

IMPROVEMENT OF VOLTAGE QUALITY OF POWER GRID INTEGRATED ANCILLARY SERVICES THROUGH WIND TURBINES AND STATCOM: CASE OF POWER GRID IN BINH THUAN

Le Thi Minh Chau¹, Tran Viet Thanh², Duong Minh Quan^{3*},
Le Xuan Chau⁴, Van Trong Nhan³, Tran Anh Tuan³

¹Hanoi University of Science and Technology, ²Centre Power Engineering Consulting, Nhatrang city

³The University of Danang - University of Science and Technology, ⁴Naval Academy, Nhatrang city

ARTICLE INFO	ABSTRACT
Received: 03/4/2024	A crucial trend for the future is the integration of wind power (WP) into the grid, in order to guarantee that the source of energy used to replace fossil fuels pollutes the environment. The generation source, the load, or the short-circuit occurrence will have an impact on the grid, therefore, have a suitable solution to ensure its safe operation. The content of the paper will mention the solution to stabilize the power grid combined with the auxiliary source of static synchronous compensator (STATCOM). This work is part of an ongoing project that seeks to provide empirical evidence and an examination of how an ancillary services can be integrated from wind turbines that is based on Digsilent Power Factor software. The STATCOM technology is investigated as an effective solution to regulate and maintain voltage quality in the context of variable WP generation. The study not only seeks to optimize the performance and stability of the power grid but also proposes tailored ancillary solutions for the unique conditions of Vietnam's Grid.
Revised: 31/5/2024	
Published: 31/5/2024	
KEYWORDS	
WECS	
Ancillary services	
Wind power	
Integrated	
Voltage	

CẢI THIỆN CHẤT LƯỢNG ĐIỆN ÁP CỦA LƯỚI ĐIỆN TÍCH HỢP DỊCH VỤ PHỤ TRỢ THÔNG QUA TUABIN ĐIỆN GIÓ VÀ STATCOM: TRƯỜNG HỢP LƯỚI ĐIỆN TẠI BÌNH THUẬN

Lê Thị Minh Châu¹, Trần Việt Thành², Dương Minh Quân^{3*},
Lê Xuân Châu⁴, Văn Trọng Nhân³, Trần Anh Tuấn³

¹Đại học Bách khoa Hà Nội, ²Công ty Cổ phần Tư vấn Xây dựng điện 4

³Đại học Đà Nẵng - Trường Đại học Bách khoa, ⁴Học viện Hải Quân, Nha Trang

THÔNG TIN BÀI BÁO	TÓM TẮT
Ngày nhận bài: 03/4/2024	Một xu hướng quan trọng cho tương lai là tích hợp năng lượng gió (WP) vào lưới điện, nhằm đảm bảo rằng nguồn năng lượng được sử dụng để thay thế năng lượng hóa thạch không gây ô nhiễm môi trường. Nguồn phát điện, tải điện, hoặc sự cố ngắn mạch sẽ ảnh hưởng đến lưới điện, do đó, cần có một giải pháp phù hợp để đảm bảo hoạt động an toàn của nó. Nội dung bài báo sẽ đề cập giải pháp ổn định lưới điện kết hợp với nguồn phụ trợ là bộ bù đồng bộ tĩnh (STATCOM). Công việc này là một phần nội dung đề tài nghiên cứu đang được thực hiện nhằm cung cấp các minh chứng về việc cải thiện điện áp thông qua giải pháp tích hợp thiết bị phụ trợ từ các nhà máy điện gió dựa trên phần mềm Digsilent Power Factor. Công nghệ STATCOM được nghiên cứu như một giải pháp phụ trợ hiệu quả để điều tiết và duy trì chất lượng điện áp trong bối cảnh phát điện gió thay đổi. Nghiên cứu không chỉ tìm cách tối ưu hóa hiệu suất và độ ổn định của lưới điện mà còn đề xuất các giải pháp phù hợp với điều kiện đặc thù của mạng lưới điện Việt Nam.
Ngày hoàn thiện: 31/5/2024	
Ngày đăng: 31/5/2024	
TỪ KHÓA	
Hệ thống chuyển đổi năng lượng gió	
Bộ bù đồng bộ tĩnh	
Tua bin gió	
Tích hợp	
Điện áp	

