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A Master/Slave Reactive Power ManagementScheme for Smart Grids with Wind Generation

K P Preetha
Associate Professor
Dept. of Electrical and Electronics Engineering
Government engineering college, Thrissur

Anusri K S
PG Scholar
Dept. of Electrical and Electronics Engineering
Government engineering college, Thrissur

Abstract—Thispaper introduces a novel coordinated voltage control (CVC) scheme for Wind generations (DGs) that relies on adaptively changing the roles (master or slave) of the devices [Wind Turbine generator, and online tap changer (OLTC)] within the smart grid, depending on system conditions. In addition, the proposed scheme imposes different control response andbandwidth on the devices to coordinate the reactive power among distributed generations (DGs) and OLTC steps. The main objective of the proposed method is twofold: 1) to maximize the reactive power reserve of WTG and 2) to provide voltage regulation during normal operating conditions. The simulated distribution system includes inverter-based DG (wind turbine), and OLTC and the potential of the CVC scheme is evaluated and analysed in view of improving voltage profile, maximizing the reactive power reserve. The proposed scheme is independent of real-time measurements and is widely adaptive to the dynamics of power systems, thus making it quite suitable for utilityimplementation.

Index Terms-Coordinated Voltage Control, Distributed Generation, Online Tap Changer.

I. INTRODUCTION

THE environmental problems created by the conventional energy sources has necessitated the use of renewable energysources. The presence and increased penetration of these distributed generation sources in the grid allows effective decentralized voltage control in distributed networks [1]. Generally, voltage control is considered as a local issue and hence most of the utilities control their voltage at load side by controlling OLTC and other reactive power compensation devices. The voltage at various locations in the feeder is maintained constant with the help of OLTC of the substation transformer and various other compensating devices. The same is done in distribution systems with the help if Line Drop Compensator (LDC)with an auto transformer which adjusts its tap to bring the voltage of pilot bus as close as possible to the reference value [1], [2]. But, with the increased penetration of distribution generation, determination of proper control settings for OLTC and voltage regulator of compensating devices become a tedious task [3], [4].

In [5], a literature review on the various decentralized voltage-control strategies using OLTC, DG, and compensator devices were presented. Faster voltage response can beachieved using decentralized voltage-control schemes as they require no communication infrastructure and, thus, communication failure or time delays will be absent [5].

Nowadays, the use of wind turbine generators are becomingmore common. It is a very good substitute for the thermal power stations which relies upon on fossil fuels. Environmental problems created by WTGs are nil. The major problems in the implementation of WTG is the voltage fluctuation. As wind is not consistent, induction generator is used for harvesting wind energy. Induction machine connected to grid creates a reactive power demand, which is drawn from the grid. This creates a dip in the system voltage.

If the voltage drops too low, some generators will disconnect automatically to protect themselves. Voltage collapse occurs when an increase in load or less generation or transmission facilities causes dropping voltage, which causes a further reduction in reactive power from capacitor and line charging, and still there further voltage reductions. If voltage reduction continues, these will cause additional elements to trip, leading further reduction in voltage and loss of the load. The result in these entire

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progressive and uncontrollable declines in voltage is that the system unable to provide the reactive power required supplying the reactive power demands.

Voltage control and reactive-power management are two aspects of a single activity that both supports reliability and facilitates commercial transactions across transmission networks. On an alternating-current (AC) power system, voltage is controlled by managing production and absorption of reactive power.

This paper introduces a novel coordinated voltage control scheme for smart grids with OLTC and DGs that relies on Master/ Slave control scheme. In this scheme, the OLTC acts as master and wind turbine generator acts as slave when reactive power limits are violated. Under normal conditions both OLTC and WTG act as masters. So the system has 2 different states of operation. State 1 deal with the condition in Load flow conducted on the 13 bus test system manifests the effectiveness of this control scheme in improving the voltage profile.

