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Power Flow Improvement by Designing and Simulating a Unified Power Flow Controller with Solar Power: A Case Study

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A B S T R A C T

A flexible AC transmission system (FACTS) device called Unified Power Flow Controller (UPFC) can adjust the voltage, phase angle and impedance of a transmission line to regulate the flow of real and reactive power. This paper shows how to design and simulate UPFC using amplifiers and rectifiers in MATLAB/SIMULINK. It also evaluates the impact of UPFC on the power quality and stability of a transmission line using data from GNDEC, Ludhiana. The results indicate that UPFC can improve the power flow capacity and ensure power continuity in the power system. The paper also contrasts the results with a reference system without UPFC to prove its effectiveness.

Keywords: Unified power flow controller (UPFC), Flexible AC transmission system (FACTS), Power flow capability, Power quality, Voltage control, MATLAB, SIMULINK, Design and Implementation, Reactive power control.

1. Introduction

One of the challenges in power system operation and planning is to ensure the efficient and reliable transmission of power from the generation sources to the load centres. The transmission lines are often subjected to various constraints such as thermal limits, voltage limits, stability limits and contingency conditions. These constraints can affect the power flow capability and the power quality of the transmission lines. Therefore, there is a need for devices that can control the power flow and the power quality of the transmission lines. A unified power flow controller (UPFC) is one such device that can manipulate the voltage, phase angle and impedance of a transmission line to regulate the real and reactive power flow. It is a type of flexible AC transmission system (FACTS) device that has the advantage of independent control of reactive compensation on the shunt side of the line. This can help to improve the voltage profile and reduce the losses in the transmission line. This paper presents the design and implementation of UPFC using amplifiers and rectifiers in MATLAB/SIMULINK software. It also evaluates the performance of UPFC on the power quality and stability of a transmission line using data from GNDEC, Ludhiana. The data is inserted into the SIMULINK model as input and the results are obtained in the form of output. The results show that UPFC can enhance the power flow capability and maintain the continuity of power in the power system.

Nomenclature

A. AC of Alternating Current and DC for Direct Current

B. FACTS of Flexible AC Transmission System

C. SSSC of Static Series Synchronous Compensator

D. STATCOM of Static Synchronous Compensator

E. UPFC of Unified Power Flow Controller

F. UPQC of Unified Power Quality Conditioner

G. VS of Voltage Source

H. VSC of Voltage Source Converter

1.1 Literature Review

FACTS devices have received more attention and publications in the last five years. Many studies have focused on UPFC, one of the devices that can enhance power flow and stability in transmission and distribution systems. A review of some relevant papers on UPFC is presented in the following subsection. The results show that UPFC can improve voltage stability and reduce reactive losses in the power system.

Table 1. Literature Review for UPFC.

Serial No.	Authors Name	Year of publish	Technique	Use and working	Testing Software
1.	Akshay and Shelly [5]	2019	FACTS devices control power	Reducing losses, and improving stability	PSAT/MATLAB simulates FACTS
2.	Ayman Alhejji *et al* [14]	2020	C-UPFC with AGOA for OPF	Power flow and voltage control	MATLAB/SIMULINK simulation
3.	Bhuvnesh Rathore *et al* [16]	2021	WAN with UPFC for protection	Fault analysis and power control	MATLAB/SIMULINK simulation
4.	Debidasi and Sidhartha [4]	2021	UC-UPFC with FOPIDF for LFC	Frequency regulation and control	MATLAB/SIMULINK simulation
5.	Jamal Alnasseir [2]	2022	FACTS with PV curves for stability	Voltage control and optimal placement	MATLAB/SIMULINK simulation
6.	Kumarasabapthy and Manohran [6]	2015	UPFC with fuzzy logic controller	Voltage sag and harmonic reduction	MATLAB/SIMULINK simulation
7.	Parvathy and Sindhu [13]	2015	Decoupled control with UPFC	Power flow and voltage analysis	MATLAB/SIMULINK simulation
8.	Prabhat and Surya [22].	2014	UPFC and SSSC with decoupled control	Power flow and voltage stability	MATLAB/SIMULINK simulation
9.	Pavlos and Nikos [14]	2019	UPFC with intelligent control	Power system stability improvement	MATLAB/SIMULINK simulation
10.	Ravindra and Vaibhav [15]	2019	UPFC with active and reactive coordination control	Power flow and voltage adjustment	MATLAB/SIMULINK simulation
11.	S. Birick [18]	2018	UPFC with STF control	Voltage sag and distortion reduction	MATLAB/SIMULINK simulation
12.	Saeed Rezaeian Marjani *et al* [20]	2022	UPFC with probabilistic-based technique	Power system reliability enhancement	MATLAB/SIMULINK simulation
13.	Setu and Maulik [3]	2021	UPFC with computer simulation software	Voltage stability improvement in renewable energy sources.	MATLAB/SIMULINK simulation
14.	Shradha and Chandrakala [19]	2019	UPFC with VSM model	Power flow improvement and stability analysis	MATLAB/SIMULINK simulation
15.	Yousef Islam Djilani Kobibi *et al* [25]	2022	FACTS with CPF technique	Voltage stability evaluation	MATLAB/SIMULINK simulation
16.	Alsammak *et al* [34]	2021	UPFC with 48-pulse GTO multilevel inverters	Harmonic reduction and power flow control	MATLAB/SIMULINK simulation
17.	Bhawoorjar and Jagtap [32	2022	UPFC in grid-connected hybrid solar photovoltaic power system	Power flow and voltage control	MATLAB/SIMULINK simulation
18.	Biswas and Nayak [26]	2021	UPFC-compensated transmission lines connecting offshore wind farms	Fault detection and classification	EMTDC/PSCAD and D-SPACE DS 1103 simulation
19.	Devassy and Singh [27]	2021	PV-B-UPQC with automatic switchover	Power quality improvement and clean energy generation	MATLAB/SIMULINK simulation

1.2 Research Gap

The previous subsection reviewed some papers that studied the power flow enhancement of a three-phase line and unified power flow controller (UPFC) and the SIMULINK model of UPFC. However, none of these papers considered the integration of solar panels (PV ARRAY) with the UPFC SIMULINK model. This is a potential research gap that needs to be addressed, as solar panels can provide an additional source of power and reduce the dependency on conventional generation. Therefore, this study aims to investigate the impact of solar panels on the power flow and stability of the system with UPFC.

1.3 Problem Formulation

To clear the voltage, sink as well as surge, UPFC is used. Amplifiers and rectifiers were used in the design and engineering of Unified Control. Changes that are actual and reactive inappropriate control orientations on the receiver side. The quality of the energy used in Unified Power Flow Control is tested using SIMULINK from MATLAB. Generally, UPFC is used to enhance the power flow capability of the transmission lines. UPFC is an abbreviation for a unified power flow controller. On the other hand, UPFC is a device and a FACT family member. It can help in the control of basic parameters like voltage, phase angle and impedance to control real and reactive power flow of transmission lines. It is also much used due to its independent control ability of reactive compensation shunt side of the line. Therefore, in its overall operational output, UPFC becomes the controller for controlling a transmission line's reactive, active power and voltage. Power system stability and power quality issue both topics are contained the same problem for reduction of voltage, sink as well as surge and therefore FACTS devices introduce several devices to solve these errors. From the FACTS family, a UPFC device came its unique advantages which use in the power system for total reduction of these errors. After the introductory part of UPFC, there is one more introductory chapter which discusses SOLAR POWER which can be used for running the UPFC in the SIMULINK environment of MATLAB software. The UPFC model was designed by many researchers and due to many numbers of paper readings then a conclusion came in front that is a case study on circuit system design and modelling of the SOLAR POWER and UPFC in the SIMULINK tool of MATLAB software.

1.4 Methodology

This paper will use MATLAB software and SIMULINK to design a UPFC model for voltage stability in a power system with a grid connection and solar power. The UPFC model will be applied to a transmission line to examine the voltage stability and power flow capacity of the power system. The paper will use the solar panel data and parameters from GNDEC (Guru Nanak Dev Engineering College) College, Ludhiana, Punjab, India to generate SOLAR AC POWER. The paper will also use the UPFC data and parameters from the reference paper.

1.5 Present Work

1.5.1 Introduction

The UPFC is a FACTS device that combines both STATCOM and SSSC. The design of both SSSC and STATCOM has been studied in several papers. However, to understand how it can be precisely designed in the SIMULINK environment, the MATHWORK website was consulted. Therefore, reference number 59 provides a SIMULINK file of UPFC with three phase sources having five errors as shown in Figure 1.

