Realising full-selective sources contribution in AC nano-grids

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Abstract: In addition to conventional load side and source side management techniques, some approaches for management of local resources have been proposed for networks in recent years. For a load section including several loads and local sources, there is no approach in which full-selective contribution of the sources has taken into account. This study deals with a full-selective method for realising different desirable contributions of the local sources in a AC nano-grid. The full-selective contribution for active and reactive powers delivery is achieved using an electric power hub (EPH) and an efficient algorithm, both suggested in this work. The EPH composed of some power control units, by which one can share each load between the sources, desirably. The performance of the approach is evaluated in different conditions using some simulations in Matlab/Simulink.

1 Introduction

Among supply side and load side managements which have been followed in conventional power systems, demand side management is a highly promising candidate in deregulated power systems [1–3]. Distributed resources in demand side and emerging structures of power system like micro-grid (MG), nano-grid (NG), and smart grid provide suitable opportunity for this purpose [4, 5]. In recent years, some new trends such as multi-agent based techniques for power management of these grids have been proposed [6, 7]. In fact, the available infrastructures of MGs and NGs such as communication links, different local sources, and controllable loads are the main motivation for such power management [8]. In this work, in particular, power flow management of NGs is investigated. NG is somehow a scaled down version of MGs. MGs and NGs from some aspects are similar. They are power distribution systems, which have capability of operating in standalone or grid connected mode. They can operate as DC, AC or hybrid power system structures, in which many renewable and non-renewable sources and some sorts of loads can be found [9–12]. However, NGs have lower power and simpler control. A NG is a power distribution system for a single house/small building with capability of connecting or disconnected from other power units via a gateway [13]. On the other hand, a NG is a compact small-scale grid including several sources, loads, and energy storages, which can work in grid connected or standalone modes. From grid scale aspect, a NG can be implemented in residential and commercial buildings with capacity about 2–20 kW [13–16]. Different studies regarding NGs can be broadly categorised into NG concept and its future developments [17–21]. NG control [15, 22–25], NG hardware [26–31], interaction of NG with other networks [32–36], and actual implementation of NG [37–40].

However, energy management of NGs is an important issue, which needs more investigation to promote the NGs capabilities. The load side management of NGs is aimed to realise different desirable contributions of the local sources for supplying the NG's loads. Droop control method is one of the well-known techniques in this regard [41–43]. This method has been utilised in conventional power systems and emerging power system structures such as MGs and NGs. In this approach, all of the system loads are considered as integrated consumers and using voltage control of point of common coupling (PCC), power delivery is controlled. However, PCC voltage may experience considerable variation in this method [44]. Moreover, this approach is not able to control contribution of the sources for supplying the loads, selectively. However, there are several approaches to modify the performance of droop control method [45–47].

In addition to the conventional methods for load side management of traditional power systems, few approaches have also been suggested for load side management of MGs and NGs. Power line switching is an interesting technique in this regard. In [40], using power line switching, connection between some power sources and loads has realised by employing a matrix power line switches. By setting the switches, a physical stream was provided from any source to any load. But this method can implement selective contribution of sources just for one load and development of the method for several loads has not been addressed. Another approach in this regard is multiplexing method. In [48, 49], energy packets were transmitted, stored, and received using multiplexing method through a common line as message packet routers. In this method, employing many storage batteries increases the system cost, comparatively. As another approach, a synchronised source-load approach has been introduced in [50], in which all power sources and loads were connected together by a common electric power line. Here, using synchronised source-load approach, contributions of the sources have been controlled by a technique, called power flow colouring. Power flows are coloured based on the corresponding sources and loads as well as contribution of the sources for supplying each load. This concept has been proposed in [51, 52], in details. However, in this method, just one load was considered for power flow colouring at any moment and it has some essential restrictions in case of having several different loads at any moment. Furthermore, it needs several controlling systems.

In Table 1, the mentioned methods are compared from different aspects. As seen in the comparison, the already proposed methods could not handle a full-selective contribution of the sources. In fact, fully selection of the sources’ contributions for supplying several loads separately has not realised in these methods. Having full-selective contribution of the sources for supplying different loads in an AC NG is an essential topic, which has not addressed by the mentioned techniques.

