Dynamic Interactions between a large PV plant and a STATCOM

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SUMMARY

STATCOM is a FACTS device used to provide reactive power compensation in transmission system. The ability to provide full reactive current even at a low voltage, and fast speed of response make STATCOM an attractive solution against Static Voltage Compensator (SVC).

The large scale Photovoltaic Solar (PV) Power Plants have seen an accelerated growth around the world in recent years. The large scale PV plants are capable of providing reactive power support to the grid, as similar to STATCOM. Large PV plants are spread across a large geographical area with multiple inverter units. These inverter units are controlled by individual inverter level controller, and the inverter controllers are supervised by the plant level controller. They can provide faster reactive power support during a disturbance by implementing voltage control at inverter level. It can also provide plant level voltage control, but this control is slower due to the delays incurred in communication between plant level and inverter level voltage controllers.

With the fast growth of large scale PV plants, it is possible for them to the installed in the vicinity of STATCOM. As both STATCOM and PV plant can provide reactive compensation, it is possible to have adverse negative interaction between them. The interactions between STATCOMs are widely reported in literature and recommendations to mitigate these interactions are also reported. But a large PV plant is different from the STATCOM, as the PV plant has multiple inverter units distributed over a large area, with cables connecting them to the substation transformer. Each inverter unit has an inverter and pad mount transformer. The multiple inverter units, transformers and cables make the response of a PV plant different from the STATCOM and could cause interactions entirely different from the interactions between two STATCOMs. This shows the need for studying the interaction between PV plant and STATCOM.

The studies show that interactions between a large PV plant and STATCOM is different from the interactions between two STATCOMs. The impact of controller parameters and distance between PV plant and STATCOM on the interactions are also presented in this paper.

KEYWORDS

STATCOM, Large PV plant, Small Signal Modelling, Reactive Power Control, Voltage Control, FACTS, PV Plant Level Voltage Control, PV Inverter Level Voltage Control.

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INTRODUCTION

Reactive power compensation using Flexible AC Transmission System (FACTS) device is widely employed to improve both dynamic and steady state performance of power system. Static Var Compensator (SVC) and STATCOM are the broadly used shunt FACTS devices. STATCOM is a voltage source converter based device and it is capable of generating three phase sinusoidal voltages with controllable amplitude and phase angle by switching of the power electronic switches. STATCOM is more preferred over SVC due to its higher transient current rating, faster response, and capability to provide rated capacitive current at low voltage [1, 2]. STATCOM is widely employed for improving voltage stability [3], power oscillation and SSR damping [4], load compensation [5], integration of distributed generators [6, 7], and to provide reactive power support to critical industrial motors [8]. The operation of multiple STATCOMs located in proximity can cause negative interactions between them and could lead to unstable operation [9].

With increasing concern over global warming, the use of renewable energy is growing at a rapid rate around the world [10]. The solar PV plants have seen an accelerated growth around the world in last decade with an average growth of 68% per year [11]. In 2017 the total global installed capacity of PV reached 398 GW [12]. It is predicted that global installation capacity of PV will reach 1100 GW by 2023 [13] and 4600 GW by 2050 [14]. The solar photovoltaic (PV) plants are connected to grid at various voltage levels. The small scale residential PVs (up to several kW) and commercial PV inverters (up to few MW) are connected to distribution networks. Large Scale centralized PV plants (ranging up to 500+ MWs) are connected to the transmission system.

The latest grid codes require the PV inverters to provide reactive and real power support to the grid apart from the conventional operation of real power production [15-17]. With the fast growth of large scale PV plants, it is likely for them to the installed in the vicinity of STATCOM. As both STATCOM and PV plant can provide reactive compensation, adverse negative interaction could occur between them.

A large centralized PV plant has multiple inverter units distributed over a large geographical area, with cables connecting them to the substation transformer. Each inverter unit has an inverter and pad mount transformer. The large PV plant can either provide plant level voltage support or inverter level voltage support [18]. Due to the structural difference, the interaction between a large PV plant and a STATCOM could be different from the interactions between adjacent STATCOMs. The interactions could be different when the PV is operating in either plant level or inverter level voltage control.