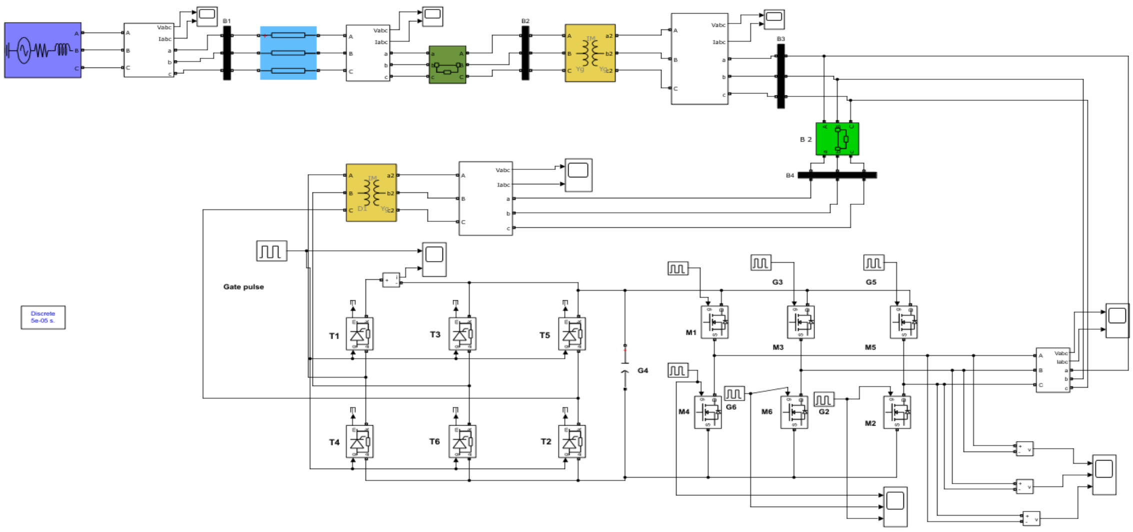

Figure 1. Original UPFC SIMULINK Model with THREE-PHASE power

The UPFC system model downloaded from the reference link [59] had five errors. Therefore, these errors were corrected with the SIMULINK software before using the model and explaining it in more detail in section 1.

1.5.2 RECTIFY FIVE ERRORS AND IMPROVE THE ORIGINAL SIMULINK MODEL

The reference model had errors because the FROM and GOTO blocks were not specified for the VI measurement block. These were fixed by either specifying or removing them. The removal method was applied because these blocks were only used for creating the BUS structure, which was not a BUS block. Thus, the errors were eliminated. On the other hand, some theoretical errors were not caused by the system but by the assumption. This error stated that the overall power system required an Alternating current, which was not provided in this model after UPFC operation and the final outputs were Pulsating AC. Therefore, this error was also corrected along with the overall proposed system and presented in this section and the final figure is Fig. 3.

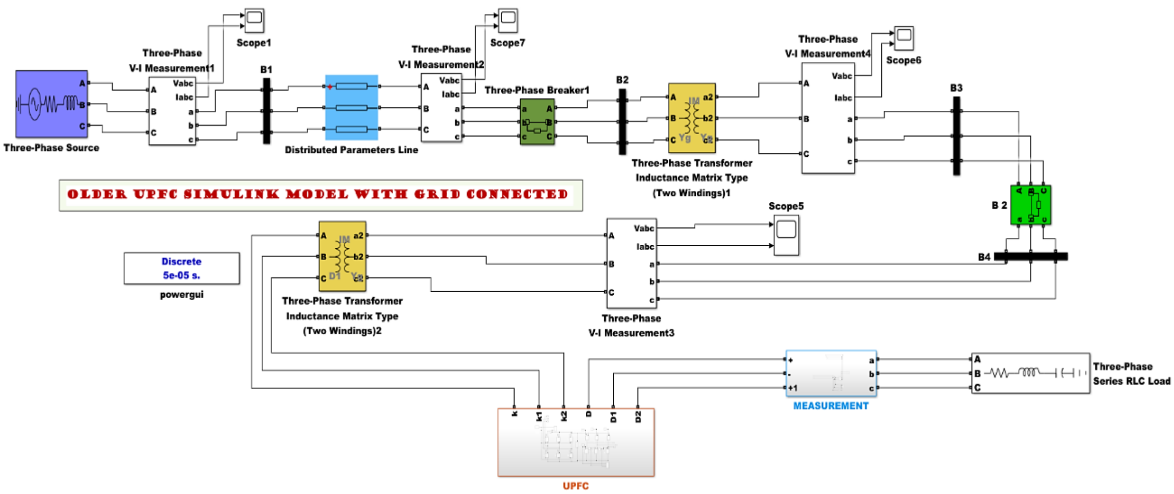

Figure 2. Error in the referred system

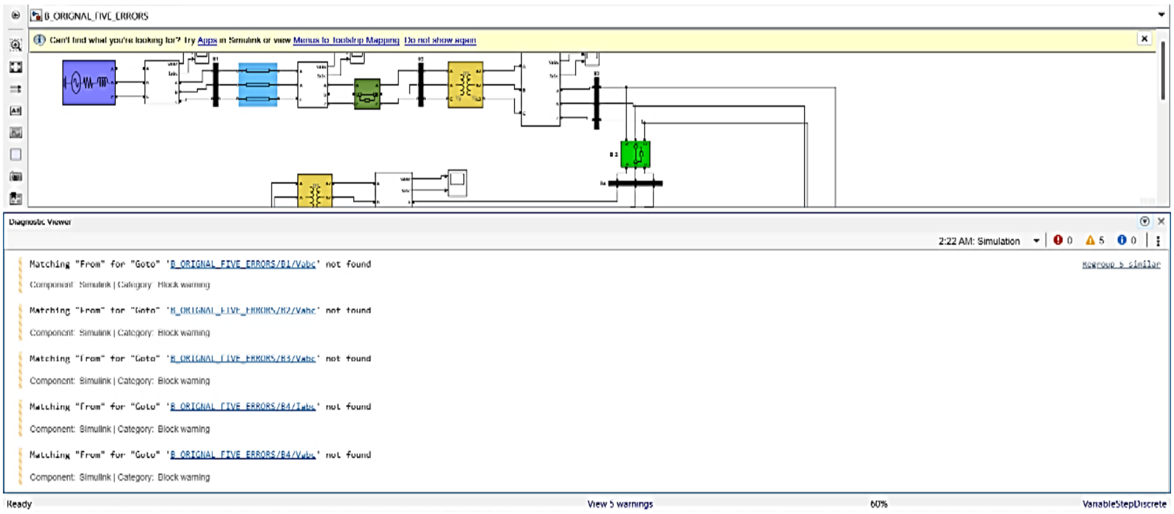

Figure 3. Older UPFC model

1.5.3 PV ARRAY SIMPLE OPERATION

The components of the proposed system need to be examined before implementing it. Therefore, the following system is built to test the PV system to verify that the single-line phase operates according to the ideal concept.

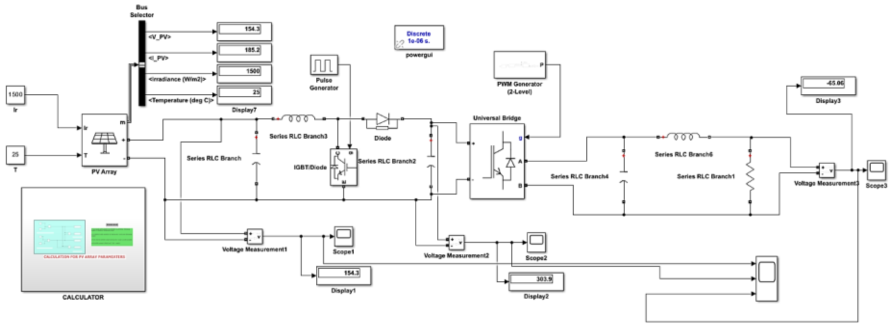

Figure 4. PV array and its operation up to dc to ac

The model produces correct outputs after running in a SIMULINK environment. The DC output displays a voltage of up to 154 volts and a current of nearly 185.2 ampere as shown in figure number 4. This system aims to generate pure AC power from the DC output of the PV array, so the voltage is boosted to 303.9 volts after the boost operation. Then, the same voltage is fed into the inverter and the output becomes pulsating AC. Moreover, this pulsating AC is passed through passive filters to reduce the harmonics and obtain pure AC power.

