CCSA Algorithm Compensator Designing in a Solar wind Hybrid Energy System

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Abstract- In recent years, there has been a growing interest in moving away from large centralized electricity production towards distributed energy resources. In this paper are designing of a Hybrid solar/wind system as well as integrating it with the grid system in MATLAB/SIMULINK environment. And Designing of a compensating device and compare it with the basic STATCOM compensator for active power output enhancement in the system. The compensating device control has to be designed with a linear crow optimizing algorithm to obtain a smooth voltage and current waveform. Reduction in the distortion level of the voltage output at the grid system is to be done by using the proposed optimizer. The description concludes that the hybrid system is made efficient for driving the loads having enhanced active power output at its terminal. The voltage available has been made less distorted and the THD level in current output has also came down.

Keywords: STATCOM, THD, hybrid system, DG.

I. INTRODUCTION

In recent years, there has been a growing interest in moving away from large centralized electricity production towards distributed energy resources. Solar energy production offers numerous advantages for use as a distributed energy source, particularly as a peak energy source. Energy suppliers are currently facing the great challenge of connecting distributed generators (DG) based on renewable energy, while ensuring stability, voltage regulation and energy quality. At night, energy loads are generally much lower than during the day, while wind farms (WF) produce more electricity due to the increase in wind speed.

With the present growth rate of energy consumption the world’s energy consumption is doubling every 10 years, which will lead to the depletion of the fossil fuel supply in a few hundred years. This will lead to the necessity to begin relying on other forms of energy in the near future.

Recently there has been a growing interest in expanding electric generating capacities through the use of Distributed Energy Generation (DEG). DEG consists of placing small (up to tens of megawatts) generation assets around communities and industrial facilities at the distribution level. These generation assets include natural gas micro-turbines, fuel cells, wind and solar energy sources. DEG offers many advantages to the generation companies and customers alike. The generation company will benefit by not having to sink large sums of capital into a generation facility that will not produce any return on investment for several years. Another advantage to the utility company is the reduced load on the Transmission & Distribution (T&D) network. By moving the energy source closer to the end user, losses in T&D lines are reduced. All of the benefits above can be passed on to the end user in the form of lower utility costs. Another benefit to the user would be improved power quality and reliability.

II. LITERATURE REVIEW

Emad Jamil et al. [1] this paper presents power quality improvement for effective power transfer in a grid-integrated solar photovoltaic-wind energy hybrid system. The hybrid system constitutes a renewable energy farm, based on photovoltaic energy generation system and wind energy conversion system. The system experiences frequent disturbances in AC loads and power output from the renewable farm. This creates reactive power mismatch and raises voltage instability and power quality issues. This gap can be eliminated using an adjustable reactive power source i.e. static synchronous compensator. Three case scenarios of the hybrid system, i.e. hybrid system in (I) standalone mode, (II) grid-integrated mode and (III)
grid-integrated mode with STATCOM, are tested to compare their dynamic and transient performances. Results show that scenario-III best fulfilled the dynamic compensation requirement among all cases.

Tariq Kamal et al. [2] this work provides the dynamic operation and supervisory control of a hybrid renewable energy system which supplies power in stand-alone as well as in grid-connected mode. It contains a photovoltaic as a primary source controlled via fuzzy and a Proton Exchange Membrane Fuel Cell (PEMFC) as a secondary source controlled via Proportional Integral Differential (PID) controller. The high intermittency nature of photovoltaic is addressed through the integration of supercapacitor and battery bank in the proposed architecture. The overall strategy of the proposed system is achieved using dynamic power switches of the power converters.

Gilberto Gonzalez-A et al. [3] The modelling in bond graph of a Skystream wind turbine composed by the blades, a permanent magnet synchronous generator (PMSG), three-phase rectifier, Boost converter and an inverter which is classified as a small scale system is presented. Bond graphs permits to model systems formed by different energy domains.

