International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

A Distributed Generation Based Inverter for Voltage Control in Distribution System

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Abstract: ***In recent years, DG penetration in the 8distribution systems has become faster and tangible. The implementation of DGs in the distribution network will likely lead to power quality problems, degradation in system reliability, reduced efficiency, over voltages and other safety issues. However, in the distribution network with a DG the voltage profile maintenance becomes important issue. This paper proposes the optimization technology based on the global information of distribution network is utilized to determine the control actions of voltage control equipments. At the same time, it tries to offer the ancillary services to the DN such as voltage regulation, and it tries to minimize DN active power losses and the reactive power exchanged with the DN by the DG units. The validation of the proposed control technique has been conducted through a several number of simulations.***

Keywords: Renewable Energy Sources Distributed Generation, Distribution Network

Nomenclature

ε_d ,ε_u Down and upper threshold values for each DG.
f_{max} Maximum frequency.
f_{loss} Active power losses objective function.
f_{QDG} Reactive power objective function.
I_{DN} DN feeder current.
ΔP_{DG} DG active power variations at the PCC.
ΔV_{DG}^{P} DG output voltage variations due to ΔP_{DG}.
ΔV_{DG}^{Q} DG output voltage variations due to ΔQ_{DG}.
ΔQ_{DG} DG reactive power variations at the PCC.
V_{DG} DG output voltage at the PCC.
P_{DG} DG active power.
PF Power factor.
PV Photovoltaic system.
SAB-DC Sensitivity analysis-based decentralized control.
WDG Wind Distributed Generation unit

1. Introduction

Distributed generation is increasing in penetration on power systems across the world in recent years. In recent years, the renewable energy sources have promising solution for power quality problems and for a cleaner and economical energy society. Various incentive programs have encouraged the adoption of renewable energy sources (RES) based DG's [7] in order to achieve the ambitious government targets. Connection of a large amount of distributed generator causes voltage deviation beyond the statutory range in distribution system, voltage rise is one of the main issues. There is a necessity to develop proper control techniques [4] to ensure power delivery to customers in [2] compliance with power quality and reliability standards requirements and to provide the ancillary services to the network is becoming a relevant issue.

Centralized and distributed approaches have been used for voltage control in the distribution system with high DG penetration. Fully centralized approaches depend heavily on real time measurement and communication tools.[9] The application of centralized control strategies to the existing networks faces several drawbacks, they require significant investments necessary for devices and control systems, all centralized approaches require a highly reliable communication channel through the overall DN.[6] This motivates the use of decentralized control methods which are expected to overcome the aforementioned issues. Therefore, the decentralized approaches have been proposed.

The adoption of the decentralized approaches DN can have positive effects on both loss minimization and increased generation capacity because of their flexibility.[1] One of the most relevant features of this type of approach is to implement the control action at the point of common coupling (PCC) allowing efficient, flexible and scalable control configurations. The local voltage control strategy allows to obtain the maximum allowable active power production for each DG and tries to maximize active power production by controlling the DGs' reactive/active power exchange with the DN and avoiding, as much as possible, the DG disconnection due to the infringement of voltage regulatory limits.

2. Distributed Generation

Distributed generations include generators, reciprocating engines, micro turbines, combustion gas turbines, fuel cells, solar photo voltaic, and wind turbines. There are many reasons a customer may choose to install a distributed generator. DG can be used to generate a customer's entire electricity supply; for peak shaving; for standby or emergency generation; as a green power source; or for increased reliability [6]. In some remote locations, DG can be less costly as it eliminates the need for expensive construction of distribution and/or transmission lines.The penetration of distributed generation power plants into distribution networks is rapidly increasing across the world in recent years [2]. Various incentive programs have encouraged the adoption of renewable energy sources (RES) based DGs in order to achieve the ambitious governments targets related to the promotion of a more sustainable development in the energy sector.