DOI: <https://doi.org/10.34238/tnu-jst.10023>

* Corresponding author. Email: dmquan@dut.udn.vn

Current flows in the direction from the grid to the STATCOM if the magnitude of the compensator's voltage is lower than the voltage at the connection point. In this case, the reactive power will be absorbed. In the opposite case, active power will be transmitted back to the power grid from STATCOM. When STATCOM pushes reactive power to the grid, it will cause the grid voltage to increase. Oppositely, the grid voltage will drop when STATCOM takes in reactive power. The STATCOM control process is depicted as an overexcited generator or capacitor in the first case and as an under-excited generator or reactor in the second. Therefore, the power flow constraints of STATCOM [11], [12] will be expressed as follows:

In which, V_{grid} and θ_{grid} respectively the busbar voltage and deflection angle at the connected Statcom's node, and are the voltage and deflection angle of STATCOM and the total conductance of the synchronous voltage power supply is $g_{SANH} + b_{SANH} = Y_{SANH}$

$$\begin{aligned}
 P_{SANH} &= V_{grid}^2 \cdot g_{SANH} - V_{grid} \cdot V_{SANH} (g_{SANH} \cos(\theta_{grid} - \theta_{SANH}) + b_{SANH} \cos(\theta_{grid} - \theta_{SANH})) \\
 Q_{SANH} &= -V_{grid}^2 \cdot b_{SANH} - V_{grid} \cdot V_{SANH} (g_{SANH} \cos(\theta_{grid} - \theta_{SANH}) - b_{SANH} \cos(\theta_{grid} - \theta_{SANH}))
 \end{aligned}
 \tag{1}$$

Where: g_{SANH} is conductance, b_{SANH} is reactance, Y_{SANH} is short-circuit admittance, V_{SANH} voltage of the circuit, P_{SANH} is active power and Q_{SANH} is reactive power (shown in Figure 3b).

2.1. Established mode

According to Vietnam's requirements for voltage quality, when the grid system operate stably, there are no anomalous voltage fluctuations at nodes higher than 0.95 p.u. As a result, $U_{STATCOM} - U_{Grid} = 0$. There is no compensating or absorbing reactive power.

2.2. Short circuit mode

Assuming a 3-phase short circuit, the total fault impedance. The suggested remedy is to install a STATCOM power adjustment device to address the short circuit issue. This study's focus is on the equipment's capabilities. The following calculation is made using the branch circuit-based superposition method to determine the STATCOM's location and capacity. Modeling a node in the power system connected to STATCOM is shown in Figure 3.

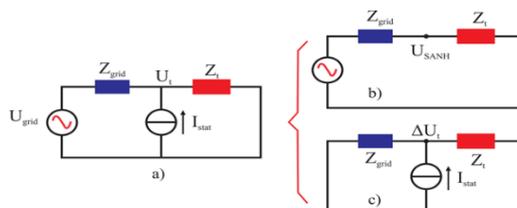


Figure 3. Diagram of one-node power grid with STATCOM

A simplified structure is shown in Figure 3(a) which includes a voltage source and a STATCOM at the load node [13]. Z_{grid} and Z_t represent the total impedance of the power source and load, respectively. It is possible to adjust the voltage at the load node to the value U_t through STATCOM, which will inject I_{STAT} into the grid. Figure 3(b) and 3(c), which are two superposition circuits of Figure 3(a), can be used to calculate the I_{STAT} .