The studies [19-22] shows that the PV plant interacts with the adjacent traditional reactive power compensation device like STATCOM. These studies considered an equivalent model of the PV plant, and thus neglect the influence of multiple inverter units, collector system etc. The interactions during different voltage control strategies is also not studied in [19-22].

In this paper, the interaction between a large PV plant and a STATCOM is studied for the different voltage control strategies of a PV plant, considering a detailed model of PV plant with multiple inverter units.

STUDY SYSTEM

The single line diagram of the study system is depicted in Figure 1. The study system comprises a 200 km single circuit radial transmission system having four 138 kV line sections of 50 km each. These 138 kV line sections are represented as equivalent pi models. L_1, L_2, L_3, L_4, and R_1, R_2, R_3, R_4 represent the inductances and resistances of the different transmission line sections, respectively. Capacitances C_1, C_2, C_3, C_4 and C_5 represent the sum of transmission

line capacitance and shunt capacitor at various sections of the 138-kV line. This radial transmission system is supplied by a 230-kV transmission system at transformer station T_1. The Thevenin equivalent impedance of the 230-kV network is represented by inductance L_g and resistance R_g. A 75 MW PV solar farm is connected to the middle of the 138-kV transmission system. The 138-kV transmission line feeds a total load of 80 MVA through 138/27.6 kV transformer T_2. The voltage dependent model is used to represent the load L_s. A 50 Mvar STATCOM is connected at 100 km away from transformer station T_1. A large PV plant of 45 MW is connected at a distance of 50 km from the STATCOM as shown in Figure 1
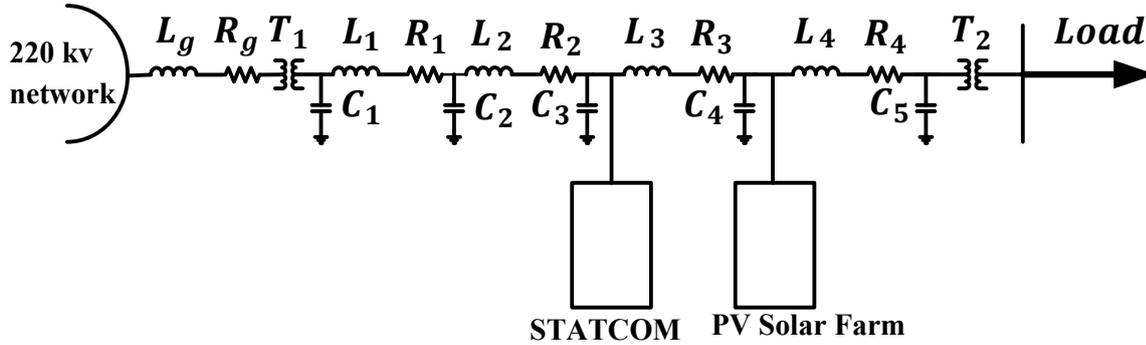

Figure 1. Single line diagram of study system

Model of STATCOM

The model of the STATCOM used in this study is depicted in Figure 2. The voltage source converter is represented by average model [2]. The inductor L, capacitor C and inductance of $\Delta - Y$ transformer constitutes the LCL filter of the STATCOM. R_{f1} and R_{f2} represents the resistance of the inductor and capacitor respectively.
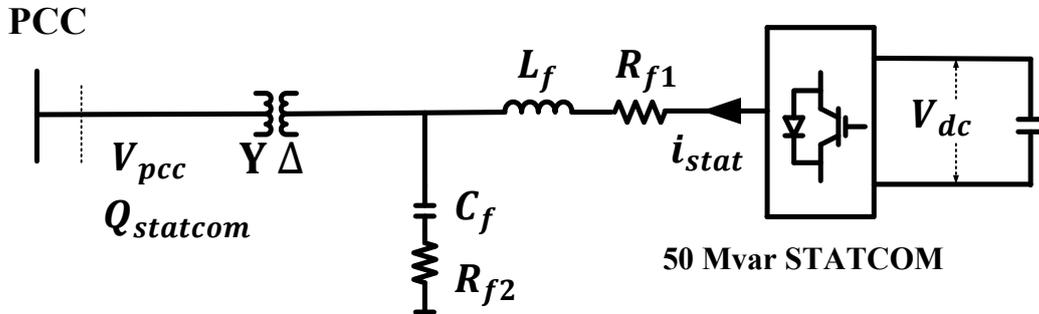