A. Inverter Based DG's

Flexible voltage support control scheme is proposed for inverter based DG, aiming at regulating voltage limits and supports the grid under the fault. The main concern of the DG inverter is to equalize voltages by reducing the negative symmetric sequence and clear the phase jump. Thus, over and under voltage can be avoided, and the proposed control scheme prevents disconnection while achieving the desired voltage support which can be analyzed. Inverter based DG inject all the generated active power in to the grid. The structure of the proposed control System applied to a generic schematic diagram of an inverter Based RES-DG is depicted in Fig. 1.

Typically, RES-DGs are connected to the DNs by means of electronic power converters. Approach could be useful to regulate voltage profiles and/or to offer ancillary services to the DN, maximizing active power production at the same time .The structure of the proposed control system applied to a generic schematic diagram of an inverter based RES-DG is depicted in the figure1. Concerning the inverter-based DG, the converter voltage depends on the dc-link voltage and the parameters of the adopted modulation technique. The reactance represents the total reactance of the transformers and grid filters used for the DG connection to the DN. From the equations (1)-(3) necessary to compute P_{DG} and Q_{DG} it is possible to with an analogous approach.

Among decentralized approaches, the ones facing with DGs capability to provide reactive power support to the DN represent. An emerging class of reactive dispatch technologies not yet extensively investigated. One of the most relevant features of this type of approach is to implement the control action at the point of common coupling (PCC), allowing efficient, flexible, and scalable control configurations [4]. An optimization technique aimed at minimizing power losses within the network and voltage deviation with respect to a reference signal is proposed in [5] for photovoltaic systems (PVs) and applied to the single feeder DN presented in [8].

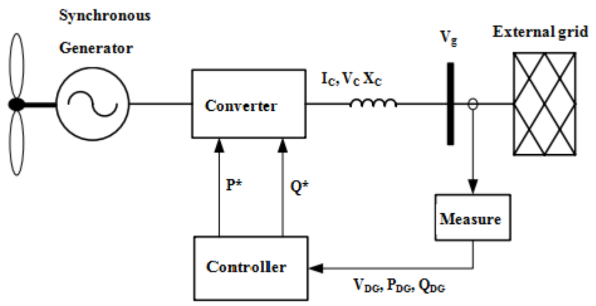

Figure 1: Control System Structure

$$P_{DG}=V_{DN}I_{DN}COS\theta \quad (1)$$

$$Q_{DG}=(V_{DN}\sin\theta+X_{DN}I_{DN})I_{DN} \quad (2)$$

$$P^2_{DG}+Q^2_{DG}\leq(V_{DG}I_C)^2 \quad (3)$$

For each working point, the boundary of reactive power deviation available for the control action must be contained within the capability curve defined by

$$Q_{DG}=\min\{Q^C_{DG},Q^V_{DG}\} \quad (4)$$

3. Proposed Algorithm

Among the various control techniques able to perform voltage regulation, local sensitivity analysis based decentralized control are suitable to regulate voltage profiles with in standard limits. In this paper a decentralized sensitivity based control technique is able to regulate voltage profiles the implemented control strategy allows voltage regulation avoiding, as much as possible, disconnection of DG.

The proposed control strategy consists of a local regulation of reactive and active power in to the grid at the DG unit connection bus. The voltage control is realized conducting a sensitivity analysis of the distribution bus voltage with respective to the reactive/active power injections in order to determine the value of sensitivity parameters.

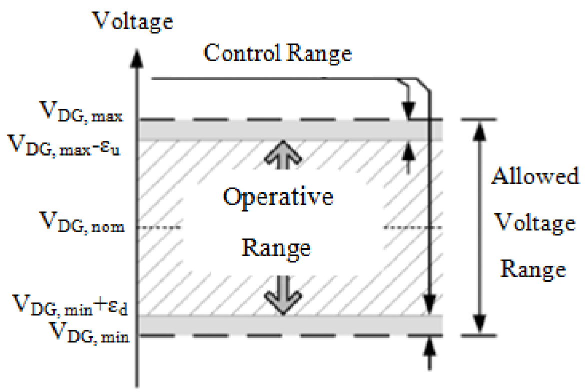

Figure 2: Allowed, operative, and control ranges for the SAB-DC

The control operations begin only if the DG bus voltage level enters the CR, causing a violation of the OR limits. More precisely, when the voltage value enters the CR, a certain amount of reactive and/or active power is injected/absorbed proportionally to the difference between the voltage value within the AR and the threshold value placed between the CR and the OR. The proportionality terms are represented by the sensitivity coefficients as in the equation,

