Power Quality Improvement In 8-Bus System Using DVR and D-STATCOM

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Abstract - The deterioration in the quality of the power supplied has the root cause of dilating gap between the supply and the demand. The occurrence of voltage sag and swell is predominant over other power quality issues like harmonics. The simulation of distribution network using FACTS devices for tempering the power quality issues is prevailing these days but there exist speculative theories which don’t provide effective and robust system on voltage stability and power quality control. This paper focuses on simulation of eight-bus system using D-STATCOM and DVR which is connected with closed loop PID and PI controller. The system is simulated to reduce the peak time, settling time and the steady state error thus proves to be effective in mitigating the voltage sag and swell occurring at the load point distribution system. The simulation is processed in the MATLAB software and the comparison of using PI and PID controller is tabulated and the system is implemented using the PIC16F84A micro-controller.

Keywords - Voltage Sag, Swell, PI controller, PID controller, closed loop.

1. Introduction

In the recent days of technological growth and instantaneous population overflow as well as electronic goods, the high quality of electric power which is reliable poses a high demand significantly. It is estimated that the demand might double by next few years. This expands the horizon between the power generation and the demand. This poses a great challenge for engineers to meet the demand with best quality of power. If the power quality is not maintained then it will rise the power quality (PQ) crisis such as voltage and frequency fluctuations and others. These PQ problems pull the system at the edge of its crucial stability and thermal limits. The consequences of these power quality issues increase the frequency of voltage sags and swells which thereby raises the operational and maintenance charges of the power system. To confront these adverse issues the power electronic devices are modified and simulated thereby it can boost the quality of power supplied to the consumers.

Among these, power electronic devices the Dynamic Voltage Restorer (DVR) and Distributed Static Compensator (D-STATCOM) are considered as best compensating devices due to their extraordinary performance characteristics such as their rapid response and real-time control ability which owes to the rapid switching of solid-state power semi-conductor devices present in the Voltage Source Converter.

Besides, these FACTS devices are the best suitable for reactive power compensation, voltage stability and other such PQ parameters. In spite of having many modern techniques which resolves the many power quality issues the voltage sags and swells are seen as the major challenge among modern electrical utilities. Therefore, the compensation provided must have greater endurance and greater accuracy.

This paper proposes the simulated system which provides the alleviation of these sags and swells in the power system which is compensated by using DVR and D-STATCOM using closed loop PI and PID controller. The system thus improves the power quality, power compensation, input power factor, voltage regulation and fewer harmonic. The power compensation provided by the system is enhanced and has greater durability besides having greater accuracy. Along with that the response of the system is fast as compared to others since it is a closed loop system. The system finds application in grid system where the power compensation is required, voltage stability must be improved and power and voltage control in grid system.

2. Overview of Power Quality Problems and Proposed System

The PQ has ‘n’ number of problems which has the consequences in electrical equipment’s performance or it may damage the equipment sometimes. Nevertheless, the major and ubiquitous problems are voltage sag, voltage swell, voltage harmonics, interruptions and voltage unbalances. Thus, for these PQ problems compensation is required to overcome all these issues[12].

The proposed system consists of D-STATCOM which is a voltage source converter based control, a shunt power electronics device which is used to regulate the system voltage level by exchanging the real and reactive power with the supply with the help of DC energy storage (DES) and DVR which is a static series compensator which injects voltage into system to keep up the susceptible load at certain point. All these are PSCAD/ETDMD environment. In order to effectively reduce the PQ problems, the study about eight-bus system without any compensating devices is considered. The following Figure 1 is the schematic of eight bus system without DVR or D-STATCOM. The real and reactive power and voltage characteristics are simulated.
It can be clearly seen from the above Figure 3 that the real and reactive power is increased from 0.2ms as the voltage sag causes it to increase. To get a clear perspective in understanding the PQ issues in eight-bus system the following simulations have been made and the output graph is noted and tabulated.

As shown in Figure 4 and Figure 5, the distributed STATCOM is a custom power device which consists of three parts namely VSC, a set of coupling reactors and a controller. D-STATCOM consists of DC link capacitance C, inverter, coupling inductance L used for current filter and reactive power exchange between D-STATCOM and power system and a control unit to generate PWM signals. The real and reactive power of D-STATCOM can be thus formulated as below,

\[ Q = \frac{V_s}{X} (V_s - V \cos \delta) \]
\[ P = \frac{V_s V_i}{X} \sin \delta \]
From Figure 6 and Figure 7, it has been noted clearly that the eight-bus system with D-STATCOM is compensating the voltage sag that commonly occurs in the bus voltage at 4. The sag is dominant between 0.2 sec to 0.27 sec, after that the voltage is steadily compensated to normal. The real and reactive power of the bus-4 is also noted as the sag causes distortion and gradual increase in both the real and reactive power of the system. From the graph it is seen that the effect of sag prevails between 0.2 sec to 0.3 sec. It is also seen the gradual increase of reactive power is smoother than the real power. The real power is distorted at the time of recovering from the sag. The perfect tuning of D-STATCOM will also mitigate the harmonics in the PQ.

