate control volume consideration</u>**

**Application of Energy conservation theorem**

$\dot{m}_{side} \left(\frac{po}{\varsigma} + \frac{V02}{2}\right) = \Delta\dot{w} External\ work\ rate + \dot{m}\left(\frac{po}{\varsigma} + \frac{u12}{2}\right)$ (11)

$\Delta\dot{w} External\ work\ rate = \dot{m}\left(\frac{vo2}{2} - \frac{u12}{2}\right)$ (12)

$= 0.5\ \rho u A\ [v_o^2 - u_1^2]$ (13)

1. Definition of Axial Induction, "a"

U = (1 - a) Vo (14)

But, u = 0.5 (Vo + u1) (15)

Combining equations 14 and 15, yields :

u1 = (1 - 2a)Vo (16)

2. Introduction of Axial Induction, "a", into External work rate (Power) Equation:

We know:

$p = \Delta\dot{w} External\ work\ rate = 0.5\ \rho\ U\ A\ [Vo2 - U12]$ (17)

Introduce Equation 14 and 16 into equation 17 to obtain:

$p = 0.5\rho A(1 - a)\ Vo\ [Vo2 - (1 - 2a)2Vo2]$

$= 0.5\rho A(1 - a)\ Vo^3\ [1 - (1 + 4a2 - 4a)]$

$= 0.5\rho A V_o^3\ [4a - 4\ a2]$

$= 2\rho A V_o^3\ a(1 - a)2$ (18)

**Introduction of Axial induction, "a" into axial thrust, Fn**

$Fn = \rho U\ A\ [Vo - U1]$ (19)

$u1 = (1 - 2a)\ Vo$ (20)

$u = (1 - a)\ Vo$ (21)

Combining Equations 20 – 21, yields:

$Fn = \rho(1 - a)\ Vo\ \ A\ [Vo(1 - 2a)\ Vo]$ (22)

$Fn = 2\rho A\ Vo2\ \ a\ (1 - a)$ (23)

**Definitions and Formulations**

*1 Available power, pavail*

$pavail = 0.5\rho A\ vo3$ (24)

*2 Available power, pavail*

$Cp = \frac{p}{pavail} = \frac{p}{0.5\rho A\ vo3}$ (25)

*3 Thrust coefficient, CT*

$CT = \frac{Fn}{0.5\rho A\ vo2}$ (26)

**Cp in terms of induction factor, a**

$Cp = \frac{p}{0.5\rho A\ vo3} = \frac{2\rho A\ vo3}{0.5\rho A\ vo3} a(1 - a)3$ (27)

$Cp = 4a(1-a)2$ (28)

$\frac{dcp}{da} = 0 = a(1 - a)(1 - 3a)$ (29)

$a^* = 1/3$ (30)

$C_{pmax} = 16/27 = 0.59$ (31)

