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Voltage Adjustment on a Distribution Network with Distributed Producers

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***Abstract*— The liberalization of the electricity market has brought about a complete restructuring of the electricity sector. This opening of markets as well as the technological developments of the means of production of small and medium power strongly encourages this evolution.In this paper, we discuss the influence of decentralized producers on the voltage of distribution networks, and we discuss voltage regulation devices, such as the OLTC, as a technical solution that could accommodate more producers on the networks. in good conditions of voltage level.**

Keywords—OLTC; Distributed Generation; Power factor; voltage regulator;

I. INTRODUCTION

Originally, the electricity grid was built and sized to transport the electrical energy produced by the production centers to the most distant consumption centers. Thus, the power transits flow from the upstream since the production of electric power type large thermal or hydraulic power plants, downstream represented by consumers (Figure 1. left).

The current context of the liberalization of the electricity market has caused a disruption in the way of managing and operating the electricity grid. In fact, the decentralized productions (DG) connected in the distribution network have increased rapidly in recent years. The reception of these productions posed new problems to the manager since the current distribution network was not designed for this change. On the other hand, power consumption is increasing in the current network. These two factors mean that distribution networks may be more and more constrained. One of the problems is that the voltage stress is more complicated, and it cannot be managed by conventional voltage control alone in some cases. A more appropriate method must be put in place to control the voltage plan in this new configuration of the distribution network.

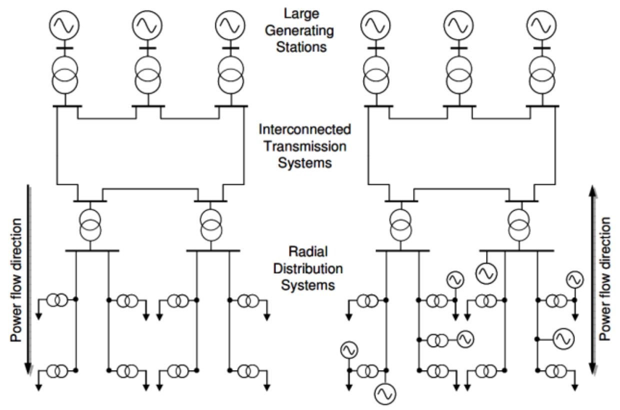

Fig. 1. Electric power System: Traditional (left) and with distributed générations (right).

II. VOLTAGE REGULATION IN DISTRIBUTION NETWORK

A. On load tap changer transformer HV/MV

The regulator within the transformer is an electromechanical system that adjusts the transformation ratio by adding or removing a few sets of turns in series with the turns of the high voltage winding. This adjustment can be performed under load. The On-Load Tap Changer (OLTC) installed on the HV/MV transformer is the most commonly used voltage setting device in the MV distribution network. A typical load adjuster has 17 outlets (8 up and 8 down) with the 0.625% pitch, that is, it allows to change the voltage ratio in the range ± 5%.

In general, the setpoint of the on load regulator is related to the voltage at the MV busbar. But it can also be related to the voltage at the end of the departure, using a compounding of the drop of tension (Line Drop Compensation or LDC). The compounding electrical circuit is shown in Figure 2. The compounding technique increases the voltage level at the busbar taking into account the voltage drop along the start. This keeps the voltage at a point in the network away from the source station in a critical situation.

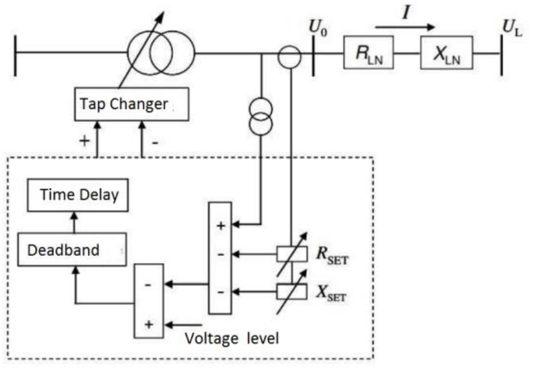

Fig. 2. On load Tap changer

The U_L voltage at the point of regulation and the voltage deviation U_{dev} are given by the following equations.

$$U_L=U_0-I.(R_{LN}\cos\phi+X_{LN}\sin\phi) \quad (1)$$

$$U_{dev}=U_C-U_L \quad (2)$$

$$\alpha+\beta=\chi. \quad (1)$$

(1)

where U_0 and I are respectively the voltage and current measurement at the busbar, $R_{LN} + j \bullet X_{LN}$ is the model for the impedance of the line, cos ϕ is the load power factor, U_c is the voltage setpoint. By setting the R_{SET} and X_{SET} rheostat value correctly, the load adjuster can work well with compounding.