As shown in Figure 8, The DVR is a static var device which protects sensitive load from PQ issues. The basic principle of DVR is restoring the load side voltage by means of injecting required voltage and frequency even after the source voltage is distorted. The source of injected voltage is the commutation process for reactive power demand and an energy source for the real power demand. The DVR system is capable of injecting a voltage up to 50%. Figure 9 shows the eight bus system with DVR.

The load current injected by the DVR is calculated as follows,

\[ V_{DVR} = V_L + Z_L I_L \]

\[ V_S I_L = (P + jQ) / V_L^* S_{DVR} = V_{DVR} I_L^* \]
The independent usage of two FACTS devices alleviates the sag and swell level but it’s up to certain range. If both these devices are used together the best compensation can be acquired. The effectiveness in mitigating the sag and swells is increased when both these custom devices are used together. The following Figure 12 is the eight-bus system with DVR and D-STATCOM [14-15].

**Fig 12:** Eight-bus system with DVR and D-STATCOM

As shown in Figure 13 and Figure 14, The voltage characteristics of the eight-bus system with DVR and D-STATCOM mitigates the sag created during the time period of 0.2 to 0.27 sec. The DVR injects the voltage required by the system and the D-STATCOM exchanges the reactive power between the D-STATCOM and the power system. Thus, the effectiveness of mitigating these sags and swell and other power quality issues is high than implementing it independently.

**Fig 13:** Voltage at bus-4 due to DVR and D-STATCOM.

**Fig 14:** Real and Reactive power at bus-4 due to DVR and D-STATCOM

The following Table 1 shows the real (MW) and reactive power (MVAR) values injected in each buses of eight-bus system,

**Table 1:** Depicts the comparison of real and reactive power values at each bus connected with D-STATCOM and DVR

| BUS NO | MW-LINE   | MVAR-LINE   | MW-STATCOM plus, DVR | MVAR-STATCOM plus, DVR |
|--------|-----------|-------------|----------------------|------------------------|
| 1      | 0.0921    | 0.0962      | 0.567                | 0.571                  |
| 2      | 0.0369    | 0.0477      | 0.477                | 0.589                  |
| 3      | 0.0221    | 0.0313      | 0.595                | 0.601                  |
| 4      | 0.0312    | 0.0351      | 0.389                | 0.412                  |
| 5      | 0.0471    | 0.0493      | 0.419                | 0.541                  |
| 6      | 0.0417    | 0.0523      | 0.397                | 0.411                  |
| 7      | 0.0320    | 0.0435      | 0.483                | 0.491                  |
| 8      | 0.0321    | 0.0431      | 0.462                | 0.486                  |

**Table 2:** Comparison of voltage for eight-bus system with and without D-STATCOM and DVR.

| Load BUS NO | Without DSTATCOM & DVR | With DSTATCOM & DVR |
|-------------|------------------------|---------------------|
| BUS-2       | 3500                   | 4250                |
| BUS-3       | 2800                   | 4410                |
| BUS-4       | 3720                   | 4260                |
| BUS-7       | 3710                   | 4320                |
| BUS-8       | 3680                   | 4280                |

It can be clearly observed from the Table 1 and 2 that the reactive power and the voltage is increased to a certain level by the use of DVR and D-STATCOM which
acts as the compensation. Though, the system provides good compensation the instantaneous value of voltage and power has some distortions, the sag is not eliminated completely. Thus, the proposed system is about simulation of eight-bus system with FACTS devices along with closed loop PI and PID controller as shown in Figure 15.

![Figure 15: Eight-bus system with D-STATCOM and DVR along with PI controller](image)

The control unit is used for proper operation of such FACTS devices. The DVR and D-STATCOM helps in detecting the unregulated voltage and immediately functioned to mitigate the dip. A Pulse Width Modulation (PWM) technique is used by implementing this PI and PID controller for effectively alleviating the dip as shown in Figure 16.

![Figure 16: Eight-bus system with DVR and D-STATCOM using PID controller](image)

Since, the PI and PID controller are implemented by closed loop the system has increased accuracy, stability and perfect waveform without any harmonics.

3. Simulation and Test Results

The simulation and testing is done in MATLAB and the output is noted as in Figures 17-22 and they are tabulated and compared with each other finally the inference and suggestion is made for the best system which alleviates the sag at its best. The following is the output result of eight-bus system implemented suing PI controller.