**This is the equation obtained for Bet'z limit.**

**Optimal Value of power Extractor, pmax**

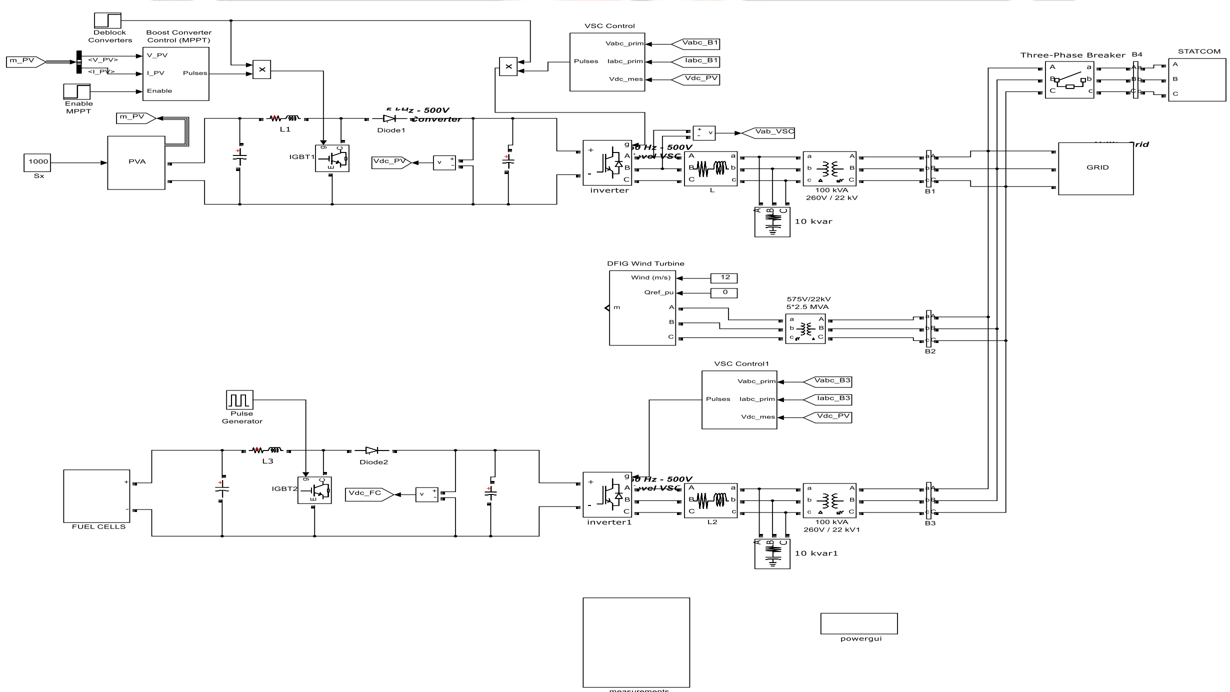
$p_{max} = 2\rho A v_o^3 (0.33)(1-0.33)^2$ (32)

$p_{max} = 0.296\rho A v_o^3$ (33)

This is the equation which gives maximum power depending upon volume of air and area covered by blades.