Figure 2. Model of STATCOM

Model of Large PV plant

The 45 MW PV solar farm is modelled as a PV system consists of three 15 MW inverters, as shown in Figure 3. The inverter output power is fed to the substation transformer using MV collector cables. The cables are represented by their equivalent π model. The inductor L, capacitor C and inductance of $\Delta - Y$ transformer constitutes the LCL filter of the PV inverter. R_{f1} and R_{f2} represents the resistance of the inductor and capacitor respectively.

In Plant Level voltage control (PLC), the controller regulates V_{poi}. The voltage controller generates the reactive power reference for each inverter, with an objective of maintaining V_{poi} at the set point. Usually a large time delay is incurred in plant level voltage control, and it is set as 0.5 sec in this study [18].

In Inverter Level voltage control (ILC), the voltage controller at each inverter regulates its PCC voltage (V_{pcc}) independently. Compared to plant level control, there is no delay incurred in the inverter level voltage control and thus can provide rapid voltage support during transients.
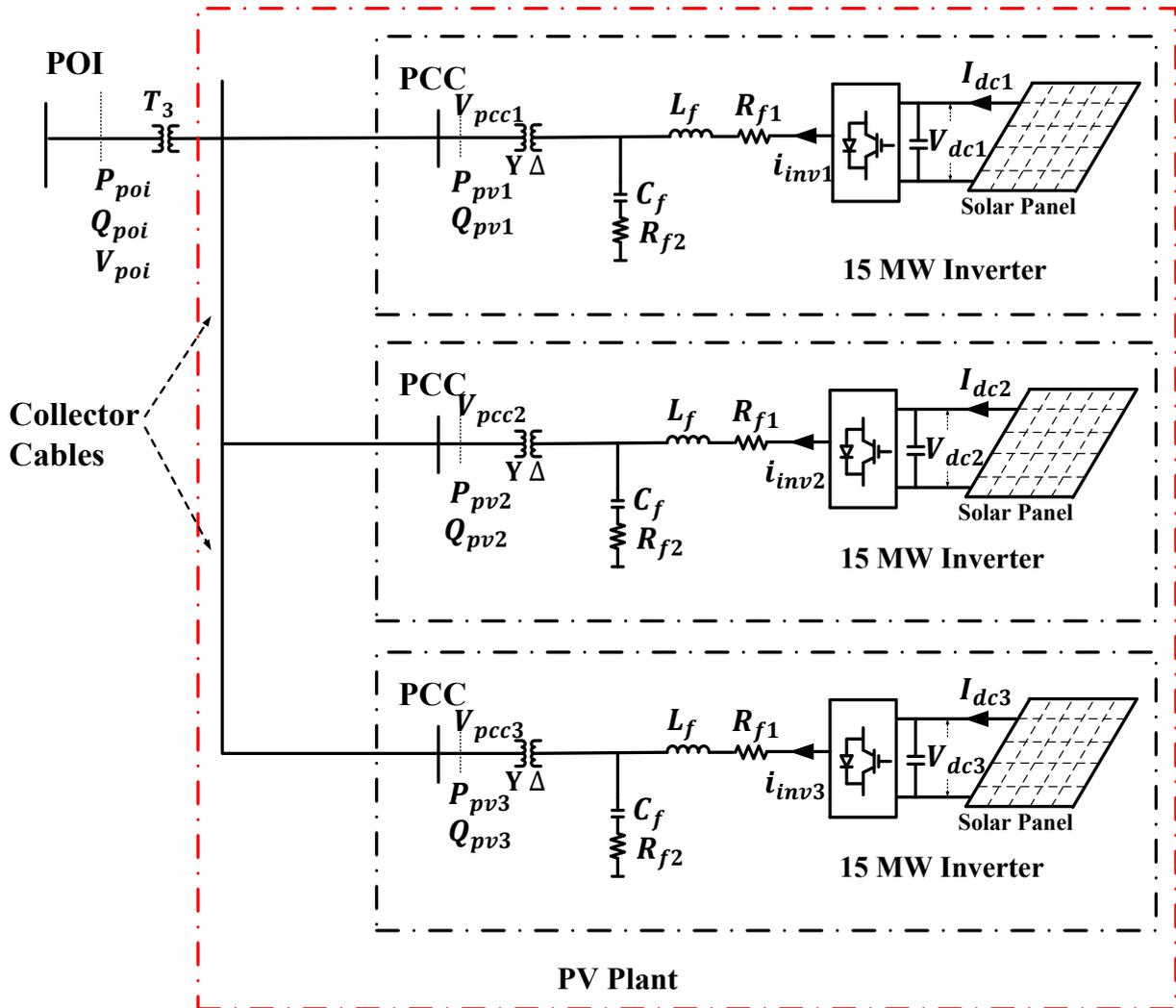

