Voltage Control and Stability for Solar PV - Wind Energy Hybrid Micro-Grid using Optimized STATCOM

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Abstract:

Power generation from renewable energy sources like solar PV and wind energy systems are highly influenced by weather conditions. Solar PV and wind systems generates two distinctive fluctuating powers. To achieve constant power both of them should be stabilized separately. So, a control action is needed. Hence, it is a need for rapid compensation of energy for power transmission and distribution systems. Hence, compensation using STATCOM (Static Synchronous Compensator) is employed for reactive power compensation, to control voltage fluctuations in power generation and to attain a stable operation. STATCOM is provided with 4 PI controllers based on Genetic algorithm. In this model we're using 2MW wind turbine model based on DFIG, 0.4MW solar PV energy system model and a STATCOM rated at 3MVAR. While as compared with conventional controllers, when conventional PI controllers based on GA is used, a higher stability is obtained and voltage fluctuations at the end of busbar are decreased with the aid of 8%.

Keywords: *Genetic Algorithm; Static synchronous compensator; Voltage control; Flexible AC transmission systems***.**

1.Introduction

In recent years consumption of electrical energy has been increased, energy production techniques are also improved and public are much aware of environmental protection. The renewable energy systems which include wind or solar PV alone or a hybrid wind/PV are not enough to meet the existing energy demand. Reactive power compensation should be done rapidly, due to which different power stability, power quality problems and power losses are incurred.

In order to reduce all the power quality issues and to obtain better system stability and improved power transfer capability FACTS (Flexible AC transmission systems) are used. [1]. STATCOM is a FACTS device and it is commonly a shunt connected inverter[28]. In order to achieve control strategies for effective operation of power systems various controllers such as Proportional and integral controllers (PI Controller), Proportional and derivative controllers (PD Controller), Proportional integral derivative controllers (PID controllers), Fuzzy Logic controllers and Artificial Neural Networks based controllers are used.

In STATCOM devices PI controllers are used, hence the operation of STATCOM device depends on effectiveness of these PI controllers. The genetic algorithm is used in PI controllers for obtaining optimized power in solar-wind hybrid microgrid [12].

Many researchers did the research on grid connected hybrid system with different controllers for obtaining voltage stability in the grid. Interconnection of two or more power system the reactive power is not satisfied to maintain the grid as stability [23].

In this proposed approach, we're considering optimal adjustment of PI parameter in STATCOM with GA[22]. The novelty of proposed approach is to adjust different PI parameter to control the reactive power in grid connected hybrid system and to obtain stable and reliable operating limit. We can achieve our aimed response of STATCOM by performing optimal adjustments to the PI controllers on the basis of Genetic Algorithm.

2.Modelling of Wind Power System

It offers the study and the modelling of a variable speed wind system based on Doubly Fed Induction Generator controlled with the aid of a linear control type PI, in order to independently control the active and reactive stator powers generated by means of the wind turbine [25]. The proposed control is applied to a Doubly Fed Induction Generator whose stator is directly connected to the grid in contrast to the rotor which is connected via “back-to-back” converters. The objective of the modelling is to apply the direct and indirect control of the active and reactive power generated by the wind turbine based on Doubly Fed Induction Generator through Maximum Power Point Tracking (MPPT) technique, to extract maximum power from the wind [14]. Simulation results are examined and compared in order to evaluate the performance of the proposed system.

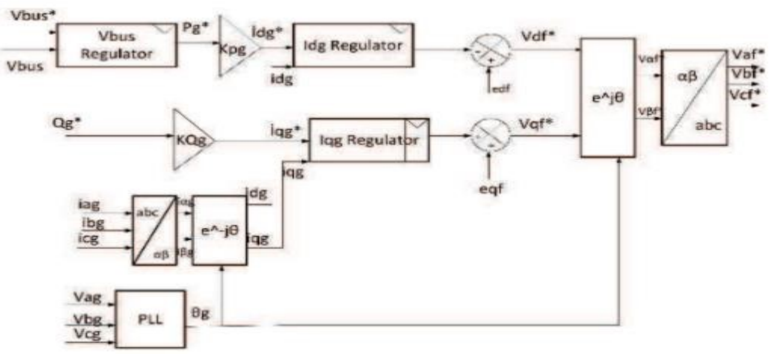


Fig.1. Grid side control circuit

The power equation produced by wind turbine is given in (1).

$$P_w = 1/2C_p\rho av^3{}_w. \quad (1)$$

The equation for the developed aerodynamic torque is given in (2).