II. POWER SYSTEM DESCRIPTION

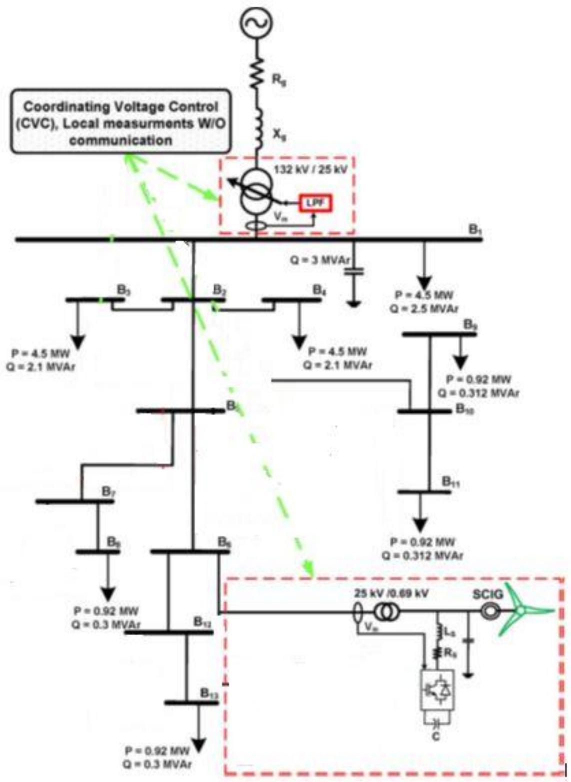

Fig. 1. Distribution test system comprised of a WTG connected to an MV grid.

The proposed coordinated voltage control scheme is applied to the distributed system shown in Fig:1. The distribution test system includes DG source at bus B_6. It includes a wind turbine generator (WTG)and an OLTC. Squirrel Cage Induction Generator is implemented for the WTG. Fixed speed wind generator is simulated with a wind speed of 12 m/s. The WTG is connected to the medium-voltage bus via a 0.69/25- kV transformer. The reactive power absorbed by the SCIG is compensated by a STATCOM located at the wind turbine. The loads in the given distribution system are a mix of static and dynamic loads. This distribution system is connected to transmission equivalent grid through 25/132 kV substation transformer. The CVC scheme coordinates, in an indirect way, the reactive power among the OLTC and VSC-DGs (WTG).

A. Online Tap Changer

OLTC is modelled in time domain with tap ratio as a discrete variable, which can be varied within 16 steps and eachstep is adjusted to 0.00625 p.u. The tap changer is governed by a dead band, time delay, and switching tap ratio logic to respond to system dynamics. The switching logic can be moved (up or down) one step if the deviation of the measured voltage at the regulated bus with respect to the referencevoltage exceeds the dead-band voltage [6], [7].

B. Fixed Speed Wind Generator

The fixed speed wind generator is modelled as an induction machine. The wind turbine is modelled based on the mathematical equation [8].

$$P_w = \frac{1}{2}\rho A V_u^3 C_p \quad (1)$$

Where P_w the mechanical power is extracted by the blades of wind turbine, ρ is the air density, V_u is the velocity of wind and C_p is Betz's constant given by

$$C_p(\lambda,\theta) = C_1(C_2\frac{1}{\beta} - C_3\beta\theta - C_4\theta^x - C_5)e^{-C_6\frac{1}{\beta}}$$

Here the values of $C_1 - C_6$ and x depends on type of turbines and β can be obtained from the equation

$$\frac{1}{\beta} = \frac{1}{\lambda + 0.08\theta} - \frac{0.035}{1+\theta^3}$$

When a wind turbine generator is connected to the grid, it creates a reactive power demand. In order to compensatethis a STATCOM is connected as shown in the Fig.1. The STATCOM works based on the voltage control principle to regulate the terminal

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bus voltage $V_m$to follow the reference voltage V_{ref}. A proportional - integral control is used for the STATCOM control. The STATCOM injects/ absorb reactive power by controlling the quadrature axis component of current I_{qref}.

The control scheme for STATCOM is shown in Fig. 2

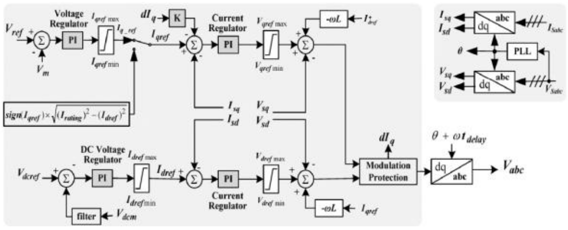

Fig. 2. Control scheme for STATCOM

In this control scheme, decoupled current loops are employed and it uses grid side synchronous reference frame for controlling the active and reactive power output through dq currents separately. q axis reference is obtained from the desired grid voltage and d axis current is used to maintain a constant dc link voltage and thereby to control the active power.