In particular, the circuit in Figure 3(c) of the power grid diagram does not take into account the grid and ignores the STATCOM, resulting in U_{SANH} at the load node. Only then, taking into account STATCOM's pumping of the I_{STAT} , should the voltage compensation ΔU_t ($\Delta U_t = U_t - U_{SANH}$) circuit be considered. The formula below can be used the I_{STAT} value from here:

$$I_{STAT} = \frac{\Delta U_t}{Z_{th}} = \frac{U_t - U_{SANH}}{Z_{th}}
 \tag{2}$$

In which, Z_{th} total Thevenin resistance of the power grid from the load node (Figure 3c), Z_{grid} is parallel to Z_t . The voltage at the load node, U_t , which is connected to STATCOM, is presumed to be within the electrical equipment's safe voltage range. In reality, I_{STAT} calculation also adheres to the superposition principle of Thevenin's theory for the node impedance matrix for a power grid like the 16-node sample as shown below:

Without taking grid connected STATCOM into account and assuming that the grid is short-circuited as the initial state, we have the node voltage equation.

$$[U_0] = [Z_{bus}] \times [I_0] \tag{3}$$

With $[U_0]$ is the node voltage matrix in the initial state (when short circuited); $[I_0]$: The current matrix injects the nodes; $[Z_{bus}]$: Nodal impedance matrix of the power grid.

When considering STATCOM, similar to when we inject current $\Delta I_k = \Delta I_{STAT}$ into node k, the node voltage equation of the power grid is calculated as follows according to Thevenin's theory.

$$[U] = [Z_{bus}] \times ([I_0] + [\Delta I]) = [U_0] + [\Delta U] \tag{4}$$

In which $[\Delta U] = [Z_{bus}] \times [\Delta I]$

Because only one STATCOM's node is considered, the pump current matrix added to the nodes $[\Delta I]$ only has element $\Delta I_k \neq 0$, and all other elements are 0.

Assuming the voltage at node k connected to STATCOM will increase from $U_{k0} = U_{SANH.k}$ to $U_k = 1$. The corresponding STATCOM's I_{STAT} current will be:

$$I_{STAT} = \Delta I_k = \frac{\Delta U_k}{Z_{kk}} = \frac{1}{Z_{kk}} (1 - U_{SANH.k}) \tag{5}$$

Additionally, imply that STATCOM's power will

$$S_{STAT.k} = U_k \times I_{STAT} \tag{6}$$

3. Simulation power grid failures using DIgSilent Power Factor software

3.1. Grid specification of Binh Thuan, VietNam

Table 1. The grid's 40-node of Binh Thuan's power grid

No.	Nodes in PowerFactory	Voltage (kV)	No.	Nodes in PowerFactory	Voltage(kV)
1	Phan Ri 2	110	21	Bus 18-1	0.95
2	ECO 110	110	22	Bus 18-2	35
3	ECO 35	35	23	Bus 19-1	0.95
4	Phong Dien 1	110	24	Bus 19-2	35
5	Phong Dien	35	25	Bus 20-1	0.95
6	Phu Lac 110	110	26	Bus 20-2	35
7	Phu Lac 35	35	27	Bus 21-1	0.95
8	Phuoc The 110	110	28	Bus 21-2	35
9	Phuoc The 35	35	29	Bus 22-1	0.95
10	Vinh Hao 4	110	30	Bus 22-2	35
11	Vinh Hao 35	35	31	Bus 23-1	0.95
12	Vinh Tan 2	110	32	Bus 23-2	35
13	Vinh Tan 35	35	33	Bus 24-1	0.95
14	Phuoc Minh	110	34	Bus 24-2	35
15	Phuoc Minh 35	35	35	Bus 25-1	0.95
16	Phuoc Ninh	35	36	Bus 25-2	35
17	Phuoc Minh ADANI	35	37	Bus 26-1	0.95
18	WIN ENERGY 110	110	38	Bus 26-2	35
19	ENERY 35	35	39	Bus 27-1	0.95
20	Ninh Phuoc 2	110	40	Bus 27-2	35

A survey and calculation for the Phong Dien-1 wind farm took into plants in the circuit 2 line of Ninh Phuoc-Tuy Phong-Phan Ri [14]. Accordingly, it does not consider changes in the generating capacity of power plants or changes loads in these situations since the research in this study is limited to evaluating voltage quality in steady mode during the operating phase. The grid's 40-node are listed in Table 1.