Figure 3. Model of a large PV plant
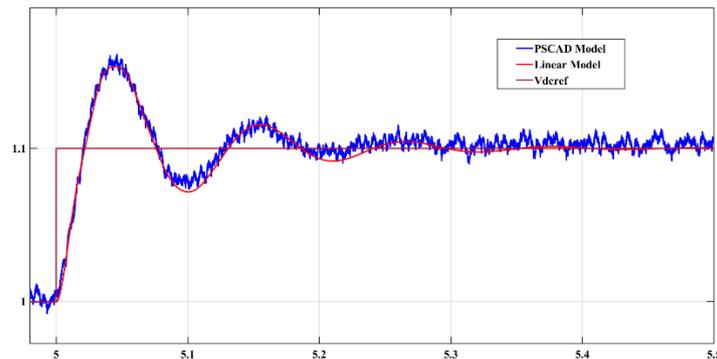
Small Signal Model

Figure 4. Step Response of the linear model and nonlinear model for a step input for DC link voltage reference of Inverter 1 of PV solar farm.

The inverter, transformer, filter, transmission lines and cables are represented by their equivalent model and the developed state space model is linearized around the operating point for the small signal studies [23, 24]. The detailed model of the different components is not included here due to space limitation.

The developed linear model is first verified by comparing its response with the response of the non-linear model in PSCAD, for a step input for DC link voltage reference of an inverter at PV solar farm. The verification result is shown in Figure 4. The model is further verified by comparing the response of STATCOM voltage controller, PV plant level, and inverter level voltage controllers, but the results are not shown here due to space constraint.

The small signal studies are done to find the influence of the various parameters on the interaction between a STATCOM and a PV plant and how these interactions are different from the interaction between STATCOMs. For these studies, following three cases are considered, Case (1) The large PV plant is replaced with an equivalent STATCOM- to study the interaction between two STATCOMs, Case (2) The large PV plant is doing voltage control at plant level – to study the interaction between a STATCOM and PV plant providing voltage control at plant level, and Case (3) The PV plant is providing voltage control at inverter level – to study the interaction between a STATCOM and a PV plant providing voltage control at inverter level. The results of the small signal studies are discussed below.

