Optimizing Power Quality in Grid-Connected Wind Energy Systems Using D-STATCOM

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Abstract—Renewable energy sources, long anticipated as a promising alternative energy solution, present new challenges upon integration with the power grid. This project addresses power quality issues arising from the connection of a wind turbine to the grid. Our proposed solution involves the integration of a Distributed Static Compensator (D-STATCOM) and a battery energy storage system (BESS) at a point of common coupling. This setup effectively mitigates power quality fluctuations. The BESS plays a crucial role in stabilizing real power output amidst varying wind conditions. We model and simulate the D-STATCOM control scheme using both PID and Fuzzy logic controllers in MATLAB. The simulation results clearly illustrate the efficacy of our proposed D-STATCOM system in improving power quality.

Keywords— Voltage sag, Distribution-static compensator (D-STATCOM), Total Harmonic Distortion (THD).

I.INTRODUCTION

To attain sustainable growth and social progress, it is essential to meet energy needs by harnessing renewable energy resources such as wind, biomass, hydro, co-generation, among others. In a sustainable energy system, conserving energy and utilizing renewable sources are foundational principles. The integration of renewable energy sources like wind energy into the power system is vital for reducing environmental impact on conventional plants.[1] However, this integration poses technical challenges that require attention to voltage regulation, stability, and power quality issues. Power quality, a crucial customer-focused metric, is greatly influenced by the operation of distribution and transmission networks.

The matter of power quality holds significant importance for wind turbines [2]. There has been extensive growth and rapid development in the utilization of wind energy in recent years. Individual units can have large capacities of up to 2 MW, feeding into the distribution network, especially with customers connected in close proximity [3]. Currently, more than 28,000 wind generating turbines are successfully operating worldwide. The proposed D-STATCOM control scheme for grid-connected wind energy generation aims to improve power quality and has the following objectives.

1. Unity power factor at the source side.
2. Reactive power support only from D- STATCOM to Wind Generator and Load.
3. Simple PI controller for D- STATCOM to achieve fast dynamic response.

II.BASIC CONFIGURATION AND OPERATION OF D-STATCOM

The D-STATCOM is a three-phase, shunt-connected power electronics-based device typically installed near the load within distribution systems. Its major components, as depicted in Fig. 1, include a DC capacitor, a three-phase inverter module (utilizing IGBTs or thyristors), an AC filter, a coupling transformer, and a control strategy.

At the heart of the D-STATCOM lies the voltage-sourced inverter, responsible for converting an input DC voltage into a three-phase output voltage at the fundamental frequency.

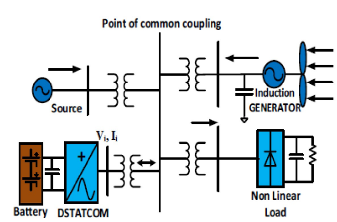


Figure 1.Basic Building Blocks of the D-STATCOM

The D-STATCOM utilizes an inverter to convert the DC link voltage (Vdc) stored on the capacitor into a voltage source with adjustable magnitude and phase. Consequently, the D-STATCOM can be regarded as a voltage-controlled source.

The D-STATCOM can also be viewed as a current-controlled source. In Fig. 1, the inductance (L) and resistance (R) represent the equivalent circuit elements of the step-down transformer, with the inverter being the main component of the D-STATCOM. The voltage (Vi) denotes the effective output voltage of the D-STATCOM, while δ represents the power angle. The reactive power output of the D-STATCOM can be either inductive or capacitive depending on its operational mode. In Fig. 1, the construction and controller of the D-STATCOM are utilized to operate the inverter in a manner that dynamically adjusts the phase angle between the inverter voltage and the line voltage. This adjustment ensures that the D-STATCOM generates or absorbs the desired VAR at the point of connection. The phase of the output voltage of the thyristor-based inverter, Vi, is controlled similarly to the distribution system voltage, Vs.