III. COORDINATED VOLTAGE CONTROL ANDREACTIVE POWER-MANAGEMENT SCHEME

A. Principle of coordination

Along with voltage control system coordination is necessaryto enhance the transient stability margin. This is due to the time variance in the response of various components in the system. The distributed generation systems respond to voltage deviation in few milliseconds whereas OLTC take a few seconds. The master/ slave operation of various DGs and OLTC is shown in the Fig. 3

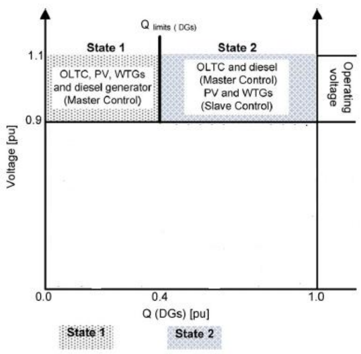

Fig. 3. State master/slave control operation for OLTC and DGs in steady state operation

The CVC algorithm has 2 major operating states as follows

1) State : 1 : In this state the system voltage and DGreactive power satisfy the constraints. The WTG as wellas OLTC acts as master in this state and hence hold theresponsibility of regulating the system voltage.
2) State : 2 : In this state the WTG reactive power hitsthe limit and OLTC acts as master and the WTG actas slave. Here OLTC alone is responsible for regulatingsystem voltage.

During the steady state operation the reactive power limit is set as 40%: When the WTG has not reached this limit it acts as master and set the reference value as 1pu. When this limit is reached, the OLTC set the reference voltages for the DGs as OLTC is the master responsible for voltage regulation. Hence the coordination is implemented by using the following rules [Fig.4].

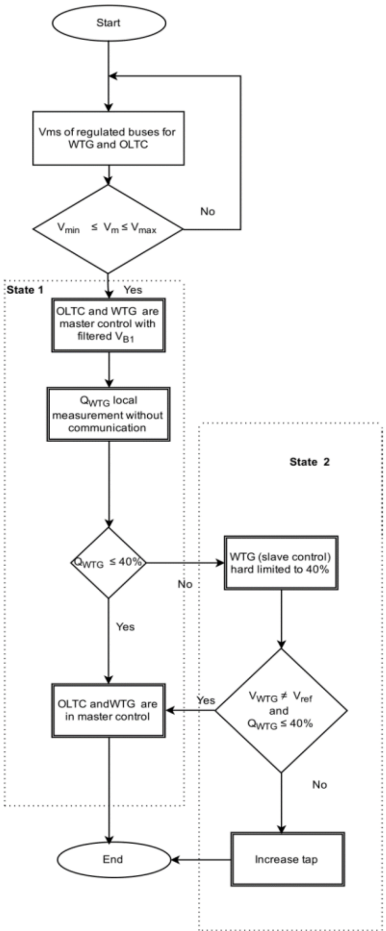

Fig. 4. Coordinated voltage control and reactive power-management algorithm.

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1) Set the reference values of the WTG as 1pu to the decentralized controller of PV WTG.
2) The OLTC consists of _16 steps, each step has a value of 0.0625pu. When the controller voltage exceeds thedead band limit of the OLTC it operates.
3) The reactive power limit of the WTG is set at 40%understeady state operation.
4) WTG reacts immediately due to the inherent time delayin OLTC.

IV. EVALUATION AND SIMULATION STUDY

The medium voltage distribution system shown in Fig.1.was simulated using MATLAB 2015b to evaluate the performance of CVC scheme under steady state condition.

A. Wind Turbine Generator

The simulink model of the wind turbine is shown in the Fig.5.

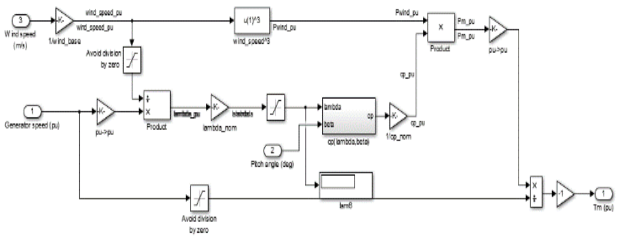

Fig. 5. Simulink model of wind turbine

This turbine is connected to a squirrel cage induction motorwhich acts as the wind turbine generator. The simulink model of WTG is as shown in Fig.6.

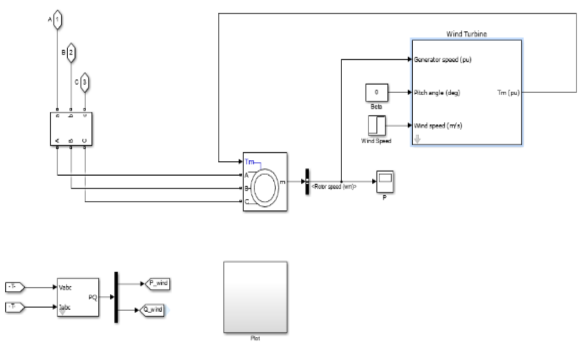

Fig. 6. Simulink model of wind turbine generator

The output waveforms of wind turbine generator are shown in Fig.7.- Fig.9.

