Electrical Power and Energy Systems 57 (2014) 64–72

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Active management of renewable energy sources for maximizing power production

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ARTICLE INFO

Article history:
Received 8 January 2013
Received in revised form 29 August 2013
Accepted 19 November 2013

Keywords:
Distributed generation
Distribution networks
Neural Network
Reactive power support
Renewable energy sources
Voltage control

ABSTRACT

The continuous increasing penetration of Distributed Generation systems (DGs) into Distribution Networks (DNs) puts in evidence the necessity to develop innovative control strategies capable to maximize DGs active power production. This paper focuses the attention upon this problem, developing an innovative decentralized voltage control approach aimed to allow DGs active power production maximization and to avoid DGs disconnection due to voltage limit infringements as much as possible. In particular, the work presents a local reactive/active power management control strategy based on Neural Networks (NNs), able to regulate voltage profiles at buses where DGs are connected, taking into account their capability curve constraints. The Neural Network controller is based on the Levenberg–Marquardt algorithm incorporated in the back-propagation learning algorithm used to train the NN. Simulations run on a real Medium Voltage (MV) Italian radial DN have been carried out to validate the proposed approach. The results prove the advantages that the flexibility of the proposed control strategy can have on voltage control performances, generation hosting capacity of the network and energy losses reduction.

1. Introduction

The future development of the energy sector must face twin challenges: the first is to make more energy available at affordable prices to meet the growing power demand; the second is to improve energy efficiency and to use more environmentally sustainable energy sources [1]. In order to face these issues, Renewable Energy Sources (RESs) are gaining relevance in recent years, mainly because RESs represent a good compromise between costs and emissions. Within the European Union (EU), electrical power production from wind and solar sources is expected to represent almost 50% of the RES installed capacity (42% and 4%, respectively) in 2020. Compared with flexible and relatively controllable hydro and biomass power generation, estimated at around 31% and 22% of total RES installed capacity in 2020, wind and Photovoltaic (PV) power sources will be more difficult to be integrated into the power system [2]. However, despite the global financial crisis period, wind and PV markets have shown quite successful results in recent years, increasing their relevance in the energy mix of many countries. In 2012, Denmark remained the country with the highest penetration of wind power electricity consumption (27.1% of the annual electrical energy consumption), followed by Portugal (16.8%). 16.3% of Spain's load was served by wind, and Texas, the center of the US oil industry, produced about 7.4% of its electricity from the same source. Furthermore, today, Ireland receives about 12.7% of its annual electrical energy from wind, which many times supplies more than 50% of the national total load [3–5]. Concerning solar sources, annual PV installed generating capacity grew at an average rate of about 50% over the last ten years. In particular, the German (7.6 GW), Chinese (5 GW), Italian (3.4 GW), USA (3.3 GW) and Japan (2 GW) markets drove almost 60% of 2012 demand for PV [6].

Typically, these RESs are installed as Distributed Generation power plants (DGs) in Distribution Networks (DNs). At low penetration levels they simply reduce the equivalent load at the substation Point of Common Coupling (PCC), while at high penetration levels their generated power can even exceed the load at the substation PCC, causing unusual power flow patterns, voltage rise, energy losses increase, maintenance issues and system restoration problems in case of faults [7–10]. If RES development represents one of the top priorities for the future sustainable economic growth, the consequences of their integration within power systems must be adequately evaluated in order to plan a reliable and flexible electricity supply system. Thus, the rising questions become: what changes in technical design or operating practices could increase RES penetration within the grids? How to get maximum production from RES sources to meet the growing load demand?

In recent years, the answer to the second question has been given producing interesting and sophisticated Maximum Power Point Tracking (MPPT) techniques, while the first one still

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0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.11.040

represents an open challenge. A large number of peak-power tracking methods have been designed and implemented for PV systems, [11–15]. MPPT algorithms for wind power systems have been adequately covered, too [16–20]. In order to increase RES penetration levels within electrical grids, it is fundamental to design DG systems in such a way that allows their participation to the ancillary services necessary to allow better grid working conditions, (e.g. voltage regulation, reactive power support services, etc.). The implementation of ancillary services at the DG level, aimed at maintaining both acceptable voltage profiles and high power factor values, is quite new through the actors involved in control strategies implementation at a local level for DG issues. Electronics converters, usually used to adapt RES output levels to the power grid, have a key role for this purpose. In particular, their capability to manage reactive/active power in order to implement voltage profiles control actions is becoming a very interesting issue.