B. Capacitor banks

The capacitor banks installed at the source station allow the reactive power to be injected into the busbar. The reactive power injected is expressed by the equation below.

$$Q_C = Q_N \,.\, U_C^2 \quad (3)$$

Where Qc is the reactive power injected by the capacitor in MVAr, QN is the nominal value of the capacitor in MVAr, Uc is the voltage of the capacitor in pu.

The reactive power injected by the capacitor is capable of compensating the reactive power transferred via the transformer and thus reducing the reactive power transfer from the upstream network. The capacitor bank compensation improves the power factor with respect to the transport network and thus reduces voltage drops. It also reduces active losses in the transmission system as there are fewer current transits.

The operation of the capacitors is done when the consumption of charges is at its maximum (in ON state) and at its minimum (in OFF state). Generally the network manager can switch 1 to 3 banks per busbars. Capacitor bank control is managed by the manager's daily schedule and the frequency of its change is very limited (once a day or much less) to reduce device wear. Capacitors are means of compensation and not of control of the voltage. As a result, the capacitor is not a reliable means of responding to a rapid change in the voltage profile due to the intermittent nature of the distributed generation. It is also not done for this because the engagement of a capacitor bank degrades the quality of the energy because of transient overvoltages.

C. Connection of productions on the decentralized grid and their impacts

The distribution networks have been designed and operated for a flow of energy passing from the substation to the users. This choice has consequences for the management of the voltage and the protection plan. The connection of decentralized productions (Distributed Generations or DG) modifies this fundamental characteristic. The term "decentralized generation" qualifies any low-power generation connected to the public transmission grid in MV or distribution (in HV or LV). Here we limit ourselves to decentralized generation connected to the public medium voltage distribution network (MV). DG's connection has grown very rapidly in recent years and they represent a sizeable part of production. They play an increasingly important role for sustainable development. However, the connection constraints in the power grid will limit their penetration rate [1].

D. Local DG control at the connection in the HV network.

For converter-based wind turbine technologies, it is possible to regulate the reactive power by changing the setpoint of the converter. Some ways of the reactive power adjustment are presented below.

1) Fixed power factor operation

Fixed power factor (PF) operation is to control the power factor of the DG at a constant value. It can be unitary if the DG does not exchange any reactive power. In general the DG works with an inductive PF to avoid the problem of voltage rise due to the active power injected by DG. A disadvantage of this control is the increase in Joules losses compared to Q = 0. If the voltage at the terminals of DG is far from the regulatory limit, it is not necessary to exchange the reactive power.

2) Control with a local voltage regulator

Sometimes the DG is equipped with a local voltage regulator that keeps the voltage at its terminals around a set point set by its local manager. It should be noted that the local trimmer can not maintain the voltage at a fixed value if the reactive power of DG reaches its limits imposed by its dimensioning PQ diagram. The illustration of this voltage check is given in Figure 2.

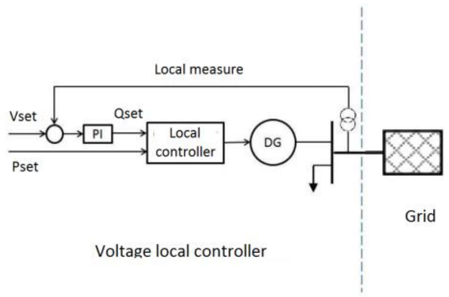

Fig. 3. Local Voltage Adjustment.

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III. VOLTAGE OPTIMUM REGULATION IN PRESENCE OF DECENTRALIZED PRODUCTION (DG).