The Skystream turbine is a good case study to show that the bond graph model is presented in a unified representation approach. The electric power generation system based on this turbine is three-phase, the use of multibond graphs to model the PMSG, three-phase rectifier and inverter are proposed. However, the blades and Boost converter are modelled by single bond graphs. The mathematical representation of a section of a blade and the PMSG are obtained.

Sujit Kumar Bhuyan et al. [4] The proposed Hybrid Energy System (HES) consists of solar photovoltaic (PV) system, the electrolyzer, the storage tank and the solid oxide fuel cell (SOFC). The HES is used to supply the electricity to the 3Ø load as well as 1Ø load which is synchronized to the grid with the help of voltage source converter (VSC).

In this technology when PV power is not sufficient to fulfill the load demand, then SOFC power is utilized to fulfill the required demand. A fuel cell controller is proposed in which a PID controller is used to regulate the amount of hydrogen (H2) flow through the valve and utilized as a fuel of SOFC. In this paper, H2 is generated from electrolyzer which takes extra PV energy and water as input elements.

III. OBJECTIVE

The work has been focused on obtaining following key objectives:

- Designing of a Hybrid solar/wind system as well as integrating it with the grid system in MATLAB /SIMULINK environment.
- Designing of a compensating device and compare it with the basic STATCOM compensator for active power output enhancement in the system.
- The compensating device control has to be designed with a linear crow optimizing algorithm to obtain a smooth voltage and current waveform.
- Reduction in the distortion level of the voltage output at the grid system is to be done by using the proposed optimizer.

IV. METHODOLOGY

The large-scale wind/solar hybrid system is connected to grid via a booster station. The system consists of wind power system and photovoltaic system. In order to improve the transient voltage stability of the large-scale wind/solar hybrid system, reactive power compensation device STATCOM is connected to grid. The compensator is being proposed for further enhancement in the output parameters like THD in voltage, THD in current and active power output.

![Fig.1. Hybrid energy system topology](image)

As shown in Fig. 1, the wind power generation system consists of DFIG wind turbine and AC/DC inverter.

A. PV Module modelling
PV cells have single operating point where the values of the current (I) and voltage (V) of the cell result in a maximum power output. These values correspond to a particular resistance, which is equal to V/I. A simple equivalent circuit of PV cell is shown in Fig. 2.

![Fig. 2. Modeled solar system](image)

A cell series resistance (Rs) is connected in series with parallel combination of cell photocurrent (Ip), exponential diode (D), and shunt resistance (Rsh), Ipv and Vpv are the cells current and voltage respectively. It can be expressed as:

\[
I_{pv} = I_p - I_s \left( e^{(V_{pv} + I_{pv}R_s)/(nKT) - 1} - \left( V_{pv} + I_{pv} \right) \right) / R_s
\]

Where:

- \( I_p \) - Solar-induced current
- \( I_s \) - Diode saturation current
- \( q \) - Electron charge (1.6e-19 C)
- \( K \) - Boltzmann constant (1.38e-23 J/K)
- \( n \) - Ideality factor (1~2)
- \( T \) - Temperature 0 K

The solar induced current of the solar PV cell depends on the solar irradiation level and the working temperature can be expressed as:

\[
I_{ph} = I_{sc} - k_i(T_c - T_r) \times \frac{I_r}{1000}
\]

Where:

- \( I_{sc} \) Short-circuit current of cell at STC
- \( K_i \) Cell short-circuit current/temperature coefficient (A/K)
- \( I_r \) Irradiance in w/m²
- \( T_c, T_r \) Cell working and reference temperature at STC

A PV cell has an exponential relationship between current and voltage and the maximum power point (MPP) occurs at the knee of the curve as shown in the Fig 4.

![Fig. 4. Characteristic PV array power curve](image)

The P&O algorithm will track the maximum power to supply the DCMGs system. The assumptions for model derivation are that the ideal current source can be presented as the PVs behavior. In addition, all power converters are operated under the continuous conduction mode (CCM) and the harmonics are also ignored.

| Table 1. PV module Parameters |
|-------------------------------|
| Maximum Power                  | 213.5 Watts |
| Number of parallel strings     | 40          |
| Number series modules          | 10          |
| Open circuit voltage           | 36.3 Volts  |
| Short circuit current          | 7.84 Ampere |

B. Wind energy system modeling

Model of wind turbine with PMSG Wind turbines cannot fully capture wind energy. The components of wind turbine have been modelled by the following equations [8-10].