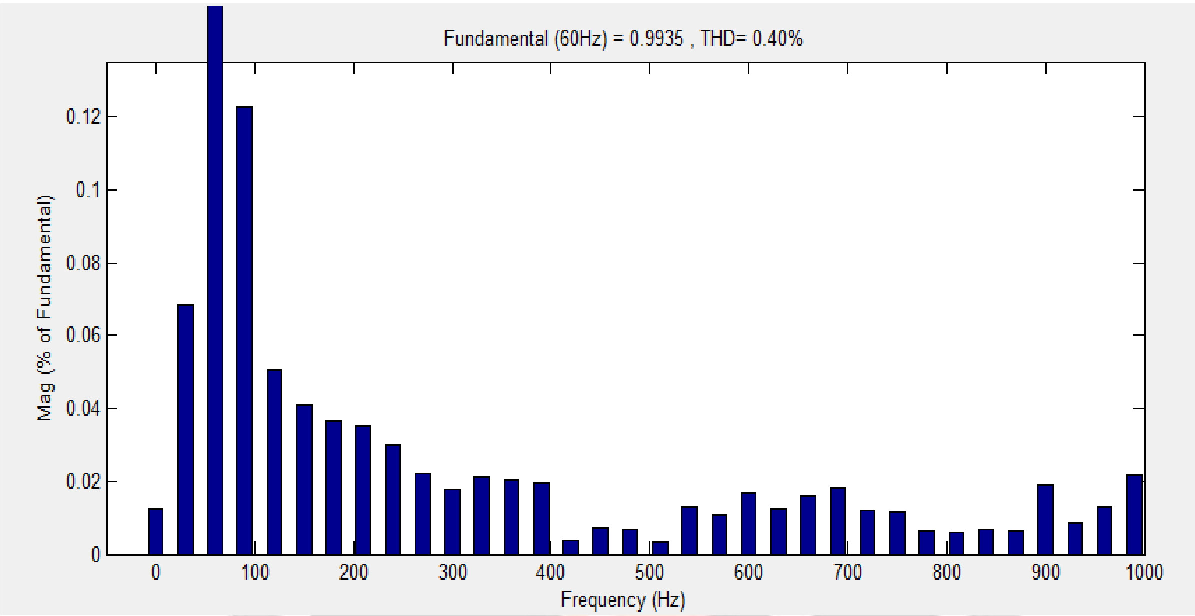
## 5. SIMULATION

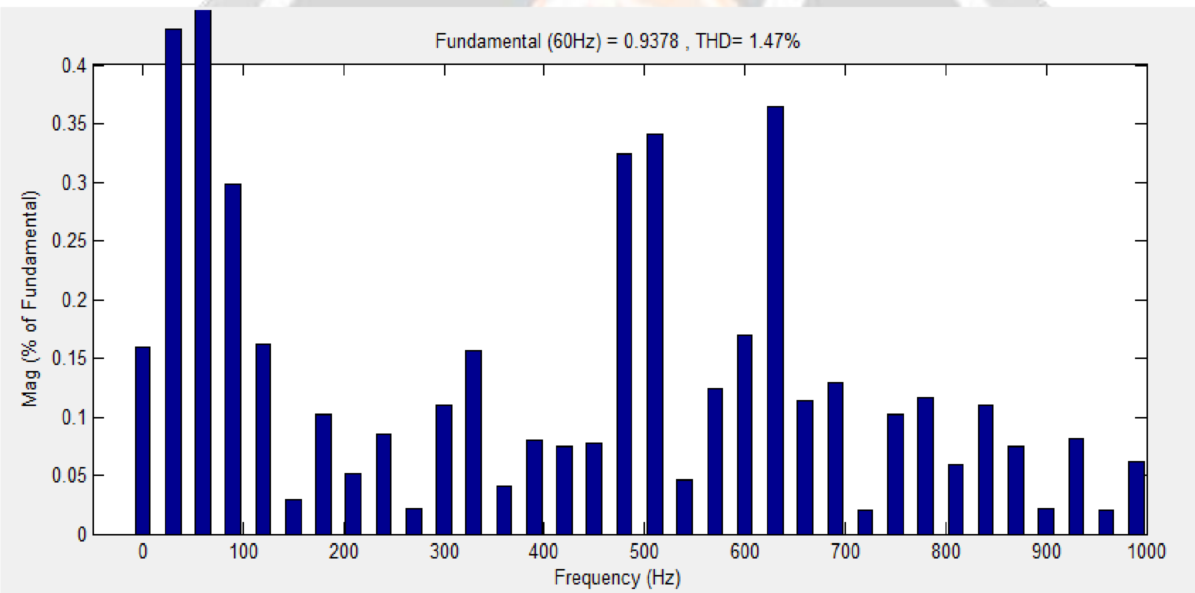
Statcom works based upon feedback control strategy. Statcom converts DC to AC using inverter. Gate pulses are generated using any of method like PWM or PI control etc. Here in this approach PI control method is used which senses voltage from grid side and compares with reference 1p.u. If any difference is observed between two inputs, error is generated and error is given as input to PI control and output will be control signal. For Statcom out of PI will be modulation index for PWM generated. Six different pulses re generated for three phase inverter and DC to AC conversion takes place according to dip observed at grid side bus.




## 6. RESULT

After doing simulation results are obtained for hybrid system when connected with grid. Attached figures are for harmonics analysis at below.




It is clear from the figure that before 2 second when no Statcom as fact device was connected, harmonics were more. After 2 seconds when circuit breaker closes and Statcom gets connected, harmonics gets reduced to very much extreme level and power quality is improved.

## 7. CONCLUSION

Statcom and facts devices are more convenient to use for harmonic reduction and FRT/LVRT improvement. Statcom is most easy and convenient device use in today. Fact devices are at-most compulsorily needed because of penetration of renewable energy sources input fluctuations. As we moving toward cheapest and easily available energy sources, we need to grow with security of power quality and fact devices are well proven.

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