$$T_t = 1/2\rho R^3V^2{}_wC_t. \quad (2)$$

End velocity ratio of Wind turbine is given in (3).

$$\partial = R\Omega_t/V_w. \quad (3)$$

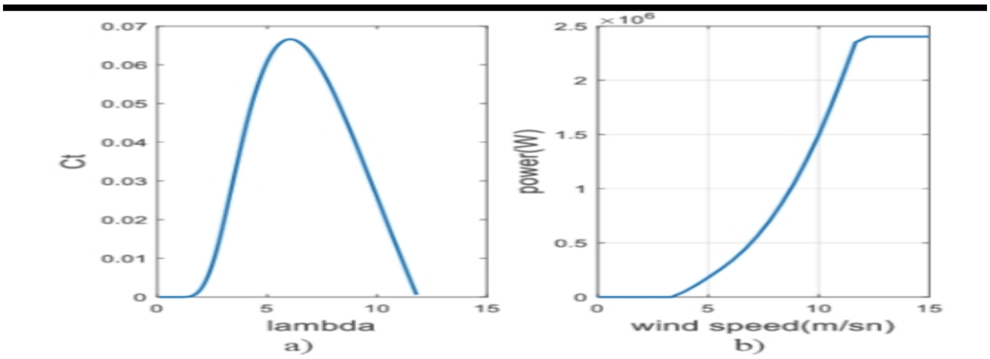


Fig. 2. Characteristics of wind turbine:a) Tip speed ratio(λ)-Power coefficient (Ct) characteristics; b) Velocity-Power characteristics.

From the figure, it is observed that if wind speed is 12 m/s, 2MW output power is obtained. Based on power and torque equations, we build a wind turbine model and some indirect methods are used to find out maximum power point like MPPT technique.

3.Photovoltaic Power System Modelling

Solar cells are connected in series or parallel to form a solar cell module in order to get the output power. Solar cells capture sun rays and generates DC power. The PV current can be determined through the underneath equation (4)[16].

$$I=I_{ph} - I_0[e^{(V+IRs)q/nKTNs-1}] - I_{sh} \quad (4)$$

where

K = Boltzmann constant (1.38×10^{-23} J/K),

T = absolute temperature(K),

q = electron charge (1.6×10^{-19} C),

R_s = shunt resistance of cell,

N_s =No. of PV modules in series,

V = output voltage of solar cell and

I_0 = dark saturation current value.

The Solar PV system is employed with MPPT technique based on P&O algorithm in order to grab more power [16].

4.Static Synchronous Compensator

STATCOM (shunt connected inverter) also called as STATCON (Static synchronous condenser). The term synchronous in STATCOM conveys that either it receives or produces reactive power to enhance with demand and to produce stabilized voltage. First of all, the setting of magnitude and frequency of ac output voltage of inverter in STATCOM circuit has to be done for proper and efficient operation of STATCOM.

STATCOM is united to Renewable Energy Sources like Solar PV and wind systems at PCC (Point of common coupling) in order to obtain reduced voltage fluctuations in grid and to achieve reliable operation of microgrid even under abnormal conditions[25].

Flow of reactive power can be in two ways:

1) If magnitude of $V_{statcom}$ is more than V_{ac}, then reactive power will from source $V_{statcom}$ to V_{ac}

2) If magnitude of $V_{statcom}$ is less than V_{ac}, then reactive power will flow from source V_{ac} to $V_{statcom.}$.

The active power delivered from AC system to STATCOM is given in (5)

$$P=V_{ac}V_{statcom}\sin\alpha/X \qquad (5)$$

If $\alpha > 0$, the capacitor in inverter gets charged($P>0$). If $\alpha<0$, the capacitor is discharged ($P < 0$).

The Reactive power flow from either STATCOM to AC system or AC system to STATCOM is explained in (6).

$$Q = V_{ac}V_{statcom}\cos\alpha-V^2_{ac}/X \qquad (6)$$

Where,

Vac = AC system voltage,

Vstatcom= inverter output voltage,

X = equivalent reactance of transformers,

α = phase difference between voltages.

In the STATCOM, Vdc is kept constant and we can calculate magnitude of AC output voltage of inverter by changing Modulation Index(m_a).It lies in between 0&1

If m_a = 0.75, V_{ac} = $V_{statcom}$(i.e. no power exchange).

If m_a = 0.65, V_{ac} > $V_{statcom}$(Inductive mode operation of STATCOM).

If m_a= 0.85,$V_{statcom}$ > V_{ac} (Capacitive mode operation of STATCOM).