In this paper, a new approach for realising fully selective contribution of the sources of an AC-NG is proposed. To do so, a new concept called electric power hub (EPH) and an algorithm are suggested to attain desirable contribution of the sources for active and reactive powers delivery. The EPH as a stream composed of
some power control units (PCUs), by which each load shares between the sources, appropriately. A schematic of full-selective contribution of sources concept is shown in Fig. 1a. Output voltage of the PCUs is regulated to control active and reactive powers of the streams. In spite of the previous methods, the proposed method is capable of realising power sharing among various loads and sources with different characteristics at any moment. Furthermore, no need of any matrix switches or battery storages in the power streams is another merit of the method. A centralised control for power management is considered in the method. Since the required communication infrastructures are available in NGs, it can be implemented in such grid, straightforwardly. Although, recently the idea of full-selective contribution of sources in DC NGs is proposed by Samet et al. [53], the proposed approach and the utilised tools are different here. The difference is due to the inherent difference between AC and DC NGs.

The main novelties and contributions of this work are:

1. A novel approach for realising an AC-NG is proposed. Based on our knowledge after a comprehensive literature survey, realising the full selective contribution of sources has not been reported by now. The proposed approach provides a great degree of freedom for contribution control of multiple sources to multiple loads, which can be employed for various purposes.

2. For realising the proposed fully selective contribution of sources, a new concept called EPH was suggested, which is controlled using an interesting algorithm.

### Table 1 Load side management methods advantages and disadvantages

| Method                  | Advantages                        | Disadvantages          | Full-selective contribution of sources to several loads |
|-------------------------|-----------------------------------|------------------------|--------------------------------------------------------|
| droop control           | simple to implement               | deviations of PCC      | no                                                     |
| power line switching     | high reliability                  | the need of many switches | no                                                     |
| power routing           | using common stream to deliver power | the need of storage batteries | no                                                     |
| synchronised source-load control | using common stream to controlling systems | it needs several | no                                                     |
|                         |                                   |                        |                                                        |

**3 Proposed full selective contribution of sources**

For full-selective contribution of sources in AC-NG, it is necessary to utilise a central manager (CM) to manage power flow between sources and loads and set system parameters. The CM is structured as shown in Fig. 2a. There are some power supplies (PSs) and power loads (PLs) in the system. Source agent and load agent are denoted by SA and LA, respectively, by which the required data are measured and the PCUs and voltage of the sources are controlled. As seen in Fig. 2a, SAs, LAs, and the CM are connected through some communication links.

The CM determines contribution of the sources to provide active and reactive powers for all loads using the following matrices:

\[
PPFS = \begin{bmatrix}
PP_{11} & \cdots & PP_{in} \\
\vdots & \ddots & \vdots \\
PP_{m1} & \cdots & PP_{mn}
\end{bmatrix}
\]

(1)

\[
QQFS = \begin{bmatrix}
QQ_{11} & \cdots & QQ_{in} \\
\vdots & \ddots & \vdots \\
QQ_{m1} & \cdots & QQ_{mn}
\end{bmatrix}
\]

(2)

where \(PP_{mn}\) and \(QQ_{mn}\) are the ratio of active and reactive powers sharing supplied by \(m\)th PS to \(n\)th PL and they are values between 0 and 1. The sum of arrays values existed in the same row or column should be equal to 1. These values are selected based on the strategy of the NG CM which are not in the scope of this paper. Computation of the sharing is an issue which falls outside the scopes of this work. However, it can be performed by different approaches in this regard, reported in literature [54]. Here, considering some typical sharing coefficients, the proposed method is introduced.

Then the active and reactive powers of each load are measured with an appropriate sampling time using the related LAs and sent to NG manager centre. The active and reactive powers in the streams which link the sources to the loads are calculated as follows:

\[
PP = \begin{bmatrix}
PP_{11} & \cdots & PP_{in} \\
\vdots & \ddots & \vdots \\
PP_{m1} & \cdots & PP_{mn}
\end{bmatrix} \times
\begin{bmatrix}
P_{11} & \cdots & P_{in} \\
\vdots & \ddots & \vdots \\
P_{m1} & \cdots & P_{mn}
\end{bmatrix}
\]

(3)

\[
QQ = \begin{bmatrix}
QQ_{11} & \cdots & QQ_{in} \\
\vdots & \ddots & \vdots \\
QQ_{m1} & \cdots & QQ_{mn}
\end{bmatrix} \times
\begin{bmatrix}
Q_{11} & \cdots & Q_{in} \\
\vdots & \ddots & \vdots \\
Q_{m1} & \cdots & Q_{mn}
\end{bmatrix}
\]

(4)

where \(P_{mn}\) and \(Q_{mn}\) are the active and reactive power of the connecting stream of source \(m\) to load \(n\). \(P_{La}\) and \(Q_{La}\) are the active and reactive powers of load \(n\).