Impact of AC Voltage Controller Bandwidth
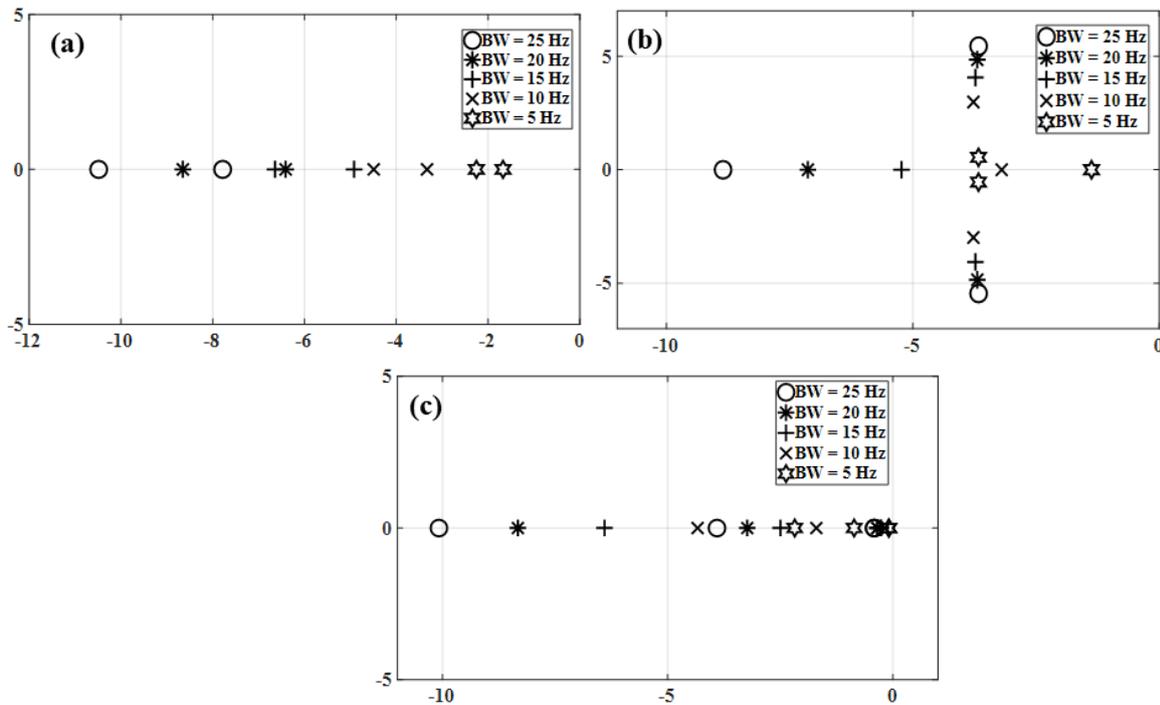
Figure 5. Dominant poles for variation of voltage controller bandwidths (a) Two STATCOMs (b) STATCOM and a PV plant with PLC, (c) STATCOM and a PV plant with ILC.

The impact of bandwidth of AC voltage controller on the interactions between a STATCOM and large PV plant is studied and results for Case (1) – Case (3) are depicted in Figure 5. For two neighbouring STATCOMs, two dominant poles shift right with decrease in bandwidth of controller. Similar to Case (1), two dominant poles are affected by varying controller bandwidth in Case (2). One pair of pole moves right with decrease in controller bandwidth. For the second mode, the frequency reduces with decrease in bandwidth whereas damping of this mode is not significantly influenced by the variation in controller bandwidth. For Case (3), the locus of the dominant poles is similar to Case (1), but the poles shift to more right with reduction in bandwidth. The participation factor analysis showed that the pole closer to origin is due to the interaction between AC voltage controllers at inverters in PV plant.

This study shows that the interaction between a large PV plant and STATCOM is different from the interactions between two adjacent STATCOMs. For the same bandwidth of AC voltage controller, unstable operation can occur for Case (3), but not for the other cases.

Impact of DC link Voltage Controller Bandwidth

The impact of bandwidth of DC link voltage controller is assessed and results are shown in Figure 6. Figure 6 (a) illustrates the dominant poles for the system with two STATCOMs for variation of bandwidth of DC link voltage controller of STATCOMs. The roots of the system with a STATCOM and a large PV plant for variation of DC link voltage controller bandwidth for the STATCOM and inverters of the PV plant is shown in Figure 6 (b).