$$\Delta V^Q_{DG}(K)=\Delta Q_{DG}(K)/\rho Q \quad (5)$$

$$\Delta V^P_{DG}(K)=\Delta P_{DG}(K)/\rho P \quad (6)$$

A. Flow Chart

To better explain the operation of the SAB-DC, the control algorithm flow chart in the case of upper threshold violation is shown in Fig.2.

At the generic time instant k, the procedure begins evaluating the difference between $V_{DG}(k)$ and the threshold value , ($V_{DG\,,Max}$- $€_{u,}$) as follows:

$$\Delta V_{DG}(k)=V_{DG}(k)-(V_{DG\,,Max}-€_{u,}) \quad (7)$$

If reactive power injection is contained within the capability region of the DG converter and the voltage value is in the upper CR, the control system tries first to compensate the entire amount of voltage variation by increasing reactive power injected into the DN. Thus, the amount of Q_{DG} to be varied is computed as

$$\Delta Q_{DG}(k)= V^{Q}_{DG}(k).\ \rho Q \qquad (8)$$

The maximum amount of $\Delta Q_{DG}(k)$ used to bring back voltage levels within the OR is limited by the DG capability coverage $Q_{DG\text{-}cap}(k)$. For each working point, $Q_{DG\text{-}cap}(k)$represents the maximum value of reactive power that the converter is able to absorb and/or inject into the DN.

Therefore, the DG reactive power is chosen to yield $Q_{DG}(k)$

$$Q_{DG}(k) = \max\{Q_{DG\text{-}cap}(k), Q_{DG}(K-1)-V^{Q}_{DG}(k).Pq\} \qquad (9)$$

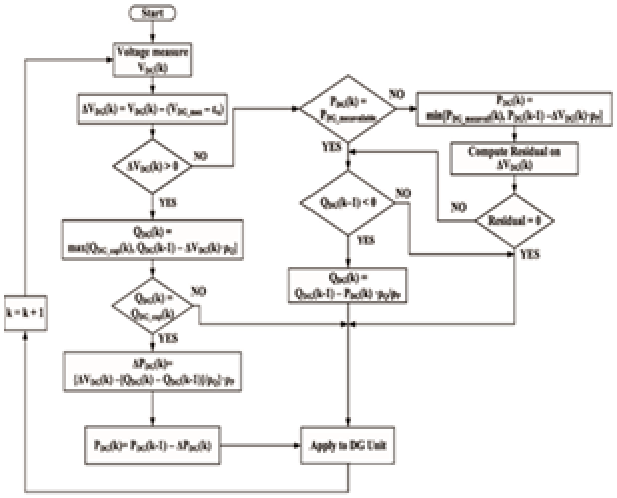

Figure 3: flow chart

The necessary amount is evaluated according to the equations as follows:

$$\Delta P_{DG}(k)= -[\ \Delta V_{DG}(k)-\ \Delta Q_{DG}(k)/\ \rho Q]\ \rho p \ (10)$$

This active power curtailment allows to decrease voltage levels and to obtain a higher reactive power injection capability because the working point is moved leftmost on the capability curve.[10] The right part of the flow chart depicts the SAB-DC in the case of DG bus voltage contained within the OR. If a control action has been previously performed, the SAB-DC tries to recover a $P_{DG}(k)$ at its maximum available value and to reduce the Q_{DG} exchanged with the DN.