In the proposed algorithm, the CM updates the system control parameters to reach the streams power flow pattern according to (1)-(4). System control parameters consist of magnitude and phase of sources voltage except the first source also the magnitude and phase of injected series voltage of the PCUs.

The proposed algorithm contains some steps which all are based on two specific equations. Equations (5) and (6) represent the active and reactive powers of the streams based on the voltage of source and load sides as shown in Fig. 3:

\[
P = \frac{(V_i \times V_L \times \sin(\theta_i - \theta_L) + R \times Q)}{X}
\]

(5)
\[ Q = \frac{(V_s \times V_L \times \cos(\theta_s - \theta_L) - V_L^2 \times R \times X)}{X} \]  

where \( V_L, V_S, \theta_L, \theta_S, R, \) and \( X \) are load voltage magnitude, source voltage magnitude, load voltage angle, source voltage angle, line resistance, and line reactance, respectively.

In this approach, voltage of the first source, \( P_{FS} \) and \( Q_{FS} \) matrices are considered as the known input parameters. Outputs of the system are the reference voltage of the other sources and also the injected voltage of the PCUs. The proposed approach is presented in four steps as follows:

1. **Step 1: Calculation of the required loads voltage magnitude and phase angle**

   The first source is considered as the main source with a fixed known voltage. Using (5) and (6) for streams between the first source and all the loads, voltage magnitudes and phases of the loads are determined. Hence, values of the first row of \( P_{FS} \) and \( Q_{FS} \) matrices (\( P_{11} \) to \( P_{1m} \) and \( Q_{11} \) to \( Q_{1m} \)) as well as voltage magnitude and phase of the first source are utilised for this purpose. As a result, the required load voltages are calculated by solving the following equations for all the loads (\( j = 1, \ldots, n \)):

   \[ P_{ij} = \frac{(V_{si} \times V_{Lj} \times \sin(\theta_{si} - \theta_{Lj}) + R_{ij} \times Q_{ij})}{X_{ij}} \]
\[ Q_{ij} = \frac{V_{n_1} \times V_{L_j} \times \cos(\theta_{n_1} - \theta_{L_j}) - V_{L_j} \times R_{ij} \times P_{ij}}{X_{ij}} \]

where \( P_{ij}, Q_{ij}, R_{ij}, \) and \( X_{ij} \) are the known active power, reactive power, resistance, and reactance between the first source and load \( j \). \( V_{n_1} \) and \( \theta_{n_1} \) are the known voltage magnitude and phase of the first source. The unknown parameters are \( V_{L_j} \) and \( \theta_{L_j} \), which can be derived by (7) and (8) for all the loads.
which was calculated in the first step. The unknown parameters are the PCU connection points in the load sides. In this step, using (5) and (6) for streams between the first load and the first source are calculated by (9) and (10) for \( i = 2, \ldots, m \) and \( j = 2, \ldots, n \):

\[
P_{ij} = \frac{(V_{ai} \times V_{Lj} \times \sin(\theta_{aij} - \theta_{Lj})) + (R_{ij} \times Q_{ij})}{X_{ij}} \quad (9)
\]

\[
Q_{ij} = \frac{(V_{ai} \times V_{Lj} \times \cos(\theta_{aij} - \theta_{Lj})) - (V_{Lj} \times R_{ij} \times P_{ij})}{X_{ij}} \quad (10)
\]

where \( P_{ij}, Q_{ij}, R_{ij}, \) and \( X_{ij} \) are the known active power, reactive power, resistance, and reactance between the source \( i \) and the first load \( j \). The voltage magnitude and phase of the first load which was calculated in previous step. The unknown parameters are \( V_{ai} \) and \( \theta_{aij} \) which can be determined by (9) and (10) for all sources except the first one.