The management of decentralized productions is an essential element to meet the needs of the good functioning of an active distribution network. The objective is to approach an approach to optimal voltage regulation in the presence of DGs in the context of the active distribution network. This approach consists in coordinating DG active and reactive power setpoints as well as setting the controller in load in a centralized manner. The sensitivity matrix is calculated in order to relate the voltage variation and the control variables. The voltage profile of the proposed approach is analyzed in steady state with the scenarios studied.

A. *Approximation with the sensitivity coefficient*

In this study we will use a method that consists in linearizing the coupling between the control variables and the quantities to be controlled. Sensitivity coefficients are derived from the Jacobian matrix of the network or analytic analysis

In this study, the Jacobian matrix is used to calculate the coefficient of sensitivity. We start with the following load-flow equations [2] :

$$\begin{aligned} P_i &= \sum_{j=1}^{N} V_i . V_j . Y_{ij} . \cos(\delta_i - \delta_j - \theta_{ij}) \\ Q_i &= \sum_{j=1}^{N} V_i . V_j . Y_{ij} . \sin(\delta_i - \delta_j - \theta_{ij}) \end{aligned} \quad (4)$$

α + β = χ.
(1) (1)

where Y_{ij} and θ_{ij} are the elements (module and phase) of the admittance matrix of the network. By calculating the differential of (4), we obtain the Jacobian matrix:

$$\begin{bmatrix} dP \\ dQ \end{bmatrix} = \begin{bmatrix} \partial P/\partial\delta & \partial P/\partial V \\ \partial Q/\partial\delta & \partial Q/\partial V \end{bmatrix} . \begin{bmatrix} d\delta \\ dV \end{bmatrix} \quad (5)$$

α + β = χ.
(1) (1)

In the case of transport network, the R/X ratio of the lines or cables in the network is very low (less than 1/10 in general), the Jacobian matrix can be simplified as (6) [3][4].

$$\begin{bmatrix} dP \\ dQ \end{bmatrix} = \begin{bmatrix} \partial P/\partial\delta & 0 \\ 0 & \partial Q/\partial V \end{bmatrix} . \begin{bmatrix} d\delta \\ dV \end{bmatrix} \quad (6)$$

α + β = χ.
(1) (1)

From Equation (5), we can calculate the sensitivity coefficients for the coupling between the voltage and the power flow in the next part. The coupling between the voltage and the loader tap is also presented.

1) *Sensitivity coefficient of the V-Q coupling*

It is assumed that $\Delta P = 0$ in equation (5). So we have

$$\begin{bmatrix} 0 \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \partial P/\partial\delta & \partial P/\partial V \\ \partial Q/\partial\delta & \partial Q/\partial V \end{bmatrix} . \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \quad (7)$$

α + β = χ.
(1) (1)

Hence

$$\Delta Q = \partial Q/\partial\delta . \Delta\delta + \partial Q/\partial V . \Delta V \quad (8)$$

α + β = χ.
(1) (1)

and

$$\Delta\delta = -\left(\partial P/\partial\delta\right)^{-1} . \left(\partial P/\partial V\right) . \Delta V \quad (9)$$

α + β = χ.
(1) (1)

Equation (9) is injected into equation (8)

$$\Delta Q = \left(-\partial Q/\partial\delta . \left(\partial P/\partial\delta\right)^{-1} . \partial P/\partial V + \partial Q/\partial V\right) . \Delta V \quad (10)$$

Finally, the sensitivity coefficient of the V-Q coupling is obtained by inverting the matrix of equation (10)

$$\Delta V = \left(-\partial Q/\partial\delta . \left(\partial P/\partial\delta\right)^{-1} . \partial P/\partial V + \partial Q/\partial V\right)^{-1} . \Delta Q \quad (11)$$

(1)

$$\Delta V = S_Q . \Delta Q \quad (12)$$

The nodes of the system are classified in two categories: g for the generators and l for the loads.

$$\begin{bmatrix} \Delta V_g \\ \Delta V_l \end{bmatrix} = \begin{bmatrix} S_{Qgg} & S_{Qgl} \\ S_{Qlg} & S_{Qll} \end{bmatrix} . \begin{bmatrix} \Delta Q_g \\ \Delta Q_l \end{bmatrix} \quad (13)$$

So we got the coupling between the voltage and the reactive power of DG

$$\Delta V_l = S_{Qlg} . \Delta Q_g \quad (14)$$

2) *Sensitivity coefficient of the V-P coupling*

The sensitivity coefficient of the P-V coupling can be obtained in a similar way assuming that $\Delta Q = 0$.