3.2. STATCOM parameters

According to STATCOM requirements, a DC power source must deliver 1 kW before converting it into AC and pumping into the LV_Node busbar at a voltage of 0.4 kV. STATCOM has $S = 20$ MVA, a reactive power set point of 3 MVA, and an active power set point of 10 MW.

3.3. Simulation results for hypothetical cases

3.3.1. Case 1: Short circuit 3-phase at Line 18- PD-1 35kV

At $t = 0.1s$, 3-phase short circuit occurs in the between of Bus 18-2 and Bus PD 1 35kV cable, the protection system cuts off the line after $t = 0.2s$. After that, the WT plant's Tb-18 to Tb-23 were detached, leaving only Tb-24 to Tb-27 running and each WT continuing to produce 3.3 MVA. In order to continue to support the fault recovery grid, the system's responsiveness graph of active power is shown in Figure 5 and reactive power in Figure 6.

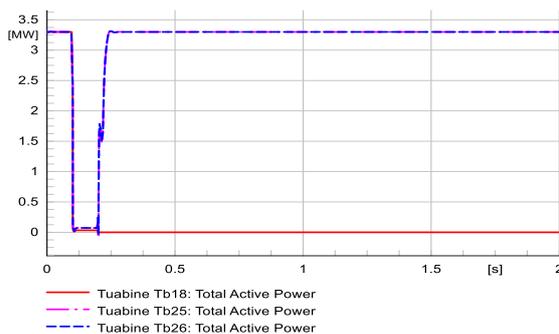


Figure 5. Active power of Tb18, Tb25, Tb26 (CI)

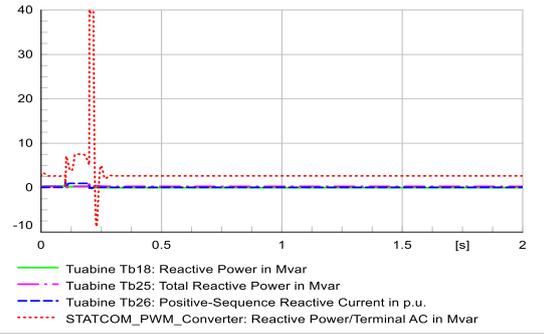


Figure 6. Reactive power of Tb18, Tb25, Tb26 and reactive power of STATCOM (CI)

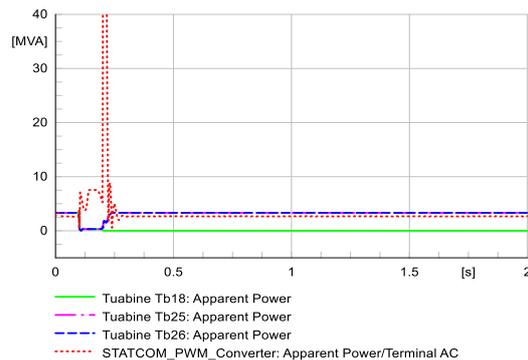


Figure 7. Apparent power of Tb18, Tb25, Tb26 (CI)

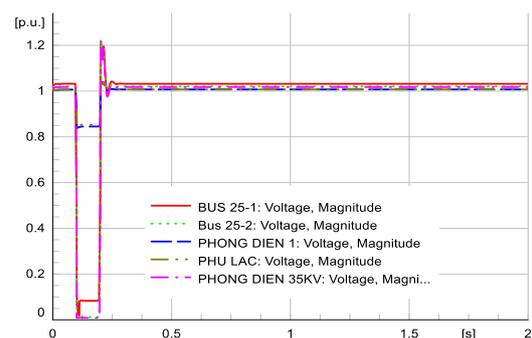


Figure 8. Voltage magnitude at BUS 25-1, BUS 25-2, Phong Dien 1, Phu Lac, Phong Dien 35kV (CI)