A. POWER QUALITY IMPROVEMENT

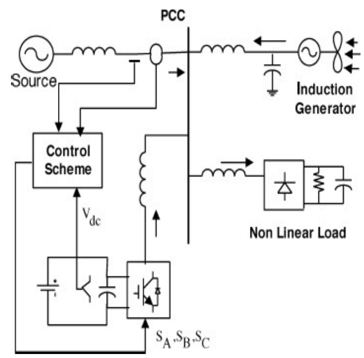


Fig 2. System operational scheme in grid system

The D-STATCOM, operating on current control voltage source inverter principles, injects current into the grid in a manner that ensures the source current remains harmonics-free and maintains a desired phase angle with respect to the source voltage. This injected current effectively neutralizes both the reactive and harmonic components of the load and induction generator currents, thereby enhancing power factor and improving power quality. To achieve these objectives, grid voltages are sensed and synchronized to generate the current command for the inverter. The proposed grid-connected system, illustrated in Fig. 2, is implemented to enhance power quality at the point of common coupling (PCC). This system includes a wind energy generation system, a battery energy storage system, and a D-STATCOM.

B. BESS- D-STATCOM

The battery energy storage system (BESS) is used as an energy storage element for the purpose of voltage regulation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in D-STATCOM since it rapidly injects or absorbed reactive power to stabilize the grid system. It also controls the distribution and transmission system in a very fast rate. When power fluctuation occurs in the system, the BESS can be used to level the power fluctuation by charging and discharging operation. The battery is connected in parallel to the dc capacitor of D-STATCOM. The D-STATCOM is a three- phase voltage source inverter having the capacitance on its DC link and connected at the point of common coupling. The D-STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling.

C.FILTER

A transmission network used to selectively modify the components of a signal according to their frequencies. In most cases a filter is used to enhance signals of desired frequencies while suppressing signals of undesired frequencies. An ideal filter would pass only desired frequencies while completely suppressing all unwanted frequencies, without any dispersion in time of the frequencies. Unfortunately, ideal filters are impossible to achieve. Electric filters are used in most electronic communication systems. Whether communication is over wire, free space, or optical fiber, multiple channels of information can be multiplexed on different frequency bands. Unwanted signals and noise are introduced along the communications path. The main function of electric filters is to separate the desired signal or channel from all others and from any noise.

D.LIMITER

A limiter is a circuit that allows signals below a specified input power to pass unaffected while attenuating the peaks of stronger signals that exceed this input power. An FM radio receiver usually has at least one stage of amplification for this purpose. It provides a constant level of signal to the FM demodulator stage, reducing the effect of signal level changes in the output. If two or more signals are received at the same time, a high performance limiter stage can greatly reduce the effect of the weaker signals on the output. This is commonly referred to as the FM capture effect. Generally, FM demodulators are not affected by amplitude variations, since the baseband is contained in the frequency deviations. Some detectors, including the radio detector inherently limit gain by a nature of the circuit design. In AM radio, the intelligence is located in the amplitude variations, and distortion can occur due to spurious signals that could cause the baseband to be misrepresented. Mastering engineers often use limiting combined with make-up gain to increase the perceived loudness of an audio recording during the audio mastering process.

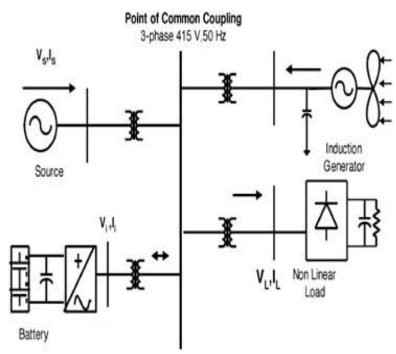
E.GAIN

Gain is a measure of the ability of a circuit (often an amplifier) to increase the power or amplitude of a signal from the input to the output. It is usually defined as the mean ratio of the signal output of a system to the signal input of the same system. It may also be defined on a logarithmic scale, in terms of the decimal logarithm of the same ratio ("dB gain"). A gain greater than one (zero dB), that is, amplification, is the defining property of an active electronic components or circuit, while a passive circuit will have a gain of less than one.