Step 3: Calculation of the required voltage magnitude and phase at the PCU connection points in the load sides

In the third step, the currents between the PCUs and loads are used to calculate voltage magnitude and phase at the PCU connection points in the load sides, denoted by \( V_{aim} \) to \( V_{sim} \) in Fig. 2a. Using PFS and QFS matrices (rows 2 to \( m \) and columns 2 to \( n \)), and the load voltages \( V_{lim} \) are calculated by the following equations:

\[
P_{ij} = \frac{(V_{aij} \times V_{Lij} \times \sin(\theta_{aij} - \theta_{Lij})) + (R_{ij} \times Q_{ij})}{X_{ij}} \quad (11)
\]

\[
Q_{ij} = \frac{(V_{aij} \times V_{Lij} \times \cos(\theta_{aij} - \theta_{Lij})) - (V_{Lij} \times R_{ij} \times P_{ij})}{X_{ij}} \quad (12)
\]

where \( P_{ij}, Q_{ij}, R_{ij}, \) and \( X_{ij} \) are the known active power, reactive power, resistance, and reactance between the source \( i \) and load \( j \). \( V_{aij} \) and \( \theta_{aij} \) are the voltage magnitude and phase of the load \( j \) which was calculated in the first step. The unknown parameters are \( V_{aij} \) and \( \theta_{aij} \) which can be determined by (11) and (12).

Step 4: Calculation of PCUs injected voltages

By subtracting the voltages \( V_{aim} \) to \( V_{sim} \) from the corresponding sources voltages, the required injected voltage (magnitude and phase) of PCUs are attained as follows:

\[
V_{PCUij} = \begin{cases} 
V_{ai} & j = 1, \ldots, m,
V_{ai} - \theta_{aij} & j = 2, \ldots, n
\end{cases}
\]

Table 2 summarises the four mentioned steps of the proposed approach.

After calculating magnitudes and phases of the sources voltages and injected voltages of the PCUs, they are sent to the control system of the sources and PCUs as the set points. Control systems of different sources may be different types. For example, the DC–AC converters, connected to DC sources can realise their output AC voltage as the desired set values using pulse width modulation (PWM) controllers. Also, the proposed PCUs use PWM technique in their control system to achieve the desired injected voltage. However, all these devices need the output voltage of the first source in their control systems to build the desired voltages.

### 4 Simulation results

The simulated system shown in Fig. 4 includes three sources: national grid, photovoltaic (PV), and diesel generator. Furthermore, it consists of two loads and two PCUs. The PV source is connected to NG through a DC/AC converter. \( L_{PCU} \) and \( L_{PCU} \) represent the resistance and inductance of the transformer employed for the proposed PCUs. All converters in the simulations are controlled using real-time PWM strategy with switching frequency equal to 20 kHz. A schematic of the connections of SAs and LAs to the CM is shown in Fig. 5 in details. SA1 and LA1 only measure active and reactive power of the first source and first load then they send the values to the CM. Also, SA2 receives values of the reference voltage magnitude and phase from CM and exports them to the related PWM controller. LA2 receives PCU1 and PCU2 voltages and phase angles from the CM and exports them to the PWM controllers of PCU1 and PCU2. SA3 is the same as SA2, which receives values of the reference voltage, but it exports them to the controller system of the diesel generator. The loads are constant impedance type. More details about the simulated system are presented in Table 3.

In order to evaluate the performance of the proposed method in case of load change and change in the source contribution matrices (PPFS and QQFS), two scenarios are considered. In the first scenario, firstly load #1 is changed and after a specified duration, new contribution values are dictated to the sources to supply the new consumed power. In the second scenario, similar load and source contribution changes are carried out for load #2 after passing the transient of the first scenario.

In Tables 4 and 5, change in loads values and dictated desired sources contributions at different time intervals are presented for the first and second scenarios, respectively. Load #1 is changed at 3.5 s, while change in the sources contributions is dictated at 8 s. In Fig. 6, ratio of the sources contributions for delivering active and reactive powers at 3.5 and 8 s for the first scenario can be observed. From these figures, it can be observed that the employed PCUs can set the desired sources contributions correctly for the different conditions such as the loads change and change in the desired contribution from the CM.

