Fluctuation Voltage Control of Wind Turbines via STATCOM

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Abstract

This paper presents distributed STATCOM for controlling voltage in distribution line with wind turbines generations at 48 volts. The connection of wind turbine to distribution systems may affect the voltage quality offered to the consumers. One of the factors contributing to this effect is the rapid variations of the wind turbine output power, which cause respective fluctuations in the supply voltage. This paper presents the design, control and analysis of a Distributed STATCOM when combined with a wind turbine comprising small variable speed generators, in this paper it is shown that the distributed STATCOM, controlled via a rotating referent frame: RRF and recursive DFT are simple method to DSP control technique. The result of experiments the STATCOM can improve the transient stability voltage of wind turbine that we have referred the IEEE1159:1995 standard of power quality.

Key words: STATCOM, Recursive DFT, Wind turbines

1. Introduction

Voltage fluctuation is a power quality problem in a power transmission system which could affect to sensitive loads such as electronic loads, control board of a machine, etc. The loads might malfunction, lose control or stop. Most industrial factory has many machines in a production process. [1] In the case, malfunction of a machine in the process could lead to the whole process failed, product damaged and a lot of money lost. Like the power transmission system, a system of power generating by a wind turbine might have the fluctuation voltage depending on the condition of wind which is the power source. An example of the voltage from a wind turbine is shown as Fig.1. [2]

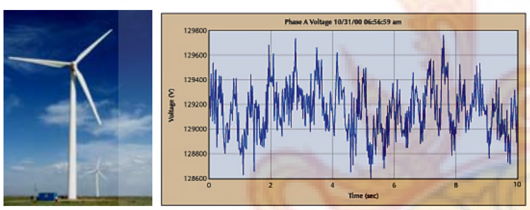


Fig1.Voltage of a wind turbine generator

Many solutions for solving the power quality problem including the fluctuation voltage have been researched in order to protect the loads which are connected into the system. The power flow control in a transmission line is an interesting solution. Recently, power electronic devices play an important role in the power quality solution. They make an efficient way to control the power flow. The complete topology is known as UPFC (Unified Power Flow Controller) which combines two sub-topologies, i.e. SSSC (Static Synchronous Series Compensator), STATCOM (Static Synchronous Compensator) [3]as shown in Fig.2. SSSC is connected in series and STATCOM is connected in parallel into a system.

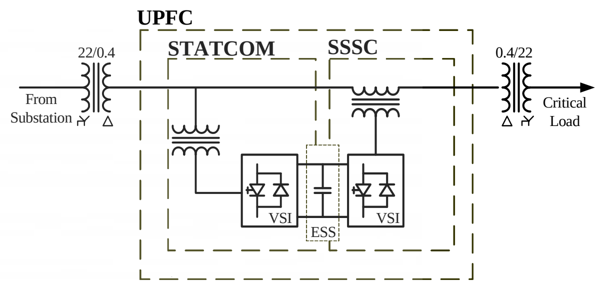


Fig.2 Power flow control topology

Fluctuation voltage could be solved by only a sub-topology; SSSC or STATCOM which each sub-topology has their advantage and disadvantage over the other. The interesting sub-topology in this research is STATCOM. It will be used to solve the fluctuation voltage of a wind turbine generator.

2. STATCOM

STATCOM is a device which connected in parallel into a system and could be varied both generating and drawing reactive power. Generally, STATCOM is used to regulate the AC voltage level at PCC. STATCOM is, furthermore, also used to maintain the stability of a system. A structure and installation of STATCOM into a system are shown in Fig.3. STATCOM consists mainly of VSI (Voltage Source Inverter) and has a DC capacitor which is a power source. VSI will be connected into a system via three interface reactors; L_C. By this method, VSI could be controlled as CSI (Current Source Inverter) in order to control power flow. R_C is defined as losses of the inverter. Mainly, STATCOM could exchange only reactive power with a system. In case of active power, it could not be exchanged by this structure due to small power source. STATOM could, however, be modified in order to control both of reactive and active power by changing the DC source such as battery instead of the existing DC capacitor.

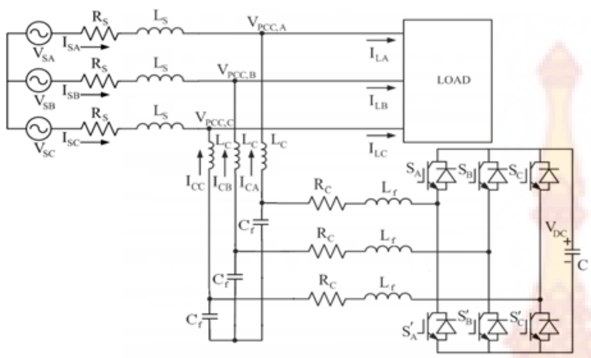


Fig.3 Structure and installation of STATCOM

3. Principle of operation

Fig.4 shows an operation diagram of STATCOM in this research. IPM is a power electronic module which is used as the inverter. The DSP (Digital Signal Processor) board is TMS320F2812.