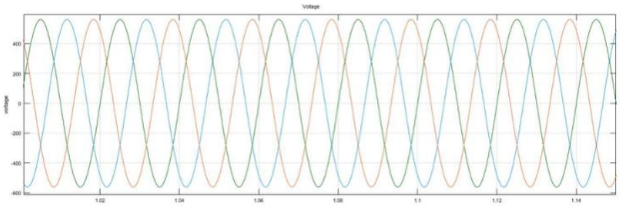

Fig. 7. Output Voltage Waveform of WTG

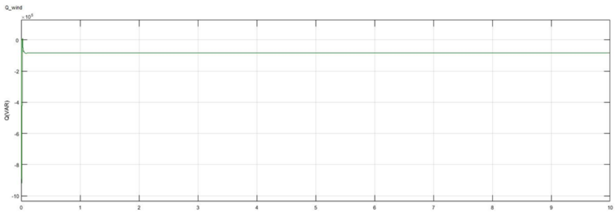

Fig. 8. Reactive power waveform of WTG

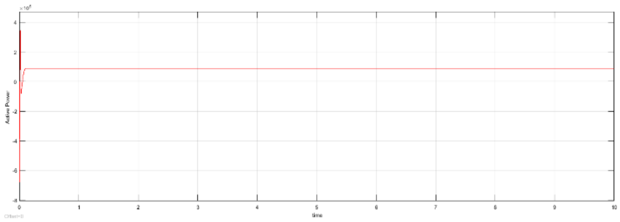

Fig. 9. Active power waveform of WTG

B. Steady State Operation

In this section, load flow study of the distribution systemshown in Fig.1.in different configurations are done. First load flow is done without DGs and OLTC.

The simulink diagram of the complete test system is shown in Fig.10

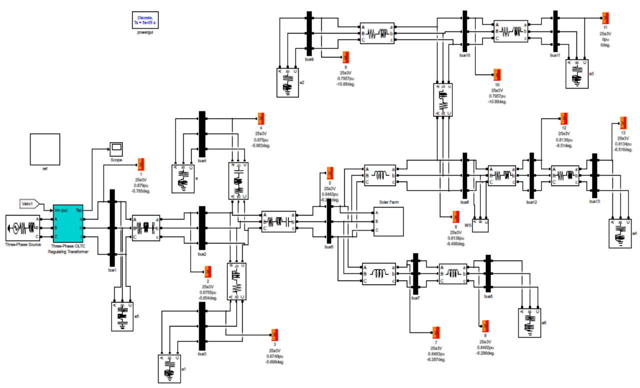

Fig. 10. Simulink diagram of the complete test system

The load flow results shows the superior results with theimplementation of CVC algorithm. The results are tabulated in Table 1.

TABLE I
VOLTAGE PROFILE

Voltage Profile					
Bus in-dex	Without DGs	With WTG	With WTG and OLTC	With WTG and STAT-COM	With WTG STAT-COM and OLTC
1	0.9687	0.8807	1.0000	0.8823	1.0000
2	0.9655	0.8772	0.9960	0.8788	0.9960
3	0.9649	0.8767	0.9954	0.8782	0.9954
4	0.9650	0.8767	0.9955	0.8783	0.9955
5	0.9543	0.8504	0.9651	0.8522	0.9655
6	0.9507	0.8157	0.9258	0.8181	0.9269
7	0.9543	0.8503	0.9650	0.8522	0.9654
8	0.9542	0.8503	0.9650	0.8521	0.9654
9	0.9296	0.7976	0.9052	0.8000	0.9063
10	0.9296	0.7977	0.9053	0.8000	0.9063
11	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.9505	0.8156	0.9256	0.8180	0.8156
13	0.9502	0.8153	0.9254	0.8177	0.8153

V. CONCLUSION

In this paper CVC scheme which is presented which dynamicallychanges the master/ slave roles of OLTC and WTG depending on the voltage and reactive power constraints. When WTG is connected, the voltage is decreased. With the connection of STATCOM, that decrease is slightly compensated. . To this system CVC is implemented through the control of OLTC. Thus the voltage profile is improved.

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