Figs. 3a and b show magnitude and phase of voltages, injected by the PCUs to the system. As shown, although PCUs voltage phases have considerable values, the voltages magnitudes are not significant in comparison with the NG voltage. Hence, PCUs nominal power can be chosen lower than the rated power of the NG, which makes them cost-effective. Fig. 3e shows voltage of the back-to-back converter capacitor, which has a deviation in permissible range.
In this section, the required voltage and current capacities of the PCUs are discussed. Generally, three parameters should be calculated including: parallel and series voltages and current of each PCU. These parameters are calculated based on the mentioned four steps. However, their values are dependent on the active and reactive powers sharing coefficients in (1) and (2) as well as the loads active and reactive powers. The worst scenarios which cause the maximum values of the parameters are considered.

5.1 PCU maximum parallel voltage

Passing current through PCU between source $i$ and load $j$ will be maximum when

$$PP_{ij} = QQ_{ij} = 1$$  

(14)
Visi reaches its maximum value when the following two conditions happen, simultaneously. First, there is no active and reactive powers flow from the first source to the first load \(PP_{11} = 0, QQ_{11} = 0\). In this case, based on the first step, \(VL_{1} = V_{s1}\) will be equal to \(V_{s1}\) and reaches its maximum value. Second, \(PP_{i1} = QQ_{i1} = 1\), in this case based on step 2, the ratio of \(V_{si}\) to \(VL_{1}\) will be maximum. So, as a result, \(V_{si}\) is maximum when the following two conditions happen, simultaneously:

\[
PP_{11} = QQ_{11} = 0 \\
PP_{i1} = QQ_{i1} = 1
\]  

(15)

\(V_{aij}\) is maximum when two conditions happen, simultaneously. First, \(VL_{j}\) reaches its maximum which happens when \(PP_{1j} = QQ_{1j} = 0\). Second, based on step 3 when \(PP_{ij} = QQ_{ij} = 1\). So, as a result, \(V_{aij}\) is maximum when the following two conditions happen, simultaneously:

\[
PP_{1j} = QQ_{1j} = 0 \\
PP_{ij} = QQ_{ij} = 1
\]  

(16)

5.2 PCU maximum series voltage

The voltage across the series transformer of PCU is calculated using (13). It can be seen that it reaches the maximum value in the following cases:

- \(V_{aij}\) is maximum and \(V_{aij}\) is minimum

| Table 3 | System quantities |
|---------|-------------------|
| System quantities | Value | Unit |
| \(V_{\text{National grid (RMS)}}\) | 220 | \(V\) |
| \(V_{\text{National grid}}\) | 0 | \(\text{deg}\) |
| \(R\) | 0.642 | \(\Omega\) |
| \(X\) | 3.14 | \(\Omega\) |
| \(R_{\text{PCU}}\) | 0.02 | \(\Omega\) |
| \(L_{\text{PCU}}\) | 0.05 | \(H\) |
| PWM switching frequency | 20,000 | \(Hz\) |

| Table 4 | AC load sharing for load #1 |
|---------|-----------------------------|
| Time, s | 0–3.5 | 3.5–8 | 8–18 |
| load #1 (Ω) | 10 + j28.27 | 29.68 + j29.61 | 29.68 + j29.61 |
| active power sharing | \(PP_{11} = 0.60\) | \(PP_{11} = 0.60\) | \(PP_{11} = 0.50\) |
| \(PP_{21} = 0.35\) | \(PP_{21} = 0.35\) | \(PP_{21} = 0.40\) |
| \(PP_{31} = 0.05\) | \(PP_{31} = 0.05\) | \(PP_{31} = 0.10\) |
| reactive power sharing | \(QQ_{11} = 0.25\) | \(QQ_{11} = 0.25\) | \(QQ_{11} = 0.20\) |
| \(QQ_{21} = 0.35\) | \(QQ_{21} = 0.35\) | \(QQ_{21} = 0.30\) |
| \(QQ_{31} = 0.40\) | \(QQ_{31} = 0.40\) | \(QQ_{31} = 0.50\) |