From fig(3) we can see that STATCOM is directly fed to reactors and fig(4) shows the control circuit of STATCOM.

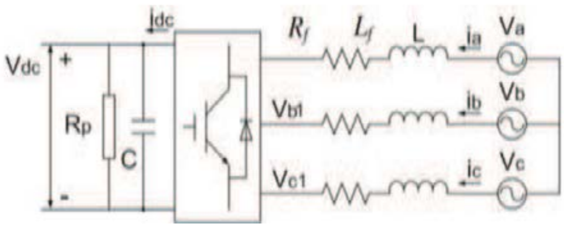


Fig. 3. The equivalent circuit of STATCOM

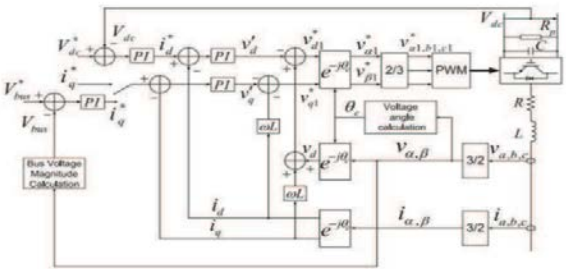


Fig. 4. Control circuit of STATCOM.

Table 1. System parameter of STATCOM model.

Parameter	Numerical Value
Grid line voltage	25 kV
Equivalent resistor	0.0012Ω
Equivalent inductor	1.2 mH
Shunt capacitor	16000 µF
Capacitor voltage	2400 V
System frequency	60 Hz

Fig (5) shows the Simulink diagram of voltage control and stability for Solar PV-Wind Energy Hybrid Micro-Grid using optimized STATCOM. The modelling of 2MW wind turbine fed with double-fed induction generator is done and using an indirect method such as MPPT we have determined maximum wind speed and torque produced. For a controlled action control of both rotor side and grid side has been done. Modelling of a 0.4 MW PV system was done and accurate synchronization is obtained by using PLL technique to provide high degree of immunity against voltage fluctuations and various imbalances in grid. The modelling of 3MVAR STATCOM is done by connecting it at PCC (point of common coupling) for reducing voltage fluctuations, to stabilize voltage of grid and for reactive power compensation[27]. First, we will measure current, voltage, active and reactive power values at the end of busbar without STATCOM. To maintain reference voltage at 1p.u., STATCOM is programmed at 1.077 p.u.

In this study , we used time domain criterion for the sake of PI controllers because we will determine wind speed or solar energy for particular regular intervals of time and adjust maximum power to be grabbed while using MPPT technique.

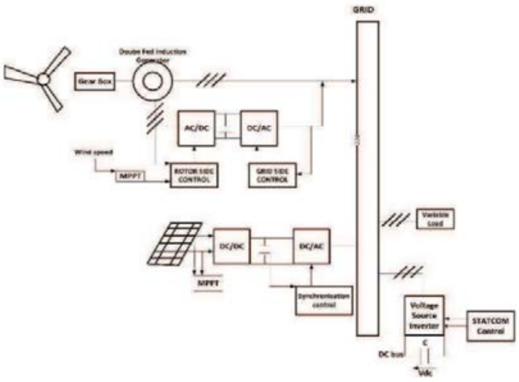


Fig. 5. Solar PV- Wind Energy Hybrid using optimized STATCOM

Everytime when we are integrating power to grid, some amount of power is lost and we are getting some voltage fluctuations. So, when we are comparing the amount of power delivered to grid and required amount of power to be supplied from the grid we are getting error. This error should be minimized in order to optimize power[22]. A performance criterion called ITAE (integral absolute time error) is used for PI controllers in order to optimize the output power and results of optimization are indicated in Table 2. Some other criterions like IAE (integral absolute error) and ISE (integral square error) are not used in our study because their performance in minimization of errors is low and their transient response is also very bad.