$$\Delta V = \left(-\partial P/\partial\delta . \left(\partial Q/\partial\delta\right)^{-1} . \partial Q/\partial V + \partial P/\partial V\right)^{-1} . \Delta P$$

(15)
α + β = χ. (1)
(1)

It is also written simply:

$$\Delta V_l = S_{Plg}.\Delta P_g \quad (16)$$

α + β = χ. (1)

(1)

3) Sensitivity coefficient of the V-T coupling

Note that the sensitivity coefficient for the coupling between the voltage and the tap of the regulator in charge can not be derived from the Jacobian matrix. So, we use an approximation approach that consists of calculating the load-flow several times with a small variation of a variable to estimate its sensitivity coefficient. The coefficient of sensitivity of coupling between the voltage and the transformer can be expressed in equation (17):

$$\frac{\partial V}{\partial n} = \frac{\Delta V}{\Delta n}\bigg|_{\substack{\Delta P=0 \\ \Delta Q=0}} \quad (17)$$

α + β = χ. (1)

(1)

where n represents the primary/secondary ratio of transformer equipped with the tap changer. The ratio n is linearly connected to the tap-changer socket T:

$$\Delta n = \frac{dn}{dT}.\Delta T \quad (18)$$

α + β = χ. (1)

(1)

From wich

$$\Delta V = \frac{\partial V}{\partial n}.\frac{dn}{dT}.\Delta T = S_T.\Delta T \quad (19)$$

α + β = χ. (1)

(1)

Then we obtained the coefficient of the coupling of the voltage with the catch of the regulator in charge. Since the variable ΔT is integer, the formulation of the optimization with this variable concerns rather an entire programming or mixed programming with the continuous variables.

B. Control Variables and their priority to the participation of the voltage adjustment

A standard voltage control approach called "Volt Var Control" consists of optimizing both types of variables: the tap changer (OLTC) and the reactive power compensation typically provided by the capacitor banks. Since these two variables are all discrete, solving this optimization is a combinatorial problem [5].

Derived from the calculation of the sensitivity coefficients in the previous section, the voltage variation as a function of the different control variables is presented in equation (20).

$$\Delta V = S_P.\Delta P + S_Q.\Delta Q + S_T.\Delta T \quad (1)$$

α + β = χ. (1)

(1)

That is, the voltage module in the network can be impacted by the three variables: P, Q and T in a linear fashion and their slope depends on the characteristics of the grid.

IV. CASE STUDIES.

The distribution network used in our study comes from a standard IEEE 34 node start. The characteristics of this departure have been modified so that it is more representative of the situation in Madagascar. Two voltage regulators are removed since these devices do not exist in the MV networks of Madagascar. To create a case of multiple departures, we made a duplicate of this departure and the two departures are connected to the same set of bar of the source post. The topology of the network is presented in Figure 4, where the nodes of the second departure are renumbered. The peak load power provided by each feeder is 9.52MW. The rated voltage of this network is 20 kV. The permissible variation of the voltage in this network is ± 0.05p.u. around the nominal voltage. The source substation is connected to the distribution network via a 63/20 kV transformer with an apparent power of 36 MVA and a load adjuster.

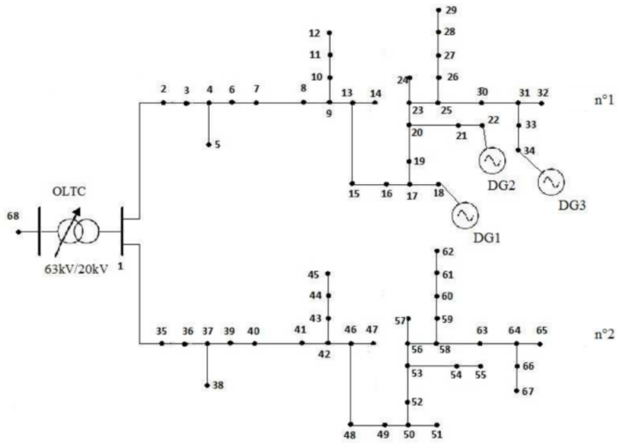

Fig. 4. Test Network

We simulate a case where the distribution of DG is not homogeneous on all departures. So a number of DGs were added at start # 1 and no production was added at start # 2. These productions are of several types and their location and size are detailed in Table 1. The reactive power range produced by these productions is imposed between -0.3 and +0.3 times of its maximum active power.