Output aerodynamic power of the wind-turbine is expressed as:

\[
P_{Turbine} = \frac{1}{2} \rho AC_p(\lambda, \beta)v^3
\]
Where, $\rho$ is the air density (typically 1.225 kg/m$^3$), $A$ is the area swept by the rotor blades (in m$^2$), $CP$ is the coefficient of power conversion and $v$ is the wind speed (in m/s).

The tip-speed ratio is defined as:

$$\lambda = \frac{\omega_m R}{v}$$

Where $\omega_m$ and $R$ are the rotor angular velocity (in rad/sec) and rotor radium (in m), respectively.

The wind turbine mechanical torque output $T_m$ given as:

$$T_m = \frac{1}{2} \rho A C_p(\lambda, \beta) v^3 \frac{1}{\omega_m}$$

The power coefficient is a nonlinear function of the tip speed ratio $\lambda$ and the blade pitch angle $\beta$ (in degrees). Then Power output is given by

$$P_{\text{Turbine}} = \frac{1}{2} \rho A C_p_{\text{max}} v^3$$

A generic equation is used to model the power coefficient $C_p$ based on the modeling turbine characteristics described in [2], [7-9] and [11] as:

$$C_p = \frac{1}{2} \left( \frac{116}{\lambda_i} - 0.4\beta - 5 \right) e^{-\left(\frac{21}{\lambda_i}\right)}$$

For each wind speed, there exists a specific point in the wind generator power characteristic, MPPT, where the output power is maximized. Thus, the control of the WECS load results in a variable-speed operation of the turbine rotor, so the maximum power is extracted continuously from the wind.

**C. CCSA algorithm**

Conventional search methods have long been applied to solve engineering design problems. Although these methods find promising results in many real problems, they may fail in more complex design problems. In real design problems, the number of decision variables can be very large and their effect on the objective function can be very complicated. The objective function may have many local optima, whereas the designer is interested in the global optimum. Such problems cannot be handled by conventional methods that only find local optima. In these cases, efficient optimization methods are needed.

Crows (crow family or corvids) are considered the most intelligent birds. They contain the largest brain relative to their body size. Based on a brain-to-body ratio, their brain is slightly lower than a human brain. Evidences of the cleverness of crows are plentiful. They have demonstrated self-awareness in mirror tests and have tool-making ability. Crows can remember faces and warn each other when an unfriendly one approaches. Moreover, they can use tools, communicate in sophisticated ways and recall their food’s hiding place up to several months later.

**V. RESULTS**

In this world of depleting energy resources the use of renewable based source of energy is highly required to meet the demands of future. The use of solar and wind energy resources for the generation of electricity is the
best choice for combating the use of the exhaustible resources. The best part is that it is also a clean source for generating electricity. This field is henceforth chosen for our work on these resources.

The work focuses on analysis of a hybrid solar/wind energy system by implementing it in MATLAB/SIMULINK software. The system is made to get integrated with the grid system also in order to enhance its efficiency. The chapter here discusses the solar/wind energy system in the following two cases.

Case 1: Hybrid wind energy system with STATCOM
Case 2: Hybrid wind energy system with constrained crow search algorithm regulated compensator

The hybrid system is created with two inputs to the solar panel being temperature and irradiation. The DC output voltage from the solar energy system is combined with the output from the wind energy system. However, the wind energy system produces three-phase output and hence it is first converted to DC voltage and merged with the output of the solar system. This combined output is then fed to the inverter for its DC/AC conversion.

The solar panel has been modelled with PV arrays having 10 cells connected in each series with 40 parallel branches that together give out the DC output from the system. The variable illumination of 1000 lux is provided along with varying temperature of 25°C. This output is then merged with the DC output from the wind energy system and further sent to the inverter for its AC conversion. The DC output waveform have been illustrated in the fig. below.