III.TOPOLOGY FOR POWER QUALITY IMPROVEMENT

The D- STATCOM based current control voltage source inverter injects the current into the grid in such a way that the source current are harmonic free and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC), as shown in Fig.3. The grid connected system in Fig.3, consists of wind energy generation system and battery energy storage system with D-STATCOM.

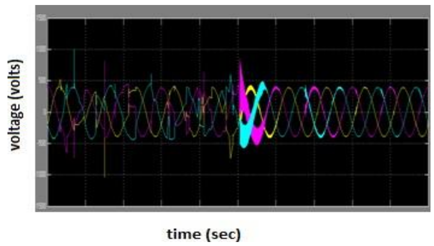
A. Wind energy generating system



The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads and has natural protection against short circuit.
Fig.2 Grid connected system for power quality improvement

B.D- *STATCOM* – Distribution Static Compensator

D-STATCOM (Distribution Static Compensator) to meet the load current compensation requirement such as reactive power Compensation, load balancing and harmonic elimination. Performance of D-STATCOM system depends on the algorithm used for control of the system so that dynamic compensation of



the load can be provided. There are various control algorithms used for

Fig.3 wind source

detection of reference current for switching of VSC e.g. instantaneous reactive power theory, instantaneous id-iq theory, and method for estimation of current reference by maintaining the voltage of DC bus of D-STATCOM. The important requirement for the control algorithm is that it should be simple, easy to implement and work well with non-sinusoidal and unbalanced ac mains, which is a practical situation in present day distribution system for D-STATCOM to work.

D-STATCOM can improve power-system performance in such areas as the following:

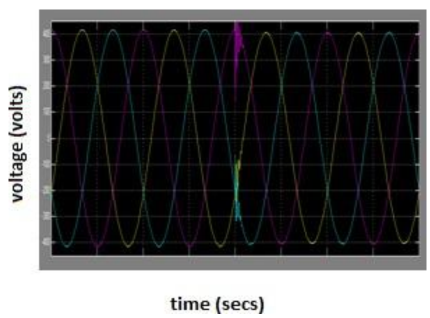


Fig.4 without D-STATCOM

1. The dynamic voltage control in transmission and distribution systems;
2. The power-oscillation damping in power transmission Systems;
3. The transient stability;
4. The voltage flicker control;
5. The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

Furthermore, D- STATCOM does the following:

1. It occupies a small footprint, for it replaces passive banks of circuit elements by compact electronic converters;
2. It offers modular, factory-built equipment, thereby reducing site work and Commissioning time;
3. It uses encapsulated electronic converters, thereby minimizing its environmental impact.

D- STATCOM is analogous to an ideal synchronous machine, which generates a balanced set of three sinusoidal voltages at the fundamental frequency with controllable amplitude and phase angle. This ideal machine has no inertia, is practically instantaneous, does not significantly alter the existing system impedance, and can internally generate reactive (both capacitive and inductive) power.

IV.SIMULATION RESULTS

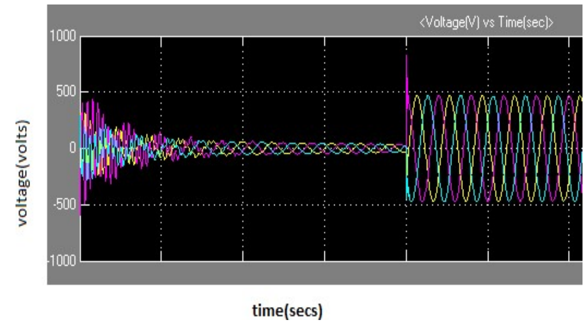


Fig.5 with D-STATCOM

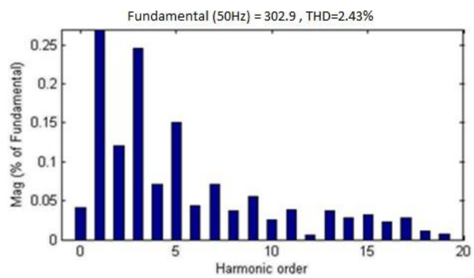


Fig.6 FFT analysis of output D-statcom (PID)

V. FUZZY LOGIC CONTROLLER

Fuzzy logic control is a new addition to control theory. Its design philosophy deviates from all the previous methods by accommodating expert knowledge in controller design. Fuzzy logic control is derived from fuzzy set theory introduced by Zadeh in 1965. FL controllers are an attractive choice when precise mathematical formulations are not possible.