Genetic Algorithm codes with suitable m-function codes are providing better solutions to optimization problems using natural evolution techniques like mutation, inheritance, selection, cross over and population size values. The m-function file is programmed in MATLAB and the optimization is performed in 8-d search space and K_p and K_i values are determined.

$$ITAE=\int t|e(t)|d(t) \quad (9)$$

GA based method

Genetic algorithm solves optimization problem in 3 steps:

1. Initialization and identification of fitness function;

2. Coding (genetic coding);

3. Selecting the starting population to be random individuals.

Table 2. ITAE Controller Gain Constant in STATCOM

ITAE	For AC regulator		For DC regulator		For (Id and Iq) Current regulator	
PI Constant	Kp1	Ki1	Kp2	Ki2	Kp3 Kp4	Ki3 Ki4
GA result	0.3747	0.5694	0.0114	0.8051	0.9748 0.4292	0.3043 0.7021

At first, conventional method is used to initialize Kp and Ki values, then after for every individual fitness function is calculated. From all those individuals, best individuals are selected and allowed to cross over and mutation to form new generation. Following this process, repetition is done for many times in order to get optimized Kp, Ki values.Fig (6) indicates steps to optimize Kp, Ki values using GA in STATCOM

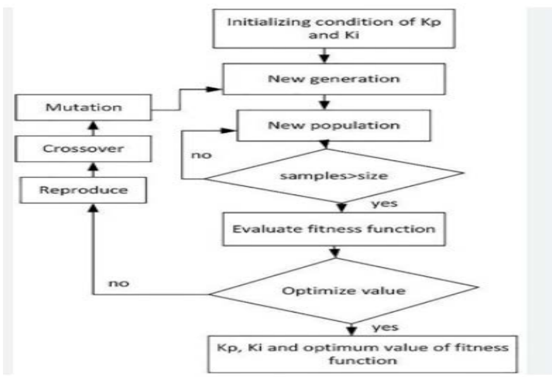


Fig. 6. Flow chart

5.Simulation Results and Discussion

When solar PV and wind hybrid energy systems are connected to grid and then to distribution networks, voltage fluctuations, voltage instability, power quality issues like slow voltage variations, harmonics and frequency imbalances are caused. But, because of our implemented controlling scheme of the STATCOM circuit with GA voltage fluctuations are reduced and reactive power compensation is also performed.

A.Results for Power Factor Compensation of STATCOM

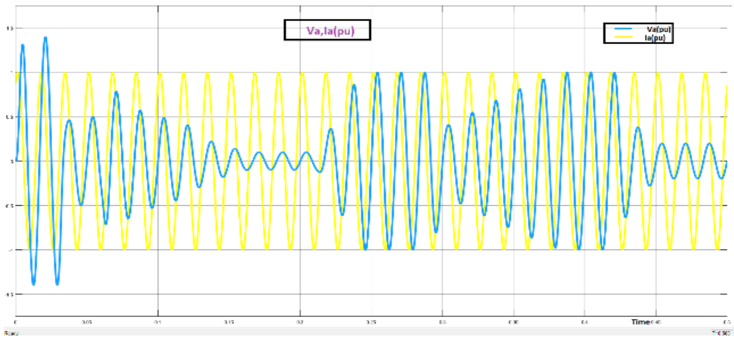


Fig.7(a): output voltage profile of STATCOM

From this figure, we can observe that the magnitude of voltage source is increased at 0.2 seconds and STATCOM absorbed +2.7 MVAR of reactive power.

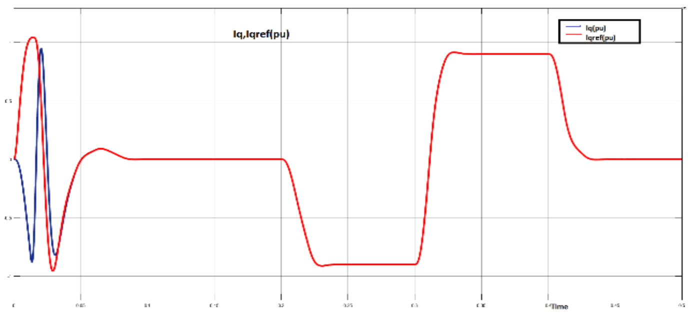


Fig.7(b): reactive current component of STATCOM

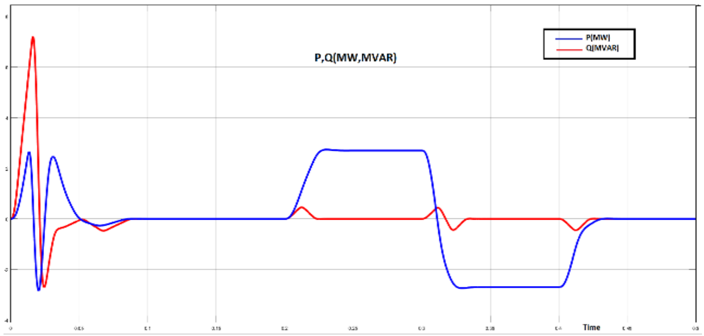


Fig.7(c): produced or absorbed active and reactive power by STATCOM.