Fig. 7. DC output voltage from the hybrid energy system when STATCOM compensator is used

Fig. 8. Voltage output from the inverter in system having statcom at bus B1

Fig. 9. Current output from the inverter in system having statcom at bus B1

Case 1: Hybrid wind energy system with STATCOM

Fig. 10. Voltage output from the system with STATCOM at bus B2 (loads)
Case 2: Hybrid wind energy system with constrained crow search algorithm regulated compensator
Fig. 18. Voltage output from the system with constrained crow search algorithm regulated compensator

Fig. 19. FFT window of Voltage output from the system with CCSA regulated compensator

Fig. 20. THD% of Voltage output from the system with CCSA regulated compensator

Fig. 21. Current output from the system with constrained crow search algorithm regulated compensator

Fig. 22. FFT window of Current output from the system with CCSA regulated compensator

Fig. 23. THD% of Current output from the system with CCSA regulated compensator
VI. VALIDATION

This chapter shall discuss the comparative outcomes of the compensators. The compensator modeled with constrained crow search based algorithm is expected to produce better results as compared to the traditional STATCOM.

|                  | System with STATCOM | System with CCSA regulated compensator |
|------------------|----------------------|----------------------------------------|
| Active power output | 28 MW                | 30 MW                                  |
| Voltage Output    | $20 \times 10^4$ V   | $20 \times 10^4$ V                     |
| Current Output    | 1500 A               | 1600 A                                 |
| THD% in voltage   | 0.87 %               | 0.04 %                                 |
| THD % in current  | 1.07 %               | 0.07 %                                 |
| Reactive Power output | 6 MVar              | 2MVar                                  |

The above results show the comparative values of all the parameters. The active power output available has been enhanced from approximately 28MW at the load distribution bus in the system having STATCOM to 30 MW in the system which is made with the compensator driven by the constrained crow search algorithm (CCSA).

VII. CONCLUSION

The demand for electricity is increasing day by day, which cannot be fulfilled by non-renewable energy sources alone. Renewable energy sources such as solar and wind are omnipresent and environmental friendly. The renewable energy sources are emerging options to fulfill the energy demand, but unreliable due to the stochastic nature of their occurrence. Hybrid renewable energy system (HRES) combines two or more renewable energy sources like wind turbine and solar system.

The work here presents a hybrid renewable energy system in MATLAB/SIMULINK environment for analysis. We have designed a controller for the compensator based on the optimizing algorithm which is a part of artificial intelligence. Following main conclusions were drawn:

- The active power output from the system has enhanced to 30MW in the system having compensator regulated from the proposed controller that is constrained crow search algorithm from 28MW which is also stable as compared to the system having STATCOM.

- The Crow search algorithm is so constrained in a manner such that the output voltage and current distortion has also reduced. The voltage output distortion level from the hybrid solar wind energy system was found to be 0.04% which is less than 0.87 % of the system having basic STATCOM.

- The crow search algorithm has collectively proved to be effective reducing the distortion level of current output also. The current distortion level has also come down to 0.07% using the proposed controller from the 1.07% in the solar wind hybrid system with basic STATCOM.

- The system is also integrated with the grid energy system. The line voltage being maintained to 20 KVolts. The reactive power output has also reduced. The algorithm has proven to be more effective in the compensating the reactive power as well.

The above description concludes that the hybrid system is made efficient for driving the loads having enhanced active power output at its terminal. The voltage available
has been made less distorted and the THD level in current output has also came down.

VIII. Future Scope

The modulation technique is easy and simple to be implemented; use of proper facts devices can make it more robust and easy to handle inverter. With the advent of more powerful artificial intelligence, the requirements for low computational complexity and memory consumption of the algorithms will drop and it might be even possible to implement more complicated and more efficient algorithms. The proposed controller has proved be effective while designing the compensator. This algorithm can further work in an enhanced manner by making a hybrid technique for this algorithm. Therefore, it is certainly true that the area of compensator is and for a long time will remain widely opened sphere for scientific research and commercial applications.

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