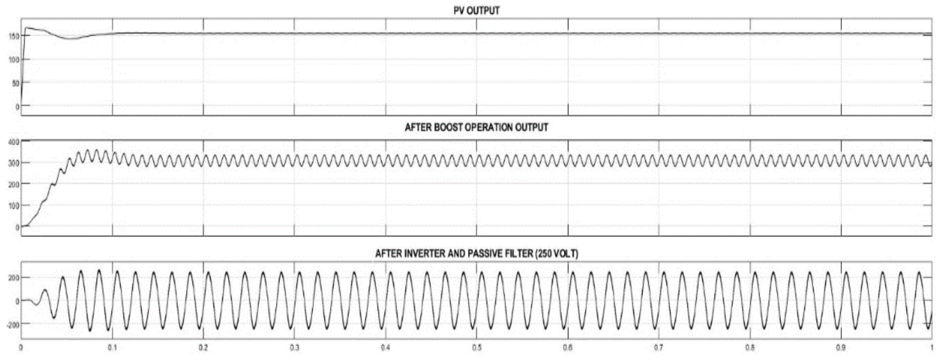

Figure 5. PV, Boost Converter, Passive Filter waveform

Figure number 5 shows the waveforms related to the PV, Boost Converter, and Passive Filter that have been discussed. The PV and boost converter output are DC waveforms and the passive filter output is a pure AC waveform.

1.5.4 Testing of the proposed overall system

After completing all of the models, the overall model design using combine these models in one place in SIMULINK. Because now the aim of testing is to the analysis of an improved system with a SOLAR POWER system. Figure 8 illustrates the overall proposed system.

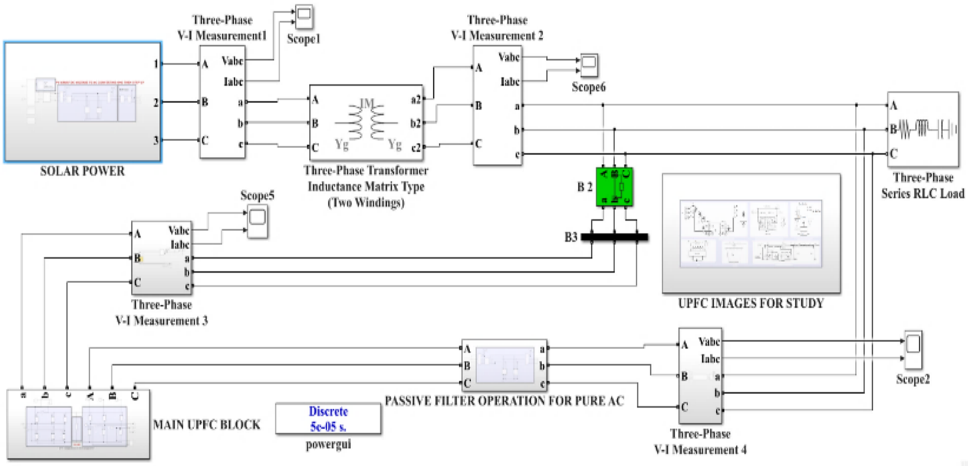

Figure 6. proposed the overall system

In Figure number 9 illustrate the PV system

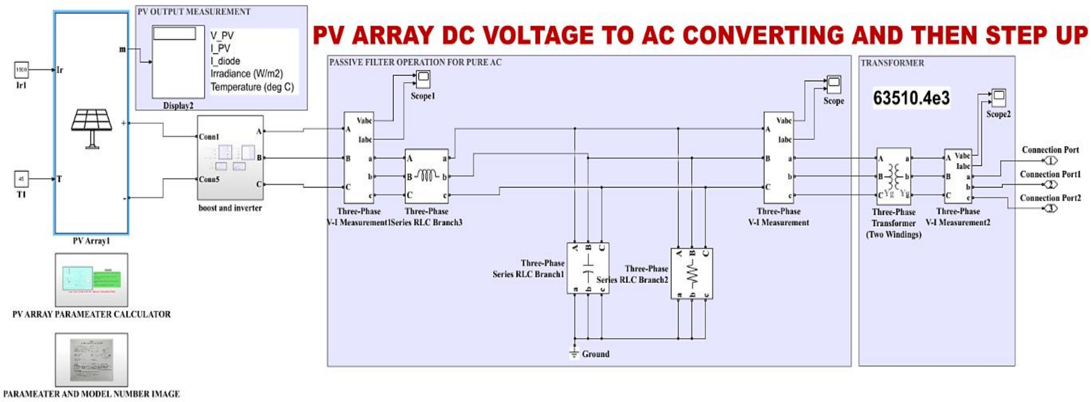

Figure 7. PV SYSTEM

Figure number 6.10 illustrate the design of the SIMULINK model of the main block for UPFC.

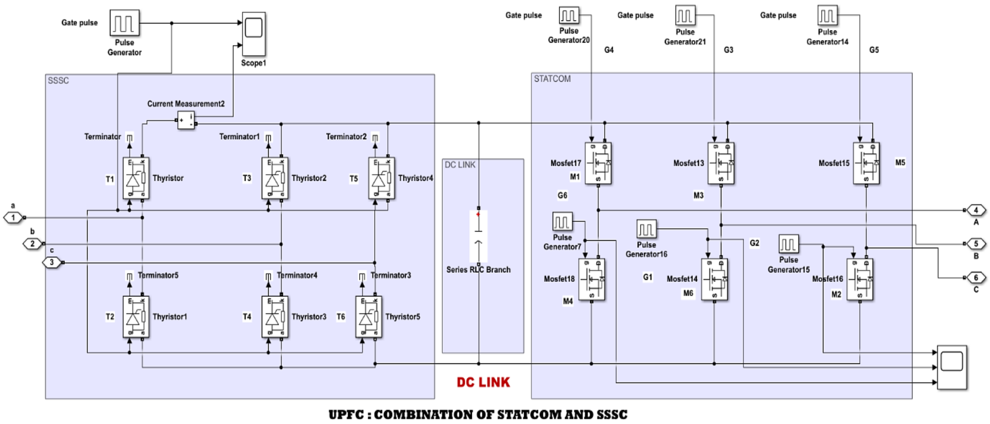

Figure 8. Model of STATCOM AND SSSC

Figure number 6.11 shows that the PV array data are used to generate power for the main system or also known as UPFC and load.

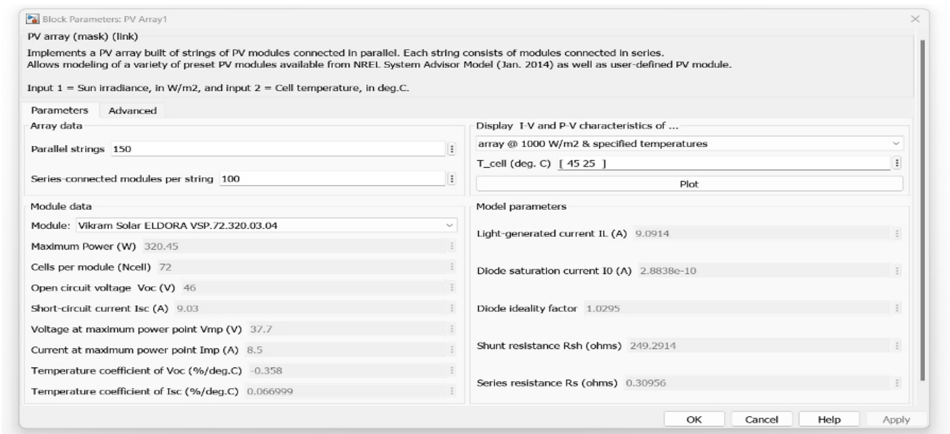

Figure 9. PV ARRAY PARAMETER

Figure number 12 is used for designing the exact data requirement of PV ARRAYS in the number of parallel and series for required power generation. Here ohms law is used for the calculation of voltage, current and resistance. Further, the power calculation was done using the P=V*I formula.

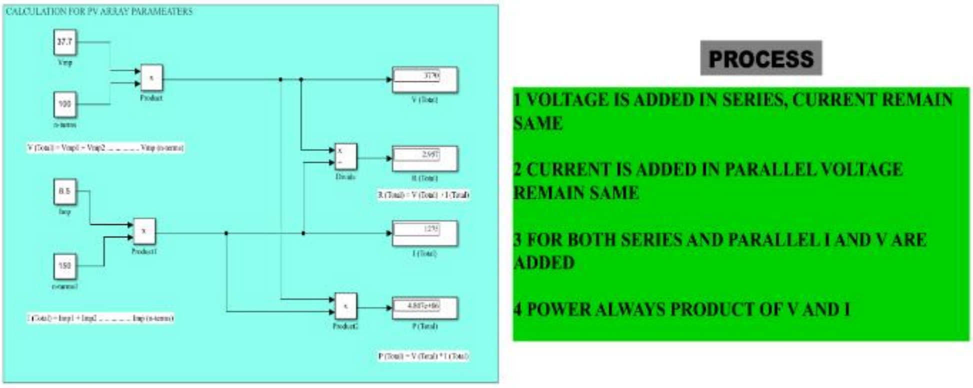

Figure 10. PV Array parameters calculation

Figure number 13 describes that the boost converter can up the power up to the needful range. PV array voltage given in the same figure shows 3581 volts and after boost operation same voltage increases by nearly 7186 volts.