TABLE I. DIMENSIONING OF DGS

	DG1	DG2	DG3
Type	Wind Farm	Centrale CHP	Wind farm
Locationt	Node 18	Node 22	Node 34
Pmax	3.1MW	2MW	4.5MW

To check the performance of the proposed approach in the worst case, we chose "snapshot" scenarios that consist of configuring the consumption / production of the network at an instantaneous value, and not sequentially. Load consumption along departures can be either significant or low. It is assumed that the starting load power is respectively equal to 0.6 Pmax and 0.9 Pmax for low and high consumption. The power of production at the beginning n ° 1 is always at the maximum so that the situation of the network is more constraining.

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We study the case where the charge at departure No. 1 is low, the charge at departure No. 2 important and the production of DG maximum. The following figures show the results of the voltage plane, which are respectively without voltage regulation (FIG. 5), after a setting of the OLTC (FIG. 6), after an adjustment of the OLTC and Q (FIG. 7) and after a setting of the OLTC and P (Figure 8). The profiles come from the load-flow calculation performed with Matpower 4.0v under Matlab.

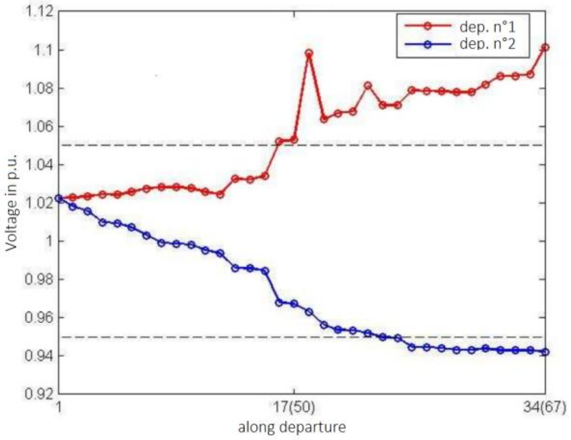

Fig. 5. Voltage profile without voltage adjustment

This figure 5 reveals a severe voltage violation on all departures without any adjustment. It can be seen that the nodes at the end of departure No. 1 undergo an overvoltage because all the productions are in full power and increase the plane of tension of the nodes in their proximity. Some nodes at the end of the departure No. 2 have a problem of undervoltage due to the high consumption of the distributed load on this departure.

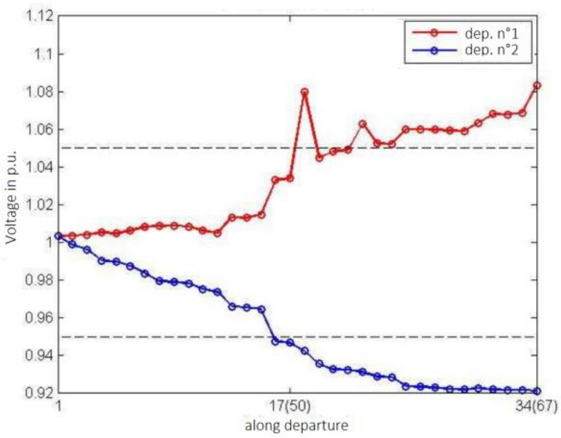

Fig. 6. Voltage profile with adjustment by OLTC

Following an optimization, the change of the tap in the loader tried to lower the tension at the start # 1 while the problem of undervoltage at the start # 2 becomes more severe. This is because optimization attempts to minimize the voltage violation at nodes whose weighting factor ωi is larger, ie nodes with DGs. He showed that the regulator in charge is not enough to solve the voltage violation.