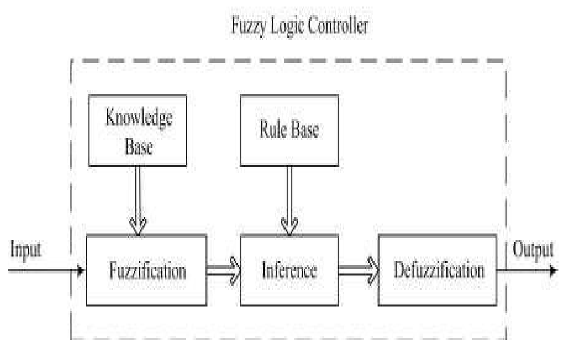


Fig.7 Functional block diagram

The fuzzy logic control system (Fig.7) can be divided into four main functional blocks namely Knowledge base, Fuzzification, Inference mechanism and Defuzzification. The knowledge base is composed of data-base and rule-base. The data-base, consisting of input and output membership functions, provides information for appropriate fuzzification operations, the inference mechanism and defuzzification. The rule-base consists of a set of linguistic rules relating the fuzzy input variables to the desired control actions.
Fuzzification converts a crisp input signal, the error, and error change into fuzzified signals that can be identified by level of membership in the fuzzy sets. The inference mechanism uses the collection of linguistic rules to convert the input conditions to fuzzified output. Finally, the defuzzification converts the fuzzy outputs to crisp control signals, which in the system acts as the changes in the control input.

TABLE-I Rule base

e/Δe	NB	NM	Z	PM	PB
NB	NB	NB	NB	NM	Z
NM	NB	NB	NM	Z	PM
Z	NB	NM	Z	PM	PB
PM	NM	Z	PM	PB	PB
PB	Z	PM	PB	PB	PB

TABLE-II

	PID	FLC
WITH D-STATCOM (THD)	2.43%	1.03%

V. CONCLUSION

This paper introduces a D-STATCOM-based control scheme aimed at improving power quality in grid-connected wind generation systems, particularly in the presence of nonlinear loads. The paper begins by discussing power quality issues and their implications for both consumers and electric utilities. The operation of the control system developed for the D-STATCOM-BESS in MATLAB/SIMULINK is simulated to maintain power quality. However, it is observed that the harmonic content remains relatively high compared to the method implemented with a PID controller, resulting in a total harmonic distortion (THD) value of approximately 2.43%. Conversely, employing FUZZY LOGIC yields a reduced harmonic content, with a THD value of around 1.03%. This approach effectively mitigates harmonic components in load currents, maintains in-phase source voltage and current, and supports reactive power demand for both the wind generator and loads at the point of common coupling (PCC) in the grid system. Consequently, it offers an opportunity to improve the utilization factor of transmission lines. The integration of wind generation with PID and FUZZY LOGIC demonstrates improved system performance. Furthermore, the potential for further enhancement through the implementation of NEURAL NETWORKs is highlighted for future development.

REFERENCES

[1] M. Ali, A. youssef and A. Ali, “Comparative study of different pitch angle control strategies for DFIG based on wind energy conversion system”, International Journal of Renewable Energy Research IJRER, vol. 9, no. 1, pp. 157– 163, March 2019.

[2] Wang, X. Wang, X. Wang, C. Shao, P. D. Judge, and T. C. Green, “An analytical approach to evaluate the reliability of offshore wind power plants considering environmental impact,” IEEE Transactions on Sustainable Energy, vol. 9, no. 1, pp. 249–260, 2018.

[3] T. Kang, S. Choi, A. S. Morsy, and P. N. Enjeti, “Series voltage regulator for a distribution transformer to compensate voltage sag/swell,” IEEE Transactions on Industrial Electronics, vol. 64, no. 6, pp. 4501–4510, 2017.