Only a pair of poles are affected by the variation of bandwidth of DC link voltage controller for the case with two STATCOMs (case (1)), and these poles shifts right with reduction in bandwidth of voltage controller. This shows the higher bandwidth of voltage controller can ensure better stable operation for adjacent STATCOMs.

For the system with PV plant and STATCOM, multiple pair of poles are affected by the DC voltage controller bandwidth. Multiple poles are affected because the PV system has multiple inverters and it cause interaction between the DC link capacitors in the PV plant, and also between the DC link capacitor of STATCOM with the DC link capacitors of PV plant. The poles shift right with the decrease in speed of DC link voltage controller and cause unstable operation for bandwidth = 5 Hz, whereas same bandwidth controller ensured stable operation for Case (1) as depicted in Figure 6 (a).
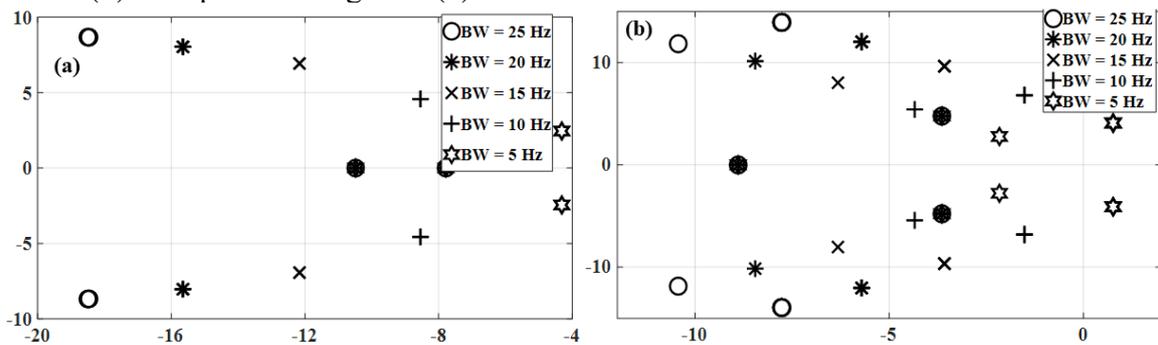

Figure 6. Dominant poles for variation of DC link voltage controller bandwidths (a) Two STATCOMs (b) a STATCOM and a PV plant.

This study confirms that for the same controller bandwidth, the interactions between PV plant and STATCOM is different from the interactions between STATCOMs, and the slower controller bandwidth can cause unstable operation in system with PV plant and STATCOM compared to system with two STATCOMs.
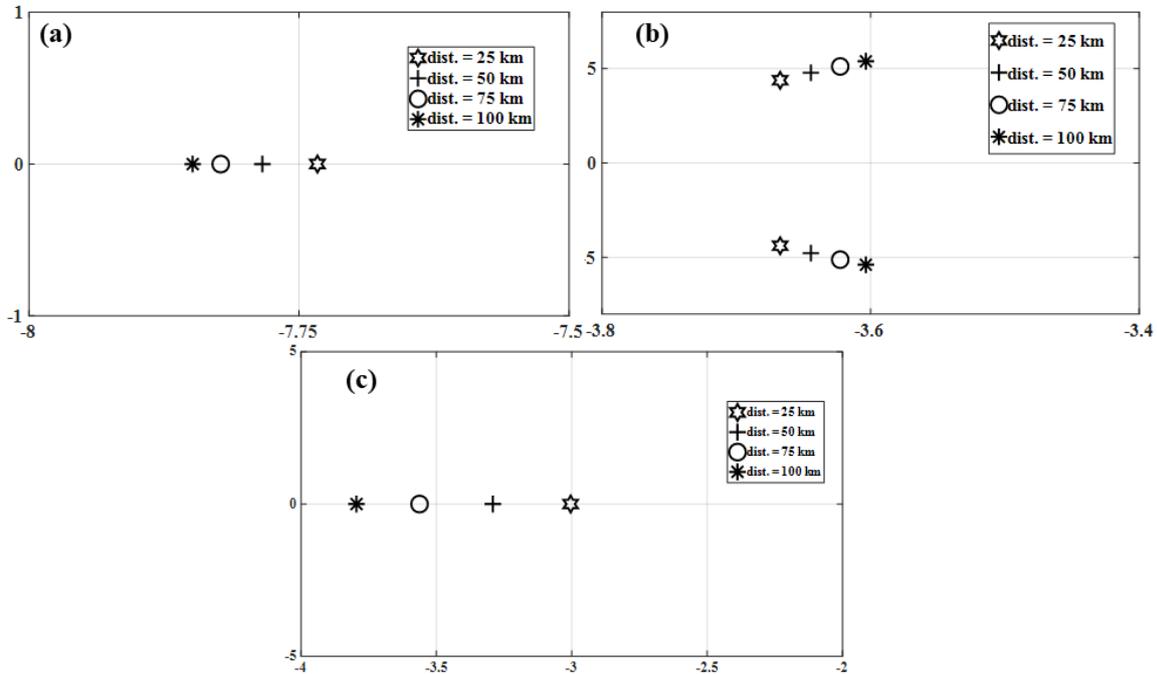
Impact of distance between STATCOM and PV plant