STATCOM's reaction when the issue arises: STATCOM, together with WP at the plant, adjusts reactive power during the fault, to restore the voltage lost due to the fault, as can be shown in Figure 7. At time $t = 0.2s$, the system's power fluctuation process is stabilized under the influence of STATCOM. The voltage on the Phong Dien-1 110 kV busbar was only 0.85 p.u. at the time of the occurrence, as can be shown in Figure 8. When the fault period is eliminated, the

voltage immediately returns to 1 p.u. The voltage loss is caused by the WPs being overloaded. The voltage at other nodes on the system also fluctuates during the fault but recovers to stability after the fault is eliminated. This shows the effectiveness of STATCOM's support process for the power grid when an incident occurs, eliminating grid instability in the shortest time.

3.3.2. Case 2: Short circuit 3-phase at Bus Eco 35kV

Similar to the problem mentioned above, at time $t = 0.1s$, a short circuit 3-phase occurred in Bus Eco 35kV, at time $t = 0.2s$. The protection system eliminates the fault and assume isolate the connections to the Eco solar power plant from the system. The parameters of power P, Q, S and voltage U are shown in Figure 9 to Figure 12, respectively. In Figure 9 shows the value of active power of WP including TB-18, TB-23 and DMT ECO, similarly Figure 10 shows the value of reactive power.

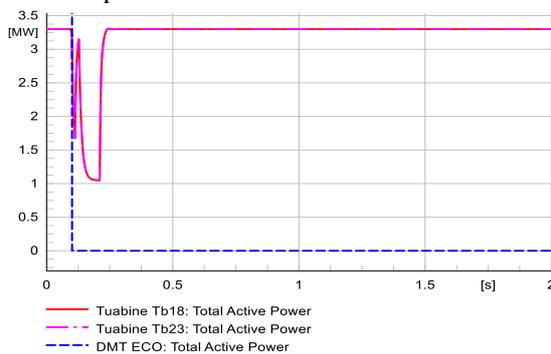


Figure 9. Active power of Tb18, Tb23, DMT ECO (C2)

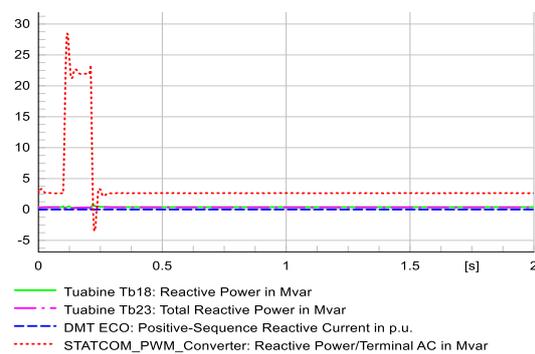


Figure 10. Reactive power of Tb18, Tb23, DMT ECO and reactive power of STATCOM (C2)

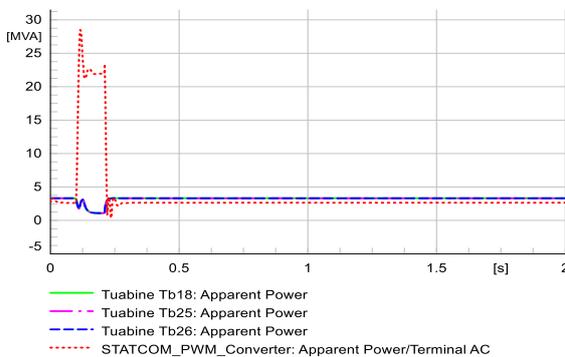


Figure 11. Apparent power of Tb18, Tb25, Tb26 and STATCOM (C2)