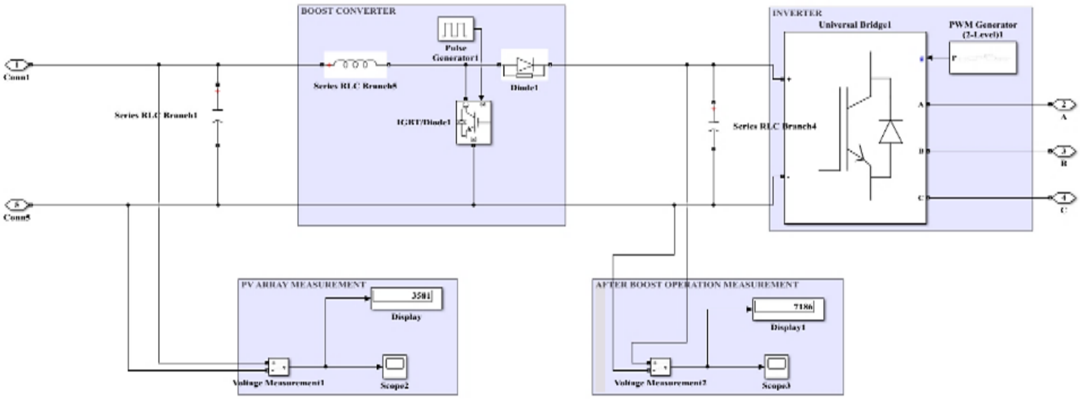

Figure 11. Operation of Boost Converter and Inverter

Figure number 15 describes the waveform for a step-up voltage after the operation of the step-up transformer.

	Value	Time
Max	6.748e+04	1.549
Min	-6.582e+04	1.559

Figure 12. Maximum and Minimum Values

In Figure number 14, the maximum and minimum value is given after the operation of the transformer in step-up mode. This is also demonstrated using the waveform and these outputs are displayed using a scope block. Figure 15 describes the same outputs in the sinusoidal waveform.

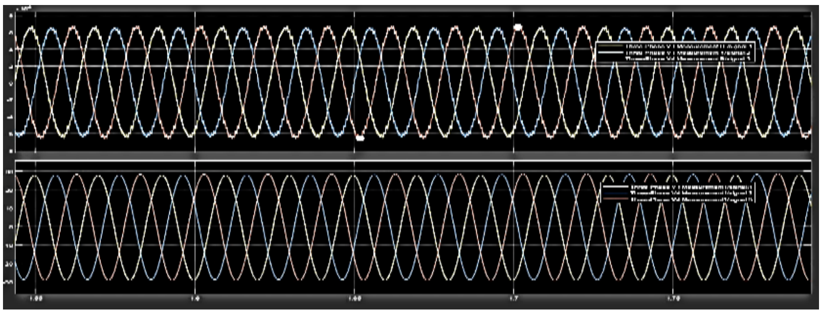

Figure 13. V And I value after Transformer Operation

In this system, UPFC works on 254.3 volts of pulsating AC. For this reason, the high voltage was down by another transformer from 63510.4 to 254.03 volts. Therefore, after UPFC operation we just need to install a load to get a stable value of power. Further, when the system is run on these all above-given operations then the output gets out as Figure number 16. Hence, figure 16 shows that the output voltage is nearly 250 volts.

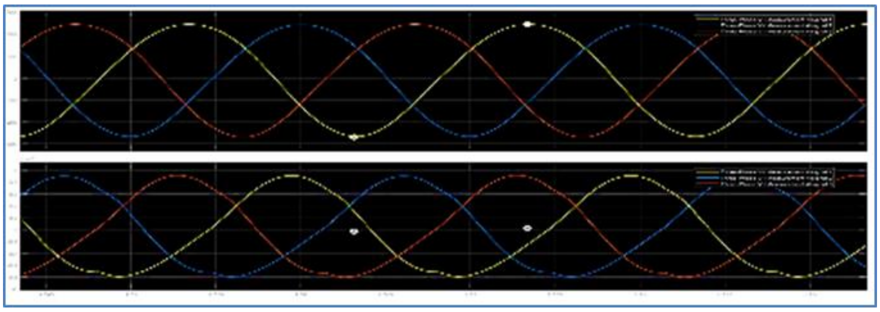

Figure 14. After UPFC and Passive Filter

1.6 Conclusion

The analysis and simulation results show that the proposed system can perform any kind of calculation based on the PV array and UPFC data. The main objective of this work was to test the whole system in the SIMULINK environment, which has been achieved successfully. This chapter ends here and the next chapter presents the results and conclusion based on the real-time data and parameters of GNDEC, Ludhiana in SIMULINK software.

1.7 Data Collection

1.4.1 TOTAL PV ARRAY OF ROOFTOP OF PRINCIPAL OFFICE

The Principal Office at Guru Nanak Dev Engineering College has a rooftop with several Array Modules, as shown in Table 1. These PV arrays are connected in a combination of series and parallel modules.

Table 2. Calculation of the total number of PV MODULE

Sr. No.	Array in numbers	Array in numbers	Array in numbers	Number of Lines	Multiply or add	Total of all
1.	8					8
2.	10					10
3.	16			6	*	96
4.	24			2	*	48
5.	26					26
6.	20					20
7.	8					8
8.	8					8
9.	12					12
10.	12	4	12		+	28
11.	12		12		+	24
12.	8	10	8		+	26
						=314

PARAMETER images of a single PV array Module are shown in Figure number 17 below.

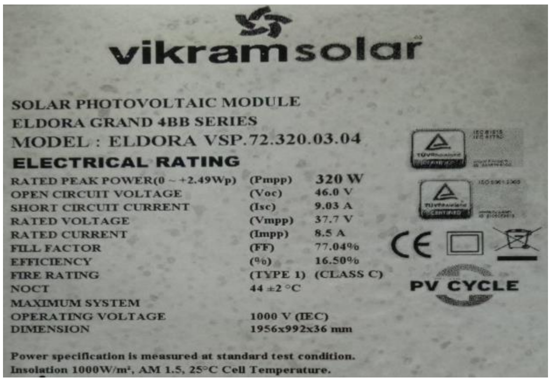

Figure 15. Parameter figure for PV array Model

1.4.2 Data collection for one month

Table number 7.2 has been demonstrating the one-month data from 04-04-2023 to 03-05-2023 on energy generated, expected energy and radiation with performance ratio. In between these days, energy generated data look different from the range 68 to 404 (in kWh). The radiation or most say irradiance range occurs from 7 and gradually increases or decreases in these days to nearly 13 (in kWh/m²). The performance ratio table also performs visible during these different days which do not reach up to 50 per cent.

Time	Energy Generated(kWh)	Expected Energy(kWh)	Radiation(kWh/m²)	Performance Ratio (%)
04-04-2023	391	1034.76	10.35	37.79
05-04-2023	313	1043.58	10.44	29.99
06-04-2023	349.2	1191.68	11.92	29.3
07-04-2023	402.32	1216.32	12.17	33.08
08-04-2023	401.02	868.92	8.69	46.15
09-04-2023	395.91	1198.45	11.99	33.04
10-04-2023	376.65	930.85	9.31	40.46
11-04-2023	349.81	1001.87	10.02	34.92
12-04-2023	357.17	1150.42	11.51	31.05
13-04-2023	363.38	887.21	8.88	40.96
14-04-2023	363.65	898.27	8.99	40.48
15-04-2023	361.47	1085.76	10.86	33.29
16-04-2023	340.99	799.81	8	42.63
17-04-2023	300.85	942.92	9.43	31.91
18-04-2023	288.41	1077.41	10.78	26.77
19-04-2023	374.57	987.24	9.88	37.94
20-04-2023	361.21	1090.58	10.91	33.12
21-04-2023	403.42	1112.9	11.13	36.25
22-04-2023	68.1	1254.52	12.55	5.43
23-04-2023	320.12	1077.34	10.78	29.71
24-04-2023	372.43	936.85	9.37	39.75
25-04-2023	395.22	809.68	8.1	48.81
26-04-2023	345.93	955.48	9.56	36.2
27-04-2023	216.56	1002.07	10.03	21.61
28-04-2023	355.62	1039.94	10.4	34.2
29-04-2023	320.76	844.02	8.44	38
30-04-2023	281.54	1059.4	10.6	26.58
01-05-2023	155.67	975.02	9.75	15.97
02-05-2023	172.87	1057.2	10.58	16.35
03-05-2023	349.44	969.09	9.7	36.06