[4] L. Amen, L. Djamel, M. Zohra et al., “Influence of the wind farm integration on load flow and voltage in electrical power system,” International Journal of Hydrogen Energy, vol. 41, no. 29, pp. 12 603– 12 617, 2016.

[5] C.Nagarajan and M.Madheswaran - ‘Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter’ - Journal of ELECTRICAL ENGINEERING, Vol.63 (6), pp.365-372, Dec.2012.

[6] C.Nagarajan and M.Madheswaran - ‘Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis’- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011.

[7] C.Nagarajan and M.Madheswaran - ‘Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques’- Taylor & Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011.

[8] C.Nagarajan and M.Madheswaran - ‘Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis’- Iranian Journal of Electrical & Electronic Engineering, Vol.8 (3), pp.259-267, September 2012.

[9] C. Nagarajan C., Neelakrishnan G., Akila P., Fathima U., Sneha S. “Performance Analysis and Implementation of 89C51 Controller Based Solar Tracking System with Boost Converter” Journal of VLSI Design Tools & Technology. 2022; 12(2): 34–41p.

[10] C. Nagarajan, G.Neelakrishnan, R. Janani, S.Maithili, G. Ramya “Investigation on Fault Analysis for Power Transformers Using Adaptive Differential Relay” Asian Journal of Electrical Science, Vol.11 No.1, pp: 1-8, 2022.

[11] G.Neelakrishnan, K.Anandhakumar, A.Prathap, S.Prakash “Performance Estimation of cascaded h-bridge MLI for HEV using SVPWM” Suraj Punj Journal for Multidisciplinary Research, 2021, Volume 11, Issue 4, pp:750-756

[12] G.Neelakrishnan, S.N.Pruthika, P.T.Shalini, S.Soniya, “Perfromance Investigation of T-Source Inverter fed with Solar Cell”

Suraj Punj Journal for Multidisciplinary Research, 2021, Volume 11, Issue 4, pp:744-749
[13] C.Nagarajan and M.Madheswaran, “Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation” has been presented in ICTES’08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007
[14] M Suganthi, N Ramesh, “Treatment of water using natural zeolite as membrane filter”, Journal of Environmental Protection and Ecology, Volume 23, Issue 2, pp: 520-530,2022
[15] M Suganthi, N Ramesh, CT Sivakumar, K Vidhya, “Physiochemical Analysis of Ground Water used for Domestic needs in the Area of Perundurai in Erode District”, International Research Journal of Multidisciplinary Technovation, pp: 630-635, 2019
[16] J. Hussain et al., Vol.9, No.3, September, 2019 1396 transfer, reactive power compensation, and voltage conversion,” IEEE Transactions on IndustrialElectronics, vol. 60, no. 10, pp. 4512–4524, 2013.
[17] Singh and Arya,“Back-propagation control algorithm for power quality improvement using D-Statcom,” IEEE Transactions on industrial electronics, vol. 61, no. 3, pp. 1204–1212, 2014.
[18] K .S. Hook, Y. Liu, and S. Atcitty, ”Mitigation of the wind generation integration related power quality issues by energy storage,”EPQU J., vol.XII,no. 2,2006
[19] R. Billinton and Y . Gao, “Multistate wind energy conversion system models for adequacy assessment of generating systems incorporating wind energy,” IEEE Trans. on E. Conv., vol. 23, no. 1, pp. 163-169, 2008.
[20] J . Manel Carrasco, “Power electronic system for grid integration of renewable energy source: A survey,”IEEE Trans. Ind. Electron ., vol . 53, no.4, pp.1002-1014,2006
[21] A .Nazarloo, S.H. Hosseini and E. Babaei, “Flexible DSTATCOM performance as a flexible distributed generation in mitigating faults,” in Proc.IEEE 2nd Power Electronics, Drive Systems and Technology Conference (PEDSTC), 2011, pp 568- 573.
[22] Babaei, A. Nazarloo, and S. H. Hosseini,“Application of flexible control methods for D-STATCOM in mitigating voltage sags and swells,” iProc. IEEE International Power and Energy Conference(IPEC), Singapore, 2010 pp. 590-595