The dominant eigen value for the variation of distance between the STATCOMs for Case (1), and variation of distance between PV plant and STATCOM for Case (2) and (3) are illustrated in Figure 7 (a) – (c) respectively. The distance is varied between 25 km – 100 km in this study.

The range of distance considered in this study did not cause unstable operation for all the three cases. For Case (1), the dominant roots moved right with decrease in distance, and thus showing that the interactions between STATCOMs are higher, when the distance between them is lower. For Case (2), the dominant mode showed an opposite trend. The frequency of this mode increases with increase in distance, and the damping reduce with increase in distance. The participation analysis showed that this mode is due to the STATCOM voltage controller, PV plant delay, and PV plant voltage controller, with state corresponding to plant delay has highest contribution. The delay considered is 0.5 sec in this study, which is well within the typical delay for PLC [18]. Thus, the interaction between a STATCOM and a large PV plant

providing voltage control at plant level with a large delay slightly increases with increase in distance, which is entirely opposite to the interactions between STATCOMs. This behavior is mainly due to the large plant level delay.

For Case (3), the dominant poles move right with the decrease in distance showing that the interactions are minimal when the PV plant is located far away from the STATCOM.

Figure 7. Dominant poles for variation of distance between (a) Two STATCOMs (b) STATCOM and PV plant with PLC, (c) STATCOM and PV plant with ILC.

CONCLUSION

With the current growth in PV technology, it highly favorable to have a large PV plant connected in the vicinity of STATCOM. The current grid codes require PV plant to participate in the voltage support of the power system. Thus, the PV plant can have negative control interaction between other voltage regulating device like STATCOM in its vicinity. Due to the structural, and operational characteristic difference of a PV plant from STATCOM, these interactions are different from the interactions between traditional voltage regulating devices.

The interaction between a PV plant and STATCOM increase with decrease in AC voltage controller bandwidth. This behaviour is similar to the interactions between two adjacent STATCOMs. However, for the same controller bandwidth, the interactions are higher for PV plant providing inverter level voltage control compared to the interactions between a (i) PV plant providing plant level voltage control and a STATCOM and (ii) two STATCOMs.

The dominant poles of the system move right with slower DC link voltage controller for system with PV plant and a STATCOM, which is similar to the behaviour of the system with two STATCOMs. A smaller bandwidth of DC controller can cause unstable operation for the system with PV plant and STATCOM, whereas it can ensure stable operation for the system with two STATCOMs.

The interactions between two STATCOMs and interaction between STATCOM and a PV plant providing voltage control at inverter level decrease with increasing distance between them. Whereas the dominant modes shift right with the increase in distance for the system with STATCOM and PV plant providing voltage control at plant level, and this behaviour is due to the large delay of the PV plant level voltage controller.

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