From the above figure 7(c) we can observe that STATCOM absorbed reactive power +2.7 MVAR from 0.2seconds to 0.3 seconds and after 0.3 seconds it produced reactive power of -2.7 MVAR.

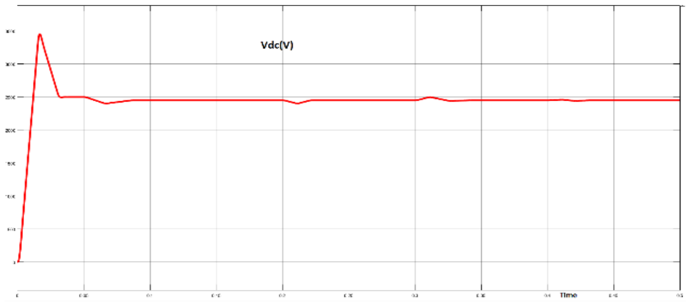


Fig .7(d) : DC Voltage

From the above figure we can observe that the DC voltage is kept constant in STATCOM.

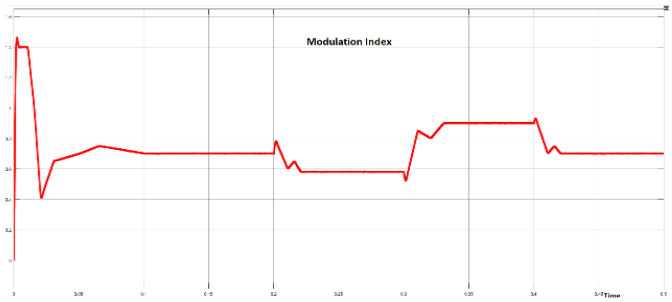
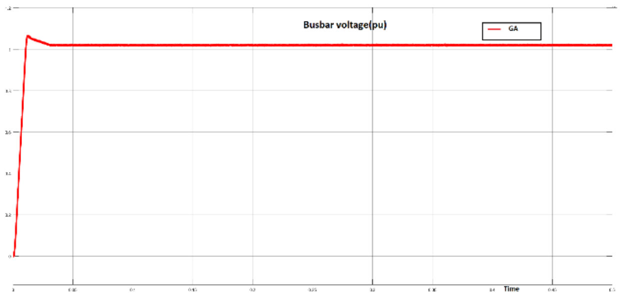


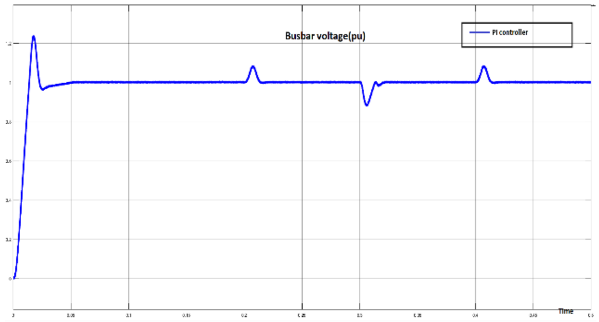
Fig. 7(e) : modulation index waveforms .

From the above figure, we can observe that from 0.2 seconds to 0.3 seconds the modulation index(m_a) is 0.65 i.e., inductive mode of operation of STATCOM. But, from 0.3 seconds the modulation index(m_a) is 0.85 i.e., capacitive mode of operation of STATCOM.

B.Simulation Results of Solar-Wind Hybrid System with STATCOM for Reactive Power Compensation



(a)



(b)

Fig.8: voltage profile at the end of the busbar GA optimized controller, with STATCOM(a), conventional PI controller, with STATCOM (p.u) (b).

From the above two figures we can observe that according to ITAE criterion when PI controller is used, highest overshoot and peaks are obtained at some points, but when GA is used voltage profile is maintained at 1p.u. and lowest overshoot is obtained.

6. Conclusions

On this study, Voltage control and stability for Solar PV -Wind energy hybrid Micro-Grid using optimized STATCOM is investigated. In this study, a 2MW wind turbine based DFIG and a 0.4MW solar PV energy system are hybridized & this hybrid system is provided with 3MVAR STATCOM which provides reactive power compensation. When the results from both STATCOM based PI controller and GA are compared GA is providing better voltage stability and reduced voltage fluctuations.

On basis of this work, reduced voltage fluctuations, voltage stability and reactive power compensation can be obtained in large transmission systems when Renewable Energy Sources are used as power sources.

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