![Figure 17: Output voltage for eight-bus system with DVR and D-STATCOM using PI controller](image)

![Figure 18: Output RMS voltage for eight-bus system with DVR and D-STATCOM using PI controller](image)

![Figure 19: Real and Reactive power for eight-bus system with DVR and D-STATCOM using PI controller](image)

![Figure 20: Output voltage for eight-bus system with DVR and D-STATCOM using PID controller](image)
Fig 21: Output RMS voltage for eight-bus system with DVR and D-STATCOM using PID controller

Fig 22: Real and Reactive Power for eight-bus system with DVR and D-STATCOM using PID controller

Table 3: Shows the comparison between the system using two different control.

| Controller | Peak time (s) | Settling time (s) | Steady state error (V) |
|------------|--------------|------------------|-----------------------|
| PI         | 0.36         | 0.44             | 4.6                   |
| PID        | 0.32         | 0.33             | 3.2                   |

By observing the above Table 3, it can be clearly inferred that the usage of PID controller in closed loop the Peak time is reduced from 0.36 Sec to 0.32 Sec, the Settling time is reduced from 0.44 Sec to 0.33 Sec, Steady state error is reduced from 4.6V to 3.2V. Thus, it is inferred that the closed loop PID controller shows better performance than the closed loop PI controller.

4. Conclusion

This paper focuses on implementing a closed loop controller of eight-bus system which is connected with DVR and D-STATCOM. The simulation is made on the MATLAB/SIMULINK environment. The tabulation and comparison of PI and PID controller shows the best performance characteristics of each system such as peak time, settling time and steady state error. Hence, outcomes represent that Eight bus system D-STATCOM and DVR connected system in closed loop PID controller is superior to Eight bus system D-STATCOM and DVR in closed loop system with PI controller. The closed loop PID controller shows best performance in mitigating the sag and can be preferred among others.

References

[1]. Q. Fu, L. F. Montoya, A. Solanki, A. Nasiri, V. Bhavaraju, T. Abdullah and D.C Yu, “Microgrid Generation Capacity Design with Renewables and Energy Storage Addressing Power Quality and Surety”, IEEE Transaction on Smart Grid, Vol.3, No. 4, pp. 2019-2027, Dec. 2012.
[2]. P. Kundur, Power System Stability and Control, McGraw-Hill, Newyork, 1993.
[3]. S. H. Laskar and Mohiullah, “Power Quality Environment,” International Journal of Energy Technology and Advance Engineering, Vol.2, pp. 63-69, September, 2012.
[4]. E. Acha, B. G Age lidis, O. Anaya-Lara and T.J.E Miller, Power Electronics Control in Electrical System, Newnes, Butterworth, Linacre House, Jordan Hill, Oxford, 2000M.
[5]. A. Polycarpou, Power Quality and Voltage Sag Indices in Electrical Power System, M. S. Thesis, Fredrick University Cyprus, 2013.
[6]. A. Haldorai and A. Ramu, “Security and channel noise management in cognitive radio networks,” Computers & Electrical Engineering, vol. 87, p. 106784, Oct. 2020. doi:10.1016/j.compeleceng.2020.106784
[7]. A. Haldorai and A. Ramu, “Canonical Correlation Analysis Based Hyper Basis Feedforward Neural Network Classification for Urban Sustainability,” Neural Processing Letters, Aug. 2020. doi:10.1007/s11063-020-10327-3
[8]. IEEE, Standard Dictionary of Electrical and Electronic Terms, 6th edition, IEEE Std 100-1996, March 2012.
[9]. B. Kanchanpalli and M. Valavala, “Implementation of Custom Power Device in PSCAD/EMTDC for Power Quality Improvement”, International Journal of Electronics and Communications (IJECS), Vol. 1, Issue-1, pp. 47-52, August 2012
[10]. M. Malla, N. Pradhan, N. B. Araya and T. A. Adamu, Power Quality Improvement in Smart Distribution Grids Using Power Electronics Converters, Mini-report in Power Electronics for Renewable Energy, TET4190, Norwegian University of Science and Technology, 2010.
[11]. H. P. Tiwari and S. K. Gupta, “DVR based on Fuel Cell: An Innovative Back-up System”, International Journal of Environmental Science and Development, Vol. 1, No.1, pp. 73-78, April 2010.
[12]. Y. K. Abdulrahman, “PSCAD Simulation of Grid-Tied Photovoltaics Systems and Total Harmonics Distortion Analysis”, International Journal on Electrical Power and Energy Conversion Systems, Vol. 4, No. 2, pp. 1-6, October 2013.
[13]. Science Engineering, 8(5), 702- Shehu, G., Tankut, T., Kunya, A. A “Modelling and Simulation of Cascaded H- Bridge Multilevel Single Source Inverter Using PSIM”, World Academy of Science, Engineering and Technology, International Science Index 89, International Journal of Electrical, Electronics,2014.
[14]. R. Resmi, V. Reshmi and J. Jacob, “Mitigation of Voltage Sag, Swell and Harmonics by Dynamic Voltage Restorer using Matrix Converter,” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2, Issue-2, pp. 297-304, Dec. 2013.
[15]. R. Suguna, R. Senthil Kumar, S. Srikrishnakumar, “Transient Stability Improvement using Shunt and Series Compensators”, Indian Journal of Science and Technology, Vol9(11), DOI:17485, Mar.2016.