Table 3. Data of Energy Generated(kWh), Expected Energy(kWh), Radiation(kWh/m²), Performance Ratio (%)

1.4.1.Data collection related to the PARAMETERS

Table 4. Parameter detail for SIMULINK Model

Sr. No.:	PV PARAMETERS:	Values
1.	Irradiance (W/m2)	1000-1500
2.	Temperature (Deg. C)	25-45
Sr. No.:	ARRAY DATA:	Value
1.	Parallel strings	157
2.	Series-connected modules per string	157
Sr. No.:	MODULE DATA:	Value
1.	Module TYPE OR NAME	VIKRAM SOLAR ELDORA VSP .72.320.03.04
2.	The voltage at maximum power point Vmp (V)	37.7 V
3.	Current at maximum power point Imp (A)	8.5 A
Sr. No.:	I-V, P-V characteristics	Value
1.	Temperature of cell Tcell (deg. C)	25 degrees Celsius

In table number 7.3, the main data are represented for the PV array block of MATLAB/SIMULINK software.

2. Results

2.1 Introduction:

A PV array generates solar power and converts it from DC to AC, as discussed in section 3. A three-phase transformer steps down the voltage for UPFC operation. UPFC means UNIFIED POWER FLOW CONTROLLER and it enhances the power flow capability of the main system. Passive filters convert the pulsating AC into a pure sinusoidal AC waveform. An electrical load consists of motors, light bulbs, fans and other similar devices. They work for a small area and supply power to the same type of device, so the three-phase series RLC is set to standards.

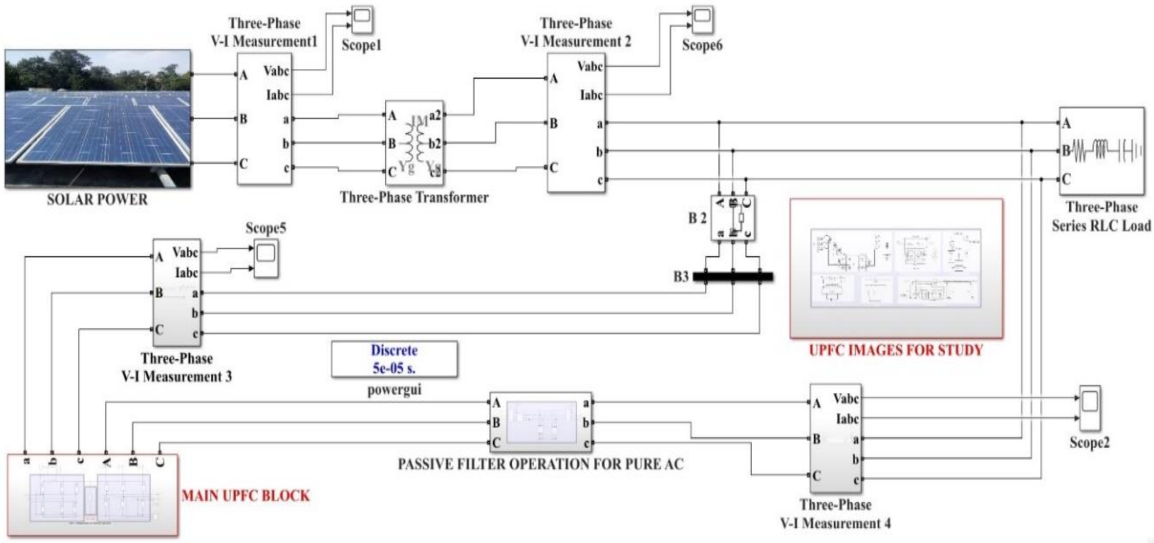

Figure 18. Overall system

2.2 PV System or SOLAR POWER

This is a subsystem that contains more subsystems and their circuits for generating SOLAR POWER. A SOLAR POWER system or a PV system has different parts that convert the DC power of a PV array into a sinusoidal waveform. These parts are as follows. PV array block has a parameter window to enter the data related to PV MODULE or PV model. This is a subsystem that has voltage, current and power measurement scopes and displays. Boost converter operation was explained in the introduction part and its circuit diagram was also shown there. Passive filter operation and this subsystem also have a passive filter circuit that converts the pulsating AC into pure AC. The transformer can change the voltage to a specific range. Here, a step-up transformer is used to increase the power to the required level for the whole system.

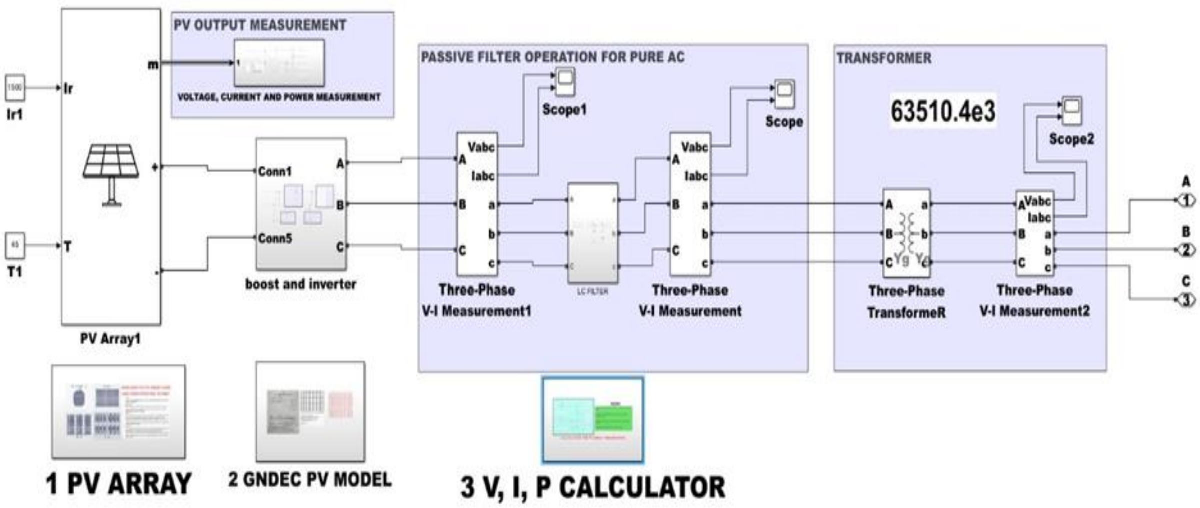

Figure 19. SOLAR POWER

2.3 PARAMETER USED

Data need for the generation of solar energy for all parameters are shown in Figure 8.3.

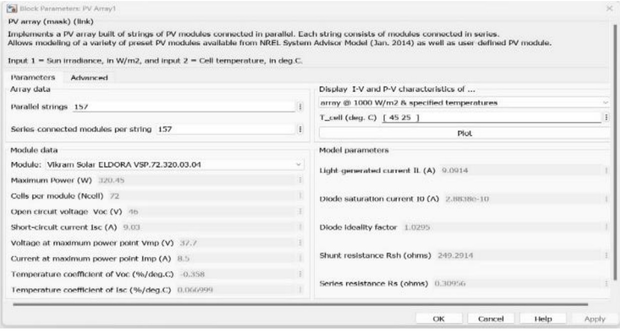

Figure 20. PV array data

2.4 RESULTS AND OUTCOMES

2.4.1 PV OUTPUTS

In Figure number 8.4, the value ranges out to 4461 volts for the PV array. Current 2129, Power 9.497 and resistance 2.095.

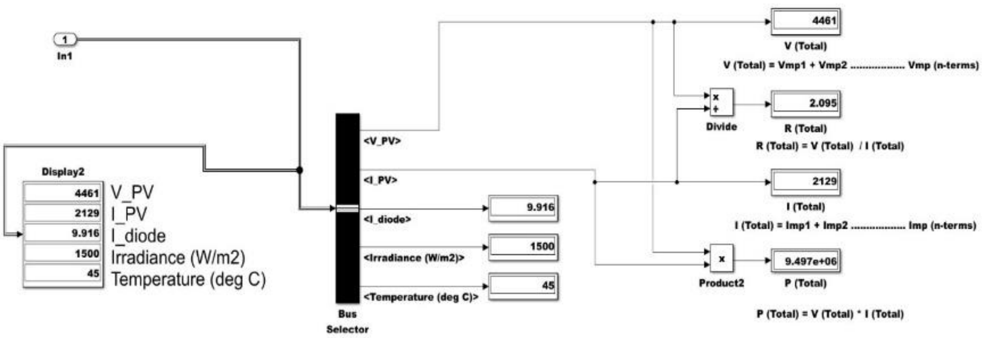

Figure 21. V, I, and P MEASUREMENT

2.4.2 OUTPUTS AFTER AND BEFORE BOOST OPERATION

In waveform figure number 8.5, Before the value range out to 4461 volts for the PV array and after the boost-up range increases up to 9000.