| Table 5 | AC load sharing for load #2 |
|---------|-----------------------------|
| Time, s | 0–11 | 11–14 | 14–18 |
| load #2 (Ω) | 20 + j42.95 | 29.68 + j42.18 | 29.68 + j42.18 |
| active power sharing | \(PP_{12} = 0.25\) | \(PP_{12} = 0.25\) | \(PP_{12} = 0.50\) |
| \(PP_{22} = 0.35\) | \(PP_{22} = 0.35\) | \(PP_{22} = 0.05\) |
| \(PP_{32} = 0.40\) | \(PP_{32} = 0.40\) | \(PP_{32} = 0.45\) |
| reactive power sharing | \(QQ_{12} = 0.55\) | \(QQ_{12} = 0.55\) | \(QQ_{12} = 0.45\) |
| \(QQ_{22} = 0.20\) | \(QQ_{22} = 0.20\) | \(QQ_{22} = 0.25\) |
| \(QQ_{32} = 0.25\) | \(QQ_{32} = 0.25\) | \(QQ_{32} = 0.30\) |

\(V_{aij}\) is maximum when the following two conditions happen, simultaneously. First, there is no active and reactive powers flow from the first source to the first load \((PP_{11} = QQ_{11} = 0)\). In this case, based on the first step, \(VL_{1}\) will be equal to \(V_{s1}\) and reaches its maximum value. Second, \(PP_{i1} = QQ_{i1} = 1\). So, as a result \(V_{aij}\) is maximum when the following two conditions happen, simultaneously:

\[
PP_{11} = QQ_{11} = 0 \\
PP_{i1} = QQ_{i1} = 1
\]  

(15)

\(V_{aij}\) is maximum when the following two conditions happen, simultaneously. First, \(VL_{j}\) reaches its maximum which happens when \(PP_{1j} = QQ_{1j} = 0\). Second, based on step 3 when \(PP_{ij} = QQ_{ij} = 1\). So, as a result \(V_{aij}\) is maximum when the following two conditions happen, simultaneously:

\[
PP_{1j} = QQ_{1j} = 0 \\
PP_{ij} = QQ_{ij} = 1
\]  

(16)

5.2 PCU maximum series voltage

The voltage across the series transformer of PCU is calculated using (13). It can be seen that it reaches the maximum value in two following cases:

- \(V_{aij}\) is maximum and \(V_{aij}\) is minimum

Fig. 6 Load sharing for load #1
(a) Ratio of sources active power sharing of load #1, (b) Ratio of sources reactive power sharing of load #1, (c) Active and reactive powers of load #1

\(V_{aij}\) is maximum value when \(15\) is satisfied. \(V_{aij}\) is minimum when two conditions happen, simultaneously. \(VL_{j}\) reaches its minimum, when \(PP_{1j} = QQ_{1j} = 1\) and \(PP_{ij} = QQ_{ij} = 0\). So, as a summary, this situation happens when the following four conditions happen, simultaneously:
$$PP_{11} = QQ_{11} = 0$$
$$PP_{i1} = QQ_{i1} = 1$$
$$PP_{ij} = QQ_{ij} = 1$$
$$PP_{ij} = QQ_{ij} = 0$$

(17)

b. $V_a$ is minimum and $V_{aj}$ is maximum

$V_a$ is minimum when the following two conditions happen, simultaneously. $V_{aj}$ be minimum which happens when

$$PP_{11} = QQ_{11} = 1$$ and $$PP_{i1} = QQ_{i1} = 0$$ in which ratio of $V_a$ to $V_{aj}$ will be minimum. $V_{aj}$ is maximum when (16) is satisfied. So, as a summary this situation happens when the following four conditions happen, simultaneously:

Fig. 7 Load sharing for load #2
(a) Ratio of sources active power sharing of load #2, (b) Ratio of sources reactive power sharing of load #2, (c) Active and reactive powers of load #2

Fig. 8 PCUs voltage
(a) Magnitude of PCUs injected voltage, (b) Phase of PCUs injected voltage, (c) Capacitor voltage in PCU2
confirm that in spite of simplicity, it is able to handle different
and 6.42 A, respectively.