The reactive power injection is decreased proportionally to the entire amount of $\Delta V_{DG}(k)$ if no active power curtailment has occurred during previous time step and is shown as follows,

$$\Delta Q_{DG}(K)=-\Delta V_{DG}(K).\rho Q \qquad (11)$$

4. Test Results

In order to prove the validity of the proposed OSAB-DC, a real Italian radial DN has been used. The single-line diagram of the DN is depicted in the figure 4.It consists of a 20-kV distribution system fed by a 132-kV, 50-Hz sub transmission system with a short-circuit level of 750 MVA through a 150/20-kV /Yg transformer with rated power 25 MVA, V_{CC}=15.5%.The primary substation transformer's tap is fixed to 1.006 p.u. Two different DGs penetration scenarios applied to the DN [7].Under test have been supposed in order to obtain a general validation of the proposed strategy. In Scenario A, four WDGs have been connected to the DN. In Scenario B, four PVs have been added to the previously defined scenario.

The connection buses are highlighted in Fig.4 and Table I, where the rated power values of the DGs are specified [6].

The same rated power has been supposed for the WDGs, while two different configurations have been used for the PVs due to the modular characteristic of PV plants.

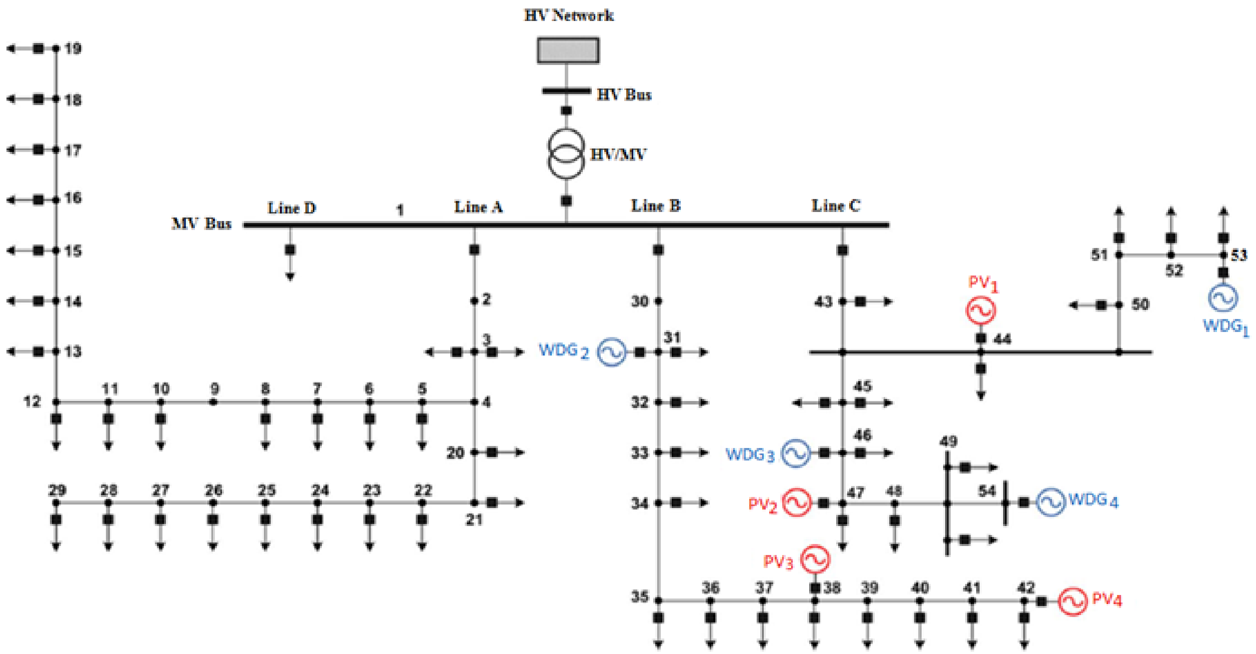

Figure 4: radial DN under test

Table 1: DGS Rated Power and PCC

Parameters		
DG	Rated Power(MW)	Connection Bus
WDG_1+WDG_2	2.5	53,46,54,31
PV_1+PV_2	2.2	44,47
PV_3+PV_4	1.4	38,42