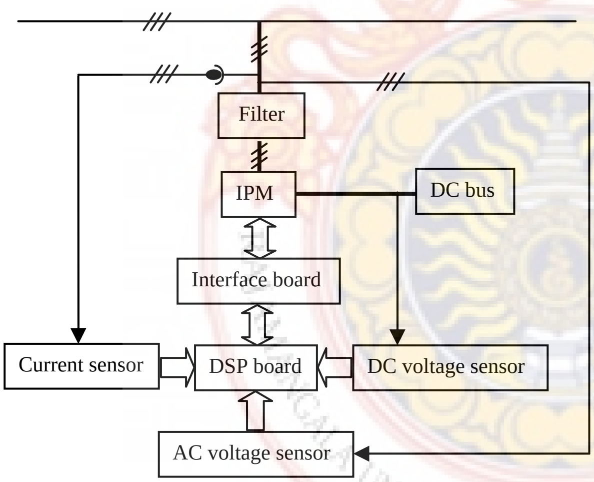


Fig.4 Diagram of STATCOM structure

The system voltage is measured and sent to the processor unit in order to detect voltage fluctuation and control the flow of reactive power for regulating the voltage. The fluctuation voltage will be detected on d-q axis or rotating referents frame (RRF). Furthermore, the voltage signal will be improved by filtering which is called “recursive discrete Fourier transform or recursive DFT” [4], [5], [6]. The reactive power flow will be controlled via controlling the current of STATCOM which is injected via the power module and through passive low pass filter into the system. The principle control of the STATCOM according to the operation principle could be explained briefly as following.

3.1 dq detection method

The voltage detection method in this research is referred to the previous research [7] which detects a voltage vector on the rotating reference frame. The three phase voltage of a system will be transformed to a vector voltage on the stationary reference frame (SRF) according to equation (1). The vector on SRF consists of V_α and V_β. Next, it would be transformed to be the vector voltage on RRF which consists of Vd and Vq via equation (2). Fig.5 shows an example of d-q voltage component.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{SA} \\ V_{SB} \\ V_{SC} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \quad (2)$$

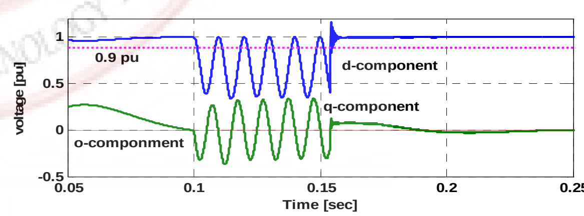


Fig.5 Signal of d-q voltage component

3.2 Recursive DFT

A voltage signal in a system might consist of the symmetrical components, harmonic components as well as some noise depending on each individual system. So the filtering process has to perform in order to eliminate the undesired signals. Recursive DFT (RDFT) which is a filtering method is applied in this research in order to obtain only the positive component of the voltage. RDFT could easily implement in the digital world and does not quite effect to the control. The voltage signal obtained from the d-q detection method on d-q axis rotates at fundamental frequency in positive direction. Therefore, the positive sequence which has the same frequency will become a DC signal on d-q axis. On the other hand, the undesired periodic signals, negative and zero sequence as well as all harmonics will still oscillate around the DC signal. This means that the DC signal, positive sequence, could be obtained easily by using the moving average filter as equation 3. The block diagram of RDFT is shown in Fig.6.