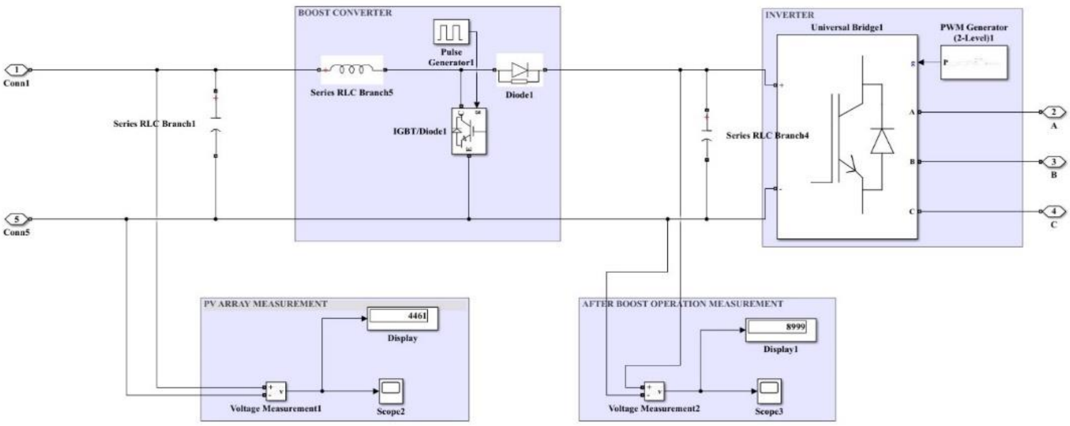

Figure 22. Boost and inverter operation

2.4.3 OUTPUT FROM INVERTER

In waveform figure number 8.6, the Value range out 6000 volts.

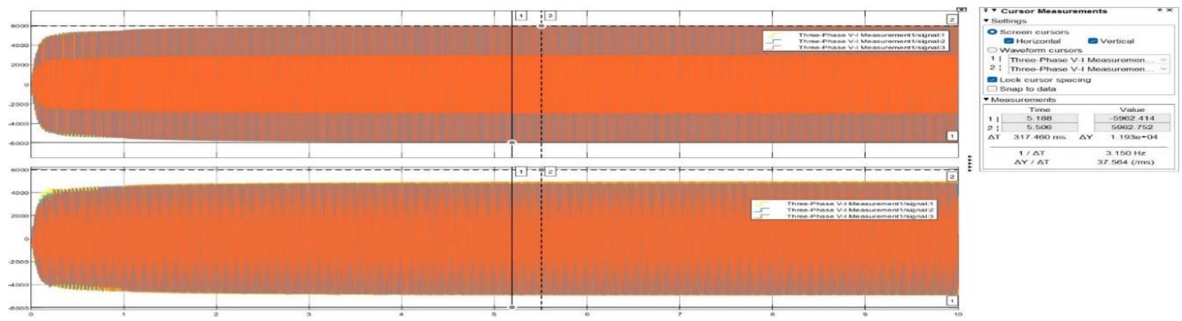

Figure 23. PULSATING AC FROM INVERTER

2.4.4 PASSIVE FILTER OPERATION

In waveform figure number 8.7, the Value range out to 1400 volts.

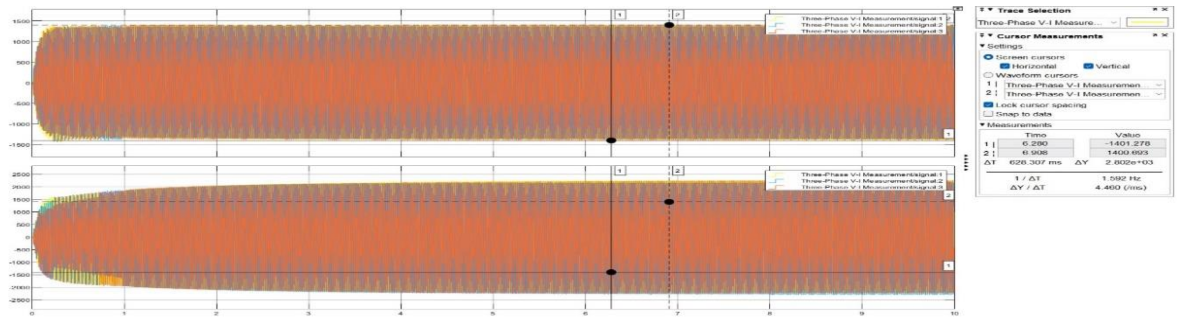

Figure 24. AFTER PASSIVE FILTER

2.4.5 TRANSFORMER OPERATION

In waveform figure number 8.8, the Value range out to 80750 volts.

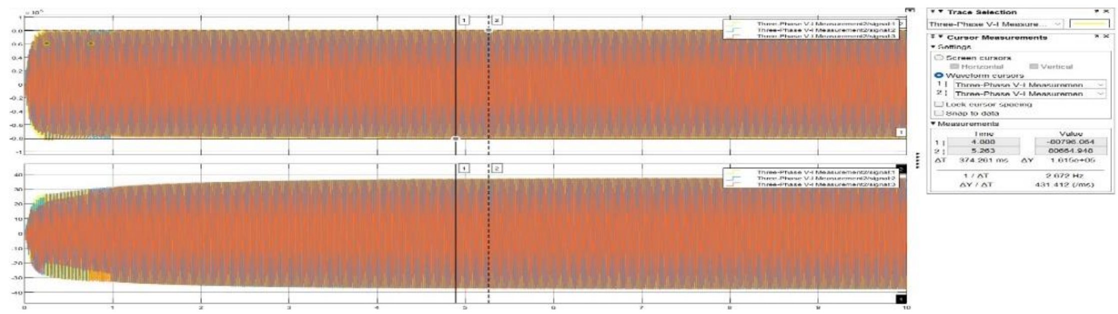

Figure 25. AFTER STEP-UP

2.4.6 STEP DOWN OPERATION

In waveform figure number 8.9, the Value range out 330 volts.

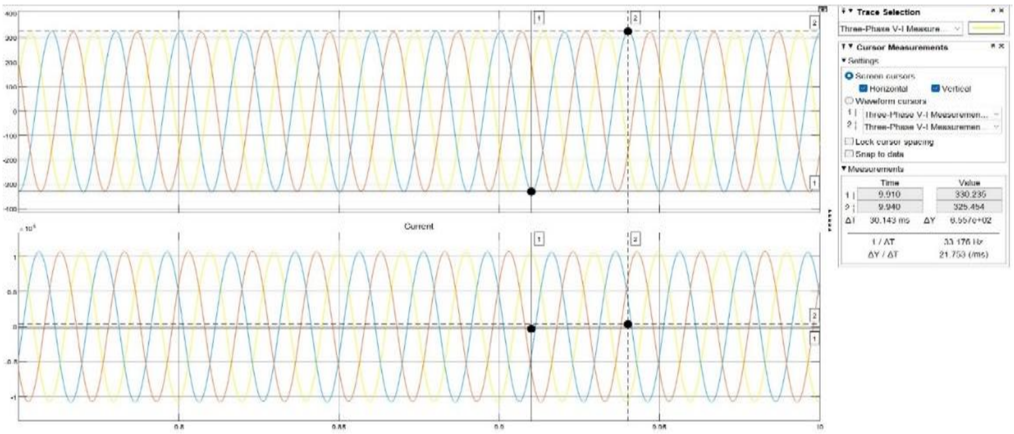

Figure 26. AFTER STEPPING DOWN FROM UPFC

2.4.7 UPFC AND PASSIVE FILTER OPERATION

In waveform figure number 8.10, the Value range out 330 volts.