Two different DGs penetration scenarios applied to the DN under test have been supposed in order to obtain a general validation of the proposed strategy. In Scenario A, four WDGs have been connected to the DN. In Scenario B, four PVs have been added to the previously defined scenario. The connection buses are highlighted in Fig. 5 and Table I, where the rated power values of the DGs are specified.

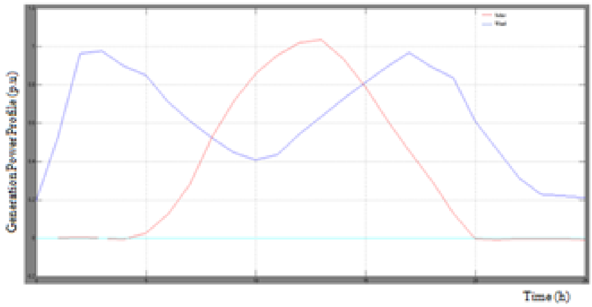

Figure 5: Generation Wind Profiles For Solar and Wind

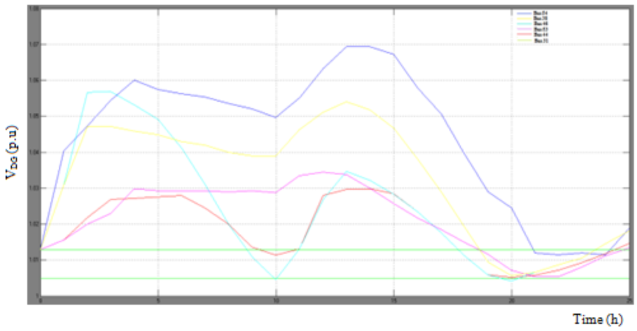

Figure 6: DGs bus voltages without control action

Without loss of generality and due to the upper OR infringement shown in Fig.7 the optimization strategy has been run to calculate only the upper thresholds. Thus, several simulations of the optimization strategy have been computed varying the multi objective genetic algorithm parameters, in order to investigate the assessment of the optimal solution.

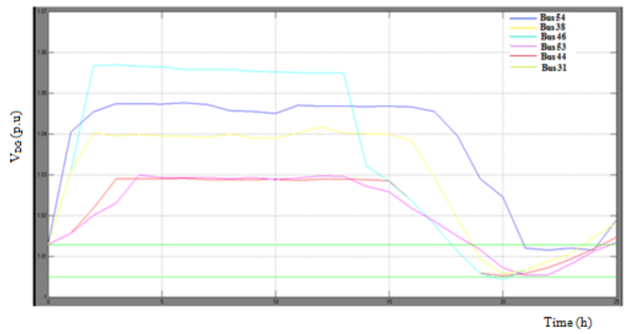

Figure 7: DGs bus voltages with control action

The controlled voltage values obtained using the solution that minimizes the reactive power objective function is shown in Fig 7.The voltage values are contained within regulatory limits.

5. Conclusion

This paper has presented the interac with inverter based DGs to achieve a coordination scheme for optimizing the reactive power and voltage control problem.This paper has demonstrated the validity of the proposed sensitivity based decentralized control approach applied to the DN. Simulations carried out on a radial distribution system, have highlighted the good performances of the proposed local voltage control strategy. Infact, it is clear that the voltage profiles at buses are maintained within regulatory limits.

Results obtained by the optimized sensitivity analysis based decentralized control application to different DGs scenarios have been shown. Its robustness with respect to unpredicted changes in generation power profiles has been proved through the simulations as well. This property allows reducing the communication channel reliability requirements that mainly concern only the optimized thresholds sharing and out ages communications. No continuously detailed information is required to implement the correct control action.

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