It obtain the required capacities of the CPUs, (17) and (18) are dependent on characteristics of loads and generation units. The

Table 6 Numerical results for the maximum scenarios

| Scenario | 1   | 2   |
|----------|-----|-----|
| $P_{11}$, W | 1000 | 1000 |
| $Q_{11}$, VAr | 1000 | 1000 |
| $P_{22}$, W | 1000 | 1000 |
| $Q_{22}$, VAr | 1000 | 1000 |
| $PP_{11}$ | 0   | 1   |
| $Q_{11}$ | 0   | 1   |
| $PP_{22}$ | 0   | 1   |
| $Q_{22}$ | 0   | 1   |
| $v_{s1}$, V | 220 | 220 |
| $\theta_{s1}$, deg | 0   | 0   |
| $v_{s2}$, V | 237.46 | 202.65 |
| $\theta_{s2}$, deg | 2.74 | -3.83 |
| $v_{l1}$, V | 220 | 220 |
| $\theta_{l1}$, deg | 0 | -3.83 |
| $v_{l2}$, V | 202.65 | 220 |
| $\theta_{l2}$, deg | -3.83 | 0 |
| $v_{pp22}$, V | 202.65 | 237.46 |
| $\theta_{pp22}$, deg | -3.83 | 2.74 |
| $v_{pCu22}$, V | 42.94 | 42.94 |
| $\theta_{ppCu22}$, deg | -144.56 | 35.43 |
| $p_{pCu2}$, V | 0 | 6.42 |
| $\theta_{ppCu2}$, deg | 0 | -0.78 |

\[ PP_{11} = Q_{11} = 1 \]
\[ PP_{22} = Q_{22} = 0 \]
\[ PP_{ij} = Q_{ij} = 0 \]
\[ PP_{ij} = Q_{ij} = 1 \]

5.3 Numerical results for the maximum voltage and current scenarios

It can be seen that (14)-(16) are included in (17) and (18). So, to obtain the required capacities of the CPUs, (17) and (18) are enough. Here, the mentioned scenarios are considered for the system of Fig. 5. The results of two scenarios related to (17) and (18) for $PCU_2$ are presented in Table 6. The maximum parallel voltage, series voltage, and current of $PCU_2$ are 237.46 V, 42.94 V, and 6.42 A, respectively.

6 Conclusion

For a NG including several loads and local sources, an approach for realising full-selective contribution of the sources was proposed. Using an EPH including some PCUs and the considered algorithm, desirable full-selective contribution for active and reactive powers delivery was fulfilled. The proposed method is not dependent on characteristics of loads and generation units. The performance of the approach was evaluated in different conditions using simulations of various possible scenarios. The results confirm that in spite of simplicity, it is able to handle different conditions, desirably.

7 References

[1] Fadlullah, Z.M., Quan, D.M., Kato, N., et al.: ‘GTES: an optimized game-theoretic demand-side management scheme for smart grid’, IEEE Syst. J., 2014, 8, (2), pp. 588–597

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storage and active power smoothing for modular pv systems’. 2014 Twenty-Ninth Annual IEEE Applied Power Electronics Conf. and Exposition (APEC), Fort Worth, TX, USA, 2014, pp. 647–649

[32] Sun, C., Sun, F., Moura, S.J.: ‘Data enabled predictive energy management of a PV-battery smart home nanogrid’. American Control Conf. (ACC), 2015, Chicago, IL, USA, 2015, pp. 1023–1028

[33] Khodayar, M.E., Wu, H.: ‘Demand forecasting in the smart grid paradigm: features and challenges’, Electr. J., 2015, 28, (6), pp. 51–62

[34] Boroyevich, D., Cvetkovic, I., Burgos, R., et al.: ‘Intergrid: A future electronic energy network?’, IEEE J. Emerg. Sel. Top. Power Electron., 2013, 1, (3), pp. 127–138

[35] Mishra, S., Ray, O.: ‘Advances in nanogrid technology and its integration into rural electrification in India’. 2014 Int. Power Electronics Conf. (IPEC-Hiroshima 2014/ECE-ASIA), Hiroshima, Japan, 2014, pp. 2707–2713

[36] Tesfahunegn, S.G., Ulleberg, O., Undeland, T.M., et al.: ‘A simplified battery charge controller for safety and increased utilization in standalone PV applications’ 2011 Int. Conf. on Clean Electrical Power (ICCEP), Ischia, Italy, 2011, pp. 137–144