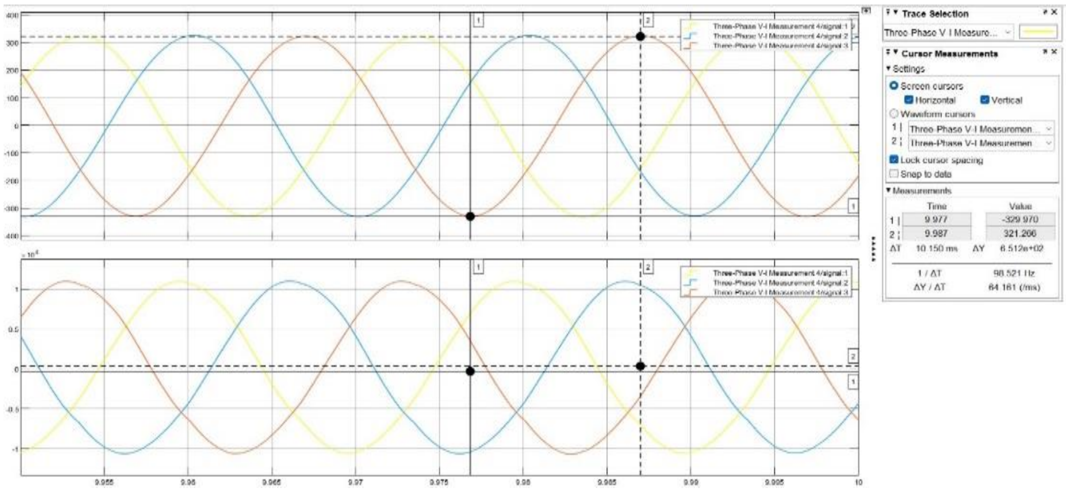

Figure 27. AFTER UPFC AND PASSIVE OPERATION

3. Conclusion

The paper has investigated the application of a UNIFIED POWER FLOW CONTROLLER (UPFC) to enhance the power system performance of a model that includes a PV system. The UPFC is a FACTS device that comprises a Static Synchronous Series Compensator (SSSC) and a Static Synchronous Compensator (STATCOM) with a shared DC link. The research paper has also presented the PV system and its components, and the methods of converting PV DC to pure sinusoidal AC waveform. The model was built and simulated in MATLAB (SIMULINK) using data and parameters from real-time calculations. The results demonstrated that the UPFC improved the power quality and stability of the model under various operating conditions. The paper has also proposed some potential applications and future directions for the model, such as combining it with nuclear or solar power resources or using it for desalination purposes.

References

1. Alhejji, M. Ebeed Hussein, S. Kamel and S. Alyami, "*Optimal Power Flow Solution with an Embedded Centre-Node Unified Power Flow Controller Using an Adaptive Grasshopper Optimization Algorithm*," in IEEE Access, vol. 8, pp. 119020-119037, 2020, Doi: 10.1109/ACCESS.2020.2993762.

2. Alnasseir, "*Improving Performance of Transmission Networks Using FACTS through Continuation Power Flow Method*," FACTA Universitatis. Series Electronics and Energetics, vol. 35, no. 3, pp. 437–454, Jan. 2022, Doi: 10.2298/fuee2203437a.

3. Amin, Setu. "*Review on Voltage Stability Improvement with Renewable Energy Source Using UPFC*," International Journal of Engineering Research & Technology (IJERT), vol. 10, no. 03, 2021. Accessed 22 Apr. 2023.

4. D. Mohanty and S. Panda, "*Moth Flame Optimization Based Fractional Order Controller for Frequency Regulation of Hybrid Power System with UC and UPFC*," 2021 1st International Conference on Power Electronics and Energy (ICPEE), Jan. 2021, Doi: 10.1109/icpee50452.2021.9358618.

5. Dwivedi and S. Vadhera, "*Reactive Power Sustainability and Voltage Stability with Different FACTS Devices Using PSAT*," 2019 6th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2019, pp. 248-253, Doi: 10.1109/SPIN.2019.8711587.

6. K. Asabapathy, N, and P S Manoharan, "*MATLAB Simulation of UPFC for Power Quality Mitigation Using an Ant Colony Based FUZZY Control Technique*," The Scientific World Journal vol. 2015 (2015): 304165. Doi:10.1155/2015/304165.

7. Khan and Uttam Kumar Thakur, "*A Design of Supplementary Controller for UPFC to Improve Damping of Inter-Area Oscillations*," Journal Européen des Systèmes Automatisés, vol. 54, no. 02, pp. 303–308, Apr. 2021, Doi: https://Doi.org/10.18280/jesa.540212.

8. Komoni, Vjollca & Krasniqi, Isuf & Kabashi, Gazmend & Alidemaj, Avni. (2014), "*Control Active and Reactive Power Flow with UPFC connected to Transmission Line*," Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion MANPOWER.

9. Kumari, Yogita & Gupta, Anmol & Bihari, Drshiv & Chaubey, R.N. & Sehgal, B. (2015). "*Performance and Analysis of Reactive Power Compensation by Unified Power Flow Controller*," Indonesian Journal of Electrical Engineering and Informatics (IJEEI). 3. 10.11591/ijeei. v3i3.153.

10. N. Alsammak and H. A. Mohammed, "*Power Quality Improvement Using Fuzzy Logic Controller Based Unified Power Flow Controller*," Indonesian Journal of Electrical Engineering and Computer Science, vol. 21, no. 1, p. 1, Jan. 2021, Doi: 10.11591/ijeecs.v21.i1.pp1-9.

11. Panigrahi, S. N. and Sibasish Panda. "*Design and Analysis of Unified Power Flow Controller in MATLAB/SIMULINK by using Fuzzy Logic*," International Journal of engineering research and Technology 5 (2016): n. pages 1-10.

12. P. K. Rathore and M. C. Rav, "*Various Custom Power Devices for Power Quality Improvement: A Review*," International Journal of Trend in Scientific Research and Development, vol. Volume-6, no. Issue-3, Apr. 2022, Accessed: Apr. 22, 2023.

13. P. S. and K. C. S. Thampatty, "*Dynamic Modeling and Control of UPFC for Power Flow Control*," Procedia Technology, vol. 21, no. 2212-0173, pp. 581–588, 2015, Doi: https://Doi.org/10.1016/j.protcy.2015.10.061.

14. P. S. Georgilakis and N. D. Hatziargyriou, "*Unified power flow controllers in smart power systems: models, methods, and future research*," IET Smart Grid, vol. 2, no. 1, pp. 2–10, Mar. 2019, Doi: https://Doi.org/10.1049/iet-stg.2018.0065.

15. R. M. Malkar and V. B. Magdum, "*A study of Unified Power Flow Controller (UPFC) in Power System — A Review*," 2019.

16. Rathore, O. P. Mahela, B. Khan and S. Padmanaban, "*Protection Scheme using Wavelet-Alienation-Neural Technique for UPFC Compensated Transmission Line*," in IEEE Access, vol. 9, pp. 13737-13753, 2021, Doi: 10.1109/ACCESS.2021.3052315.

17. Razzaq Altahir, Ali Abdul, and Marwa M. Marei. "*An Optimal Allocation of UPFC and Transient Stability Improvement of an Electrical Power System: IEEE-30 Buses*," International Journal of Electrical and Computer Engineering (IJECE), vol. 11, no. 6, 1 Dec. 2021, p. 4698, https://Doi.org/10.11591/ijece.v11i6.pp4698-4707. Accessed 17 May 2022.

18. S. Biricik, "*Design of Unified Power Quality Conditioner for Power Quality Improvement in Distribution Network*," www.semanticscholar.org, 2018.

19. S. N. Waghade and C. R. Gowder, "*Enhancement of Power Flow Capability in Power System using UPFC- A Review*," www.semanticscholar.org, 2019.

20. Saeed Rezaeian Marjani, Sajjad Miralizadeh Jalalat, Behroz Tousi, S. Galvani, and Vahid Talavat, "*A Probabilistic Approach for Optimal Operation of Wind-integrated Power Systems Including UPFC*," Iet Renewable Power Generation, Nov. 2022, Doi: 10.1049/rpg2.12627.

21. Samiksha Thakare, M. Janaki, and R. Thirumalaivasan, "*Improvement in Power Flow Control and Voltage Regulation using UPFC*," 2019 Innovations in Power and Advanced Computing Technologies (I-PACT), Mar. 2019, Doi: 10.1109/i-pact44901.2019.8960151.

22. Singh, Er. Prabhat Kumar and Dr. Surya Prakash. "*Modeling and Comparative Analysis of UPFC and SSSC for Transmission Line*," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Energy 3 (2014): 9527-9532.

23. U. Raj and R. Shankar, "*WOA Based LFC of Interconnected Power System Incorporating UPFC*," 2019 2nd International Conference on Power Energy, Environment and Intelligent Control (PEEIC), Greater Noida, India, 2019, pp. 254-258, Doi: 10.1109/PEEIC47157.2019.8976835.