$$D_h'(z) = \frac{1}{N}\frac{1 - z^{-N}}{1 - z^{-1}} \qquad (3)$$

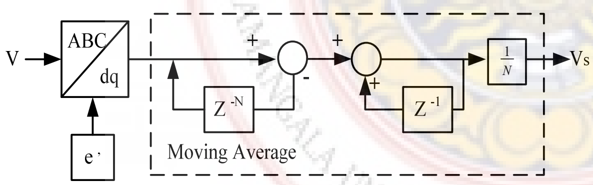
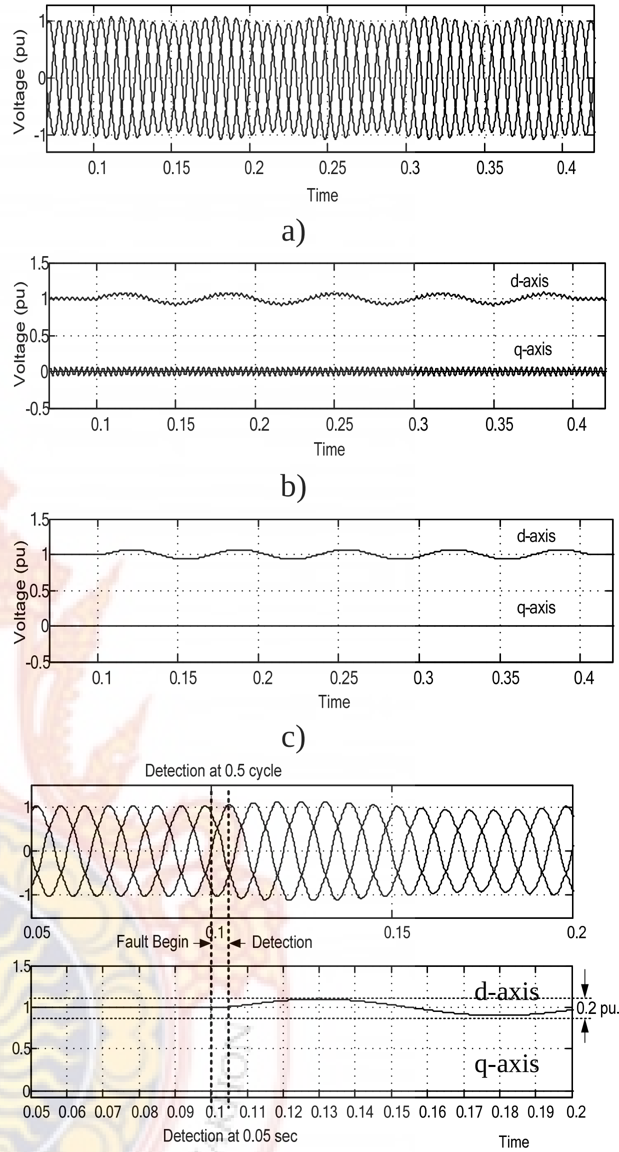


Fig.6 Recursive DFT Method

A simulation [8] of the RDFT with window length of 10ms is shown as Fig.7. The voltage of the simulation is modulated by some harmonics and its magnitude is modulated by 0.1pu., 15Hz sinusoid as shown in Fig.7a. The fluctuation voltage starts at 0.1st second and end at 0.4th second.



d)

Fig.7 Simulation of fluctuation voltage detection
a) Fluctuation voltage with harmonics
b) d-q voltage c) d-q voltage by RDFT
d) Delay time of the signal

Fig.8b shows the voltage on d-q axis which consists of the positive sequence and harmonics. Fig.8c shows the d-q voltage which is filtered by RDFT. The signal has only the positive sequence. This means that the RDFT could eliminate the undesired signals which are harmonics in this case.

Fig.7 shows the result of delay time of RDFT that it could detect the magnitude change of the voltage at 0.105th second after the magnitude of the voltage started to increase at 0.1st second. This means that the method could detection the magnitude of voltage within 0.005 second or 0.4 cycle and it could detect the change of voltage magnitude between 0.9pu. and 1.1pu. Therefore, the d-q detection method could be applied for detecting the voltage fluctuation in order to control STATCOM. Its accuracy and delay time, however, depends on the window length of the moving average filter and the frequency of voltage fluctuation.

3.3 Software

DSP is applied in this research in order to implement the algorithm of the principle control via C language. A flowchart of control software is illustrated in Fig.8.

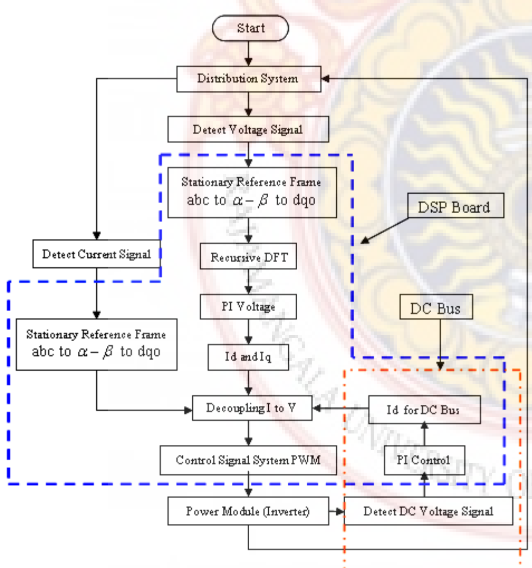


Fig.8 Flow chart of STATCOM software

After DSP received the system voltage signal, they will be transformed to d-q component and filtered by RDFT. Next, the d component of the voltage is controlled by the current on q axis which will be injected into the system in order to control the reactive power flow via PI control. Finally, the q current signal will be converted to a voltage signal via Decoupling control to control VSI acting as CSI. At this state, the actual current on d-q axis is also required. For DC bus voltage control, the DC voltage is controlled by controlling the injected current on d axis in order to draw the active power from the system. Like the q current signal, the d current signal will also be sent to the Decoupling control.