[37] Mäkipää, T.: ‘Nanogrid system implementation possibilities in Russia’. Master’s Thesis, Lappeenranta University of Technology, 2019, Available at https://luta.lut.fi/bitstream/handle/10024/159496/Master's%20Thesis_Makipaa%20Tuomas.pdf

[38] Jackson, S., Bennie, D., Cochran, S., et al.: ‘Nanogrid, final report’. University of California-Santa Cruz, 2014, Available at https://users.soec.ucsc.edu/~pnaud/reports/257-report-b.pdf

[39] Nanogrid TOGO. Available at https://www.victronenergy.com/blog/2019/10/22/nanogrid-togo/

[40] ‘Cost-effective rehabilitation of public buildings into smart and resilient nanogrids using storage’. Available at http://www.enichemec.eu/projects/berlin

[41] Guerrero, J.M., Vasquez, J.C., Matas, J., et al.: ‘Hierarchical control of droop-controlled AC and DC microgrids – A general approach toward standardization’, IEEE Trans. Ind. Electron., 2011, 58, (1), pp. 158–172

[42] Barklund, E., Pegaku, N., Prodanovic, M., et al.: ‘Energy management in autonomous microgrid using stability-constrained droop control of inverters’, IEEE Trans. Power Electron., 2008, 23, (5), pp. 2346–2352

[43] Liu, Z., Liu, J., Boroyevich, D., et al.: ‘Stability criterion of droop-controlled parallel inverters based on terminal-characteristics of individual inverters’. 2016 IEEE 8th Int. Power Electronics and Motion Control Conf. (IPEMC-ECCE Asia), Hefei, China, 2016, pp. 2958–2963

[44] Mohamed, Y.A.-R.I., El-Saadany, E.F.: ‘Adaptive decentralized droop controller to preserve power sharing stability of parallel inverters in distributed generation microgrids’, IEEE Trans. Power Electron., 2008, 23, (6), pp. 2806–2816

[45] Wang, X., Dougal, R.A., Zhangy, J.: ‘Cycle-by-cycle error reduction droop method to improve power sharing in low-voltage microgrid’, Int. Trans. Electr. Energy Syst., 2017, 28, (4), pp. 1–15

[46] Azim, M.I., Molah, K.U.Z., Roy Pota, H.: ‘Design of a dynamic phasor-based droop controller for PV-based islanded microgrids’, Int. Trans. Electr. Energy Syst., 2018, 28, (7), pp. 1–16

[47] Sabzevari, K., Karimi, S., Khoostavi, F., et al.: ‘Modified droop control for improving adaptive virtual impedance strategy for parallel distributed generation units in islanded microgrids’, Int. Trans. Electr. Energy Syst., 2019, 29, (1), pp. 758–771

[48] Takano, T., Kitamori, Y., Takahashi, R., et al.: ‘AC power routing system in home based on demand and supply utilizing distributed power sources’, Energies, 2011, 4, (5), pp. 717–726

[49] Abe, R., Tsuoka, H., McQuilkin, D.: ‘Digital grid: communicative electrical grids of the future’, IEEE Trans. Smart Grid, 2011, 2, (2), pp. 399–410

[50] Javaid, S., Kurose, Y., Kato, T., et al.: ‘Cooperative distributed control implementation of the power flow coloring over a nano-grid with fluctuating power loads’, IEEE Trans. Smart Grid, 2017, 8, (1), pp. 342–352

[51] Matsuyama, T.: ‘i-Energy: smart demand-side energy management’, in Mah, D., Hills, P., Liu, V. (eds.): ‘Smart grid applications and developments’ (Springer, London, England, 2014), pp. 141–163

[52] Matsuyama, T.: ‘Creating safe, secure, and environment-friendly lifestyles through i-energy’, New Breeze, 2009, 21, (2), pp. 1–8

[53] Samei, H., Ghanbari, T., Kazemzadeh, E., et al.: ‘Full-selective contribution of sources in DC nanogrids using a technique based on back/boost converter’, IET Energy Syst. Integration, 2019, 1, (1), pp. 14–22, DOI: 10.1049/iet-esi.2018.0004

[54] Shayeghi, H., Shahtaheri, E., Moradzadeh, M., et al.: ‘A survey on microgrid energy management considering flexible energy sources’, Energies, 2019, 12, (11), pp. 1–26, doi:10.3390/en12112156

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