24. Y. Hu et al., "*Optimal power flow calculation of UPFC power system based on PSAT*," Journal of Physics, vol. 2254, no. 1, pp. 012019–012019, Apr. 2022, Doi: https://Doi.org/10.1088/1742-6596/2254/1/012019.

25. Y. I. D. Kobibi, M. A. Djehaf, M. Khatir, and M. Ouadafraksou, "*Continuation power flow analysis of power system voltage stability with unified power flow controller*", J. Intell Syst. Control, vol. 1, no. 1, pp. 60- 67, 2022. Doi: 10.56578/jisc010106.

26. S. Biswas and P. K. Nayak, "A Fault Detection and Classification Scheme for Unified Power Flow Controller Compensated Transmission Lines Connecting Wind Farms," IEEE Systems Journal, vol. 15, no. 1, pp. 297-306, March 2021, Doi: 10.1109/JSYST.2020.2964421.

27. S. Devassy and B. Singh, "Performance Analysis of Solar PV Array and Battery Integrated Unified Power Quality Conditioner for Microgrid Systems," in IEEE Transactions on Industrial Electronics, vol. 68, no. 5, pp. 4027-4035, May 2021, Doi: 10.1109/TIE.2020.2984439.

28. S. N. Waghade and C. R. Gowder, "Enhancement of Power Flow Capability in Power System Using UPFC- A Review," www.semanticscholar.org, vol. 06, no. 05, pp. 1146–1150, 2019.

29. K. Sarita et al., "Power Enhancement with Grid Stabilization of Renewable Energy-Based Generation System Using UPQC-FLC-EVA Technique," in IEEE Access, vol. 8, pp. 207443-207464, 2020, Doi: 10.1109/ACCESS.2020.3038313.

30. M. A. Mansor, K. Hasan, M. M. Othman, S. Z. B. M. Noor, and I. Musirin, "Construction and Performance Investigation of Three-Phase Solar PV and Battery Energy Storage System Integrated UPQC," in IEEE Access, vol. 8, pp. 103511-103538, 2020, Doi: 10.1109/ACCESS.2020.2997056.

31. S. Siddula, T. V. Achyut, K. Vigneshwar, and M. V. Uday Teja, "Improvement of Power Quality Using Fuzzy Based Unified Power Flow Controller," 2020 International Conference on Smart Technologies in Computing, Electrical and Electronics (ICSTCEE), Bengaluru, India, 2020, pp. 55-60, Doi: 10.1109/ICSTCEE49637.2020.9276496.

32. Bhawoorjar and P. Jagtap, "Grid-connected Hybrid PV Power System performance analysis using Unified Power Flow Controller," 2022 6th International Conference on Intelligent Computing and Control Systems (ICICCS), Madurai, India, 2022, pp. 136-140, Doi: 10.1109/ICICCS53718.2022.9788342.

33. M. R. Qader, "Design and Simulation of a Different Innovation Controller-based UPFC (unified Power Flow controller) for the Enhancement of Power Quality," Energy, vol. 89, pp. 576–592, Sep. 2015, Doi: 10.1016/j.energy.2015.06.012.

34. Alsammak et al., "Power quality improvement using FUZZY logic controller based UPFC," Indonesian Journal of Electrical Engineering and Computer Science, pp. 1-92, 2021.

35. Shende et al., "Enhanced Power Quality Using Unified Power Flow Controller Systems," Journal of Physics: Conference Series, vol. 2089, no. 1, pp. 12-35, Nov. 2021, Doi: 10.1088/1742-6596/2089/1/012035.

36. Hingorani, N.G. and Laszlo Gyugyi (2000), "Understanding FACTS concepts and technology of flexible AC transmission systems," New York: Institute of Electrical and Electronics Engineers, Cop. [26]

37. Rajabi-Ghahnavieh, M. Fotuhi-Firuzabad, "UPFC for Enhancing Power System Reliability", IEEE-2010.

38. Alnasseir, Jamal. (2022). Improving the performance of transmission networks using facts through the continuation power flow method. Facta Universitatis - Series: Electronics and Energetics. vol - 35. pp. 437-454. 10.2298/FUEE2203437A.

39. AmlanBarik, SidharthSabyasachi, "Control Design and Comparison of Unified Power Flow Controller for Various Control Strategies International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-3, Issue-1, March 2014.

40. Biricik, Samet. "Design of Unified Power Quality Conditioner for Power Quality Improvement in Distribution Network." Balkan Journal of Electrical and Computer Engineering 6.1 (2018): 47-52.

41. Georgilakis et al., (2019). Unified Power Flow Controllers in Smart Power Systems: Models, Methods, and Future Research. IET Smart Grid. 2. 10.1049/iet-stg.2018.0065.

42. Gyugyi, L., Schauder, C.D., Williams, S.L., Reitman, T.R., Torgerson, D.R. and Edris, A, "The unified power flow controller: A new approach to power transmission control", IEEE Transaction Power Delivery, Vol. 10, pp. 1085-1097,1995.

43. E. Tooraji and N. Abdolamir, "Improving Power Quality Parameters in AC Transmission Systems Using Unified Power Flow Controller," Research Journal of Recent Sciences, Vol.2, No.4, pp.84-90, Apr. 2013.

44. Gaurav and N. Saxena, "Power Quality Improvement using UPFC," International Journal of Electrical, Electronics and Computer Engineering, Vol.2, No.2, pp.30- 33, 2013.

45. S. Lakshmi, G. Sravanthi, L. Ramadevi, and K. H. Chowdary, "Power quality and stability improvement of HVDC transmission System using UPFC for Different uncertainty conditions," International Journal of Scientific and Engineering Research, Vol. 6, No. 2, pp. 795-801, Feb. 2015.

46. Kunal Gupta, Baseem Khan, "Available Transfer Capability Enhancement by Unified Power Flow Controller", IEEE - 2015.

47. S. Soruban, J D. Sathyaraj, and J. J. Gnana Chandran, “Power Quality Enhancement Using UPFC as an Active Power Filter for Renewable Power Generation,” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 4, No. 3, pp. 1712-1718, March. 2015.
48. Malkar, Ravindra M., and Vaibhav B. Magdum. “A study of Unified Power Flow Controller (UPFC) in Power System—A Review.” (2019).
49. Mithu Sarkar, “Effect of UPFC Allocation on Transmission System Power Loss”, Int.Conf. On Energy Efficient Technologies for power system Sustainability (ICEETS-2013), IEEE, Tamilnadu, 10th – 12th April 2013.
50. G. Hingorani and L. Gyugyi, “Understanding FACTS, Concepts, and Technology of Flexible AC Transmission Systems”, Piscataway, N IEEE Press, 2000.
51. Roopa. R, K.ShanmukhaSundar, “Enhancement Of System Performance Using Upfc”, Irf International Conference, 05th July-2014, Bengaluru, India, Isbn:978-93-84209-33-9.
52. S. Singh and S. S. Letha, "Various Custom Power Devices for Power Quality Improvement: A Review," 2018 International Conference on Power Energy, Environment, and Intelligent Control (PEEIC), Greater Noida, India, 2018, pp. 689-695, doi: 10.1109/PEEIC.2018.8665470.
53. S. Vaibhav Kale, R. P.Prashant and R. Khatri, “Unified Power Flow Controller for Power Quality Improvement,” International Journal of Emerging Science and Engineering (IJESE), Vol.1, No. 10, pp. 1-4, Aug. 2013.
54. Sadjad Galvani, MehrdadTarafdar Hagh, “Unified power flow controller impact on power system predictability”, IEEE-2014.
55. Sandeep Sharma and Shelly Vadhera, “Enhancement of Power Transfer Capability of Interconnected Power System Using Unified Power Flow Controller (UPFC)”, International Journal of Electronics and Electrical Engineering Vol. 4, No. 3, June 2016.
56. Tanushree Kaul, Pawan Rana, “Modeling, Analysis and Optimal Location of UPFC for Real Power Loss Minimization”, International journal application, 7 July 2013.
57. Waghade, Shradha N. and Chandrakala R. Gowder. “Enhancement of Power Flow Capability in Power System using UPFC- A Review.” (2019).
58. Y. I. D. Kobibi, M. A. Djehaf, M. Khatir, and M. Ouadafraksou, “Continuation power flow analysis of power system voltage stability with unified power flow controller,” J. Intell Syst. Control, vol. 1, no. 1, pp. 60-67, 2022. https://doi.org/10.56578/jisc010106.
59. PIRC (2023). UPFC (https://www.mathworks.com/matlabcentral/fileexchange/49794-upfc), MATLAB Central File Exchange. Retrieved June 3, 2023.