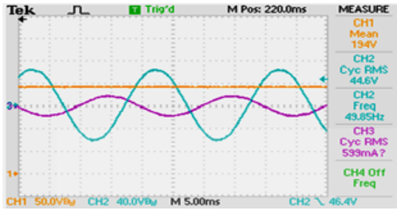
4. Experimental setup and results

These experiments just show the possibility of the proposed algorithm that the voltage could be control. There are two cases of the experiments. First case is to connect the STATCOM into the low voltage system which is supplied from the electricity network. And the STATCOM is connected into the system which has a wind turbine as a power source. A target is to regulate the line to neutral voltage as 48V. Line impedance is 9mH. The results are shown as following.

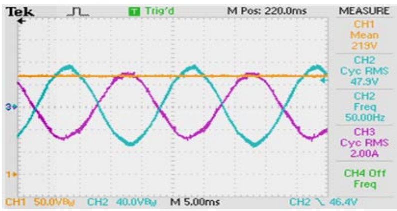
4.1 Network with STATCOM

The STATCOM is connected into the network of the electricity authority through a three phase variac and there is a three phase resistive load; 400 W at 400V. Fig.9 shows the experimental setup.

Fig9. Experimental setup for connecting the STATCOM to the network

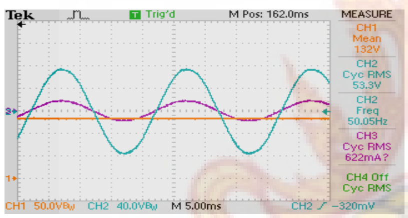


a)

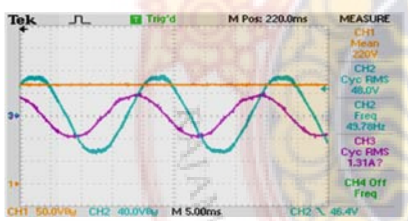


b)

Fig.10 Voltage and current of the voltage regulation experiment when under voltage
a) before compensation
b) after compensation



a)



b)

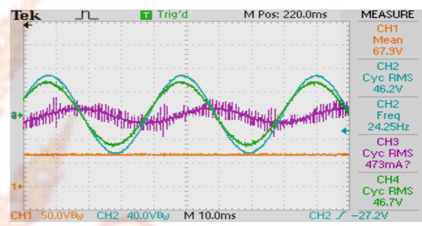
Fig.11 Voltage and current of the voltage regulation experiment when over voltage
a) before compensation
b) after compensation

Fig.10 shows the result of the voltage regulated by the STATCOM when the voltage is under 48V L-N. Fig.11 shows the result of the voltage regulated by the STATCOM when the voltage is over 48V L-N. The results illustrate that the STATCOM could regulate the voltage as 48V.

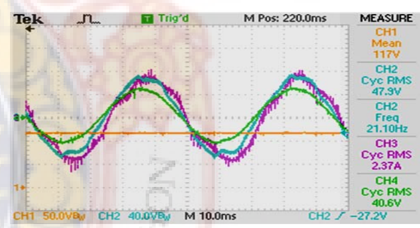
4.2 Wind Turbine with STATCOM

The STATCOM is connected into the wind turbine system and there is a three phase resistive load; 400 W at 400V. Fig.12 shows the experimental setup.

Fig12. Experimental setup of the wind turbine system with the STATCOM



a)



b)

Fig.13 Voltage and current of the voltage improvement experiment of Wind Turbine
a) before compensation
b) after compensation

Fig.13 shows the result of the voltage improvement by the STATCOM when the voltage is under 48V L-N. The green signal is the voltage of the generator and the blue signal is the voltage of the load. The purple signal is the current in the system. The result illustrates that the STATCOM could improve the voltage to 48V.

5. Conclusions

This research illustrates that the STATCOM could regulate the voltage both of coming from the network and the wind turbine. The RDFT is applied to improve the d-q detection method to immunize the undesired signals. Moreover, it is very easy to implement in DSP; however, the response time and accuracy of the detector depends on the window length of the moving average filter and the frequency of voltage fluctuation. Although the actual voltage fluctuation experiment is not performed, but the possibility of the improvement of the fluctuation voltage is tested. The further aim of the research is to regulate the voltage to achieve the international standard; IEEE1159[9] in order that all loads which are connected into the system could work properly and be safer.

6. References

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