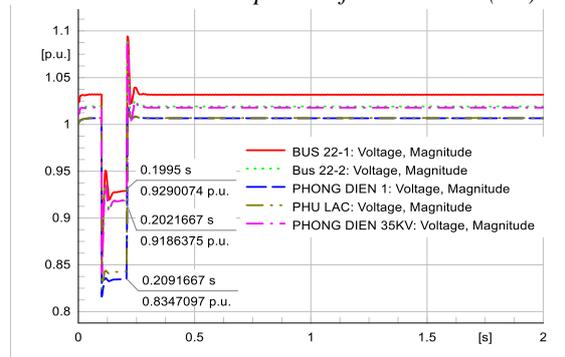


Figure 12. Voltage magnitude of Bus 22-1, Bus 22-2, Phong Dien, Phu Lac and Phong Dien 35kV (C2)

In this case, STATCOM also helps support the quick recovery of voltage when a short circuit occurs at a location outside of the Phong Dien 1 WP's plant, by injecting reactive current immediately into the system, as can be shown in Figure 11. The voltage on the busbar PHONG DIEN -1 110KV is only 0.83 p.u., as can be observed in Figure 12. When the breakdown time is minimized and the voltage immediately returns to 1 p.u., the voltage loss is caused by the WPs being overloaded.

3.3.3. Case 3: Voltage of power system and Phong Dien busbar when circuited short without STATCOM support

Figure 13 shows the voltage fluctuations at the bus bars in the scenario without STATCOM. The results show that in this case, the voltage at the bus bars drops to a lower value than the voltage in the scenario equipped with STATCOM (shown in Figure 12), although the voltage after excluding this problem still returns to a stable operating value (due to the support of the

wind turbines). For the 35kV Phong Dien busbar (busbar connecting the STATCOM system), Figure 14 shows the voltage comparison results between two scenarios with and without STATCOM, showing the role of STATCOM in restoring the voltage at the point. connection. From there, it can be proven that STATCOM can minimize the voltage drop on the system with the ability to respond quickly during a disturbance on the power grid (in this case, a short circuit).

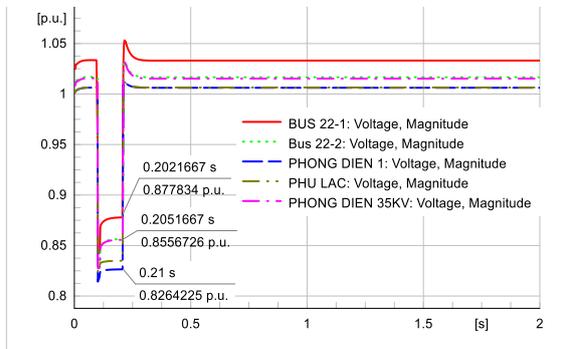


Figure 13. Voltage magnitude of Bus 22-1, Bus 22-2, Phong Dien, Phu Lac and Phong Dien 35kV (C3) – Without STATCOM



Figure 14. Voltage at Phong Dien busbar with and without STATCOM

4. Conclusion

The simulation findings demonstrate that the analyzed system's comparative transient reactions with and without STATCOM are mentioned separately. It illustrates cases 1 to case 2 of active power, reactive power, apparent power as well as voltage of the system when incidents occur on the grid. The simulation findings show that the analyzed system's transient responses efficiently decrease oscillations, and while STATCOM is operating, the system quickly reaches its steady values with quick time.

In the instance of the grid-connected WP's plants in Binh Thuan, Vietnam, the STATCOM is connected to the PD-1 35kV busbar. The grid system's stability of the low voltage system, reduction of transmission loss, improvement of the capacity to transmit power over long distances, reduction of the amplitude of system fluctuations, improvement of power factor, minimization of fluctuations, and support for post-fault voltage in particular will be aided by the results of STATCOM analysis.

Acknowledgements

The authors would like to thank Power Engineering Consulting Joint Stock Company 4 for providing data to support the research team in completing the research content. This research is funded by Hanoi University of Science and Technology (HUST) under project number T2023-PC-040.