Reactive power support has been adequately proposed in several research activities by considering two different approaches: centralized and decentralized control strategies. Centralized control approaches, used in many works [21–24], have two major drawbacks consisting in the requirement of: (i) substantial investments in sensors, communications and control systems, that make their application to massive DG penetration cases difficult to implement; (ii) a greater amount of information to be telemetered to a control center, processed and sent to local control devices. Depending on the network complexity, the large number of electrical variables to monitor in real time can give rise to unpractical control schemes [25]. On the other hand, decentralized control strategies act locally and can be implemented reducing the information burden compared to centralized ones. For example, an adaptive decentralized voltage control for PV systems, designed, modeled and tested on different Low Voltage (LV) grids prone to voltage problems has been considered in [26]. Voltage control of decentralized PV in LV network has been also presented in [27]. A decentralized reactive power management technique addressing the problem of sensitivity analysis based voltage regulation in microgrids with a single doubly fed wind energy induction generator is presented in [28].

The work presented here proposes a decentralized reactive/active power management control strategy based on a Neural Networks (NNs) approach, aimed to produce the maximum available active power from RES. It is a substantial extension of the decentralized approaches outlined in [29,30], and while the previous works provide a basic framework to face the issue, the proposed technique reach the goal to implement a completely decentralized and autonomous control approach. It answers to the previous two questions because it allows to obtain the maximum power production and to increase the grids ability to accommodate more RES being able to ensure compliance with technical and operative constraints. The control is performed by the RES unit itself and does not require remote telemetry or communication between the RES units and any central controller, reducing the economic and/or technical overhead.

In the past, learning techniques have been already applied to reactive power support and voltage regulation [31–35]. In [31–33], the proposed methods do not include DGs, taken into account in [34,35]. In particular, Madureira et al. propose a methodology for coordinated voltage support in LV distribution networks based on a meta-heuristic approach, where NNs are used only to decrease computational time, enabling the use of the tool for online operation. In [35] a Radial Basis Function Network is used to identify the multidimensional nonlinear mapping between a vector of observable variables describing the network operating point and the optimal set points of the voltage regulating devices.

The NN presented here is based on the Levenberg–Marquardt algorithm that has been adopted and incorporated into the back-propagation learning algorithm used to train the feed-forward NN. The NN input neurons are coupled to the RES PCC voltage measurement and to its time variation. If the RES bus voltage level causes an infringement of the regulatory limits, the amount of reactive power to compensate voltage variation is determined in order to keep the voltage within the allowed range. If the reactive control action is not enough, active power is reduced according to the same NN architecture. The RES unit is disconnected only if the required amount of reactive and/or active power necessary to maintain voltage levels within regulatory limits is outside the capability coverage of the RES system.

2. Maximum power production and voltage control in distribution systems with DG

The power produced by DG units connected to Distribution Networks (DNs) modifies voltage levels at customer's end. Considering the DG unit connected to the network section outlined in Fig. 1, the voltage drop across the line depends on the active and reactive power flows approximately as following [36]:

$$\begin{aligned}\Delta V &= |V_1| - |V_2| = \sqrt{(V_2 + RI\cos\varphi + XI\sin\varphi)^2 + (XI\cos\varphi - RI\sin\varphi)^2} - |V_2| \\ &\cong \frac{RP + XQ}{V_2} = \frac{R(P_L - P_{DG}) + X(Q_L \pm Q_{DG})}{V_2}\end{aligned} \tag{1}$$

where R and X are the line resistance and reactance, respectively, P_{DG} and Q_{DG} the active and reactive power exported from the DG bus toward the Bulk Supply Point (BSP), P_L and Q_L the active and reactive power of the load.

Any fluctuation in real power brings about a proportional fluctuation of voltage at the DG connection bus.

As typical, Distribution Network Operators (DNOs) require DG owners to operate in Power Factor Control (PFC) mode, thus P/Q ratio is kept almost constant so that the reactive power follows the variation of the active power. This requirement, with regard to the grid characteristics and the DGs penetration level, generally allows to keep voltage profiles within statutory limits, minimizing the interference with the voltage regulation actions provided by other devices. Nevertheless, in case of high DG penetration, this operation mode tends to increase the voltage variation, especially in rural areas, and voltage rise becomes a significant constraint for both the DNOs and the DG owners in terms of power output maximization, security and reliability. Thus, new voltage control strategies are expected in order to meet reactive compensation standards that are becoming a reality for DG systems in Europe, Asia, and USA. Specifically, RES DG plants should meet power factor requirements by using smart inverter technologies, providing ancillary services like voltage control, too. Additionally, they should stay connected to the grid in presence of power system disturbances supporting it during the recovery phase.

2.1. Control method

On the basis of these new standards, the implementation of a new decentralized control strategy is proposed within the paper.

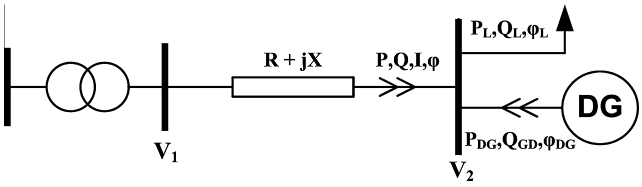

Fig. 1. Network with DG unit.