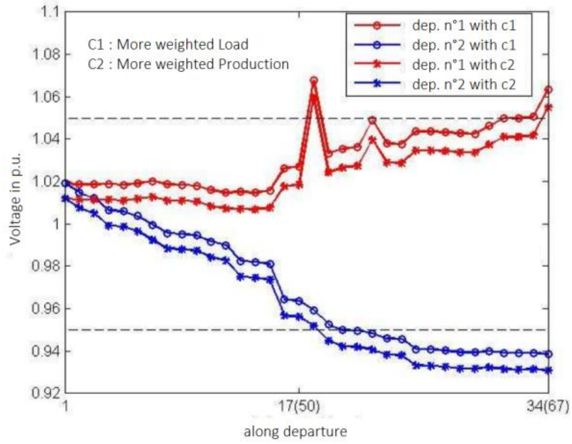

Fig. 7. Voltage profile with adjustment by OLTC and Q

In figure 7, the control of the reactive power of DG has been added. The stress of the initial voltage No. 1 is removed except that the nodes in which the DG1 and DG3 are connected still exceed the maximum limit. eligible. The undervoltage problem at the start # 2 remains unchanged. If we choose different weighting coefficients for departures # 1 and # 2, we can see that the profiles are different as shown in Figure 7.

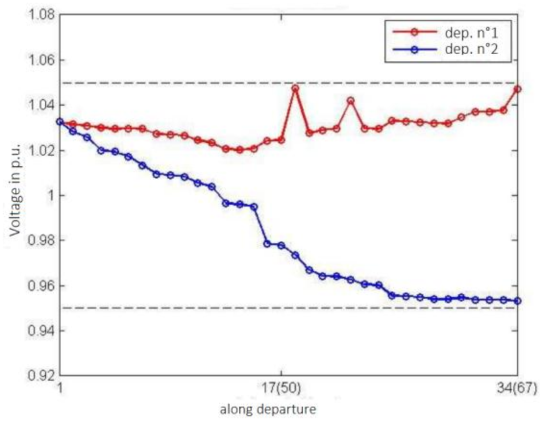

Fig. 8. Voltage profile with adjustment by OLTC, Q and P

The voltage profile in this figure 8 means that the problem of the voltage violation is solved with the aid of the erasure of the production and the coordinated optimization with the regulator in charge. This result showed that the problem of voltage violation can be managed as control variables are added to the optimization of the voltage plan. In addition, the erasure of the active power of DG is inevitable in this case although it is disadvantageous for its owner and from an environmental point of view.

V. COLCLUSION

It can be concluded that the DG regulation attempts to absorb the reactive power to reduce the voltage rise around DG. As soon as the reactive power reserve is exhausted (that is to say, it reaches the limit of its range) and if the voltage violation is not yet raised, then it needs to reduce a part of the production so that the tension on all the nodes is within the admissible limit.

The results showed that the proposed approach allows to remove the voltage violation due to the connected DG in the existing distribution network. By applying such a regulation, it is possible to facilitate the aggregation of DG and finally increase the rate of connection of the DG in the networks without voltage violation.

The coordination between the action of the adjuster in charge and the control of DG is essentially important in the adjustment of tension. This coordination will significantly increase the operation of the adjuster in charge and thus reduce the life cycle of the device.

REFERENCES

[1] B. Robyns, A. Davigny, B. François , A. Henneton, J. Sprooten (2012), “Power generation from renewable sources ” , Lavoisier, 2012.

[2] Christakou, K.; Le Boudée, J.-Y.; Paolone, M.; Tomozei, D.-C. (2013), "Efficient Computation of Sensitivity Coefficients of Node Voltages and Line Currents in Unbalanced Radial Electrical Distribution Networks/' IEEE Trans. Smart Grid 4(2): 741-750 (2013).

[3] H. E. Z. Farag (2013), "Assessment, Planning and Control of Voltage and Reactive Power in Active Distribution Networks", report of PhD thesis, in University of Waterloo, Waterloo, Canada, 2013.

[4] Kulmala, A.; Maki, Kari; Repo, S.; Jarventausta, P.(2007), "Active Voltage Level Management of Distribution Networks with Distributed Génération using On Load Tap Changing Transformers," *Power Tech, 2007 IEEE Lausanne*, vol., no., pp.455,460,1-5 July 2007.

[5] Caldon, R.; Coppo, M.; Turri, R. (2013), "Coordinated voltage control in MV and LV distribution networks with inverter-interfaced users," *PowerTech (POWERTECH),* 2013 IEEE Grenoble , vol., no., pp.1,5, 16-20 June 2013.