REFERENCES

- [1] E. A. Soto, L. B. Bosman, E. Wollega, and W. D. Leon-Salas, "Analysis of Grid Disturbances Caused by Massive Integration of Utility Level Solar Power Systems," *Eng.*, vol. 3, pp. 236–253, 2022.
- [2] V. Astapov, I. Palu, and T. Vaimann, "The Use of DigSilent Power Factory Simulator for "Introduction into Power Systems Lectures," *Electrical, Control and Communication Engineering*, vol. 14, pp. 95-100, 2018.
- [3] T. S. Dinh, N. T. N. Tran, A. T. Tran, M. Q. Duong, and T. M. C. Le, "Improve the filter of grid-tide single-phase inverter for rooftop photovoltaic system," *TNU Journal of Science and Technology*, vol. 227, no. 7, pp. 65-72, 2022.

-
- [4] M. Q. Duong, T. V. Dinh, T. Le, D. Hoang, V. P. Vo, and P. K. Ma, "The Energy Storage System Role With High Level Penetration of Renewable Energy Into The Vietnam Power System Until 2030," *Journal of Science and Technology, The University of Danang*, vol. 18, pp. 45-50, 2020..
- [5] A. A. Shobole, "STATCOM Application to Increase Voltage Stability of Wind Farms," *European Journal of Technique*, vol. 13, pp. 74-81, 2023.
- [6] M. Q. Duong, T. V. Dinh, V. T. Nguyen, H. V. P. Nguyen, N. T. N. Tran, and T. T. M. Le , "Effects of FSIG and DFIG Wind Power Plants on Binh Thuan Power Grid," *GMSARN International Journal*, vol. 12, pp. 133-138, 2018.
- [7] V. Astapov, I. Palu, and T. Vaimann, "The Use of DigSilent Power Factory Simulator for 'Introduction into Power Systems' Lectures," *Electrical, Control and Communication Engineering*, vol. 14, no. 2, pp. 95-99, 2018.
- [8] C. Han, A. Q. Huang, M. E. Baran, S. Bhattacharya, *et al.*, "STATCOM Impact Study on the Integration of a Large Wind Farm into a Weak Loop Power System," *IEEE Transactions on Energy Conversion*, vol. 23, no. 1, pp. 226-234, 2008.
- [9] R. B. Roy and M. Rokonzaman, "STATCOM Model for Integration of Wind Turbine to Grid," *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 12, no. 9, pp. 6519 - 6525, 2014.
- [10] U. Karaagac, I. Kocar, J. Mahseredjian, L. Cai, and Z. Javid, "STATCOM integration into a DFIG-based wind park for reactive power compensation and its impact on wind park high voltage ride-through capability," *Electric Power Systems Research*, vol. 199, 2021, doi: 10.1016/j.epsr.2021.107368 .
- [11] B. Blažič, L. Herman, A. Božiček, and I. Papič, "Static Compensators (STATCOMs) in Power Systems," in *Mathematical Modeling and Control Algorithms of STATCOM*, Springer Science+Business Media, 2012, pp. 111-145.
- [12] G. Stan, J. Voitkāns, and K. Kroic's, "Supercapacitor Constant-Current and Constant-Power Charging and Discharging Comparison under Equal Boundary Conditions for DC Microgrid Application," *Energies*, vol. 16, pp. 1-27, 2023.
- [13] O. D. Montoya, H. R. Chamorro, L. Alvarado-Barrios, and W. Gil-González, and C. Orozco-Henao, "Genetic-Convex Model for Dynamic Reactive Power Compensation in Distribution Networks Using D-STATCOMs," *Applied Science*, vol. 11, pp. 1-15, 2021.
- [14] M. Q. Duong, T. V. Dinh, N. T. N. Tran, G. Sava, and A. Kies, "A comparative study of wind turbine generators operating performance; a case study for the Vietnamese Binh Thuan – grid," *Bulletin of the Polytechnic Institute of Jassy, Electrical Engineering, Power Engineering, Electronics*, vol. 63, pp. 17-32, 2017.